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Experimental Investigation into Heat Transfer Enhancement of Phase Change Material

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Abstract: *It is known fact that thermal energy storage system is very promising technique used for storing energy. The present work investigates the performance of Latent heat storage system (LHS) using phase change material (PCM) i.e paraffin wax during charging and discharging. There are number of ways to improve thermal performance of energy storage systems. Thermal conductivity of PCM can be improved by addition of high thermal conductive nano particles. In this work, Latent heat storage experimental set up has been developed and series of experiments have been carried out. An appropriate geometry in the form of a concentric double pipe heat storage unit is chosen. Graphene Nanoparticles (GNP) are added to improve the thermal conductivity of PCM and its effect has been investigated. Charging and discharging performances have been evaluated in terms of contours of temperature and liquid fraction variation for both plain PCM and PCM with 3% GNP for process parameters such as Stephen number (St) and Reynolds number (Re). The obtained contours help in predicting and drawing concluding remarks for the effect of addition of GNP on charging and discharging performances of PCM..*

Keywords: Latent Heat Storage System.

I. INTRODUCTION

Thermal Energy Storage (TES) is one of the key technologies for energy conservation and therefore it is of great practical importance. One of its main advantages is that it is best suited for heating and cooling thermal applications. TES appears to be an important solution to correcting the mismatch between the supply and demand of energy. TES can contribute significantly to meeting societies needs for more efficient, environmentally benign energy use. TES is a key component of many successful thermal systems and a good TES should allow minimum thermal losses, leading to energy savings, while permitting the highest possible extraction efficiency of the stored thermal energy. The experimental and mathematical models are designed for LHS (Latent Heat Storage). Proposed work includes a description of the experimental and mathematical model of LHS with enhancement techniques.

In general, a coordinate set of actions has to be taken in several sectors of the energy system for the maximum potential benefits of thermal storage to be realized. TES appears to be an important solution to correcting the mismatch between the supply and demand of energy. TES can contribute significantly to meeting society's needs for more efficient, environmentally benign energy use. TES is a key component of many successful thermal systems and a good TES should allow minimum thermal losses, leading to energy savings, while permitting the highest possible extraction efficiency of the stored thermal energy.

There are mainly two types of TES systems i.e. sensible (e.g. water, rock) and latent (e.g. water/ice, salt hydrates). For each storage medium, there is a wide variety of choices depending on the temperature range and application. TES via latent heat has received a great deal of interest. The most obvious example of latent TES is the conversion of water to ice. The selection of TES is mainly dependent on the storage period required, i.e. diurnal or seasonal, economic viability, operating conditions etc. In practice, many research and development activities related to energy have concentrated on efficient energy use and energy savings, leading to energy conservation. In this regard, TES appears to be one an attractive thermal application and energy analysis as an important tool for analysing TES performances.

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II. PROPOSED WORK

Studies of concentric cylinder LHS, nanomaterial graphene nanoparticles in paraffin wax as a PCM is also proposed. Work is mainly carried experimental studies which encompasses effect of operational parameters on performance during charging and discharging of LHS. These studies mainly focused on solar thermal applications.

2.1 Objectives

The following are objectives of the research:

1. To study the charging/discharging processes in LHS. In order study heat transfer analysis and phase change behaviour of a PCM.
2. To investigate the effect of dispersion of nano-particles (for Graphene %=1%,2%,3%,) in PCM on the performance of LHS and comparison with basic system.
3. To study the effect of operating parameters, such as inlet flow rates and its temperature (75^0 C,80^0 C,85^0 C) on melting and solidification.

2.2 Research Methodology

The procedure and methodology adopted in this study has been described below:

1. Thorough literature survey is done in the area of enhancement in TES is analysed.
2. Experimental set up for charging and discharging is developed.
3. LHS with enhancement techniques are tested by varying operational parameters for charging and discharging.
4. Data generated through the experimentation is interpreted as to check the performance of LHS under consideration.
5. The results are presented graphically and discussed appropriately.

III. EXPERIMENTAL METHOD

In this project, thermal performance, heat storage capacity enhancement of a pipe in pipe heat exchanger-PCM storage system have considered experimentally and numerically. The pipe in pipe heat exchanger-PCM storage system is a kind of system that covered by a shell side of pipe in pipe heat exchanger with PCM. It can store and release energy during charging and discharging process. The core idea referred to this system is to improve the capability of storing and releasing energy at PCM storage system by blending paraffin with different percentage of graphene nanoparticles as a composite PCM.

3.1 Heat Exchanger Design

This heat exchanger is of tube in tube type. Here the flow through inner pipe is taken as transient flow which is in between laminar and turbulent. So, Reynold's No is Re =3000

i) Calculating inner diameter (D_i)

D_i = 24.23 mm

ii) Outer diameter of outer pipe (D_o)

D= 0.05 m

Hence inner diameter of outer pipe is 50 mm.

Taking the thickness of each inner and outer pipe is taken as 1 mm because there is almost atmospheric pressure conditions in both the pipe.

Hence Outer diameter of outer pipe is 52mm.

The inner pipe is taken as a copper because of high thermal conductivity and outer pipe is of PVC material because of low thermal conductivity so the heat will not dissipate to the surroundings.

Sample calculations are done for mass, volume, energy supplied, energy recovered, Reynolds number, Stefan number etc.

1. Volume of inner cylinder, V_{io}

$V_{io} = 0.000171766\ m^3$

2. Volume of outer cylinder, V_{oi}

$V_{oi} = 0.000589 m^3$

3. Volume of Temperature sensors, V_{TS}

Sensors of 3 mm diameter and 8.625 mm length

Sensors of 3 mm diameter and 5.75 mm length

Sensors of 3 mm diameter and 2.875 mm length

Total volume of sensors,

$V_{TS} = 2.64 \times 10^{-7}\ m^3$

4. Volume of PCM, Vp

$Vp = 4.1697 \times 10^{-4}\ m^3$

5. Mass of PCM, m_p

m_p = Density of liquid PCM × Volume of PCM

= 0.35859 kg

6. Reynolds Number (*Re*)

$Re = 1909.37 < 2000$

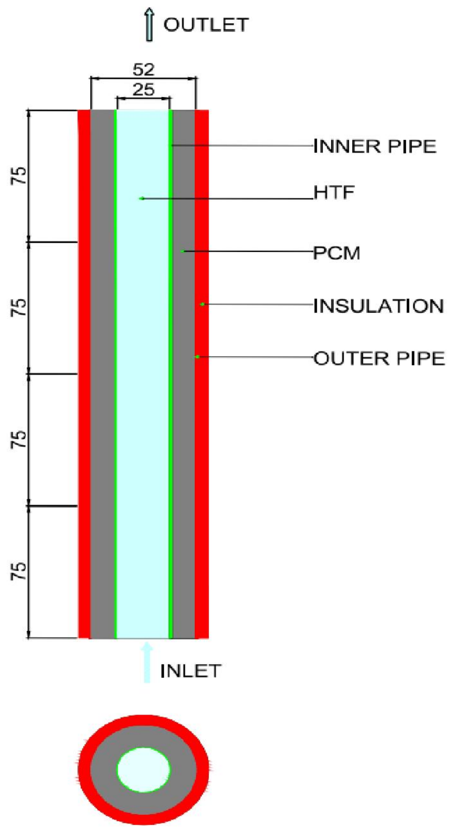

Fig 3.1 Geometry of Heat Exchanger

3.2 PCM Selection

In order to select the best qualified PCM as a storage media some criteria's are mentioned:

- Thermodynamic properties:
- Kinetic properties:
- Chemical properties:
- Physical properties:
- Economic properties:

3.3 Experimental Setup

Figure 3.2 shows block diagram of the experimental set up of concentric cylinder LHS. This is designed and fabricated for the testing of PCM. It consists of 1. LHS unit, 2. Hot / Cold water tank, 3. Flow measuring device, flow control valves and temperature measuring device (i.e. seven PT-100 thermo sensors with temperature recorder) to obtain temperature data. Figure 3.2 shows LHS consists of horizontal concentric cylinder with temperature sensors at different locations. HTF (water) is passed through inner cylindrical copper tube (L x OD x t; 0.3m x 27mm x 1mm). The outer cylinder is made up of PVC (Polyvinyl Chloride) pipe (L x ID x t; 0.3m x 52mm x 1mm). Six PT-100 thermo sensors having least count of 0.1 °C are used for measurement of temperatures of HTF and PCM in various locations.

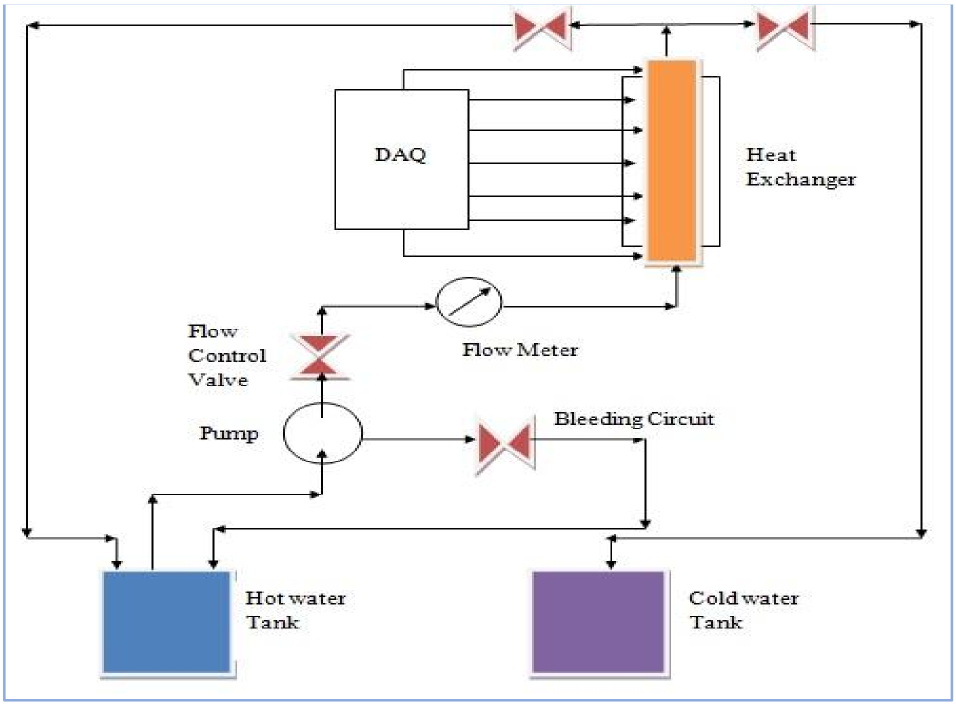

Fig. 3.2 Block diagram of experimental setup

Six thermo sensors (Th1 to Th5, Th out) are located at the positions of 0, 75, 150, 225 and 300 mm in the axial direction from the inlet of LHS for PCM and two for HTF inlet and outlet temperatures. Provision to adjust temperature sensor positions is made for measuring radially temperature distribution. Data logger is used to measure the temperatures from the thermocouple. The PCM of paraffin wax (0.45kg) is filled in the annulus of two concentric cylinders. Outer surface of outer tube is made by PVC having low thermal conductivity to prevent heat transfer to the surroundings.

3.4 Experimental Procedure

Experimental set-up and procedure are modified based on limitations of horizontal cylinder LHS experimentation. The vertical concentric cylinder LHS is developed to achieve the objectives.

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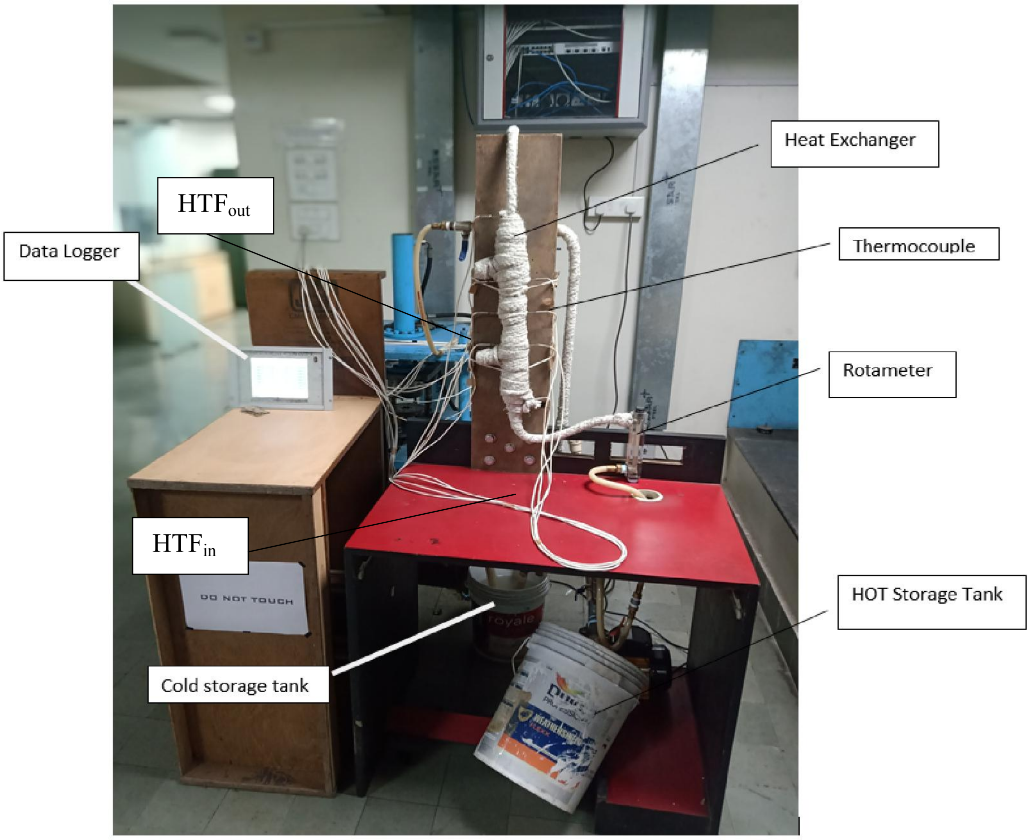

Fig. 3.3 Vertical position of the experimental setup

3.5 Operating Parameters

The selection of operating parameter is to study and analyse the proper heat transfer and it is somewhat related to the engineering applications. In order to have higher heat exchange and to avoid the evaporation of HTF, the maximum HTF inlet temperature is kept 85°C. Further, the maximum possible temperature attained in solar water heater application is about 70 to 85°C in the interval of 5^0C. The mass flow rates of HTF are varied ranging from 0.03kg/sec to 0.07kg/sec in the difference of 0.02 kg/sec. This mass flow rates are based on the three different conditions of flow i.e. 1.Laminar 2.Transient and 3.Turbulant so that it can be observed the effect of Re number on melting and solidification.

3.6 Properties of Phase Change Materials

PCM, Paraffins have been widely used for the LHS due to their high latent heat, varied phase change temperatures. They are also commercially available at reasonable cost. These PCMs are ecologically harmless and non-toxic. Paraffins are easily available. The Paraffins of CnH2n+2 are the family of saturated hydrocarbons with almost similar properties. Higher the value of n, the higher is the melting temperature and latent heat of fusion. Commonly used organic PCM is Paraffin wax whose melting temperatures are in between 23 to 67°C. These Paraffin were tested for thermal stability up to 2000 thermal cycles. Paraffin do not show degradation of thermal properties after repeated number of thermal cycles. Table 4.4.1 gives property data of paraffin wax.

SN	Property	Values
1	Density, ρ(Kg/m^3)	Solid/liquid(960/860)
2	Specific Heat, Cp (J/kg-K)	2000
3	Thermal conductivity, K (W/m-K)	0.2
4	Latent Heat, LHF (kJ/kg)	168

5	Melting point (K)	329-331
6	Dynamic viscosity, **μ** (Pa-sec**)**	0.004
7	Coefficient of Thermal expansion, k (1/K)	0.0001

Table 3.1 Thermophysical Properties of wax

Experimental Procedure

Operation of LHS with first time loading of PCM involved by pouring the PCM in liquid state from the caps provided on the LHS unit. The pouring temperature of liquid PCM is greater than the melting temperature by 10^0C.

Charging process

The charging process is started at 27°C PCM temperature. At this temperature PCM is in solid form. Throughout charging process, hot heat transfer fluid with a fix temperature and mass flow rate over the charging range of the PCM is passed into the HTF cylinder. The melting process is finished as soon as all the axial/radial temperatures are above the melting temperature range. Temperature data are recorded at intervals of 10 min.

Discharging Process:

The discharging period is initiated directly by passing the cold fluid into the inner cylinder. A fixed temperature and mass flow rate of HTF below solidification range, just after completing the charging process. Temperature distributions in the PCM and the inlet and outlet temperatures of the HTF are measured and recorded in the same way as in the melting period. Charging and Discharging of LHS is repeated for varying mass flow rate. Also inlet temperature is varied for charging process similar sets are obtained by dispersing graphene nanoparticles nanomaterial in PCM. The discharging time is taken nearly around one hour and recorded the readings.

IV. RESULTS AND DISCUSSION

This chapter collects experimental data for each thermocouple. Graphs for corresponding thermocouples are plotted based on experimental data to guarantee that the heat charging and discharging rate in the heat exchanger is symmetric. Heat charging and discharging calculations are made at every 10 minute period using the acquired data.

V. CONCLUSION

Melting process of PCM cylindrical heat exchanger is symmetric in radial direction.

1. It is concluded that at low Stefan no, melting rate of PCM is low as St increases, melting rate increases.
2. It is observed that there is exponential decrease in solid fraction during melting process while formation of liquid increases slowly. This effect is observed higher for as St increases.
3. As concentration of GNP is increased (i.e 3%), melting time is reduced. St number affects predominantly on melting time.
4. It is observed that effect of Stefan no on liquid fraction is significant and Re is negligible.
5. During charging (Melting)process trends of heat flux decreases and energy, entropy increases.
6. During discharging(solidification)process trends of heat flux increases and energy, entropy decreases.
7. Heat transmission rate has enhanced by roughly 61 percent during charging as a result of the inclusion of 3 percent GNP.
8. Heat transmission rate has enhanced by roughly 9% during discharge due to the inclusion of 3% GNP.

VI. FUTURE SCOPE

Even though good results are obtained from this work, still there is scope for further extension in various directions.

1. By addition of fins in axial and radial direction experiments can be conducted since fins are easy to manufacture, have simple arrangement and available at low cost.
2. Experiments can be conducted with other materials which are not considered in the present work. Different nanomaterial embedded and composite PCMs can be studied and analysed experimentally.

3. Study the performance of the storage system by varying the location and the mass of the PCM in the storage tank.
4. The numerical study may be extended to various geometrics and further investigations may be attempted under various geometrical parameters. Experimental investigations may be carried out for Shell and multiple tubes with fins.
5. Extending this methodology to waste heat recovery systems

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