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STUDY ON THERMOPHYSICAL PROPERTIES OF PHASE CHANGE MATEIRAL FOR LOW THERMAL APPLICATION

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Abstract***: This paper is aimed at to study the thermophysical properties of phase change material for low thermal application. This study find the thermophysical properties such as melting point, latent heat of fusion ,specific heat capacity and thermal conductivity. Commerical grade Phase Change Mateiral of stearic acid is selected for this stuy. As the thermophysical properties of phase change material play a major in effective design of thermal energy storage system. The value thermophysical properties of PCM influence in numerical simulation also. The accuracy of the value of thermaophysical properties are needed to be considered. This study tried to get the accurate value of thermophysical properties of commercial grade steraric acid.***

Keywords: ***thermal energy storage, stearic acid, thermophysical properties***

I. INTRODUCTION

Thermal energy storage (TES) is an advanced energy technology that is increasing attraction interest for thermal application such as space and water heating, cooling and air conditioning [1]. Thermal energy storage using phase change materials (PCMs) provide an effective way of accumulating thermal energy, due to their high capacity to store heat at a constant or near constant temperature [2]. Phase Change Materials (PCMs) are latent heat storage materials. As the source temperature rises, the chemical bonds within the PCM break up as the material changes phase from solid to liquid (as is the case for solid-liquid PCMs, which are of particular interest here). The phase change is a heat seeking (endothermic) process and therefore, the PCM absorbs heat. Upon storing heat in the storage material, the material begins to melt when the phase change temperature is reached. The temperature then stays constant until the melting process finishes. The heat stored during the phase change process (melting process) of the material is called latent heat. Latent heat storage has two main advantages: (i) it is possible to store large amounts of heat with only small temperature changes and therefore to have a high storage density; (ii) because the change of phase at a constant temperature takes some time to complete, it becomes possible to smooth temperature variations. They store 5 to 14 times more heat per unit volume than sensible heat storage materials such as water, masonry, or rock. A large number of PCMs are known to melt with a heat of fusion in any required range. These materials must exhibit certain desirable thermodynamics, kinetic and chemical properties. Moreover, economic consideration and easy availability of these materials should be kept in mind [3]. Fig.1 shows the change in stored energy of a PCM as a function of temperature. At the beginning of the heating process, the material is in a solid state. Before it reaches the melting point Tm, the heat absorb is sensible heat. Starting at the melting point the material undergoes a change of state form a solid to liquid. During this process, the material which absorbs heat is known as enthalpy melting.There is a very small amount of temperature change, nearly constant, and a large amount of heat can be stored [4]. PCMs themselves cannot be used as heat transfer medium. Heat transfer medium must be employed with heat exchanger to transfer energy from the source to the PCM and from the PCM to the load. The heat exchanger to be used has to be designed specially, in the low thermal diffusivity of PCMs in general.

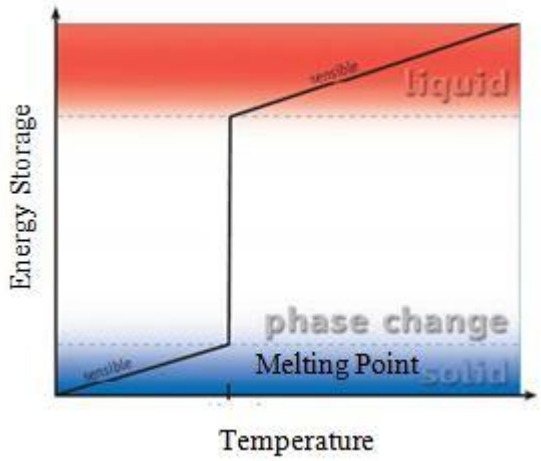

Fig.1Thermal Energy Stored in a PCM as a Function of Temperature

II. CLASSIFICATION OF PHASE CHANGE MATERIAL

A large number of phase change materials (organic, inorganic and eutectic) are available in any required temperature range. There are a large number of organic and inorganic chemical materials, which can be identified as PCM from the viewpoint of melting temperature and latent heat of fusion. However, except for the melting point in the operating range, the majority of phase change materials do not satisfy the criteria required for an adequate storage media as discussed earlier. As no single material can have all the required properties for an ideal thermal-storage media, one has to use the available materials and try to make up for the poor physical property by an adequate system design. For example, metallic fins can be used to increase the thermal conductivity of PCMs, the supercooling may be suppressed by introducing a nucleating agent or a "cold finger" in the storage material and incongruent melting can be inhibited by use of suitable thickness [5]. For their very different thermal and chemical behaviour, the properties of each subgroup

which affects the design of latent heat thermal energy storage systems. Organic phase change materials are classified as paraffins, non-paraffins and fatty acids. Organic PCMs are characterized by their ability to melt and freeze many times without phase segregation and degradation of their latent heat of fusion [5]. Inorganic phase change materials are classified as salt hydrated and metallic. Inorganic materials are classified as salt-hydrates and metallic.Salt hydrates are some of the oldest and most studied heat storage PCMs.The objective of this study is to get the accurate thermophysical properties of commercial grade stearic acid.

III. SELECTION OF PHASE CHANGE MATERIAL

Every latent heat thermal energy storage system requires a suitable PCM for use in a particular kind of thermal energy storage application. Matching of the transition temperature range of the PCM to the delivered energy temperature for a given application is an important aspect of the PCM energy storage. The feasibility of employing a latent heat storage material in a solar system should possess desirable properties as mentioned in the last section.

In the market, a wide range of PCMs with various melting points can be found. In the nature, the salt hydrates, paraffins and paraffin waxes, and fatty acids and some other compounds have high latent heat of fusion in the temperature ranging from 30ºC to 80ºC that is interesting for solar applications. Hasan, A. [6] and Baran, G. et.al. [7] Some fatty acids were also tried as PCMs for thermal energy storage by the researchers. They presented that stearic is a good PCM for solar domestic water heating. Stearic acid is selected for present study based on the following criteria: (i) desired melting point temperature (40 – 80ºC) (ii) ease of availability (iii) high latent heat of fusion (iv) high specific heat (v) nontoxic (vi) low cost.The analytical grade (100 % pure) stearic acid has melting point of 69°C [4].The analytical grade is very expensive and the stearic acid used in this study is one of commercial grade which is imported from Malaysia. Fig.2 shows the photo of stearic acid.

Fig.2 Stearic Acid

IV. MEASURING THERMOPHYSICAL PROPERTIES OF PHASE CHANGE MATERIAL

Thermal properties of a PCM play a vital role in PCM and latent heat storage research. The material properties of the PCM should be well known in order to obtain sufficiently accurate results with numerical methods. [8].The thermophysical properties of commercial PCMs are found to be much different from that quoted in the literature for laboratory grade PCMs [9]. Therefore, in the present study an attempt has been made to provide accurate values by performing measurement.

A. Measurement of Melting Point

There are different measurement techniques to measure the melting point of the PCM. The melting point of stearic acid is measured by using SaturateMelting. Point Apparatus (Model SMP-30), the product of Bibby Scientific Ltd. from United Kingdom by the authors. The apparatus is designed to measure and record the temperatures of crystalline samples held within capillary tubes. Up to three tubes are accommodated in an illuminated chamber within the aluminum block. The tubes are viewed through a magnifying lens on the front of the unit. The temperature range is ambient to 400°C and the heating rate is variable between 0.5°C per minute to 10°C per minute. Temperature measurement information is displayed on the screen. The measurement result of the melting point was concluded to be 55ºC. The measurements are also done in Department of Research and Innovation (DRI) under Ministry of Education, Myanmar.Fig.3 shows the photograph of Measurements.

(a) (b)

Fig.3 Photograph of Measurement: (a) Measurement Apparatus and (b) Situation of Measurement

B. Measurement of Latent Heat and Specific Heat Capacity

In order to measure the latent heat and specific heat capacity, the different measurement techniques can be used. These are (i) Drop Calorimeter (DC), (ii) Differential Thermal Analysis (DTA) and (iii) Differential Scanning Calorimeter (DSC). The DC method requires a long time, and the accuracy of the results is not good. A number of researchers have used DSC for measuring thermophysical properties of PCM [4]. In the present study, the properties are measured by using the Thermo gravimetric Differential Thermal Analyzer (TG/DTA). The measurement is done in the Department of Defense Services Science and Technological Research Center (DSSTRC), Pyin Oo Lwin, Myanmar. The TG/DTA can operate in either DSC or DTA mode. The TA Instruments DSC is a “HEAT FLUX” type system where the test specimen and reference material (which comprises of an empty aluminum pan with a lid) are placed on a thermoelectric disk which is enclosed in the same furnace as shown in Fig.4. The furnace is heated at a linear heating rate, and the heat is transferred to the sample and the reference pan through the thermoelectric disk. When the sample undergoes a phase transition, a temperature difference takes place between the sample and the reference. By using

calibrated experiments, this temperature difference is related to find the enthalpy change of the specimen. The difference in temperature is plotted either against the time or the temperature.

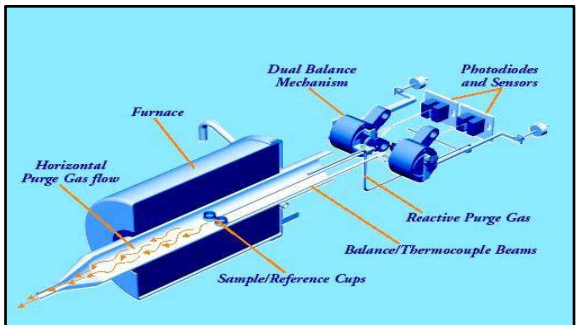

Fig.4 Measuring Principle of TA Instrument/ (DSC)

Measuring Principle

The temperature difference between them is proportional to the difference in heat flow between the two materials and the record is called the DSC curve. The solid state stearic acid of 6 mg is used as sample, the heating rate of 10ºC/minute is performed for the measurement and the output DSC curve is shown in Fig.5. The phase transition region shows a shape of an endothermic dome in the curve and the latent heat of fusion is the total area by integrating the curve and it is automatically calculated by the machine. The DSC output curve provides the value of 256 mJ/mg for the latent heat of fusion.

Specific heat capacity of stearic acid in solid and liquid sate can be calculated form DSC output curve by using the following equations:

$$C_p = \left[\frac{60 \times E}{H_r}\right] \times \frac{\Delta H}{m} \qquad (1)$$

Where E is the calibration constant (dimensionless), and H_r is the heating rate in (°C/minute), m is the sample mas in mg, ΔH is the difference in *y*-axis deflection between sample and the blank curves at the temperature of interest in m W, and C_p is the specific heat in j/gºC. The calibration constant is taken as 0.99 according to the Instrument manual. The estimated values of specific heat capacity for both solid and liquid sates are 2300 J/kg ºC and 2800 J/kg ºC, respectively.

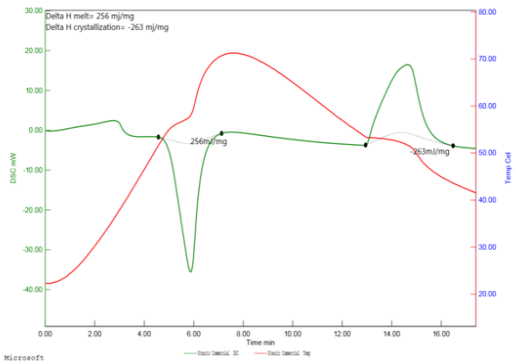

Fig. 5 DSC curve for Stearic Acid measured at 10 Cel / min

C. Measurement of Thermal Conductivity

A sample (the thickness: z_0) is placed between a heating upper rod and a cooling lower rod.One-dimensional temperature field is formed as shown in Fig.6. This temperature drop ΔT is considered to be composed of the two factors; the temperature drop ΔT_icaused by surface roughness, and the temperature drop ΔT_dcaused by thermal resistance of the sample itself. However, when the thermal interface material like grease is applied on the interface between the sample and the rods, the temperature drop ΔT_i could be neglected compared with the temperature drop ΔT_d.Therefore, by applying Fourier's law, the thermal conductivity of the sampleλ can be evaluated by the equation (2).

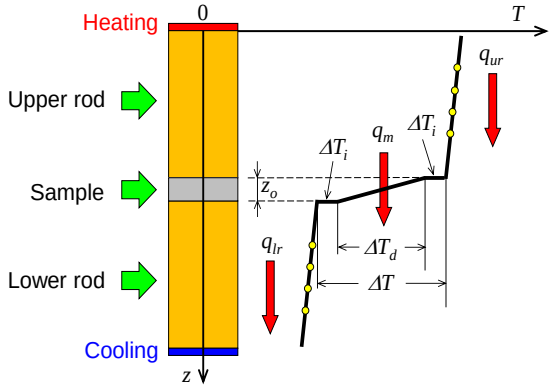

Fig. 6 Principle of Thermal Conductivity Measurement

$$\lambda = \frac{q_m}{\Delta T / z_0}, \qquad (2)$$

Where, q_m is the mean heat flux in the sample and it can be calculated by equation (3).

$$q_m = \frac{q_{lr} + q_{ur}}{2}, \qquad (3)$$

Where, q_{lr} is the heat flux in the lower rod and q_{ur} is the heat flux in the upper rod, which are evaluated by the temperature gradient and the thermal conductivity of the rod.

Fig. 7 Photograph of Samples

To measure the thermal conductivity of the stearic acid, the solid block of stearic acid with the thickness of 2.7 mm is made as the sample as shown in Fig.7. The schematic diagram of measuring apparatus is shown in Fig.8. The sample is placed between the upper and the lower rods. The top surface of the upper rod is heated by a ceramic heater while the bottom surface of the lower rod is water-cooled

using a cooling device (a small heat exchanger). The two rods and the sample are thermally insulated. In order to reduce the thermal contact resistance on the interface between the sample and the rods, a thermally conductive elastomer is used, and the mean nominal contact pressure of 0.063 MPa is applied to the sample by a lever and hanging weight arrangement. Each rod has four small holes for the temperature measurements. Thermocouples of 0.5 mm in diameter are inserted there by applying a thermal conductive silver plate.

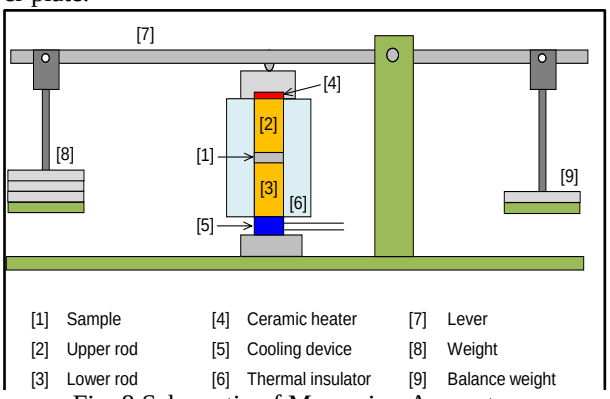

Fig .8 Schematic of Measuring Apparatus

The conductivity value obtained from this experiment is 0.36 W/mK.The thermal conductivy measurement are done in Kumamoto University in Japan.

D.Measurement of Viscosity and Density of PCM

The measurements of liquid density and viscosity were done in the Department of Defense Services Science and Technological Research Center (DSSTRC), Pyin Oo Lwin, Myanmar. The measurement is conducted with visco density meter, product from LEMIS. The visco density meter, Visco-Dense 250 m, is shown in Fig.9.The viscosity is 28.89 cP (0.0289 kg/ms) and the liquid density at the temperature 56.19 ºC is 854.2 kg/m3. The powder density and solid state density are conducted in Thermodynamics Laboratory in Department of Mechanical Engineering, Yangon Technological University. All the measurement results of thermophysical properties are summarized in Table I.

Fig.9Photograph of Visco-Dense Machine

TABLE I
ThermophysicalProperties of Stearic Acid

Property	Value
Molecular Formula	$CH_3(CH_2)_{16}COOH$
Molecular Mass	284
Melting Point (°C)	55
Latent Heat (kJ/kg)	256
Specific Heat Capacity (kJ/kg °C)	2.3 (solid)
Specific Heat Capacity (kJ/kg °C)	2.8 (liquid)@ 60 °C
Powder Density (kg/m3)	580
Solid Density (kg/m3)	899.3
Liquid Density	854.2
Thermal Conductivity (W/m K)	0.36
Dynamic Viscosity (kg/m s)	0.0289

V. CONCLUSION

This study provides the thermophysical properties of commercial grade phase change material (Stearic Acid). TG/DTA machine is used to perform the DSC output curve of the PCM. This study is expected to provide the accurate thermophysical properties of PCM for low thermal application . The melting point of PCM is 55°C.The measurement results shows that the selected PCM is have desired melting point , specific heat , latent heat for use in low thermal application.

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