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Experimental Analysis of Latent Heat Thermal Energy Storage using Paraffin Wax as Phase Change Material

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Abstract— A significant amount of heat is wasted in manufacturing process, electricity generation, chemical and industrial process. Recovery and reuse of this energy through storage can be useful in conservation of energy. In the present study, a double pipe type heat exchanger has been designed and fabricated for low temperature industrial waste heat recovery using phase change material (PCM) paraffin wax (PW). Experiments were performed for two different mass flow rates and inlet temperature of heat transfer fluid (HTF) is maintained at constant in charging process. In order to recovery of heat during discharging process temperature of HTF is maintained at atmospheric temperature. The effect of mass flow rate on the performance of the system was studied. Calculations for amount of heat stored and released during charging (melting of PCM) and discharging (solidification of PCM) and heat discharging efficiency were also made. The experimental results show the feasibility of using PCM as storage media in heat recovery systems.

Index Terms —**Charging**, Discharging, Paraffin wax, *P***hase change material.**

I. INTRODUCTION

The increasing gap between the global demand and supply of energy is becoming a major threat as well as a challenge for the engineering community to fulfill the needs of the energy hungry society. Many forums and energy management groups have been formed to emphasize the storage of energy in both industrial and domestic sectors, in any possible form. The utilization of the abundant source—solar thermal energy and hot waste streams available in industries has attracted the scientific community to provide attractive solutions for the problems on energy conservation and storage/retrieval [1], [2]. Thermal energy can be stored in the form of sensible heat in which the temperature of the storage material varies with the amount of energy stored. Water or rock can be the best example [3], [4]. Alternatively thermal energy can be stored as latent heat in which energy is stored when a substance changes from one phase to another by either melting or freezing [5]. The temperature of the substance remains constant during phase change. Of the two latent heat thermal energy storage technique has proved to be a better engineering option due to its various advantages like large energy storage for a given volume, uniform energy storage/supply, compactness, etc[6].

A. Phase change material (PCM)

The normal paraffins of type C_nH_{2n+2} are a family of saturated hydrocarbons with very similar properties. Paraffins between C_5 and C_{15} are liquids, and the rest are waxy solids. PW is the mainly used commercial organic heat storage PCM. It consists of mainly straight chain hydrocarbons that have melting temperatures from 23 to 67 °C. Commercial grade paraffin wax (PW) is obtained from petroleum distillation and is not a pure substance, but a combination of different hydrocarbons. In general the longer the average length of hydrocarbon chain the higher the melting temperature and heat of fusion [7]. PW show no tendency to segregate. They are also chemically stable although reports slow oxidation when exposed to oxygen, requiring closed containers [8]. Stable properties after 1500 cycles in commercial grade PW show high heats of fusion, safe and non-reactive .They are compatible with all metal containers and easily incorporated into heat storage systems. Commercial PW, which melt around 55 ° C and a latent heat of melting of about 210 kJ/kg, has been used by a large number of investigators. When “selecting a PCM for a particular application, the operating temperature of the heating or cooling should be matched to the transition temperature”, and so the PCM selected should have a melting temperature around 40°C - 60°C [9].

Table I: Thermo-Physical Properties of Commercial Grade Paraffin Wax

Melting temperature of the PCM	54.32 °C
Latent heat of fusion	184.48 kJ/kg
Density of the PCM (liquid phase)	775 kg/m^3
Density of the PCM (solid phase)	833.60 kg/m^3
Specific heat of the PCM (solid phase)	2.384 kJ/kg °C
Specific heat of the PCM (liquid phase)	2.44k J/kg °C
Thermal Conductivity	0.15 W/m°K
Viscosity	6.3 X10^{-3}
Kinamatic Viscosity	8.31 X10-5 m^2/sec
Prandtl Number	1001.23
Thermal Expansion Coefficient	7.14 X 10-3 /°C

Thus due to this temperature range, its high heat of fusion, stability in heat cycling and economic reasons the material selected for the thermal store was PW. PW have low thermal conductivity in their solid state. This presents a problem when high heat transfer rates are required during the freezing cycle. It is reported that this problem can be decreased through the use of finned containers and metallic fillers or through combination latent/sensible storage systems [10]. PW have a high volume change between the solid and liquid stages. This causes many problems in container design. PW's are flammable this can be easily alleviated by a proper container. Also reports that PW can contract enough to pull away from the walls of the storage container greatly decreasing heat storage capacity [11].Table I shows the thermo physical properties of PW.

II. METHODOLOGY

Fig. 1 shows the Schematic diagram of the double pipe heat exchanger and the Fig. 2 shows the experimental setup. The technical specifications of the heat exchanger are given in the Table II and III. To enhance the effective thermal conductivity of the system, the copper tube is formed in coil form. 25 number of coils are used with the distance are 5cm between the coil. The outside of the outer pipe was insulated with 25 mm thick thermo cool to reduce the heat losses during charging and discharging process of the PCM. Outer tube was filled with 1.6 Kg commercial grade Paraffin Wax being used as Latent Heat Storage media. Type T Copper Constantan thermocouples were used for measuring the inlet and outlet temperature of heat transfer fluid (HTF) and the PCM temperature at two locations in the PCM tank A two-tank system was used for maintaining a constant pressure head for inlet water to maintain nearly constant flow rate. Heaters with thermocouple were also provided in the water tanks for constant inlet water temperature during charging mode. Flowing hot water through inner tube started the energy-charging test, and the stored energy was extracted by passing cold water in the inner tube. Temperature of water at inlet and outlet of the heat exchanger at four axial locations were measured simultaneously at an interval of 15 minutes

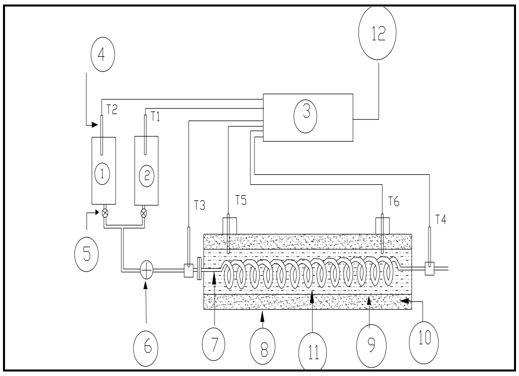

Fig 1: Double pipe Type Heat Exchanger with two stages feed water tank.

1. Cold water tank 2.Hot water tank
3. Temperature indicator 4 Thermocouple
5. Gate valve 6.Flow meter
7. Copper tube 8.PVC tank
9. MS tank 10.Thermo cool
11. Paraffin wax 12.Power supply

T1 = Temperature of hot water in the tank
T2 = Temperature of cold water in the tank
T3 = Temperature of hot water entering the PCM container
T4 = Temperature of hot water leaving the PCM container
T5 = PCM temperature at left locations
T6 = PCM temperature at right locations

Table II: Specifications of heat exchanger

Component	Material	Density	Volume	Mass
		kg/m^3	m^3	kg
PCM	Paraffin wax	834	0.001963	1.637
Piping	Copper	8816	0.00009613	0.847
Internal case	Mild Steel	7795	0.000110	0.859
Insulation	thermo cool	150	0.000587	0.088
External case	Plastic	1200	0.000785	0.942

Table III: Technical specifications of the heat Exchanger

Part name	Material/ Size	Part name	Material/ Size
Outer pipe material	Mild steel	Inner Tube length	3500mm
Outer pipe Diameter	50mm	Inner Tube Outer Diameter	6mm
Outer pipe Length	1000mm	Inner Tube Thickness	0.1 cm
Outer pipe thickness	0.4 cm	No of coil	25
Inner Tube material	copper	coil Diameter	40mm
PCM	Paraffin wax	Outer pipe Capacity	1.6 kg

Fig 2: Experimental setup

. III. EXPERIMENTATION

A. Charging process - Heat stored

The temperature distributions of HTF and the PCM in the PCM tank for two different mass flow rates are recorded during charging and discharging processes. The cumulative heat stored and system efficiency of process is studied in detail during the charging process. The first experiment was conducted with flow rate 20 litre per hour (lph) and the inlet temperature of the hot water was kept 85-90 °C and the atmospheric temperature is 32^0C. During the charging process the HTF is circulated through the PCM tank continuously. Initially temperature of PCM is 32^0C and as the HTF exchanges its heat energy to PCM, the PCM gets heated up to melting temperature (storing the energy as sensible heat). Later heat is stored as latent heat once the PCM melts and becomes liquid. The energy is then stored as sensible heat in liquid PCM. Temperature of the PCM and HTF are recorded at intervals of 15 minutes. The charging process is continued until the PCM temperature reaches maximum temperature. The temperatures of the HTF at inlet and outlet are recorded .Also the temperatures of the PCM at two locations are recorded. The basic equations [12] for heat transfer and the efficiency are

$$\eta = Q_S/Q_A \qquad (1)$$

$$Q_S = m_w * Cp_w * \Delta T \qquad (2)$$

$$Q_A = m_{pcm} * Cp_{pcm} * \Delta T + m_{pcm} L_{pcm} \qquad (3)$$

Where

Q_S = heat stored
Q_A = heat available
m_w = mass of HTF
Cp_w = specific heat of HTF
m_{pcm} = mass of pcm
Cp_{pcm} = specific heat of PCM
L_{pcm} = latent heat of PCM

The experimental results for charging process are shown in Fig. 3 and 4.From Fig. 3 it is observed that for the flow rate of 20lph, PCM temperature increasing gradually and takes 90 minutes to reach 62˚C.The total energy stored during in this process is 1276 kJ.Also Fig. 4 shows the same for the flow rate of 15lph.From fig. 5 it is observed that the energy stored during flow rate 20lph is higher than 15lph.

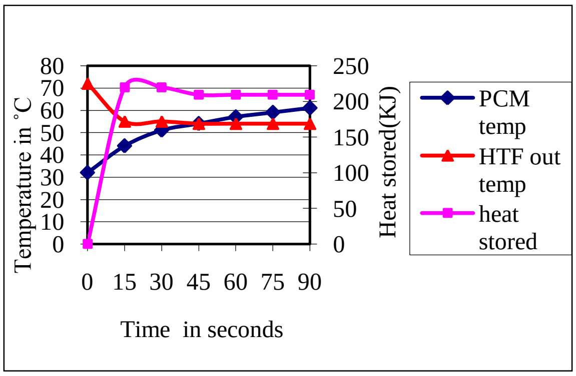

Fig 3: Variation of inlet and outlet water temperature & PCM axial temperature with time during charging mode with average flow rate of 20L/hr.

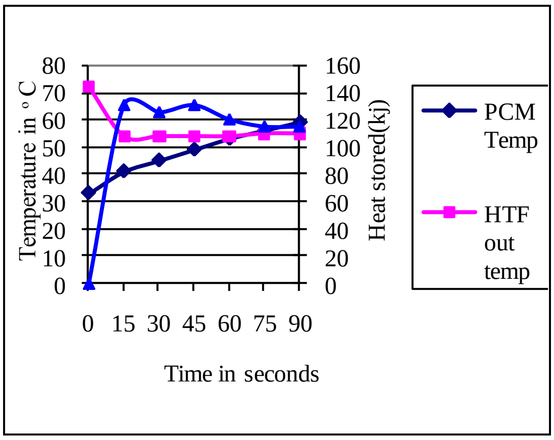

Fig 4: Variation of inlet and outlet water temperature & PCM axial temperature with time during charging mode with average flow rate of 15L/hr.

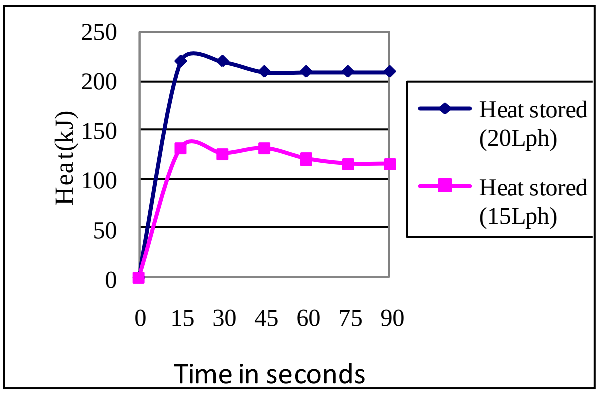

Fig 5: Heat stored for flow rate 20L/hr Vs 15L/hr

B. Discharging process

The discharging process was conducted with flow rate 20 lph and the inlet temperature of the cold water kept at the atmospheric temperature that is 32^0C. During the discharging process the cold water is circulated through the PCM tank now the heat energy stored in PCM is transferred to the cold water so the cold water temperature is increased. Temperature of the PCM and HTF are recorded at intervals of 15 minutes. The discharging process is continued until the PCM temperature reduces to atmospheric temperature. The temperatures of the HTF at inlet and outlet are recorded. Also the temperatures of the PCM at two locations are recorded. Like that the flow rate changed to 15lph and the PCM and HTF temperatures are recorded. The experimental results for discharging process are shown in Fig. 6 and 7. Fig. 6 shows the variation of inlet and outlet temperatures and PCM temperatures during discharging process for flow rate 20lph and Fig. 7 shows the variation of inlet and outlet temperatures and PCM temperatures during discharging process for flow rate 15lph. From Fig. 6 it is observed that for the flow rate of 20lph PCM temperature decreasing gradually and takes 90 minute to reach 35˚C temperature. When the PCM temperature high the HTF temperature high. The total energy stored during the charging process is retracted in this process. Also Fig. 7 shows the same for the flow rate of 15lph and it shows that after 90 minutes it reaches only 38˚C.

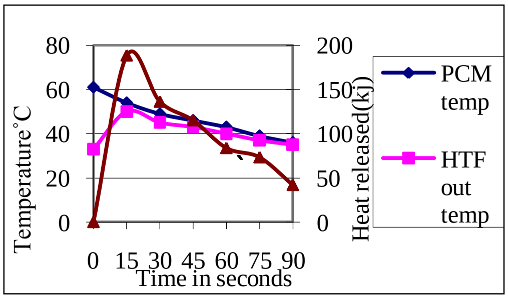

Fig 6: Variation of inlet and outlet water temperature & PCM axial temperature with time during discharging mode with average flow rate of 20L/hr.

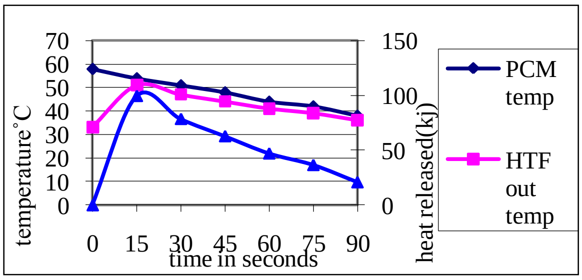

Fig 7: Variation of inlet and outlet water temperature & PCM axial temperature with time during discharging mode with average flow rate of 15L/hr

Fig. 5 and 8 graphically compare the heat stored and heat retracted when the flow rate is 20lph and 15lph.It is observed that the heat stored in 20lph is higher than 15lph.So when flow rate is increased the heat storing as well as heat releasing capacity increased.

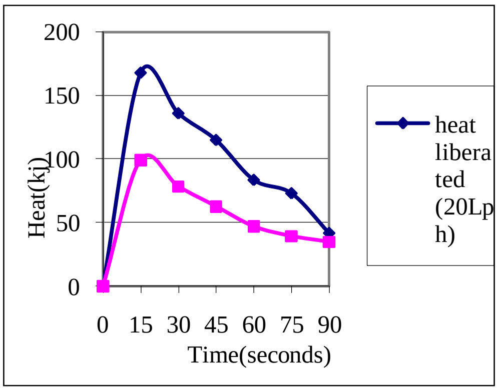

Fig 8: Heat liberated for flow rate 20L/hr Vs 15L/hr

Table IV. Shows the performance of the heat exchanger with two different flow rates. In this it is realized that when the flow rate is high the heat storing capacity is high.

Table IV: Thermal performance of the heat exchanger

Experiment No.	I	II
Flow rate during charging Mode (LPH)	20	15
Flow rate during discharging Mode (LPH)	20	15
Energy released by the hot water during charging mode(kJ)	1276.3	737.7
Time Interval during charging mode (s)	15	15
Energy gained by the cold water during discharging mode(kJ)	638.4	354.3
Time Interval during discharging mode(s)	15	15
Efficiency (%)	52	47

IV. CONCLUSION

The experimental results show the feasibility of using PCM as storage media in heat recovery systems. Latent heat storage (LHS) system with PCM can be successfully used for recovery and reuse of waste heat. When the flow rate is higher the efficiency of the setup increasing. To optimize the performance of the heat exchanger distance between tubes and mass flow rates should be selected carefully. Experiment with flow rate 20lph gives better efficiency than with 15lph flow rate.

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