Enhancement of Thermal Conductivity of a PCM Based Energy Storage System

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Abstract—The PCM based energy storage system is commonly used for storing waste heat and solar heat. Main disadvantage of such system is slow response during charging and discharging. In the present experiment thermal conductivity of wax based storage system is improved by embedding Copper, Aluminium and iron springs. Experiments shows that such systems show superior performance during charging and discharging compared simple system with wax as PCM.

Keywords—PCM, HTF, Charging, Discharging.

I. INTRODUCTION

A phase-change material (PCM) is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa; thus, PCMs are classified as latent heat storage (LHS) units.

PCMs latent heat storage can be achieved through solid–solid, solid–liquid, solid–gas and liquid–gas phase change. However, the only phase change used for PCMs is the solid–liquid change. Liquid-gas phase changes are not practical for use as thermal storage due to the large volumes or high pressures required to store the materials when in their gas phase. Liquid–gas transitions do have a higher heat of transformation than solid–liquid transitions. Solid–solid phase changes are typically very slow and have a rather low heat of transformation.

Even though PCM bases energy storage systems are commonly exists, the system is characterized with slow response. In the present experiment an innovative method is tried to enhance the thermal conductivity of conventional PCM based system.

Bansal and Buddhi(1992) A cylindrical storage unit in the closed loop with a flat plate collector has been theoretically studied by them for its charging and discharging mode. The interface moving boundary and fluid temperature calculations were made by using paraffin wax and stearic acid as PCM.

Najem et al., (1992). Developed a systematic approach that can be used to identify sites of real losses of valuable energy in a thermal device. Exergy analysis uses the conservation of mass and energy principles together with the second law of thermodynamics for the design analysis of energy systems. In a diesel engine, the first law analysis identifies significant energy losses because of cooling and heat lost in the exhaust gas of the engine.

But, when these losses are analyzed using the exergy technique, the actual exergy loss is insignificant compared to the thermodynamic losses within the engine. This work is aimed at illustrating the capability of exergy analysis to provide a systematic approach to pinpoint the waste and lost energy in a diesel engine and the TES system. This leads to significant improvement in energy utilization.

Farid et al. (1998) proposed and validated a modified form of enthalpy method, named as the Effective Heat Capacity method (EHC), where the effect of the latent heat of melting is included by using an effective heat capacity in the equation. Its value changes from a small value of solid or melts to a maximum value at the melting temperature. The variation of the effective heat capacity w.r.t melting temperature was assumed to be in four different profiles, such as the symmetrical and asymmetrical delta (triangular) functions and the symmetrical and asymmetrical rectangular functions.

Chaurasia et al(2000) A comparative study of solar energy storage systems based on the latent heat and sensible heat technique has been carried out to preserve the solar heated hot water for night duration by. For this purpose, two identical storage units were used.

One storage unit contained 17.5 kg paraffin wax (m.p. about 54.8°C) as the storage material packed in a heat exchanger made of the aluminum tubes and another unit simply contained the water as a storage material in a GI tank. Both units were separately charged during the day with the help of the flat plate solar collectors having same absorbing area. This study has revealed that the latent heat storage system comparatively yields more hot water on the next day morning as compared to sensible storage system.
Ismail and Henriquez (2000) presented a numerical study of the solidification of PCM encapsulated in a spherical capsule. A Pure conduction model with convective boundary conditions on the external surface of the sphere was used. Finite difference approximation and the moving grid approach numerical solution were followed. The results for the different Biot number and Stefan number were compared with the previous results of different researchers.

Zukowski (2007) described a short term TES unit based on an enclosed PCM in a polyethylene film bag. Paraffin wax was used as a storage medium. He presented the experimental results that included charge, discharge and pressure drop of the tested unit. The total enthalpy storage in the module was dependant on the PCM temperature change and ranged from 240 to 262 kJ/kg.

Sharma et al., (2009) TES systems have the potential to produce significant benefits and savings, particularly in low temperature heating and cooling applications. They are widely used in heat pumps, solar engineering and spacecraft thermal control applications. Use of PCMs for heating and cooling applications in buildings has been investigated in the past few years. There are large numbers of PCMs that melt and solidify at a wide range of temperatures, making them attractive in a number of applications.

Karthik Muruganantham, et al (2010) did an “Experimental study on Bio-based phase change material to improve building energy performance”. In the paper, experimental evaluation of organic-based Bio PCM in the building envelope was discussed and compared with traditional building construction without it. The setup was tested for climatic conditions of Phoenix, Arizona.

The investigation showed significant energy and cost savings as well as peak load time shift and reduction in energy usage during on-peak hours of summer months. Furthermore, BioPCM with its less flammable properties and its availability with a wide range of melting points is a proven technology for prospective energy conservation in buildings.

Antony and Velraj (2011) performed the transient analysis on the PCM based heat exchanger module by developing a mathematical model on apparent heat capacity formulation, in which the portion of the DSC curve (of the PCM) during the phase change period is interpreted as a triangular profile (299 ± 2 K, wide phase change temperature range) and a rectangular profile (299 ± 1, 0.4 and 0.25 K, narrow phase change temperature range), and concluded that the DSC results of 0.5 K/min and rectangular profile assumption is suitable for slow cooling rate experiments.

Rajesh Baby, C. Balaji (2012) did an “Experimental investigation on phase change materials based finned heat sinks for electronic equipment cooling”. The paper reports the results of an experimental investigation of the performance of finned heat sinks filled with phase change materials for thermal management of portable electronic devices. The results indicate that the operational performance of portable electronic device can be significantly improved by the use of fins in heat sinks filled with PCM.

Thus, it is clear that the idea of metallic coils for increasing thermal conductivity of PCM is not done. Hence the present experiments meant to study the effect of metallic coils in enhancing the response of a PCM based storage system

II. DETAILS OF EXPERIMENTAL SETUP

The experimental set up is designed for using wax as PCM material. Properties of wax is given below:

- Density of wax = 750 kg/m³
- Melting point of wax = 58-60°C
- Specific heat of wax = 209 KJ/kg

Water at a temperature ranging from 90 to 70 is used as the heat transfer fluid. This is to simulate the hot water from a solar water heater which is available typically in these ranges of temperature. Heat available, from engine cooling water also roughly fall in this range.

A cylindrical container of the following details is used as the PCM storage vessel:
1. Diameter of vessel = 10cm
2. Outer diameter of container = 17 cm
3. Thickness of insulation = 3 mm
4. Diameter of PCM container = 12 cm

The insulation material used is glass wool. The insulation is done for the lid in order to reduce the heat loss. Two valves are provided for inlet and outlet of HTF. A baffle is provided to support the PCM cylindrical containers. The baffle is also helpful in increasing the residence time of HTF inside the vessel. The entire system is placed on a stand. The tubes are also made of Aluminium to improve the conductivity so that heat reaches the PCM fast. To hold the tubes in vertical position, a thin disk with holes are used. To avoid PCM coming out of the tubes, a wooden cork (insulator) is provided at the top of the tubes. PCM used is Paraffin wax RT60 (Melting point is in the range 43°C to 45°C).
The reason for using paraffin wax in this experiment is because the temperature used in below 120°C and paraffin wax is the easily available PCM whose melting point lies in this range and paraffin wax is also cheap. The properties of this material don’t change after repeated cycles. The thermocouple used here is Calibrated Iron Constantan thermocouple. This thermocouple is suitable for measuring temperature below 150°C. Five thermocouples are used; sand a multi channel recorder was used. Aluminium and copper are in shape of coils, weight of the materials used is 5% of the weight of PCM material used. Total mass of wax used is 1000 grams. Wax was filled in the tubes after melting the Wax; it was filled in the tube giving provision for the rise in the level of wax once the materials are introduced. thermal conductivities of coil material are 40W/m²K, 402W/m²K, 200W/m²K fur Iron, Copper and Aluminium. The thermocouples are used to measure the temperature at different locations. Figure 1 shows the photograph of the complete set up. Figure 2 shows the cylindrical containers of PCM. Figure 3 shows the metallic springs used to enhance the thermal conductivity of PCM.

Figure 1 Photograph of storage vessel

Figure 2 PCM containers

Figure 3 Embedded metallic coils

III. RESULTS AND DISCUSSION

The wax is melted and poured into the container and allowed to freeze. The charging process is done then. Hot water is prepared at a temperature of 90°C. This is poured into the container. The PCM tubes together placed in the container and the lid is used to close the container. The baffle is placed inside. The temperature at various stations is monitored using a stop watch. The experiment is repeated and average value is used.
The discharging process is done using cold water available at 31°C. The rise in temperature of water and fall in temperature of wax is noticed. The experiment is repeated and average readings are used.

The PCM is then removed by melting. Coils of copper comprising of 5% by weight of PCM in a tube (5gm) are filled in each tube and molten wax is poured in and allowed to freeze. The time vs temperature rise is noticed for charging process with hot water at T=90°C as HTF. The temperature of wax is also noticed.

The discharging process is conducted with cold water poured in. Time vs temperature rise is noticed. The experiment is repeated. Average value is used for calculations.

Next aluminum coils are prepared comprising of 5% by weight of wax(5gm in a tube). The charging discharging experiment is conducted using hot water and cold water.

Further the experiment is repeated using iron coils. The temperature drop of hot water and rise of wax is noticed for charging. The temperature rise of cold water and fall of wax is noticed during discharging. The results are plotted in a graph for charging and discharging.

Figure 4 and 5 shows variation of temperature during charging process for both HTF and PCM. For plane wax HTF temperature dropped to 60°C in 50 minutes. For PCM enhanced thermal conductivity (named as modified) with copper it took 15 mts. PCM with aluminum took 25 mts and with iron took 40 mts. Reason being copper is having thermal conductivity (K) of 400 W/m°C. Aluminium have a K of 200 W/m°C. Iron having K of 40 W/m°C. The one with high K enhances the heat flow to PCM. The metallic coils will act as fins and will be helpful in accelerating the heat flow to the inner parts of PCMs where in normal cases there is high resistance to heat transfer. With iron the enhancement is marginal. Copper can be rated as the best material, if the heat transfer efficiency is the main consideration. From weight point of view aluminium is superior. Many previous studies, where powdered materials were added with PCM, were failure. Reason was settling of high density powders while the wax is being melted.

Figure 5 shows rise in temperature of wax during charging. For plane wax as PCM, it took approximately 2 minutes for the temperature to become 60°C (Melting point of PCM). With modified PCMs it took 15 mts, 10 mts and 8 mts for PCMs embedded with Iron, Aluminum and Copper. It is clear that with copper embedded PCM shows fast response while charging.

Figure 6 shows the discharge characteristics. With plane PCM, it took 40 mts for the wax temperature to drop to 50°C. With PCM embedded with copper, aluminum and iron it took 20 mts, 10 mts and 8 mts respectively for the temperature of PCM to drop to 50°C.

Figure 7 shows temperature rise of water during discharge. It took 40 minutes for water temperature to rise to 48°C from 31°C with PCM as plane wax. With heated PCM embedded with copper, aluminum and iron the time required for discharge becomes 20 mts, 10 mts and 8 mts. It can be seen that the time required for charging and discharging is considerably reduced with PCM embedded with metallic springs.

Figure 4 Temperature variation of water for charging for modified PCMs
V. CONCLUSIONS

Heat energy can be stored in the form of latent heat using a phase change material (PCM). Later as and when it can be recovered using a heat transfer fluid (HTF).

The metallic springs like copper aluminium and iron can be embedded in the PCM material. This material found to accelerate the charging process. The reason being high thermal conductivities and their fin like behavior in transporting heat from one location to another. The metallic springs also found to accelerate the discharge (heat recovery process).

Copper is found to be the best material in terms if its charging and discharging rates. The high thermal conductivity of Copper is responsible for this.

These findings will be useful in the design and operations of thermal energy storage systems, for building heating, solar energy storage, industrial waste heat recovery systems.
REFERENCES


