# *IMPROVEMENT OF THERMAL PROPERTIES OF PARAFFIN WAX AS LATENT HEAT STORAGE MATERIAL WITH DIRECT SOLAR DESALINATION SYSTEMS BY USING ALUMINUM OXIDE NANOPARTICLES*

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## ABSTRACT

The low thermal conductivity of paraffin wax is the main drawback of using it as latent heat thermal storage material with direct solar desalination systems. This work mainly aims to improve the thermal conductivity of paraffin wax by using aluminum oxide nanoparticles. For this purpose two samples of paraffin wax were prepared with aluminum oxide nanoparticles mass fraction 0 and 3%. The thermal properties of the two samples were measured by thermal constant analyzer. The results showed that using $Al_2O_3$nanoparticles with weight concentration 3% not only increase the thermal conductivity of paraffin wax by 18.6 % but also increase the thermal effusivity by 28.2% which result in improving the heat transfer from and to the paraffin wax. So,it is recommended using PWX/$Al_2O_3$nanocomposite as latent heat thermal storage material with direct solar desalination systems (solar still and humidification-dehumidification), where, it may improve the performance of these solar desalination systems.

**Keywords**: Water desalination, Nanoparticles, Thermal conductivity

## 1 INTRODUCTION

Paraffin wax (PWX) is considered one of the most famous phase change materials (PCM) used for thermal energy storage with solar thermal applications. This is due to its low price, safety, uniform meltingand reliability (Sharma et al., 2009). In addition to its availability in the Egyptian local market.
The v-corrugated and finned plate solar air heaters when the PWXwas used as latent heat storage material were investigated experimentally by Kabeel et al. (2016, 2017). They found that the daily efficiency improved by 12 and 10.8-13.6% when the PWXwas used as storage material in the v-corrugated and finned plate solar air heaters, respectively.The PWXwasalso used in many solar thermal applications such as solar drying (Shalaby and Bek, 2014; El-Sebaii and Shalaby, 2017;Robha and Muthukumar, 2017; Lakshami et al., 2018), solar water heating (Al-Hinti et al., 2010; Fazilati and Alemrajabi, 2013; Al-Kayiem and Lin, 2014; Mahfuz et al., 2014; Abokersh et al., 2017; Naghavi et al., 2017), and solar cooking (Hussein et al., 2008).

The utilization PWX as PCM with direct solar water desalination system especially solar stillis more attractive compared with other solar thermal applications, where, it is not only used for energy storage during the sunshine period and release this energy during night but also to befit from the drop in ambient temperature which happens during night which means that the temperature difference between basin water and glass cover increases which lead to increase the fresh water productivity. The single basin solar still with v-corrugated absorber integrated with PWX storage unit wasexperimentally investigated by Shalaby et al. (2016). They found that the daily productivity increases by 12% when 25 kg of PWX was used.The PWXwas used also by Asbik et al. (2016) and Elfasakhany (2016) to improve the thermal performance of the simple type solar still. The solar still operating time extended by 5-6 hrs/day and the daily productivity increases by 19% when the PWX was used (Elfasakhany, 2016). Few studies have been conducted to improve the performance of wire type cascade solar still using the PWX as latent heat storage (Tabrizi et al., 2010; Dashtaban and Tabrizi, 2011).

In order to select the appropriate PCM for non-membrane solar desalination applications, the thermal properties of two types of PWX have been studied by Sarwar and Mansoor(2016). They found that the two types ofPWX have reversible phase change with no degradation of thermal properties. They also recommended using the selected types of paraffin waxes in multi-stage flash and multi-effect distillation systems.

Although, significant improvements have been achieved when the PWX was used as thermal storage material in solar thermal application, but, there are two disadvantages of using the PWX as latent heat thermal storage. The increment in its volume upon melting which leads to leakage of the melted wax from the weakest points of the storage tank is consider the first problem. So, this problem should be taken into account when the system is designed. Shalaby et al. (2016) deal with this problem by introduce a new design allows for the expansion of melting wax through a net of tubes extended inside the storage tank. The other problem is the low thermal conductivity of paraffin wax which leads to decrease the heat transfer rate to/from the wax.

The current work aims to improve the thermal properties of paraffin wax particularly the thermal conductivity by adding$Al_2O_3$nanoparticles (prepared experimentally by chemical wet method) with weight concentration 3%.

## 2 EXPERIMENT

### 2.1 Samples preparation

In this study, local type of paraffin wax was used where it is available in Egyptian market with low price. The physical and thermal properties of the used PWXis presented in Table 1. In order to figure out the effect of adding Nanoparticles of $Al_2O_3$to the PWX, two samples were prepared; pure paraffin sample, and the second sample was PWX with 3 wt. % of $Al_2O_3$Nanoparticles. Firstly, the Nanoparticles of $Al_2O_3$were prepared by citrate-autocombustion method. All used chemicals were of reagent grade purity. Stoichiometric amounts of aluminum nitrate ($Al(NO_3)_2.6H_2O$) and citric acid ($C_6H_8O_7.H_2O$) with molarity ratio (1:1) were dissolved separately in distilled water. Then, their aqueous solutions were mixed together with constant stirring and heating at 40 $^oC$ for about 30min. The pH of the solution was adjusted at 7 by adding the ammonia drop-wise under continuous stirring until a kind of clear sol was formed. After that, the solution was heated at 400 $^oC$by using hot plate until the viscosity and color of the solution changed and turned into a dark puffy porous dry gel. The dried gel then ignited, forming a strong auto combustion process with the evolution of large amount of gases resulting in a dark grey ash-product. This product was grinded thoroughly in agate mortar thin sintered at 1000$^oC$ for 2hr to obtain nanosample of $Al_2O_3$.

The PWX and prepared nano-alumina were weighed to prepare the required sampleswhere mass fractions of the nano-alumina fillersare0 and 3 wt. %.The PWX/nano-$Al_2O_3$compositewasprepared using a melting-mixing procedure. Firstly, in the case of the PWX/nano-$Al_2O_3$composite, the nanofillers were added to the molten wax with required percentageand mixedby using a magnetic stirrer for 15 min.Then, the sampleswere sonicated at 65 $^oC$(to keep the samples in liquid form) for 2 h to obtain uniform distribution of nano-$Al_2O_3$fillers. After then,the melted pure PWX or PWX/nano-$Al_2O_3$composite was poured into cylindrical-shaped copper mold with a diameter (15 mm) and height (10 mm) and left to cool down gradually at room temperature and solidify through 4 hrs. This castwas removed from the mold after solidification to obtain disk-shaped sample ready to be used for the thermal measurements.

**Table 1.Physical and thermal properties of paraffin wax**

| Property | value |
|---|---|
| Melting temperature | 59.67$^o$C |
| Latent heat of fusion | 190 kJ/kg.$^o$C |
| Thermal conductivity | 0.25 W/m.$^o$C |
| Solid density | 876 kg/m$^3$ |
| Liquid density | 795 kg/m$^3$ |

## 2.2 Measurements

The pure phase of the prepared $Al_2O_3$nanoparticles was checked up by XRDBruker-D8 (accuracy < 0.002$^o$) using CuKα as a target and the incident wavelength λ = 1.5406 Å radiation.Its average crystallite size was calculated using the X-ray diffractometer software program (PANalyticalX'PertHighScore Plus) which based on Debye Scherrer's equation (Assar and Abosheiasha, 2012).

$$D_{311} = \frac{0.89\lambda}{\beta \cos \theta} . \quad (1)$$

The different thermal properties (thermal conductivity ($K_s$), specific heat capacity ($C_p$), thermal diffusivity ($\alpha_s$) and thermal effusivity($e_s$) of the pure PWX and PWX/nano-$Al_2O_3$ composite samples were measured using thermal constant analyzer, Hot Disk TPS 2500 Saccuracy ±5 %. In order to cover the specific area of the sensor (C7577) of this device, two disks of each sample were used. All measurement were obtained automatically after some calculation carried by the device's software program. The melting temperature of PWX was measured using TG/DTA Perkin Elmer analyzer PKI STA 6000.

# 3 RESULTS AND DISCUSSIONS

The XRD pattern of the prepared nano-alumina is shown in Fig. 1. It can be seen the characteristic sharp intensity crystalline peeks of a stable pure phase of α-Al2O3. The XRD pattern of the prepared nano-alumina matches well the diffraction peeks of α- $Al_2O_3$(ICSD collection code 31545) where, the diffraction peaks at 2θ values of 25.55o for (0 1 2), 35.11o for (1 0 4), 37.73o for (1 1 0), 43.30o for (1 1 3), 52.49o for (0 2 4), 57.42o for (1 1 6), 66.43o for (2 1 4), 68.13o for (3 0 0), 76.76o for (1 0 10), and 77.13o for (1 1 9).Table 2 displays the comparison between the observed values of d-spacing for the recorded peaks and the corresponding relative intensities I/Io (where Io is the maximum intensity peak) and the published standard values of α- $Al_2O_3$(ICSD collection code 31545) which seem to be in good agreement with each other. The average crystallite size of the prepared α- $Al_2O_3$estimated from the XRD resultsis 71.5 nm which confirm the nanostructure of these particles.

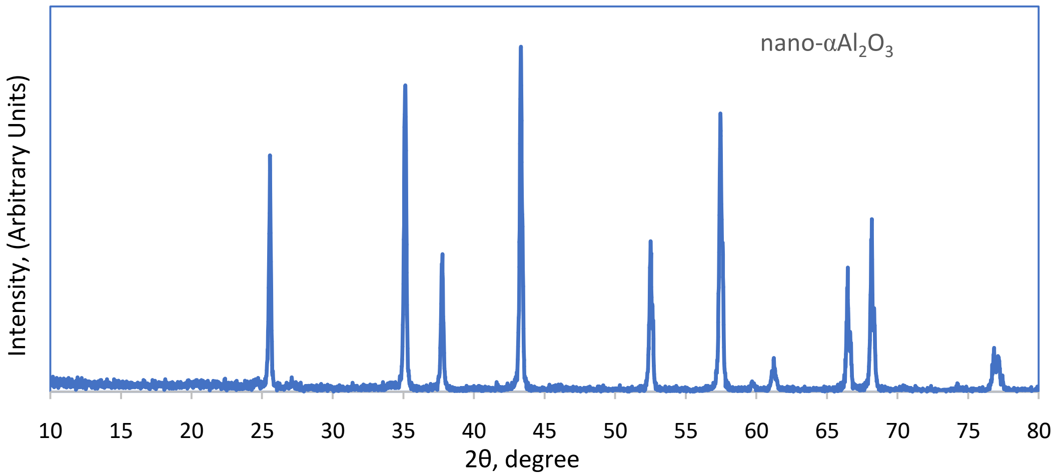


**Figure 1. The XRD pattern of α- Al2O3 nanoparticles.**

**Table 3: The d-spacing values and I/Io % of both the nano-prepared and the standard (ICSD collection code 31545) of the α-$Al_2O_3$**

| h k l | Nano-α- $Al_2O_3$(prepared) | | α-$Al_2O_3$(ICSD collection code 31545) | |
|---|---|---|---|---|
| | d(Å) | (I/Io) % | d(Å) | (I/Io ) % |
| (0 1 2) | 3.48428 | 62.42 | 3.484 | 64.4 |
| (1 0 4) | 2.55406 | 92.74 | 2.5541 | 100 |
| (1 1 0) | 2.38235 | 39.96 | 2.3820 | 46.2 |
| (1 1 3) | 2.08841 | 100 | 2.0878 | 98.6 |
| (0 2 4) | 1.7430 | 41.81 | 1.7420 | 48.8 |
| (1 1 6) | 1.60428 | 80.38 | 1.6034 | 94.5 |
| (2 1 4) | 1.40692 | 30.14 | 1.4061 | 36.3 |
| (3 0 0) | 1.37602 | 45.64 | 1.3376 | 55.6 |
| (1 0 10) | 1.23983 | 11.84 | 1.2407 | 15.6 |
| (1 1 9) | 1.23659 | 10.36 | 1.2357 | 8.5 |

The measured values of$K_s$, $C_p$, $\alpha_s$, and$e_s$ are given in Table 3. The thermal conductivity of the pure PWX and PWX/ $Al_2O_3$nanoparticles composite are found to be 0. 2528 and 0.2999 (W/mK), respectively. This means that the $Al_2O_3$nanoparticles improvethe thermal conductivity of PWX by 18.6%. The specific heat capacity is also increased by 38.5%; whereas, the thermal diffusivity decreases by 14.34%.
Where the thermal diffusivity is given by Lee et al. (2014):

$$\alpha_s = \frac{K_s}{\rho C_p} \quad (2)$$

Based on Eq. 1, thisreduction in thermal diffusivitycan be explained as the specific heat capacityis highly increased when the $Al_2O_3$nanoparticles are used.The results showed also a significant improvement in thermal effusivity as it increased by 28.2%. This means that theheattransferfrom/to the surface of PWX/ $Al_2O_3$nanoparticles composite is significantly improved. The thermal effusivity is the ability of the material to exchange heat with the surrounding and hence it is a parameter for surface heating and cooling processes. The thermal effusivity is given by (Mehrali et al., 2014):

$$e_s = \sqrt{\rho C_p K_s}\ . \qquad (3)$$

**Table 4. The thermal mesured propertites of pure PWX and PWX/ $Al_2O_3$nanoparticles composite**

| PWX Wt. % of Al2O3 | $K_s$ (W/mK) | $C_p$(MJ/$m^3$K) | $\alpha_s$ ($mm^2$/s) | es (W $s^{0.5}$/$cm^2$K) |
|---|---|---|---|---|
| 0% | 0. 252803723 | 1.610970564 | 0.156926345 | 0.638169 |
| 3% | 0.299903143 | 2.230857265 | 0.134434035 | 0.817949 |

## 4 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

The current work is conducted to mainly improve the thermal conductivity of PWX by using aluminum oxide nanoparticles. From the obtained results, the following conclusions can be drawn:

- Using $Al_2O_3$nanoparticles with weight concentration 3% not only increase the thermal conductivity of PWX by 18.6 % but also increase the thermal effusivity by 28.2% which result in improving the heat transfer from/to the PWX.
- It is recommended using PWX/$Al_2O_3$nanoparticles composite as latent heat thermal storage with direct solar desalination systems (solar still and humidification-dehumidification).
- It is also recommended to investigate the thermal properties of PWX at different concentration of $Al_2O_3$nanoparticles.

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