Improvement of Thermal Conductivity of Paraffin Wax Using High Conductive Nano-Materials

S. M. Shalaby, A. E. Kabeel, A. R. El Sayed, and H. F. Abosheiasha

***Abstract*—Paraffin wax (PW) is commonly used as latent heat storage material in solar energy systems. The low thermal conductivity of the PW is considered the main drawback when it is used as thermal energy storage medium. In order to overcome this drawback, tens types of high conductive nano-materials are added to paraffin wax to improve its thermal conductivity. In this work, nanoparticles of CuO, and TiO_2 were individually added to paraffin wax with concentrations 1, 2 and 3%. The thermal properties of pure paraffin wax, PW/CuO and PW/TiO_2 nano-composites with different mentioned concentrations were measured at different temperature. The paraffin wax/TiO_2 showed higher thermal conductivity compared to paraffin wax/CuO nano-composite and pure paraffin.**

***Index Terms*—Thermal conductivity, paraffin wax, nano-composite.**

I. Introduction

Most of solar energy applications and buildings heating require an efficient thermal energy storage system. Two types of thermal energy storage system: sensible and latent heat. The latent heat storage system includes phase change material (PCM) where the energy stored and recovered during the phase change processes. Recently, enormous phase change materials were used as latent heat storage. These PCMs presented a promising method for thermal energy storage especially in solar systems. The PCMs are chemically classified into organic PCMs (paraffin, fatty acid), inorganic PCMs (metallic, salt hydrates), and eutectics PCMs [1].

Among the several types of PCMs, the paraffin wax (PW) is the most used material for thermal energy storage within the solar systems [2], [3]. The paraffin wax was used as energy storage material in many solar thermal applications such as solar air [4], [5], and water [6] heaters, solar distiller [7] and solar drying [8]. The daily efficiency of the solar heater using PW as PCM was 12- 21.3% higher than the corresponding ones without using the PCM based on the shape of the absorber plate [5]. The productivity of the solar distiller is also significantly improved when paraffin wax is used as thermal storage under the basin absorber [7].

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The low thermal conductivity of the PW is considered the main drawback when it is used as thermal energy storage medium [1]. In order to overcome this drawback, the effect of adding high conductive nanomaterial to PW on its thermal conductivity has been investigated in many studies. From the results obtained from these studies, it is found that the enhancement in thermal conductivity reaches 60% when Fe_3O_4 is added to paraffin wax by 20 wt% [9]. While the enhancement dropped to 48% when the concentration of Fe_3O_4 is reduced to 10%. Similar result is achieved when Al_2O_3 is added to paraffin wax where the improvement in thermal conductivity reaches 43% when Al_2O_3 is added by 10% [10]. Although high improvements are achieved in these cases, the concentration of the used nanomaterial is considered very high which is associated with high cost. While, the thermal conductivity is improved by 49.6% when TiO_2 is added to the same wax material with only 4 % [11]. Significant improvement is also achieved (33.34%) when SiO_2 is added to paraffin wax by 2 wt% [12]. It is clear that significant improvements are achieved by adding small amounts of SiO_2, TiO_2 compared to Fe_3O_4 and Al_2O_3.

Recently, carbon-based nano-materials with high thermal conductivity have demonstrated promising results in improving the thermal properties of PW [13]. Laghari et al. [14] used titanium dioxide-graphene (TiO_2: Gr) binary composite (1 wt% TiO2: 0.1, 0.5, 1 and 2 wt% of graphene (Gr)) with PW to improve its thermo-physical properties. The results showed that the thermal conductivity of the PW/TiO_2-Gr nano-composite is 179% higher than base PW when Gr was used with 1%. Nanosilica-stabilized graphite particles were also used by Svetlana *et al.* [15] for improving thermal conductivity of PW. They found that the thermal conductivity is improved by 33% when graphite nanoparticles was added to PW by 15% (vol).

Adding nanoparticles not only improves the thermal conductivity of PW but also improves the convective heat transfer during liquid phase of PW [3]. In general, adding high conductive nanomaterial to the heat transfer fluids showed positive significant effective in their thermal performance [16], [17].

Although these improvements in PW thermal conductivity when high conductive nanoparticles were added, the final selection decision of nanomaterial type still needs more study regarding the level of safety and cost.

So, in this work, the effect of adding two different types of high conductive nanomaterial (CuO and TiO_2 nanoparticles) to paraffin wax on the thermal properties of the nano-composite is experimentally studied at different temperatures and weight concentrations. In order to achieve low cost of the prepared nano-composite, low concentrations were considered in this study. Where the objective of this work is to provide PCM appropriate the solar thermal application. The paraffin wax/TiO_2 showed higher thermal conductivity compared to paraffin wax/CuO nano-composite and pure paraffin.

II. Experimental Work

In this section, the experimental work is discussed in detail. Where the selection of the used material and preparation of the sample are explained. The measuring technique is also presented in this section.

A. Material and Samples Preparation

A commercial paraffin wax of white color and melting point of 60 ˚C was used in this study. This type of paraffin wax is available in the Egyptian market with considerable low cost. The thermal properties of the used paraffin wax is illustrated in Table I. Nanoparticles of CuO and TiO_2 had been previously prepared using citrate precursor method. The detail of preparation and characterization had been reported earlier [3]. Nanoparticles of CuO, and TiO_2 were individually added to the PW with concentration 1, 2 and 3% (wt.). Fig. 1 shows a photograph of the prepared samples of PW/TiO_2 nano-composite and the pure paraffin.

TABLE I. The Thermal Properties of the Used Paraffin Wax [6]

Melting point (˚C)	Density (kg/m^3)	Specific heat (J/kg. K)	Latent heat (kJ/kg)
60	840 (liquid) 900 (solid)	2100	190

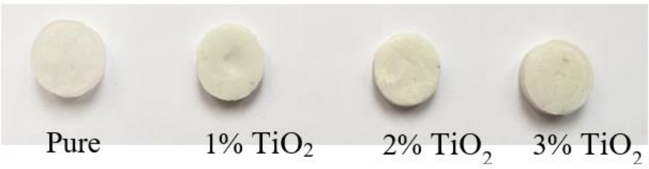

Fig. 1. The prepared samples of PW/TiO_2 nano-composite, and the pure paraffin.

In order to prepare the samples of PW/CuO and PW/ TiO_2 nano-composite with different mass fraction concentrations, firstly, a digital balance of accuracy 0.0001 g was used to measure the required weights of PW, CuO, and TiO_2 nanoparticles. In order to prepare a certain PW/CuO nano-composite for example, 100 g of PW was molten using an electrical hot plate of 1.5 kW. Before adding the required amount of CuO nanoparticles, a sodium dodecyl benzene sulfonate of 1% (wt.) of the used nanoparticles was well mixed with paraffin [18], [19] to ensure that the nano-CuO particles are uniformly distributed inside the PW and reduce the sedimentation at the bottom of the sample. Moreover, a planetary centrifugal mixers (model ARE-310) was used to enhance the dispersion of nanoparticles in PW. Where the mixture was treated for 10 min in a planetary centrifugal mixer at a speed of 1500 rpm at a temperature of 65 ˚C. After that the samples were left in room temperature to cool down. Then a suitable amount of the sample was stamped to prepare a disk of 15 mm diameter and 3 mm thickness as seen in Fig. 1. After the samples were prepared, the thermal conductivity of pure paraffin wax, PW/CuO and PW/TiO_2 nano-composite with different mentioned concentrations were measured at different temperatures.

B. Thermal Properties Measurements

Transient plane source technique has been widely adopted as a convenient tool for fast characterization of thermal properties of the energy storage materials [20]. This technique is also known as the hot disk method. One of the main advantages of transient techniques is the influence of the contact resistance can be removed in the analysis of experimental data. This enables accurate measurements over a wide range of thermal conductivity and therefore a wide range of different materials.

The hot disk thermal constants analyzer utilizes a set of concentric rings sensor in the shape of a double spiral which acts both as a planar heater for increasing the temperature of the sample and an ohmic resistance thermometer for recording the time-dependent temperature increase. The spiral, made of nickel covered on both sides with Kapton for protection and electrical insulation is simply placed between two halves of the sample tested. During the test, a small constant current is applied; the voltage generated by the sensor is proportional to the temperature. The TPS sensor 7577 of radius 2.1 mm was embedded between two identical uniform disks of the same sample (15 mm diameter and thickness around 3 mm). Output power was fixed at 50 mW and total measurement time varied between 10s and 20s. It is important to remark that the temperature difference on the sample surface is related to the measured thermal conductivity.

III. Results and Discussions

The effect of CuO nanoparticles weight concentration on the thermal conductivity (K) of PW/CuO nano-composite is shown in Fig. 2. It is clearly seen that the peak values of K, measured at several temperatures, are obtained when CuO nanoparticles are added to PW with weight concentration of 1 % (wt.). Where significant improvements in K are obtained at this concentration that reach 1.4, 1.5, 4.6 and 5.9% when the K is measured at 20, 30, 40, and 50 C, respectively compared with pure wax. While, no significant effect was found when CuO nanoparticles was used with weight concentration 2% at all considered temperatures. The unexpected result is found when the concentration was increased to 3%, where significant negative effect was obtained as the values of K are dramatically decreased to lower values compared to pure paraffin. This is due to the accumulation of nanoparticles that may be happen with increasing the weight concentration which converts most of nanoparticles to ordinary material.

The maximum improvement in thermal conductivity was also obtained at the highest PW temperature (50 ˚C) as obviously seen in Fig. 2. While, the effect of changing the wax temperature in general on the measured values of K is not clear as seen in Fig. 2. This is because of a tied range of temperature (20- 50 ˚C) was implemented in this study. This range of temperature is limited by the melting point of the used PW (60 ˚C) to avoid wax melting that has a negative effect on the measuring sensor.

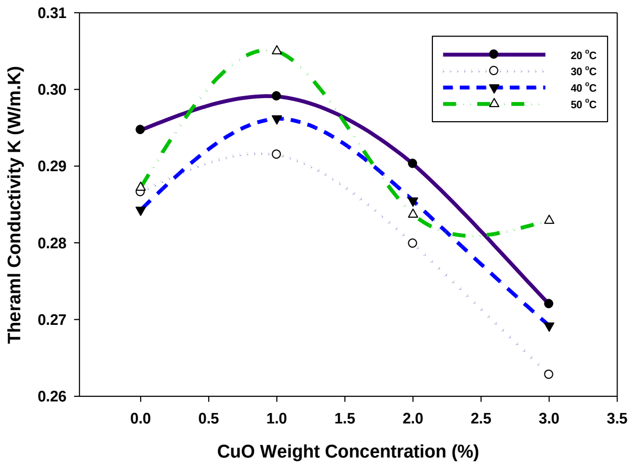

Fig. 2. The effect of CuO nanoparticles weight concentration on the thermal conductivity (K) of PW/CuO nano-composite.

The effect of TiO_2 nanoparticles weight concentration on the thermal conductivity (K) of PW/ TiO_2 nano-composite at different temperatures is illustrated in Fig. 3. The peak values of thermal conductivity were also obtained when TiO_2 was added to PW with weight concentration 1% (wt.), at all temperatures except 50 ˚C, it is obtained at concentration 2% (wt.) as seen in Fig. 3. It is also noticed that more significant improvements were achieved when TiO_2 was used with PW compared to CuO and pure PW as seen in Fig. 3. Where the maximum improvements in thermal conductivity in the case of using TiO_2 nanoparticles reach 6.1, 7.7, 8.1 and 5.9% compared to pure paraffin at temperature 20, 30, 40, 50 ˚C, respectively. It is also seen that the maximum thermal conductivity of PW was obtained at 20 ˚C when TiO_2 was used with weight concentration of 1% (wt.). The results also showed that there is a reverse proportional relation between the PW temperature and its thermal conductivity.

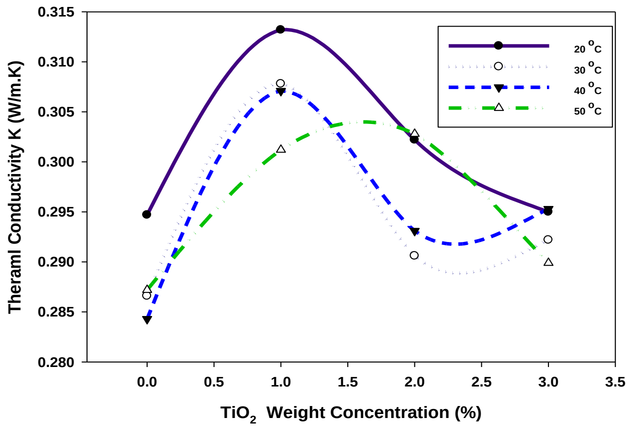

Fig. 3. The effect of TiO2 nanoparticles weight concentration on the thermal conductivity (K) of PW/TiO2 nano-composite.

IV. Conclusions

In this study, the effect of adding different types of nano-materials with different weight concentrations to paraffin wax was studied. Two types of high conductive nano-materials are added to paraffin wax to improve its thermal conductivity. From the obtained results, the following conclusions and recommendations can be drawn:

- The peak values of the PW/CuO nano-composite thermal conductivity, measured at all studied temperatures, are obtained when CuO nanoparticles are added to paraffin wax with weight concentration of 1%.
- The peak values of thermal conductivity paraffin wax/TiO_2 nano-composite were also obtained when TiO_2 was added to PW with weight concentration 1% (wt.), at all temperatures except 50 ˚C, it is obtained at concentration 2% (wt.)
- The paraffin wax/TiO_2 shows higher thermal conductivity compared to paraffin wax/CuO nano-composite and pure paraffin.
- It is also recommended to use the paraffin wax/TiO_2 as storage medium in solar thermal applications.
- The addition of graphene nanoparticles and the combination of graphene and TiO_2 to paraffin wax is also recommended for future work.
- Although the improvements in thermal conductivity of PW when the nanoparticles are added not only in this study but also the literature studies are considered, these improvements are not enough to significantly improve the heat transfer to/from the PW. So, using extended fins through the paraffin is recommended in designing the heat exchangers to increase the transfer area.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

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References

[1] M. E. Zayed *et al.*, "Applications of cascaded phase change materials in solar water collector storage tanks: A review," *Solar Energy Materials and Solar Cells*, vol. 199, pp. 24-49, 2019/09/01/ 2019, doi: https://doi.org/10.1016/j.solmat.2019.04.018.

[2] S. Shalaby, M. Bek, and A. El-Sebaii, "Solar dryers with PCM as energy storage medium: A review," *Renewable and Sustainable Energy Reviews*, vol. 33, pp. 110-116, 2014.

[3] A. Shama, A. E. Kabeel, B. M. Moharram, and H. F. Abosheiasha, "Improvement of the thermal properties of paraffin wax using high conductive nanomaterial to appropriate the solar thermal applications," *Applied Nanoscience*, 2021, doi: 10.1007/s13204-021-01903-7.

[4] S. M. Shalaby, A. E. Kabeel, E. El-Bialy, and M. K. Elfakharany, "Investigation and improvement of thermal performance of a solar air heater using extended surfaces through the phase change material," *Journal of Solar Energy Engineering*, vol. 142, no. 1, 2019, doi: 10.1115/1.4044565.

[5] A. Kabeel, A. Khalil, S. Shalaby, and M. Zayed, "Experimental investigation of thermal performance of flat and v-corrugated plate solar air heaters with and without PCM as thermal energy storage," *Energy Conversion and Management*, vol. 113, pp. 264-272, 2016.

[6] S. M. Shalaby, A. E. Kabeel, B. M. Moharram, and A. H. Fleafl, "Experimental study of the solar water heater integrated with shell and finned tube latent heat storage system," *Journal of Energy Storage*, vol. 31, p. 101628, 2020/10/01/ 2020, doi: https://doi.org/10.1016/j.est.2020.101628.

[7] F. A. Hammad, S. M. Shalaby, A. E. Kabeel, and M. E. Zayed, "Experimental investigation and thermo-economic performance analysis of a modified solar distiller design with thermal storage material and v-corrugated absorber basin," *Journal of Energy Storage*, vol. 52, p. 105020, 2022/08/25/ 2022, doi: https://doi.org/10.1016/j.est.2022.105020.

[8] S. M. Shalaby, M. Darwesh, M. S. Ghoname, S. E. Salah, Y. Nehela, and M. I. Fetouh, "The effect of drying sweet basil in an indirect solar dryer integrated with phase change material on essential oil valuable components," *Energy Reports*, vol. 6, pp. 43-50, 2020/12/01/ 2020, doi: https://doi.org/10.1016/j.egyr.2020.10.035

[9] N. Şahan, M. Fois, and H. Paksoy, "Improving thermal conductivity phase change materials—A study of paraffin nanomagnetite composites," *Solar Energy Materials and Solar Cells*, vol. 137, pp. 61-67, 2015, doi: https://doi.org/10.1016/j.solmat.2015.01.027.

[10] R. M. Al Ghossein, M. S. Hossain, and J. M. Khodadadi, "Experimental determination of temperature-dependent thermal conductivity of solid eicosane-based silver nanostructure-enhanced phase change materials for thermal energy storage," *International Journal of Heat and Mass Transfer*, vol. 107, pp. 697-711, 2017/04/01/ 2017, doi: https://doi.org/10.1016/j.ijheatmasstransfer.2016.11.059.

[11] S. Jesumathy, M. Udayakumar, and S. Sivan, "Experimental study of enhanced heat transfer by addition of CuO nanoparticle," *Heat and Mass Transfer*, vol. 48, 06/01 2011, doi: 10.1007/s00231-011-0945-y.

[12] P. Manoj Kumar, K. Mylsamy, and P. T. Saravanakumar, "Experimental investigations on thermal properties of nano-SiO2/paraffin phase change material (PCM) for solar thermal energy storage applications," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 42, no. 19, pp. 2420-2433, 2020/10/01 2020, doi: 10.1080/15567036.2019.1607942.

[13] A. S. Abdelrazik, R. Saidur, F. A. Al-Sulaiman, A. Al-Ahmed, and R. Ben-Mansour, "Multiwalled CNT and graphene nanoplatelets based nano-enhanced PCMs: Evaluation for the thermal performance and its implications on the performance of hybrid PV/thermal systems," *Materials Today Communications*, vol. 31, p. 103618, 2022/06/01/ 2022, doi: https://doi.org/10.1016/j.mtcomm.2022.103618.

[14] I. A. Laghari, M. Samykano, A. K. Pandey, K. Kadirgama, and Y. N. Mishra, "Binary composite (TiO2-Gr) based nano-enhanced organic phase change material: Effect on thermophysical properties," *Journal of Energy Storage*, vol. 51, p. 104526, 2022/07/01/ 2022, doi: https://doi.org/10.1016/j.est.2022.104526.

[15] S. N. Gorbacheva, V. V. Makarova, and S. O. Ilyin, "Hydrophobic nanosilica-stabilized graphite particles for improving thermal conductivity of paraffin wax-based phase-change materials," *Journal of Energy Storage*, vol. 36, p. 102417, 2021/04/01/ 2021, doi: https://doi.org/10.1016/j.est.2021.102417

[16] M. E. Zayed, J. Zhao, Y. Du, A. E. Kabeel, and S. M. Shalaby, "Factors affecting the thermal performance of the flat plate solar collector using nanofluids: A review," *Solar Energy*, vol. 182, pp. 382-396, 2019/04/01/ 2019, doi: https://doi.org/10.1016/j.solener.2019.02.054.

[17] S. M. Shalaby, M. K. Elfakharany, I. M. Mujtaba, B. M. Moharram, and H. F. Abosheiasha, "Development of an efficient nano-fluid cooling/preheating system for PV-RO water desalination pilot plant," *Energy Conversion and Management*, vol. 268, p. 115960, 2022/09/15/ 2022, doi: https://doi.org/10.1016/j.enconman.2022.115960.

[18] P. K. Das, N. Islam, A. K. Santra, and R. Ganguly, "Experimental investigation of thermophysical properties of Al2O3–water nanofluid: Role of surfactants," *Journal of Molecular Liquids*, vol. 237, pp. 304-312, 2017, doi: https://doi.org/10.1016/j.molliq.2017.04.099.

[19] X.-j. Wang, D.-S. Zhu, and S. yang, "Investigation of pH and SDBS on enhancement of thermal conductivity in nanofluids," *Chemical Physics Letters*, vol. 470, pp. 107–111, 02/24 2009, doi: 10.1016/j.cplett.2009.01.035.

[20] A. Palacios, L. Cong, M. E. Navarro, Y. Ding, and C. Barreneche, "Thermal conductivity measurement techniques for characterizing thermal energy storage materials – A review," *Renewable and Sustainable Energy Reviews*, vol. 108, pp. 32-52, 2019/07/01/ 2019, doi: https://doi.org/10.1016/j.rser.2019.03.020.

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