

RESEARCH PAPER

Study of Saving Thermal Energy Using Local Mixed Phase Change Materials.

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ABSTRACT:

Latent heat storage systems were reported to possess a very slow thermal response, mainly those using organic materials. This is primarily due to the relatively low thermal conductivity organic PCM (phase change material). In this study the paraffin –Al composite phase change material was prepared by mixing Aluminum powder into paraffin, in which paraffin wax was selected as organic phase change material, for the purpose of comparison pure paraffin and paraffin/aluminum composite with (0.1, 0.5, 0.8, 1, 2) mass fraction of aluminum samples were tested. To point out the effect of PCM thickness, four different thickness modules were used. It was found that increasing the thickness of PCM could decrease the heat transfer, which means more heat energy can be saved. The Thermal conductivity value changed from (0.263 W m⁻¹ K⁻¹) to (0.918 W m⁻¹ K⁻¹) by adding the mass fraction of aluminum powder from (0.1% to 2%) correspondingly. The experiment results concluded that increasing Al mass fractions result in decreased charging time. Adding aluminum powder increases heat transfer, therefore this heat gain is proportional to increasing aluminum mass fraction in paraffin wax.

KEYWORDS: Thermal energy storage, paraffin, Phase change materials, Aluminum powder, Thermal conductivity enhancement

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1 INTRODUCTION

Thermal energy storage plays as significant technologies in an effective use of thermal energy and has applications in various areas, such as building heating/cooling systems (Wasmi, Jaffal et al. 2019), solar energy collectors, insulation (Hamad, Talabani et al. 2016), power and industrial waste heat recovery (Zelba, Marin et al. 2003).

Thermal energy storage techniques can be classified as sensible heat storage and latent heat storage, Latent thermal energy storage is a particularly attractive technique that provides a high energy storage density and has the property of storing latent heat like the heat of fusion at a constant temperature, i.e. the phase change temperature. Phase change materials (PCMs) that are used as storage media in latent thermal energy storage generally can be classified into two main categories: inorganic compounds and organic compounds. Inorganic PCMs include salt hydrates; salts, metals, and alloys, as well as organic PCMs are comprised of paraffin, fatty acids/esters and polyalcohol (Zelba, Marin et al. 2003).

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Among the variety of PCMs proposed paraffin is taken as the most promising phase change material because it has many desirable characteristics such as significant latent heat of fusion, desirable phase change temperature range, non-supercooling, low cost, commercial availability, nontoxic and not corrosive (Kaygusuz and Sari 2005). However, paraffin waxes suffer from a low thermal conductivity ($0.23\text{Wm}^{-1}\text{K}^{-1}$) which reduces the rate of heat storage and extraction during the melting and solidification cycles (Zhang and Fang 2006). In order to improve the thermal conductivity of paraffin, extensive investigations have been carried out to enhance the thermal response of paraffin through the addition of different high thermal conductivity materials. These have included the use of graphite foam and graphite nanofibers with paraffin (Chintakrinda, Weinstein et al. 2011); the results showed that significant improvement can be achieved.

(Zhou, Wang et al. 2018) used the foam aluminum/paraffin composite PCM in the wall structure, and investigated that this composite material has a good thermal conductivity for the wall thermal insulation. Some investigators studied the graphite matrix embedded within paraffin, and significant improvement in thermal conductivity was achieved (Nayak, Saha et al. 2006) (Mills, Farid et al. 2006) (Mettawee and Assassa 2007). The paraffin/expanded graphite composites with the mass fraction of 2%, 4%, 7% and 10% EG were prepared by absorbing liquid paraffin into the expanded graphite. It was concluded that the composite PCM with the mass fraction of 10% EG was the most promising one for latent heat thermal energy storages (LHTES) applications due to its form-stable property, high thermal conductivity, good melting temperature (Sarı and Karaipekli 2007)

Using carbon nanotubes (CNTs) as one of the best materials to increase the thermal conductivity of paraffin has been studied by some investigators the results showed that the use of (CNTs) has apparent improving effect for the thermal conductivity without affecting the compatibility of components and thermal energy storage properties (Karaipekli, Biçer et al. 2017, Luo, Wei et al. 2018, Sarı, Biçer et al. 2018). Another technique to increase thermal conductivity of paraffin is emulsifying high

thermal conductive nanoparticles in paraffin (e.g. Al_2O_3 , TiO_2) (Ho and Gao 2009, Chaichan, Kamel et al. 2015, Farsani, Raisi et al. 2019), the results indicated that the paraffin thermal conductivity increased the risen in the nanoparticles mass fraction.

In the present study, the addition of aluminum powder to paraffin wax (n-hexacosane) to improve the thermal conductivity was investigated experimentally. This study was done using a thermal energy storage test device; the heat transfer characteristics of the charging process were discussed. A comparative study between the results using pure paraffin and that using a composite of paraffin with different aluminum powder mass fraction is presented.

2 MATERIALS AND METHODS

2.1. MATERIALS

Paraffin wax (n-Hexacosane) used as organic phase change material in this study, obtained from scharlau company with a melting point (54°C) according to a manufacturing database. Pure Copper and the aluminum powder obtained commercially. Pure copper rode prepared by lathe machine as a reference material for making four different size modules due to its known thermal conductivity (386W/m.K) (Holman 1986), and aluminum powder selected because it has high thermal conductivity (204W/m.K) (Holman 1986), also due to its economical price, other significant property advantages associated with aluminum powder is excellent corrosion resistance.

2.2. PREPARATION OF COMPOSITE PCMS

Aluminum powder in paraffin composite was formulated with five mass fractions of Al powder ranging 0.1wt.%, 0.5 wt.%, 0.8 wt.%, 1 wt.% and 2 wt.%, the weights measured using an electronic balance. The thermal conductivity of the composite is defined as:

$$k_c = k_p v_p + k_{Al} v_{Al} \quad (\text{Mettawee, 2007})$$

Where $v_p = V_p/V_c$ is the volume fraction of paraffin wax;

$v_{Al} = V_{Al}/V_c$ is the volume fraction of aluminum powder

Then each composite placed in four different thickness samples 4mm, 6mm, 8mm, and 10mm.

2.3. Experimental setup and Procedure

The thermal energy storage of paraffin and paraffin/Al composite PCM in thermal energy storage (TES) system were investigated respectively. The experimental setup is shown in figure (1). The setup mainly consisted of; lower part made of lumber (MDF type), electrical parts (current meter, voltage meter, and temperature controller screens) were placed in, upper part is the PCM module place which consists of a circular electric heater (105mm diameter) in the provided space inside the lower mold to create a uniform heat flux boundary condition at the PCM module base, and both heater and thermal control module are thermally insulated to reduce the heat loss. The voltage and Ampere to the heater are controlled and recorded by Digital voltmeter and Digital Ammeter respectively.



Figure (1) Thermal energy storage apparatus

Three K type thermocouples extended into the PCM module and measure the temperature at various locations with the same depth. A detailed view of the test section with the location of the thermocouples indicated is shown in figure (2). Three Thermocouples were arranged such that two are in the top and bottom of the module and one is in the PCM filled. All thermocouples calibrated by comparing their readings with a calibrated mercury thermometer before use then were held securely in place that did not move during the test.

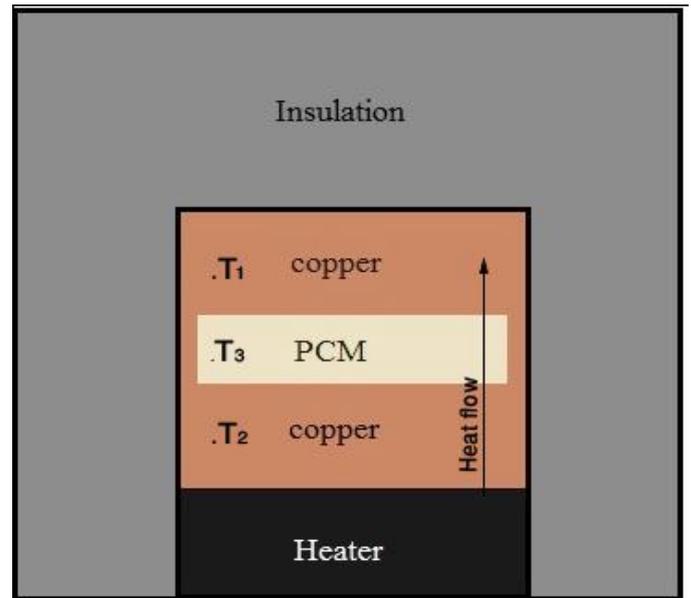


Figure (2) Schematic of the experimental setup with thermocouple points (front view)

The circular test modules are fabricated from pure copper with a dimension (105mm outer diameter and 101mm inner diameter, 15mm thickness) each and have the ring inside module (101mm outer diameter and 95mm inner diameter), with four different thickness 4mm, 6mm, 8mm, and 10mm as shown in figure (3). Each ring in the test module was filled completely with paraffin composite as shown in figure (4) with a known mass fraction of Aluminum and placed in the PCM module base for applying heat flux. Tests were run in all module design for each of five different mass fractions of Al- paraffin composite, for four different applied voltages (4, 6, 8, 10), and the test was repeated for each different thickness, the effect of PCM composite thickness was also examined, the system allowed to heat up while the thermocouples record the temperature of the system, the thermocouple responses recorded with time. In order to know the heat transfer enhancement induced by aluminum powder, the pure paraffin sample was also measured for the purpose of comparison. The temperatures and input voltage would be automatically recorded by a data acquisition system. Thus, the heat transfer rate and the thermal energy storage capacity could be obtained from the analysis of the recorded data.



Figure (3) module sample



Figure (4) module sample 6mm filled with paraffin

3 RESULTS AND DISCUSSION

In The present study, the thermal behavior of pure paraffin and Aluminum-paraffin investigated. The effects of power loading, PCM thickness and Al mass fraction are all examined.

Figure (5) represents the heat transfer of pure copper alone at the different power supply and with pure paraffin. The graph represents four different thickness samples. One is 4mm thick of pure paraffin and others 6mm, 8mm and 10mm thick. As shown in the figure the amount of average heat transfer that passed through the 4mm sample is (3.237 Watt) which is larger than all of the other samples. While the average heat transfer amount of other samples (6mm, 8mm, and 10mm) are (0.945, 0.761, and 0.691 Watt) respectively. Generally, the heat transfer amount decreased with increasing the thickness of pure paraffin, this is due to conduction heat transfer resistance and

paraffin thickness. According to the Fourier law of heat conduction, thermal resistance increases with increasing thickness of material so it results in decreasing heat transfer (Holman 1986).

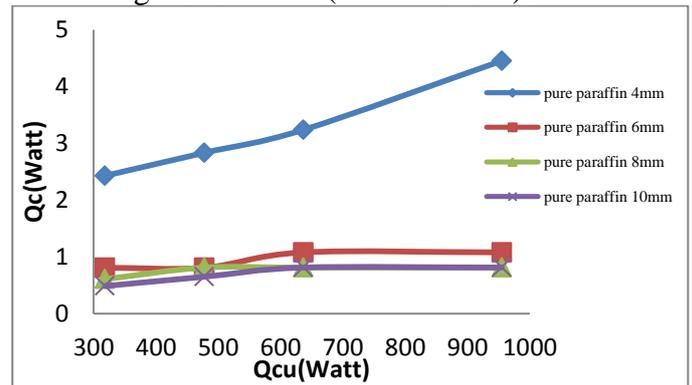


Figure (5) comparing heat transfer in pure paraffin between four different thickness module samples

Figure (6) illustrates the heat transfer of copper alone at the different power supply and with paraffin composite used. The graph shows four different thickness samples. One is 4mm thick of paraffin composite material of 0.1 mass fraction of aluminum and others 6mm, 8mm, and 10mm thick. From the figure, one can see that the average heat transfer amount which passed through a 4mm sample is (3.47 Watt) and it is larger than all of the other (6mm, 8mm, and 10mm) are (0.85, 0.81, and 0.74 Watt) heat transfer respectively. However, the change of heat transfer is very small for 6mm, 8mm, and 10mm thickness of composite paraffin, this is due to conduction heat transfer resistance and paraffin composite of 0.1 mass fraction of aluminum thickness. According to the Fourier Law of heat conduction, thermal resistance increases with increasing thickness of material so it results in decreasing heat transfer.

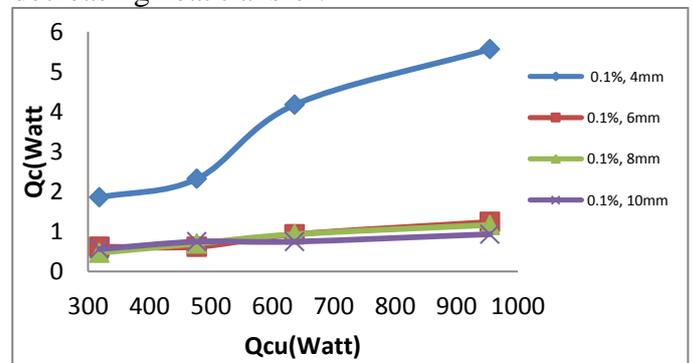


Figure (6) comparing heat transfer in 0.1% Al-paraffin between four different thickness module samples

Figure (7) shows the heat transfer of pure copper alone and with paraffin–Al composite for the same power supply and comparison of heat transfer for four different samples. One is 4mm thick of paraffin material of 0.5 mass fraction of aluminum and others 6mm, 8mm, and 10mm thick with the same fraction. Figure one shows that the average heat transfer amount which passes through 4mm thick sample is 5.77 Watt and it is greater than all of the other samples(6mm, 8mm, and 10mm) that have an average heat transfer amount (1.402, 0.968, and 0.917 Watt) respectively. Nevertheless, the change of heat transfer is very small among 6mm, 8mm, and 10mm thickness of Al-paraffin; this is due to conduction heat transfer resistance and paraffin composite of 0.5 aluminum mass fraction thickness. According to the Fourier Law of heat conduction, thermal resistance increases with increasing thickness of material so it results in decreasing heat transfer.

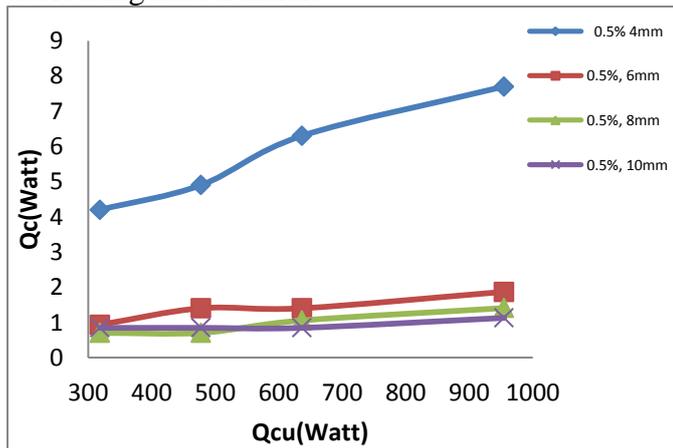


Figure (7) comparing heat transfer in 0.5% Al-paraffin between four different thickness module samples

Figure (8) represents the heat transfer of pure copper alone and with paraffin–Al for the same power supply and comparison of heat transfer for four different samples. One is 4mm thick of paraffin material of 0.8 mass fraction of aluminum and others 6mm, 8mm and 10mm thick with the same composition. The figure clearly indicates that the average heat transfer passed through 4mm thick sample is greater than all of the other samples and is about 7.45 Watt while the average heat transfer passed through three other samples 6mm, 8mm and 10mm are (1.42, 0.99 and 0.91 Watt) respectively. However, the change of heat transfer is very small for 6mm, 8mm and

10mm thickness of composite paraffin, this is due to conduction heat transfer resistance and paraffin composite of 0.8 mass fraction of aluminum thickness. According to the Fourier Law of heat conduction, thermal resistance increases with increasing thickness of material so it results in decreasing heat transfer. These results are in agreement with the results of (Shivan and Talabany 2017)

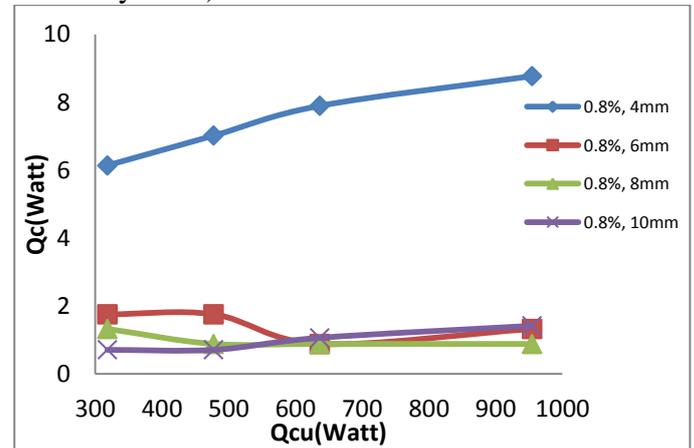


Figure (8) comparing heat transfer in 0.8% Al-paraffin between four different thickness module samples

Figure (9) illustrates the heat transfer of copper alone at the different power supply and with Al- paraffin used. The graph shows four different types of samples. One is 4mm thick of paraffin with the material of 1 mass fraction of aluminum and others 6mm, 8mm, and 10mm thick. From the figure, it is found that the average heat transfer which passed through 4mm sample is about (8.207 Watt) and it is larger than all of the other samples that the average heat transfer of other samples (6mm, 8mm, and 10mm) are (2.161, 1.128 and 1.71 Watt) respectively. However, the change of heat transfer is very small for 6mm, 8mm and 10mm thickness of composite paraffin; this is due to conduction heat transfer resistance and thickness of paraffin with 1 mass fraction of aluminum. According to the Fourier Law of heat conduction, thermal resistance increases with increasing thickness of material so it results in decreasing heat transfer.

Figure (10) represents the heat transfer of pure copper alone at the different power supply and with Al-paraffin used. The graph shows four different types of samples. One is 4mm thick of paraffin with the material of 2 mass fraction of

aluminum and others 6mm, 8mm, and 10mm thick. As shown in the figure the amount of average heat transfer that passes through the 4mm sample is (14.63 Watt) which is larger than all of the other samples. While the average heat transfer of other samples (6mm, 8mm, and 10mm) are (3.707, 2.08 and 1.933 Watt) respectively. Generally, heat transfer amount decreased with increasing the thickness of Al-paraffin, this is due to conduction heat transfer resistance in paraffin species which has low thermal conductivity. According to the Fourier Law of heat conduction, thermal resistance increases with increasing thickness of material so it results in decreasing heat transfer.

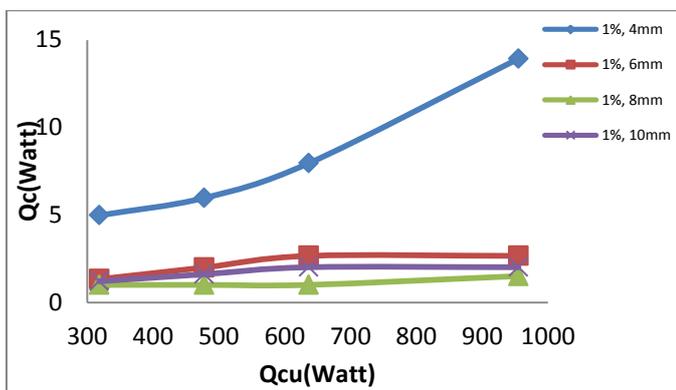


Figure (9) comparing heat transfer in 1% Al-paraffin between four different thickness module samples

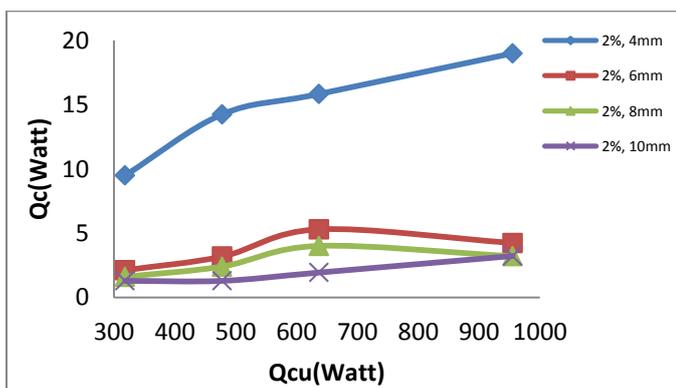


Figure (10) comparing heat transfer in 2% Al-paraffin between four different thickness module samples

Figure (11) shows the comparison of heat transfer that passed through a 4mm thick module between pure paraffin sample and five different Al powder mass fraction samples. Generally, the heat transfer is increased by increasing the power

supply for each sample. The average heat transfer of pure paraffin is 3.237 Watt and this is slightly increased to 3.478 Watt by adding 0.1% Al powder. Heat transfer improved with adding Al powder in general. As shown in the figure 2% Al-paraffin sample has the largest average heat transfer (14.634 Watt) than the other samples. This is due to thermal conductivity enhancement by adding Al powder, as shown in figure (15) thermal conductivity of the composites increased with increasing mass fraction of aluminum powder.

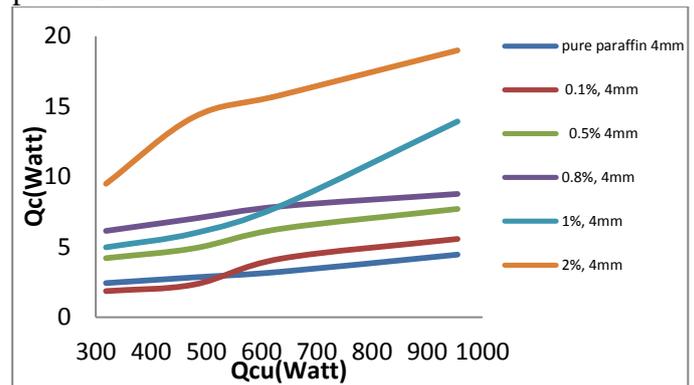


Figure (11) 4mm sample comparison of heat between paraffin and Al mass fractions

Figure (12) shows the comparison of heat transfer that passed through a 6mm thick module between pure paraffin sample and five different Al powder mass fraction samples. Generally, the heat transfer is increased with increasing the power supply for each sample, however, for 2% Al-paraffin composite heat transfer decreased when power supply higher than 6V as a result of different ambient temperatures between tests. The average heat transfer of pure paraffin is 0.945 Watt and this is increased to 1.066, 1.403, 1.699 and 2.161 Watt by adding 0.1, 0.5, 0.8 and 1% Al powder respectively. As shown in the figure 2% Al-paraffin sample has the largest average heat transfer (3.707 Watt) than the other samples. In general, the figure indicated that the Heat transfer improved by adding Al powder. This is due to thermal conductivity enhancement by adding Al powder, as shown in figure (15) thermal conductivity of the composites increased with increasing mass fraction of aluminum powder.

Figure (13) shows the comparison of heat transfer that passed through an 8mm thick module between pure paraffin sample and five different Al

powder mass fraction samples. Generally, the heat transfer is increased with increasing the power supply for each sample; however, for 2% Al-paraffin composite heat transfer decreased when power supply higher than 6V as a result of different ambient temperatures between tests. The average heat transfer of pure paraffin is 0.761 Watt and this is slightly increased to 0.814 Watt by adding 0.1% Al powder. In general, the figure indicates that the Heat transfer improved by adding Al powder. As shown in the figure 2% Al-paraffin sample has the largest average heat transfer (2.805 Watt) than the other samples. This is due to thermal conductivity enhancement by adding Al powder, as shown in figure (15) thermal conductivity of the composites increased with increasing mass fraction of aluminum powder. These results are in agreement with results from (Ho and Gao 2009) which used Alumina nanoparticles in paraffin.

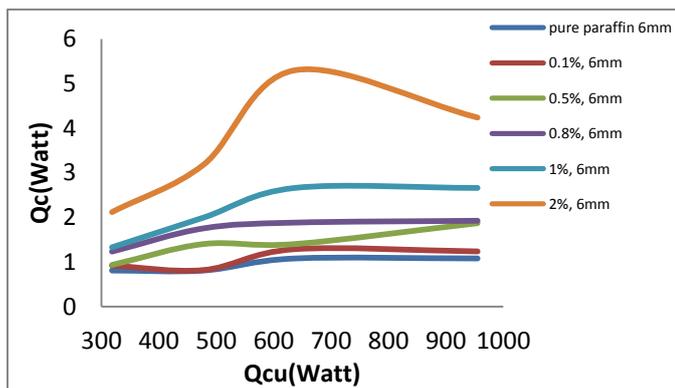


Figure (12) 6mm sample comparison of heat between paraffin and Al mass fractions

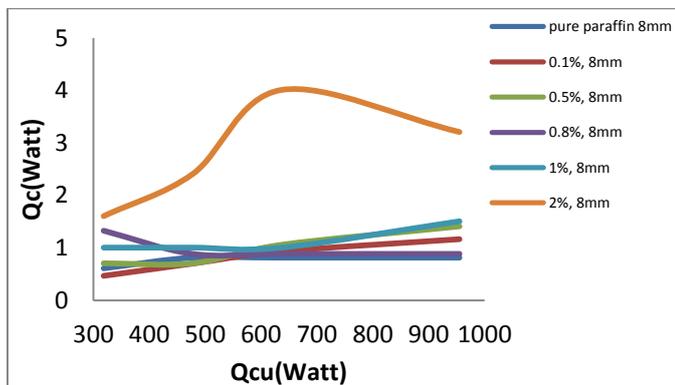


Figure (13) 8mm sample comparison of heat between paraffin and Al mass fractions

Figure (14) shows the comparison of heat transfer that passed through a 10mm thick module between pure paraffin sample and five different Al

powder mass fraction samples. Generally, the heat transfer is increased by increasing the power supply for each sample. The average heat transfer of pure paraffin is 0.691 Watt and this is increased to 0.746, 0.917, 0.974 and 1.710 Watt by adding 0.1, 0.5, 0.8 and 1% Al powder respectively. As shown in the figure 2% Al-paraffin sample has the largest average heat transfer (1.933 Watt) than the other samples. In general, the figure indicated that the Heat transfer improved by adding Al powder. This is due to thermal conductivity enhancement by adding Al powder, as shown in figure (15) thermal conductivity of the composites increased with increasing mass fraction of aluminum powder.

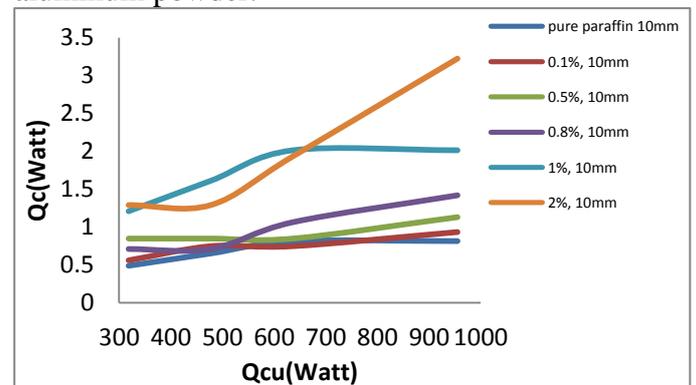


Figure (14) 10mm sample comparison of heat between paraffin and Al mass fractions

Figure (15) shows the comparison of average heat transfer between pure paraffin and five different Al mass fractions for each module sample, as shown in the figure for 4mm thick module sample the average heat transfer significantly increase with increasing Aluminum mass fraction it reaches 10.634 Watt for 2% Al-paraffin which is 2.28% higher than average heat transfer of pure paraffin. For 6mm sample the average heat transfer of pure paraffin is 0.945 watt it is increasing by 7.027%, 27.183%, 30.545%, 48.225%, 268.479% by adding 0.1, 0.5, 0.8, 1, 2 Al mass fraction respectively, the thermal conductivity curve in the figure indicates that increasing of average heat transfer with increasing aluminum mass fraction it refers to thermal conductivity enhancement in paraffin by aluminum as it has high thermal conductivity than paraffin. It can be seen that the value of thermal conductivity changed from $0.264 \text{ W m}^{-1} \text{ k}^{-1}$ to $0.919 \text{ W m}^{-1} \text{ k}^{-1}$ with increasing of Aluminum mass ratio, compared with the thermal

conductivity of pure paraffin, it is increased from 14.74% to 299.5%.

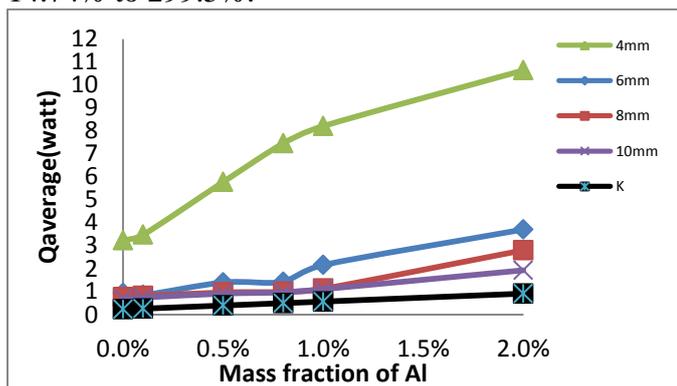


Figure (15) average heat transfer comparison between paraffin and Aluminum mass fraction for each sample

4 CONCLUSIONS

Paraffin wax considered most prospective phase change material for use in thermal energy storage systems because it has a desirable melting temperature range, low cost, commercial availability and good latent heat capability (Zhao, Lu et al. 2010), however, it has low thermal conductivity. Embedding aluminum powder in the paraffin enhances the thermal conductivity of paraffin wax. Based on the presented experimental study following conclusion can be drawn,

1. Thermal conductivity value changed from (0.263 W m⁻¹ K⁻¹) to (0.918 W m⁻¹ K⁻¹) with increasing the mass fraction of aluminum powder from (0.1% to 2%) correspondingly.

2. Adding aluminum powder with mass fraction range (0.1-2%) increases heat transfer and this heat gain is proportional to increasing aluminum mass fraction in paraffin wax.

3. The charging time decreases as the Al mass fraction is increased according to the percent mass fraction used.

4. Heat transfer which passed through the PCM is decreased with increasing thickness of paraffin composite.

An experimental study concerning heat transfer performance of the higher mass fraction of aluminum in paraffin PCM composite shall be presented in the future.

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