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

Prof. Khalid Siddiqui[1] Ruchik S. Patel[2] Ujjval B. Patel[3]
[1]Professor [2,3]BE Student
[1,2,3]Department of Mechanical Engineering
[1,2,3]Shankersinh Vaghela Bapu Institute of Technology, Vasan, Gandhinagar, Gujarat, India

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).

Key words: Charging, Discharging, Heat Storage, Phase Change Material, Paraffin Wax

I. INTRODUCTION

Energy storage is the capture of energy produced at one time for use at a later time. A device that stores energy is sometimes called an accumulator or battery. Energy comes in multiple forms including radiation, chemical, gravitational potential, electrical potential, electricity, elevated temperature, latent heat and kinetic. Energy storage involves converting energy from forms that are difficult to store to more conveniently or economically storable forms. Bulk energy storage is currently dominated by hydroelectric dams, both conventional as well as pumped.

Ice storage tanks store ice frozen by cheaper energy at night to meet peak daytime demand for cooling. The energy isn't stored directly, but the work-product of consuming energy (pumping away heat) is stored, having the equivalent effect on daytime consumption. 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. 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. 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.

A. *Phase change material (PCM)*

The normal paraffin of type C_nH_{2n+2} are a family of saturated hydrocarbons with very similar properties. The longer the average length of hydrocarbon chain the higher the melting temperature and heat of fusion. PW show no tendency to segregate. They are also chemically stable although reports slow oxidation when exposed to oxygen, Requiring closed containers. 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 º 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.

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

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. 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. 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. Table I shows the thermo physical properties.

II. METHODOLOGY

To enhance the effective thermal conductivity of the system, the copper tube is formed in coil form. 15 number of coils are used with the distance are 2cm 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 1.5 Kg commercial grade Paraffin Wax being used as Latent Heat Storage media. Temperature indicator were used for measuring the inlet and outlet temperature of heat transfer fluid 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 Temperature indicator 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.

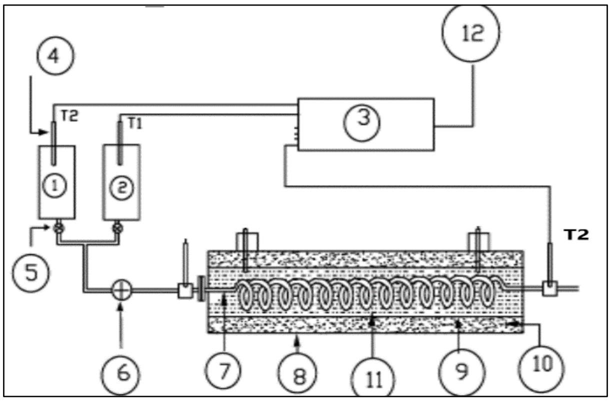

Fig. 1: Nomenclature of Type Heat Exchanger with two stages feed water tank.

The labels are as follows:

1) Cold water Tank
2) Hot water Tan
3) Temperature indicator
4) Thermocouple
5) Gate valve
6) Valve
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 leaving the PCM container

Fig. 2: Experimental Setup

Component	Material	Density Kg/m3
PCM	Paraffin wax	834
Piping	Copper	8816
Internal case	Mild steel	7795
Insulation	Thermo cool	150
External case	Plastic	1200

Table 2: Specifications of heat exchanger

Part Name	Material/Size	Part Name	Material/size
Outer pipe Material	Mild steel	Inner tube Length	3600mm
Outer pipe diameter	50mm	Inner tube Outer Diameter	8mm
Outer pipe diameter	1000mm	Inner tube Outer Diameter	0.2cm
Outer pipe diameter		No. Of Coil	15
Inner tube Material	Copper	Coil Diameter	40mm
PCM	Paraffin wax	Outer pipe Capacity	1.5Kg

Table 3: Technical specifications of the heat Exchanger

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 the inlet temperature of the hot water was kept 90 °C and the atmospheric temperature is 32°C . During the charging process the HTF is circulated through the PCM tank continuously. Initially temperature of PCM is 32°C 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 1 minutes.

The charging process is continued until the PCM temperature reaches maximum temperature. The temperatures of the HTF at inlet and outlet are recorded. The basic equations for heat transfer and the efficiency are

$$\eta = QS/QA$$

$$QS = mw * Cpw * \Delta T$$

$$QA = mpcm * Cppcm * \Delta T + mpcm\ Lpcm$$

Where

QS = heat stored
QA = heat available
mw = mass of HTF
Cpw = specific heat of HTF
mpcm = mass of pcm
Cppcm = specific heat of PCM
Lpcm = latent heat of PCM

The experimental results for charging process are shown in Fig.3.From Fig.3 it is observed that the PCM temperature increasing gradually and takes 50 minutes to reach 60˚C.Then, we start heater and increase temperature of PCM material. We record the temperature at interval of 1 minutes. We recorded the temperature of PCM at interval of 10˚C in between 60˚C to 90˚C of water temperature.

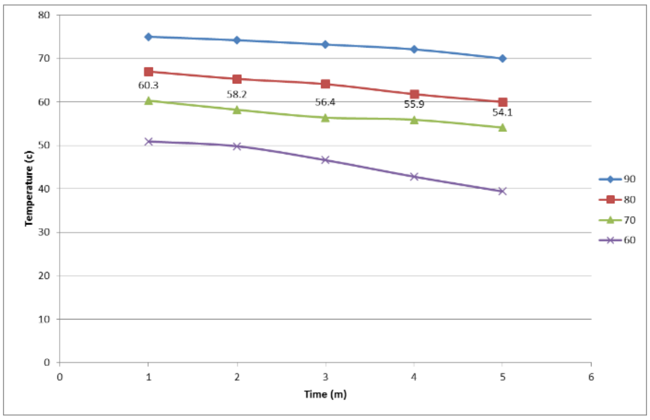

Fig. 3:

In Figure shown that we record five temperatures at interval of 1 minute at particular temperature.in shown in figure we take five temperatures at 90˚C and likewise for 80˚C, 70˚C and 60˚C temperature. As we show that the temperature of water decreasing because of PCM material absorbs heat from hot water passing through PCM.

B. Discharging process

The discharging process was conducted with the inlet temperature of the cold water kept at the atmospheric temperature that is 25˚C. 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 1 minute. 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. The experimental results for discharging process are shown in Fig. 5 Fig. 5 shows the variation of inlet and outlet temperatures and PCM temperatures during discharging process. From Fig. 6 it is observed that 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.

We recorded the temperature of PCM at interval of 5˚C in between 25˚C to 35˚C of water temperature. In Figure shown that we record five temperatures at interval of 1 minute at particular temperature.in shown in figure we take five temperatures at 25˚C and likewise for 30˚Cand 35˚C temperature. As we show that the temperature of water increasing because of PCM material relies to cold water passing through PCM.

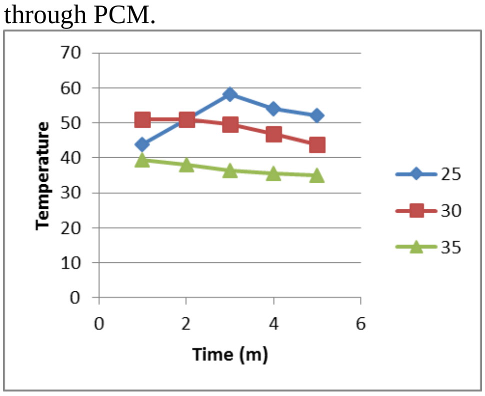

Fig. 4:

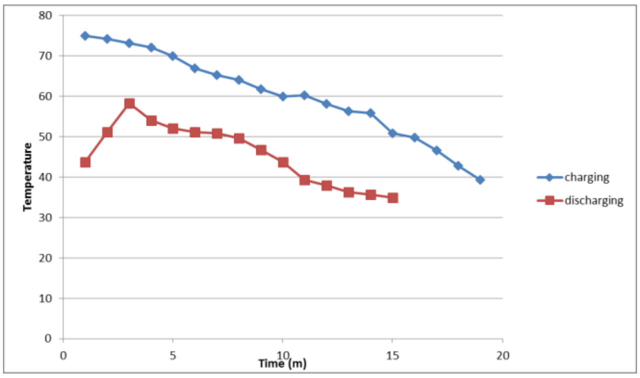

Fig. 5:

In figure 5 shows the combined process of charging and discharging process. We can see that in figure discharging Process temperature first increase and then decrease because when cold water entre in PCM tube heat energy Absorb due to heat transfer.

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 increasing. According to the phase change evolution, we notice that the paraffin can be used as thermal phase control. The useful heat gained increases by embedding aluminium powder to the paraffin. Latent heat storage is an effective method of storing wasted energy. To optimize the performance of the heat exchanger distance between tubes and mass flow rates should be selected carefully. The measurement of thermo physical properties of PCM, suitable heat exchanger with ways to enhance the heat transfer and provide the various designs to store the heat using PCM for different applications i.e. space heating/cooling, solar cooking, greenhouse heating, water heating and waste heat recovery systems.

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