Experimental Investigation on Melting Heat Transfer of Paraffin Wax-Al₂O₃ Storage System

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Abstract

Background: A system of Latent Heat Thermal Energy Storage (LHTES) based on paraffin wax (n-octadecane/C₁₈ H₃₈) have low heat transfer rates during either melting or freezing processes. To enhance paraffin wax thermal conductivity, alumina (Al₂O₃) as a material which high conductivity was employed. Paraffin wax was dispersed with alumina homogeneously with volume fraction 2%, 4%, 6%, 8% and 10%. Objective: This paper examines the thermal conductivity enhancement using paraffin wax as a heat storage material by mixed with alumina (Al₂O₃) particles. Results: At starting heat, paraffin wax absorbs sensible heat and then latent heat which takes place at a temperature nearly constant. Similarly, at the beginning of the heating process, temperature increases rapidly until paraffin reach its melting temperature and tend to increased constantly after the temperature reached 60 °C. Conclusion: The addition of Al₂O₃ particles which have a high thermal conductivity could able to increase thermal conductivity of paraffin wax as a heat storage media. Adding amount of Al₂O₃ particles will reduce latent heat thermal of energy storage material. The conduction heat transfers dominantly during melting and freezing processes. Alumina particles is play significantly in the solidification process comparing to melting process. During freezing process, solid layer was formed on top surface of heat exchanger and remain stable. It can be concluded that by adding alumina particles could increase heat extraction during solidification process. As a results, it produces low latent heat and high thermal conductivity.
Keywords: Latent Heat Thermal Energy Storage; Phase Change Material; Melting Heat Transfer; Paraffin wax-Al₂O₃.

Introduction

Increasing energy consumption and greenhouse gas emission as well as climbing in fossil fuel prices are the main of driving forces for utilizing of renewable energy. One of the renewable energy utilization that widely used is solar energy for producing electrical energy or for heating water. However, solar energy has some drawback due to is the intermittent nature of solar radiation and the amount of radiation that are affected by time, weather conditions and latitude. To adjust energy production to consumption, it is necessary needs to store energy for periods of time.

Thermal energy storage (TES) system is considered particularly suitable technology to store excess energy that would otherwise be wasted and used it for another time[1]. The system consists of a mass of material that capable to store thermal energy in the form of heat or cold. Based on its phase change, the thermal energy storage can be classified as sensible heat, latent heat and thermo-chemical energy storage. Among the types of energy storage, latent heat thermal energy storage (LHTES) system is a more attractive technology due to its higher density of energy storage capabilities. Furthermore, as comparison to the conventional sensible heat thermal energy storage (SHTES) system, LHTES system has smaller volume and less weight for a same amount of energy stored.

One of the most important elements in latent heat energy storage system is heat storage material. A lot of studies whose conduct by researcher in this area usually use salt hydrates, paraffin and organic compounds as storage material [2]. However, some of those materials having low thermal conductivity and insufficient time for melting and solidification process which reduces the overall power of the heat storage device and limiting the application of the materials[3].

To overcome this problem, various studies have been conducted to identify the ideas to increase heat transfer rate, including using a mixer, or a slurry flow in heat exchangers. However, those methods increase the cost and complexity of thermal energy storage unit. Since, further researches are needed to increase the rate of heat transfer in LHTES which could be focused on material selection and design of heat exchanger.

Mettawee, et. al[4], conduct a study to examine a method of increasing the thermal conductivity of paraffin wax by adding aluminum powder. The average particle diameter of aluminum powder used was 80 μm. Tests performed by varying mass fraction of aluminum powder which are 0.1, 0.3, 0.4, and 0.5 of the total mass of paraffin wax-aluminum for using in a solar collectors system. The ability of the material to store heat was examined by flowing water at a temperature log (T = 30 ± 2 °C) to a collector for absorbing the heat. The flow rate of water varied in 0.15 and 0.34 liter/min. Test results of heat transfer coefficient for paraffin wax-aluminum powder is greater than use only paraffin wax as a heat storage material.
Arasu[5] studied numerically the performance of the phase change material paraffin wax-alumina (Al$_2$O$_3$) in a concentric tube. The results show that amount of heat absorption can be increased by applying paraffin wax with alumina as compared to paraffin wax as phase change material.

Hamdani, et. al[6] investigated characteristics of melting heat transfer of latent heat thermal storage unit with finned tube. The experimental results show that heat transfer characteristics presenting similarity for heat exchanger tube. At initial heating process was dominated by conduction but at melting temperature dominated by convection heat transfer.

This paper examines the thermal conductivity enhancement using paraffin wax as a heat storage material by mixed with alumina (Al$_2$O$_3$) particles. To obtain reliability information paraffin wax-Al$_2$O$_3$ as the thermal storage material, a custom testing devices was developed in heat exchanger form to determine storage capacity of heat absorption and release cycle.

**Experimental Method**

This research is conducted in three main stages. The first stage is testing of paraffin wax thermal properties as a heat storage material using DSC (Differential Scanning Calorimetry). The second stage is preparation of heat storage material mixed with alumina particle (Al$_2$O$_3$). Alumina particles applied to fill and increase thermal conductivity of material. Furthermore, heat exchanger device was developed to investigate heat transfers characteristics and test paraffin wax-Al$_2$O$_3$ as a heat storage material. Paraffin wax is used as core material of latent heat storage media. The physical properties of paraffin wax including latent heat, melting temperature and specific heat are measured using DSC. Density of paraffin wax was measured using Differential Thermal Analyzer equipment (DTA). The objectives of this research is to investigate the heat transfer characteristics of the use of paraffin wax-particle alumina (Al$_2$O$_3$) as a heat storage material. To achieve these objectives, a rectangular tube heat exchanger with a heating fluid conductor tube is applied. The main components of the test are a heat exchanger, water heating tubes, pumps, data acquisition and computer.
Figure 1. Schematic of heat transfer characteristics test setup

Heat exchanger used in this research is made of flexi glass 270 cm of width, 500 mm of length and 70 mm high. On the inside of heat exchanger, copper tube with diameter 12 mm are mounted as shown in Fig. 2. For temperature measurement, K-type thermocouple with diameter 5 mm is connected directly with the data acquisition and computer is used.

Figure 2. Heat exchanger device

Testing characteristics of heat transfer in heat storage material performed by using water heat transfer fluid. To find the heat transfer characteristics of paraffin wax in the melting process, water is heated and maintained at a constant temperature of 5-8 °C above the melting temperature. Then, the water is flowed through the tube pass the heat exchanger. The temperature changes in inlet water and outlet of heat exchanger are measured using a thermocouple. Tests carried out until the PCM temperature reaches its melting temperature. For recording, the measurement data is used by the data acquisition interval of 5 seconds of data collection. PCM then cooled
using water at room temperature is 28-31 °C to obtain information on the heat transfer characteristics of PCM in the freezing process.

**Results**

The results obtained from DSC including saturated temperature, latent heat enthalpy and heat capacity of paraffin wax is shown in Table 1.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Paraffin Wax</th>
<th>Al₂O₃</th>
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</thead>
<tbody>
<tr>
<td>Density [kg m⁻³]</td>
<td>750</td>
<td>3600</td>
</tr>
<tr>
<td>Specific heat [J kg⁻¹K⁻¹]</td>
<td>2890</td>
<td>765</td>
</tr>
<tr>
<td>Thermal conductivity [W m⁻¹K⁻¹]</td>
<td>0.21 if T&lt;Tsolid</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>0.12 if T&lt;Tliquid</td>
<td></td>
</tr>
<tr>
<td>Latent heat [KJ kg⁻¹]</td>
<td>173.4</td>
<td>--</td>
</tr>
<tr>
<td>Melting temperature[°C]</td>
<td>52.24</td>
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</tr>
</tbody>
</table>

Heat transfer characteristics of storage material are shown in the form of temperature changes on material melting and freezing processes. Test results using paraffin wax as a thermal storage material shown in Fig.3. It can be seen from the graph, at the beginning of heating, the measurements at T3 point show the temperature increases rapidly until reach the melting temperature paraffin wax and then starts to slow down. It can be stated that at the beginning of heating, hot paraffin wax absorbs sensible and then followed by the absorption of latent heat which takes place at a temperature nearly constant.

Figure 4, show heat transfer characteristics of paraffin wax-Al₂O₃ with volume fraction 4%. As graph shown, at the beginning of the heating process temperature increases rapidly until paraffin reach its melting temperature and tend to increased constantly after the temperature reached 60 °C. This indicates that after the PCMs fuse and reach the liquid phase, the dominant heat transfer occurs in the process is convection. It is also to be noted that on T1 and T5 did not reach 55 °C. It proves that the PCM which is at the top of the tube has melted completely and the result of natural convection in the liquid phase as a results in movement of fluid into the tube.
Figure 3. Paraffin temperature distribution

Figure 4. Paraffin temperature distribution with 4% of Al₂O₃

Heat transfer characteristics of paraffin wax - Al₂O₃ with volume fraction 2%, 4%, 6%, and 10% are shown in figure 5 and figure 6. The graph shown that similar result with the previous test obtained. At the initial stage when heat getting started, temperature of thermal storage material increase rapidly up to melting temperature of parafin wax. At parafin temperature attains ≥ 55 °C, the rate of temperature remain constant. It shows that after paraffin wax - Al₂O₃ melting and getting liquid phase.
Based on experimental results, it can be concluded that alumina particles has effected significantly in the process of solidification rather than melting process. It occurs due to freezing process of heat transfer storage material is dominated by conduction heat transfer. During compaction, dense layer formed top surface of heat exchanger and remain stable. Even though, natural convection process occur in liquid phase of thermal storage material in the previous stage, it drastically decrease due to freezing processes. At this stage heat transfer modus dominated by conduction heat transfer. Similar result reported by KhodadadianHosseinizadeh[7] that stated adding amount of particles could able to increase heat transfer extraction during solidification process. It occurs due to low of latent heat transfer and high thermal conductivity.
Conclusion

The addition of $\text{Al}_2\text{O}_3$ particles which have a high thermal conductivity could able to increase thermal conductivity of paraffin wax as a heat storage media. However, the addition of particles will reduce the heat latent of energy storage material. Since, it causing predominantly conduction heat transfer process during melting and freezing processes. Moreover, the effect of alumina particles is play significantly in the process of solidification comparing to the melting process. It occurs due to solidification process dominated by conduction is contradictive with melting process. During freezing process, solid layer formed on top surface of heat exchanger and remain stable. It can be concluded that by adding alumina particles could increase heat extraction during solidification process. As a results, it produces low latent heat and high thermal conductivity.

Reference