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RESEARCH ARTICLE

EXPERIMENTAL INVESTIGATION OF LATENT HEAT THERMAL ENERGY STORAGE CHARACTERISTICS OF PARAFFIN/CARBON FIBER COMPOSITE AS PHASE CHANGE MATERIAL

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ABSTRACT

The objective of the present work is to investigate experimentally the thermal behaviour of a Latent Heat Thermal Energy Storage (LHTES) unit. A Thermal Energy Storage (TES) unit is designed, fabricated and integrated with blower to study the performance of the storage unit. The TES unit contains a mixture of paraffin Phase Change Material (PCM) and carbon fiber brushes (CFB). Experimental result shows that the brushes essentially improve the heat exchange rate during the charge and discharge processes even when the mass fraction of CFB is about 1%. It was concluded that the study PCM mixture was the most promising one for latent heat thermal energy storage applications due to its high thermal conductivity and also high charging and discharging rate.

INTRODUCTION

The development of efficient and cost effective thermal energy storage units is necessary for the utilization of solar energy, industrial waste heat, and distributed generation waste heat and so on. PCMs attract attention as thermal energy storage materials because their energy densities are much higher than those using sensible heat [3]. The latent heat thermal energy storage units previously studied are roughly classified into two types. One is a capsule type and the other is a shell and tube [2,4]. If vacant spaces are not considered for relaxing the volume change of the PCMs, the packing ratio of PCM in the former is no more than 0.74 (the closest packing of spheres), while that in the latter is usually is no less than 0.90 [5,7]. Thus, the shell and tube type is suitable for minimizing the volume of the thermal storage unit. However, the latter is inferior to the former regarding the heat transfer area between the PCM and the heat transfer fluid. This means that the shell and tube type hardly follows sudden changes in the load compared to the capsule type. To overcome this problem, extension of the heat transfer area and enhancement of the thermal conductivity using fins [10-13], honeycombs, porous media, fibers and so on may be useful. Actually, several researchers examined the efforts on fins and honey combs in the shell and tube type. However, no other technique was applied to this type to the best of the author's knowledge. In this study, CFB are used for enhancing the thermal conductivity of the PCMs [7]. The feature of the carbon fibers is that the volume fraction of the fibers is accurately and easily controlled [8]. In the present experiments, CFB with a thermal conductivity of 190 W/m K are mixed with paraffin wax PCM by weight 1% and the mixture is stored in finned cylindrical container. The thermo physical properties of PCM and CFB are given in table 1 [7]. The effect of the carbon fibers on the thermal responses of the heat exchanger is experimentally investigated.

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NOMENCLATURE

c_p	specific heat , kJ/kg K
L	length of TES tank, m
m	mass of PCM, kg
Q	total heat required, kJ
Q_H	heating capacity of heater, kW
Q_L	heat loss, kJ
r_1	inner radius of storage container, m
r_2	radius of insulation layer, m
T_{amb}	ambient temperature of HTF, 8C
T	average PCM temperature, 8C
V_C	volume of the PCM container, m^3

EXPERIMENTAL SETUP

A schematic diagram of the experimental setup is shown in Fig 2. The experimental set up consists of air blower, heater unit and PCM container. The cylindrical container has a volume of 0.49 m^3 with length of 0.3 m and it is placed vertically. The air from the blower passes through the heater enclosure and then heated air flows inside the tube which passes through the centre of the cylindrical PCM container.

Table 1. Physical Properties of mixture

Carbon fiber	
Diameter	10 µm
Thermal conductivity	190 W/m K
Specific heat	1000 J/kg K
Density	2120 kg/m^3
Paraffin wax	
Thermal conductivity	0.21 W/m K (Solid)
Density	900 kg/m^3 at 258C
Specific heat	2890 J/kg K at 258C

To enhance the heat transfer [1, 9], internal fins of length 0.270 m (8 Nos) are placed longitudinally inside the PCM container as shown in Fig 2.

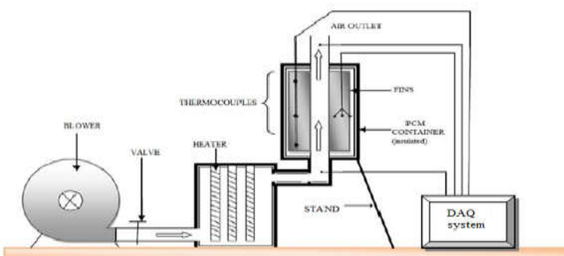

Fig 1. Experimental setup

The temperature of PCM mixture is measured by using three (K-type) thermocouples are placed radically (at 0.15 m from top of PCM container) and three thermocouples are placed at a distance of 0.03 m, 0.15 m, and 0.27 m from the top respectively. The TES tank inlet and outlet heat transfer fluid (HTF) temperature is measured by using two thermocouples. Agilent make Data Acquisition unit is used to record the series of temperature of PCM mixture and HTF during charging and discharging process. Three U shaped finned heaters (0.5 kW each) are placed perpendicular to the flow of blower outgoing air in the heater enclosure. HTF air flow rate from the blower is controlled by butterfly valve, which is placed in between the blower and the heater enclosure. Comark make Digital type pressure meter is used for measuring the mass flow rate of HTF. Ball valve is used to by-pass the air to the atmosphere. The TES tank, heater enclosure and HTF flow path are well insulated by using Glass wool insulation material.

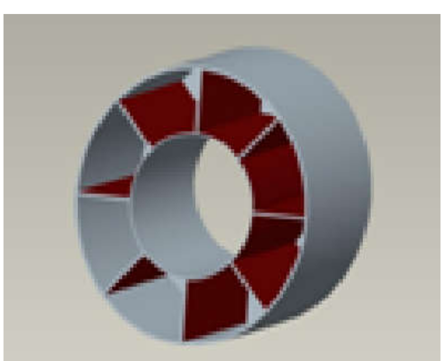

Fig 2. PCM container

EXPERIMENTAL PROCEDURE

The experimental trials are conducted for two different processes.

- Charging (storing of energy in the PCM)
- Discharging (extracting the stored energy from the PCM)

The charging experiments are conducted by allowing the HTF from the blower to the heater enclosure where the HTF gets heated and the heated air is sent to the cylindrical PCM container. Heat from the HTF is transferred to the PCM in the container through the container walls and the heat is absorbed in the PCM. When the melting point is reached, PCM inside the container is melted. Thus charging process is done. Temperature readings are taken at regular interval of time. The discharging experiments are carried out after switching of the heater unit. The ambient air from the blower is allowed to the PCM container which takes the heat from the PCM mixture. Thus the heat energy stored in the PCM mixture is discharged to the HTF. The heated air is vent out. Temperature readings are taken at regular interval of time as like in charging process. Discharging is done until the temperature of PCM mixture becomes equilibrium with the ambient air. The similar charging and discharging process is carried out for the paraffin PCM without CFB. Temperature readings are taken at regular interval of time. The history of recorded temperature during charging and discharging process are compared for with and without CFB.

RESULTS AND DISCUSSION

Charging process

The improvement in thermal conductivity of paraffin was tested by comparing melting times of the composite PCMs with that of paraffin. The experimental results shown in fig 3 represents the melting temperature curves of pure paraffin PCM and composite PCM. It is inferred from the figure that the melting time of composite PCM is decreased by 42% when compared to melting time of pure paraffin. This is due to increased heat transfer by high thermal conductivity of composite PCM. The reduction in melting time of composite PCM confirmed the improvement in thermal conductivity of the paraffin. From the fig 3, it is evident that the PCM mixture melts completely for a continuous period of seven hours which is very well lesser than that of without CFB. This is due to the higher heat transfer rate between HTF and PCM mixture. The history of HTF temperature at inlet and outlet of the TES unit with and without CFB is shown in Fig 4. It is observed from the figure that the temperature difference of HTF at inlet and outlet of TES tank with CFB is always higher than that of without CFB. This is attributed to the thermal conductivity effect of the PCM mixture, which absorbs more amount of heat energy from the HTF.

Discharging process

The temperature histories of PCM and HTF during discharging process (heat recovery) are reported. A comparative study is made between the with and without CFB and conclusions based on this study are presented Fig 5. Represents the temperature histories of PCM with and without CFB. It is seen from the figure that the heat transfer rate of composite PCM is increased by 25 % for solidification process

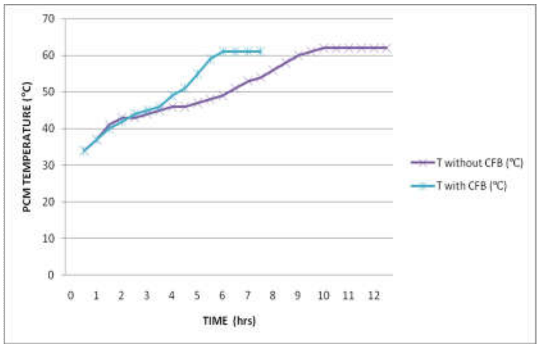

Fig 3. PCM Temperature Vs Time (with and without CFB)

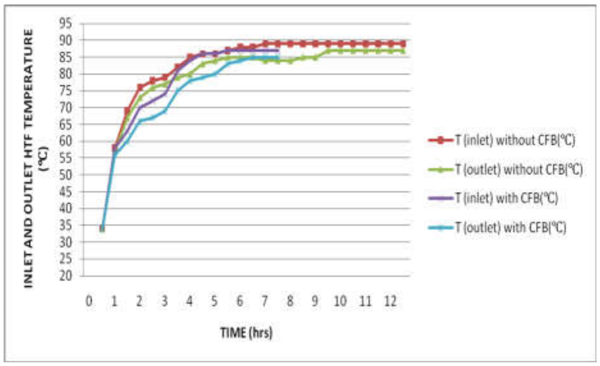

Fig 4. Inlet and Outlet HTF Temperature Vs Time (with and without CFB)

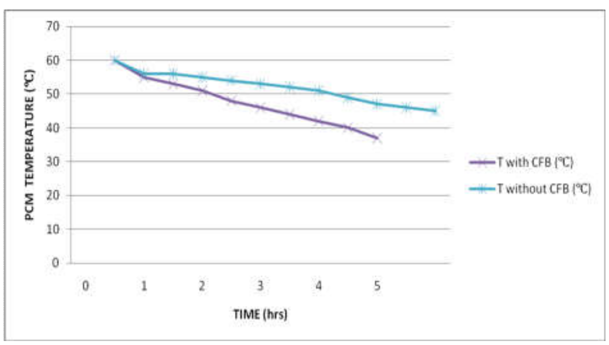

Fig 5. PCM Temperature Vs Time (with and without CFB)

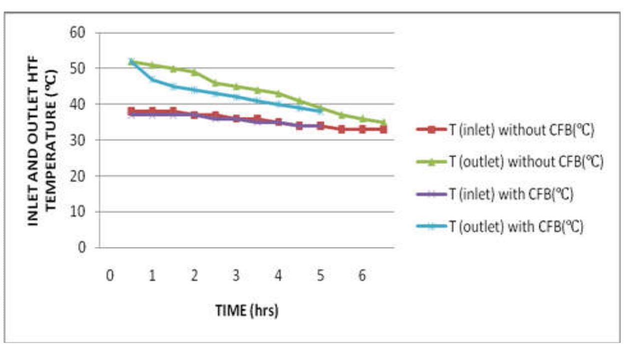

Fig 6. Inlet and Outlet HTF Temperature Vs Time (with and without CFB)

as compared with that of paraffin PCM. This because the composite PCM thermal conductivity is higher than that of pure paraffin PCM, so that the heat transfer enhanced in the conduction dominated solidification process. The history of HTF temperature at inlet and outlet of the TES unit with and without CFB is shown in fig 6. It is observed from the figure that the temperature difference of HTF at inlet and outlet of TES tank with CFB is always lesser than that of without CFB. This is due the increase of heat transfer because of higher thermal conductivity of the composite PCM.

Conclusion

In this paper, the comparative study of the thermal characteristics of latent heat thermal energy storage unit is investigated experimentally. The present experimental study suggests the following conclusions.

- The charging time decreased by 42% for composite PCM than pure paraffin PCM.
- The discharging time is decreased by 25% for composite PCM than pure paraffin PCM.
- The increased heat transfer rate during melting and solidification process is due to the high thermal conductivity of the composite.

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