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Experimental Investigation for Enhancement of Latent Heat Storage using Heat pipes in Comparison with Copper Pipes

Rupali.M. Patil [1], Chandrakishor Ladekar [2]
[1](Department of Mechanical Engineering, PCCOE, Pune University, Pune, INDIA)
[2](Department of Mechanical Engineering, PCCOE, Pune University, Pune, INDIA)

Abstract:- The work has been undertaken to study the feasibility of storing solar energy using Phase Change Materials (PCMs) utilising Heat pipes and copper pipes using the energy to heat water for domestic purposes when there are hours of low solar radiation. This ensures that hot water is available throughout the day.The PCM undergoes a phase change by absorbing latent heat, excess heat being stored as sensible heat. In this way, an analysis of Latent Heat Thermal Energy Storage with Heat pipes in domestic applications is done. The objective of the present work is to enhance the heat transfer performance in thermal energy storage system using PCM with heat pipes and copper pipes while the storage unit is integrated with solar collector (Flate Plate Collector) water heating system.The comparison is made between arrangements of 2 tanks, one with PCM and Heat pipes and other with PCM and Heat pipes. The Heat pipes effectiveness is thus justified out of the two arrangements. The results based on the Temperature, Mass Flow rate conditions, Time, are elaborated.

Keywords:- Heat pipes, Phase Changing Materials, Thermal Energy Storage.

I. INTRODUCTION

Due to increase in energy consumption, a great deal of fossil fuels is being used. This is a consequence of the present environmental problems, such as global warming, acid rain, etc. In order to decrease these problems, the use of renewable energy sources is being promoted. But the most freely available renewable energy source, called as the mother of all energies, the solar energy, present the drawback that there is a mismatch between the energy demand and supply. To cover this mismatch, the use of phase change thermal energy storage systems is required. Thermal energy storage (TES) proves to be an attractive and economical alternative for small, medium and large-scale use. Energy is accumulated in a storage medium, and the storage mechanism could be classified as sensible heat, latent heat, or chemical storage. Latent heat storage is new area of study and it received much attention during the energy crisis of late 1970's and early 1980's where it was extensively researched for use in solar heating systems. Although research into latent heat storage for solar heating systems continues, it is increasingly being considered for waste heat recovery, load levelling for power generation, building energy conservation and air conditioning applications. This work focusses the use of Latent heat thermal energy storage in domestic applications.

The system consists of two simultaneously functioning heat absorbing units. One of them is a solar water heater namely the solar Flate collector and other, a heat storage unit consisting of PCM (paraffin) and Copper and Heat pipe array. The water heater functions as it normally do and supplies hot water during the day. The storage unit stores the heat in PCMs effectively due to Heat pipes rather than same dimension's copper pipe and can supply hot water during the night. At the start of the day the storage unit is filled with water completely. This water is made to circulate between the heating panel (Solar Flat Plate collector) and both of the tanks. The water in the storage unit receives heat form the heating panel and transfers it in less time due to Heat pipes and copper pipes to the PCM.

II. LITERATURE REVIEW

There exists a need to study different theories related to the work. They are as under.

2.1Latent Heat Thermal Energy Storage

Latent heat thermal energy storage is attractive due to its property of high energy storage density. When compared to conventional sensible heat energy storage system, latent heat energy storage system requires a smaller weight and volume of material for a given amount of energy [4].Furthermore, latent heat storage stores fusion heat at a constant or near about constant temperature which correspond to the phase transition temperature of the PCMs. In practice, solid-liquid phase change is preferred because of simultaneous slight volume variation and high enthalpy variation.

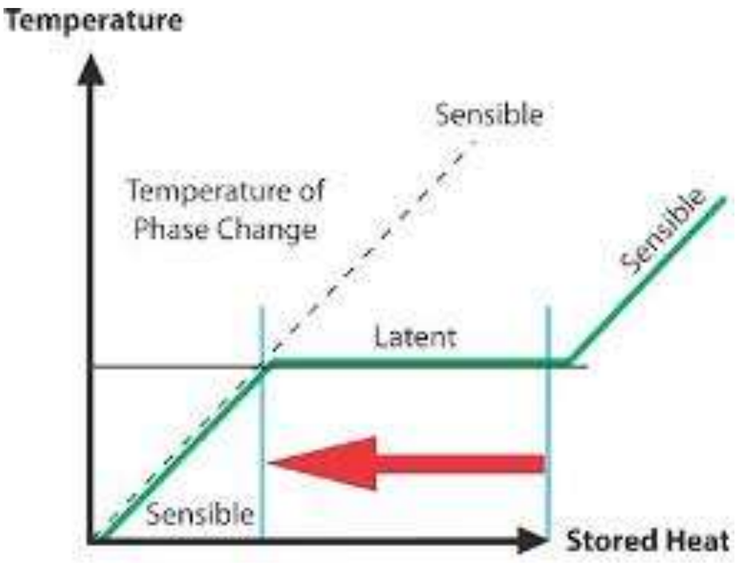

Fig 1 Principle of Latent Heat Storage

2.2 Phase Changing Material

The thermal storage/release technology based on the use of phase change materials (PCMs), which possess a great capacity of accumulation energy for consideration as heat storage media, has raised an important practical interest. This is mainly due to the high energy storage density during phase change process within a very narrow temperature range. These materials are used in applications where it is necessary to store/release energy tanks to the temporary phase change between the offer and demand of thermal energy.

However, as is well known, most inexpensive PCMs are characterized by low thermal conductivity for the solid and liquid phases, limiting the rates of solidification and melting. The large thermal resistance posed by the PCM has limited the use of LHTES in emerging applications such as large scale power generation in conjunction with concentrating solar technologies, and novel LHTES systems have been receiving increased research attention (e.g., One approach to compensate for the low thermal conductivity of PCMs is to use heat pipes or thermosyphons that are embedded in a PCM to increase heat transfer rates between a hot (cold) external fluid and the PCM solid–liquid interface during melting (solidification). Since heat pipes utilize vaporization and condensation of a heat pipe working fluid, they can operate with very low thermal resistance, with overall PCM phase change rates determined by a rather complicated conjugate heat transfer process involving the heat pipe (or thermo syphon) and the PCM. Moreover, compared to solid fins of similar dimensions heat pipes have a low thermal capacitance, further improving PCM melting or solidification rates. While selecting PCM, melting Temperature requirement should be fixed. Here, the requirement is at about 50°c. accordingly the PCM is selected.

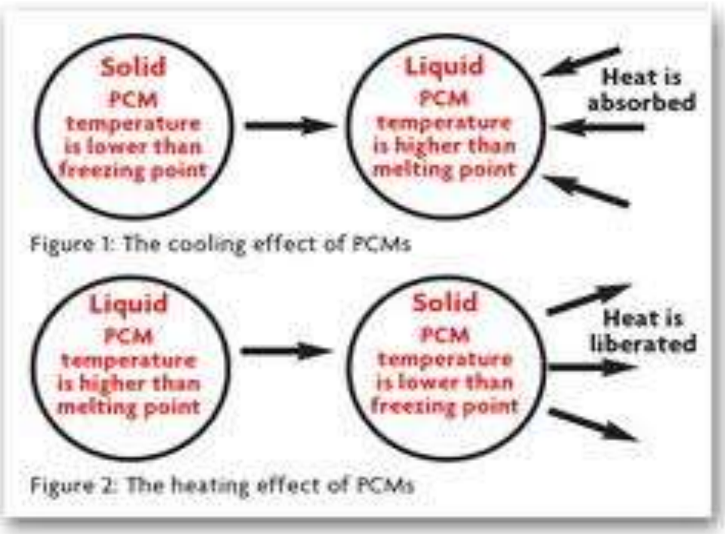

Fig 2.Principle of PCM

2.3HEAT PIPES-In Brief

Heat pipes were developed especially for space applications during the early 60´ by the NASA. One main problem in space applications was to transport the temperature from the inside to the outside, because the heat conduction in a vacuum is very limited. Hence there was a necessity to develop a fast and effective way to transport heat, without having the effect of gravity force. The idea behind is to create a flow field which transports heat energy from one spot to another by means of convection, because convective heat transfer is much than heat transfer due to conduction. A typical heat pipe consists of a sealed pipe or tube made of a material with high thermal conductivity such as copper or aluminium at both hot and cold ends. A vacuum pump is used to remove all air from the empty heat pipe, and then the pipe is filled with a fraction of a percent by volume of working fluid (or coolant) chosen to match the operating temperature. Alternatively, the pipe is heated until the fluid boils, and sealed while hot. Examples of such fluids include water, ethanol, acetone, sodium, or mercury. Due to the partial vacuum that is near or below the vapour pressure of the fluid, some of the fluid will be in the liquid phase and some will be in the gas phase. The use of a vacuum eliminates the need for the working gas to diffuse through any other gas and so the bulk transfer of the vapour to the cold end of the heat pipe is at the speed of the moving molecules. In this sense, the only practical limit to the rate of heat transfer is the speed with which the gas can be condensed to a liquid at the cold end.[1]

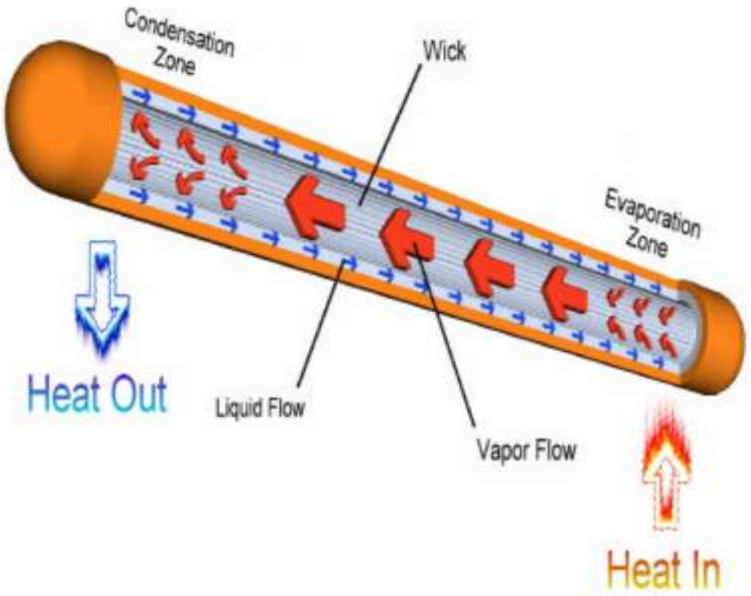

Fig 3.Principle of Heat pipe

It is also used at the Alaska pipe line, where you use the low temperature of the ground to cool the transported fluid down. The basic idea of heat pipes is based on an evaporation and condensation process. At the hot side, the working fluid is evaporated and at the cool side it condensates again

2.4 Operation

A heat pipe is broadly divided in three sections namely, evaporator, adiabatic and condenser. A typical heat pipe as shown in Fig 3 has one evaporator section that takes heat from a source. The heat absorbed in the evaporator causes change of phase of the working fluid and liquid changes to vapour. The increased vapour pressure in the evaporator causes the vapour to exit from the evaporator section and it travels through the adiabatic section. By Traveling the adiabatic section, vapour reaches the condenser region where condensation rejects the latent heat of the fluid to the sink. The condensed liquid is pumped back to the evaporator by a combination of the capillary pumping action and/or bulk forces. This fluid cycle is repeated during the normal operation of the heat pipe and can continue as long as there is sufficient vapour pressure and capillary pressure to support this operation At the evaporator end the liquid recedes into the wick pores so the menisci in the pores at the vapour interface are highly curved. On the other hand, the liquid menisci at vapour interface in the condenser end are almost flat. This difference in the interface curvature of the menisci at the vapour interface coupled with the surface tension of the working fluid causes a capillary pressure gradient at the liquid-vapour interface .This capillary pressure gradient pumps the working fluid against various pressure losses such as friction, inertia and against body forces [3]. This is illustrated in Fig 3.

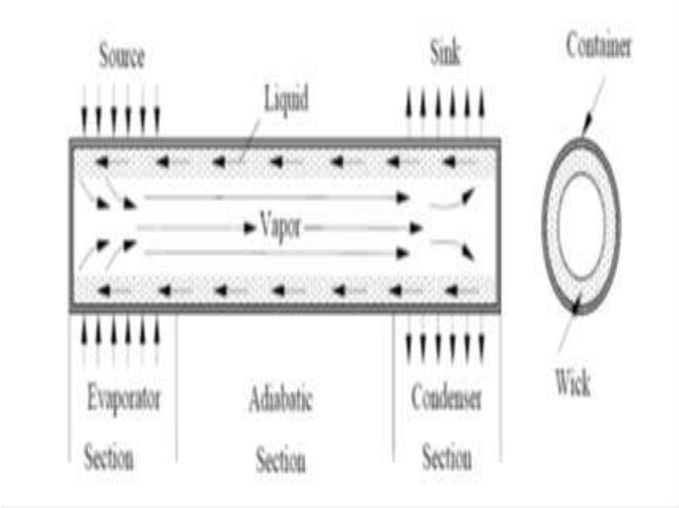

Fig 4.Schematic of operation of Heat pipe

E. Wick Structure

The wick provides a means for the flow of liquid from the condenser to the evaporator section of the heat pipe. It also provides pores that are required at the liquid–vapor interface for development of the required capillary pressure. An effective wick requires large internal pores in a direction normal conductive heat flow path for minimization of the radial surface to liquid–vapor surface temperature drop. To satisfy these requirements, following types of wick structure have been developed to the heat flow path. This will minimize liquid flow resistance. In addition, small pores are required for the development of high capillary pressure and a highly conductive heat flow path for minimization of the radial surface to liquid–vapor surface temperature drop.

Mostly Sintered, grooved and mesh type of wick structures are being used in Heat pipes .Out of these three, the sintered metal has proved to be the best [2]

Fig 4.Sintered wick Structure

F. Flat Plate Collector

The flat-plate collector is the simplest and one of the most effective means of collecting solar energy for use in systems that require thermal energy at comparatively low temperatures.It is now recognized that with the rapid depletion of fossil fuels, solar energy will be increasingly utilized. In comparison with collectors of the concentrating type, such as those used in high-temperature solar- furnace applications, flat-plate collectors offer these

Advantages:

(1) no complicated mechanisms for following the apparent diurnal motion of the sun are needed for their operation,

(2) Construction is simple and cost relatively low, and
(3) Diffuse as well as direct solar radiation is utilized. This last advantage is especially important in view of the fact that, of the total solar radiation received on the surface of the earth.

Basic to the design of any solar-energy utilization system in which fiat-plate collectors are used is the long-term average performance of these collectors. The long-term average performance, instead of the instantaneous rate of energy collection, is needed since the latter is extremely variable due to differences in cloudiness; since sufficient heat storage is usually provided, the average energy collection is also the useful energy collection.

This invention relates to solar heat collectors and has particular reference to flat plate collectors adapted to be located in a position to intercept and absorb solar radiation and to transfer the resultant heat to a fluid circulating within suitable conduits associated with the collectors. The protective glass panes are usually coated with low iron glass which promotes light and heat absorption while avoiding reflection. Flat plate collectors absorb the direct beam and diffuse solar radiation and are suitable for applications requiring moderate temperatures in the range of 50-100°C above ambient temperature. This is the requirement of project. They are fixed usually at an angle equal to the latitude of the location and the mechanical structures are simple since tracking is not required which again translates to little or no maintenance [8].

III. EXPERIMENTAL INVESTIGATIONS

The Experimental Investigations are being carried out in summer season in Pune.

3.1Experimental Setup

Experimental setup consists of a Flat Plate collector having 100 LPD capacity. There are two Latent Heat Thermal Energy Storage Tanks of 300mm×550mm, one, having Phase changing material, Paraffin ($C_{18}H_{38}$) and copper rods and the other having PCM with Heat pipes. Also there is third tank manufactured for sensible heat storage of the dimensions 300mm× 275mm.The outlet water of Flat plate collector is made to pass through one of the tanks and is then circulated to other two tanks. Photographs of the experimental setup shown with the solar collector connected to the TES tank are shown in Fig no.6. The stainless steel TES tanks has capacity of about 36 litres, out of which 18 litres is stored with wax and the remaining half is stored with water and this arrangement is capable of supplying water for a family of four. With an internal diameter of 300mm and a height of 550mm, it houses the PCM and copper pipes and allows for heat transfer between the copper pipes inserted half inside PCM and half in water. The same arrangement is done for other tank, but it is having Heat pipes in place of copper rods for comparison purpose. The copper material is having very high thermal conductivity; hence their pipes are compared with Copper heat pipes. There is a copper plate of 10mm thickness and 300mm diameter to make 2 compartments for PCM and water. In this way PCM which is on the upper portion of the tank will not be in any means come in contact with the water i.e. the HTF. The heat energy always try to give its maximum possible heat to the upper portion as its density goes on decreasing, hence the decision of placing the PCM on the upper portion of the copper plate is taken. The tank is insulated with 50mm of glass wool, density 50 and is provided with an aluminium cladding. RTDs are provided at four different locations of the storage tank and PCM temperature. The flow rate of the HTF through the system is measured using a Rotameter. There is water level indicator so that we can turn off the solenoid valve when the tank is filled.According to the literature survey done, the orientation of the flat plate collector should be in south-west direction. The inlet to the Flat plate collector is taken from the distillation point of the tank located at the top of building where setup is placed. The PCM used in the Tank is industrial grade granulated paraffin wax with a melting point range of 50-55°C and water is used as the HTF. The temperatures of the PCM and the HTF are to be continuously recorded at different locations (4 RTD inputs).

PHOTOGRAPHS OF ACTUAL SITE

Fig no.6 Photographs of Actual Site

Table below indicates the Thermophysical Properties of PCM

Table no. 1

Thermo physical Properties of PCM	
Melting temperature of PCM	50°C
Latent heat of Fusion	184.48kJ/kg
Density of PCM(Solid)	775kg/m^3
Density of PCM(Liquid)	833.60kg/m^3
Specific heat of PCM(Solid)	2.384kJ/kgk
Specific heat of PCM (Liquid)	2.44kJ/kgk
Thermal conductivity	0.15W/mk
Viscosity	6.3×10^{-3}
Kinematic viscosity	8.31×10^{-5}m^2/sec
Prandtl no.	1001.23
Thermal Expansion coefficient	7.14×10^{-3}

Table no.2

Dimensions of Heat pipes	
Length of Heat pipe	500mm
Diameter of Heat pipe	16mm
Heat transfer Fluid	Water

Table no.3

Dimensions of Copper pipes	
Length of Copper pipe	500mm
Diameter of Copper pipe	16mm

3.2. Experimental Trial

During the charging process the HTF was circulated through the TES tank and the solar collector unit continuously. The HTF absorbs solar energy sensibly, and exchanged this heat with the PCM in the PCM storage tank, which is initially at room temperature say about 30°c. The PCM slowly gets heated, sensibly at first, until it reaches its melting point temperature i.e. 50°c. As the charging proceeds, energy storage as Latent heat is achieved as the Paraffin wax melts at constant temperature (50±2°C). After complete melting is achieved, further heat addition from the HTF causes the PCM to superheat, thereby again storing heat sensibly. The charging process continues till the PCM and the HTF attain thermal equilibrium. The PCM is charged through the day, whenever hot water is not demanded by the user. In this way, the PCM melts and stores the heat energy accordingly. The discharging process used is termed as batch wise process. In this method, a certain quantity of hot water is withdrawn from the TES tank and mixed with cold water to obtain a nominal temperature of 45 ± 0.5°C for direct use and the tank is refilled with cold water to maintain a constant amount of water in tank. This is then repeated for intervals of 10 minutes, in which time transfer of energy from the PCM would have occurred. This procedure is continued till PCM .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. This charging experiment was conducted starting with flow rate 2 litre per minute (lpm) up to 18 litres per minute (lpm) .Therefore, readings of 2 to 18 litres was taken in the steps of 5 i.e. 2 litre,4 litre, 10litre,14 litre and 18 litres and the inlet temperature of the hot water was kept 70-75 °C and the atmospheric temperature is 30°C. Initially temperature of PCM is 30°C i.e. at about room temperature and as the HTF exchanges its heat energy to PCM with the help of Heat pipes inside both the tanks, 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 30minutes. 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. [5]

During the discharging process, the discharging process was conducted with same flow rate of 2litre per minute (lpm) and the inlet temperature of the cold water kept at the atmospheric temperature that is 30°C. During the discharging process the cold water is circulated through the PCM tank now the heat energy stored in

PCM with the help of Heat pipe in one tank and copper tank in another is transferred to the cold water so the cold water temperature is increased gradually. Temperature of the PCM and HTF are recorded at intervals of 30 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. The flow rate is then changed to 6lpm uptil 18lpm up to 5 steps and the PCM and HTF temperatures are recorded.

IV. RESULTS AND DISCUSSIONS

The temperature distribution of HTF and PCM in the Setup 1and 2 for different mass flow rates are recorded during charging and discharging process.

The temperature histories of HTF and PCM are shown in Fig and .Fig represents the temperature variation of HTF inside the Setup 1 and 2 for the mass flow rate of 6Lit/min. The temperature histories of Setup 1 and Setup 2 are shown. It represents the temperature difference variation with time inside the Setup 1 and 2. It is observed from the fig that the temperature of water at all segments increases gradually from temperature difference equal to 5°C until it reaches the temperature difference of 13°C, where it remains constant for a period of 30minutes.The results are good in Setup 1 than in Setup 2.

Table no.4 Temperature Analysis For 6Lit/min Flow rate

Time in Min	0	30	60	90	120
Temperature Difference for Setup 1	0	5	10	12	13
Temperature Difference for Setup 2	0	2	5	8	10

Table no.5Temperature Analysis for 10Lit/min Flow rate

Time in Min	30	60	90	120
Temperature Difference for Setup 1	20	15	10	8
Temperature Difference for Setup 2	25	20	15	12

During this charging process 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 nonce 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 30 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.

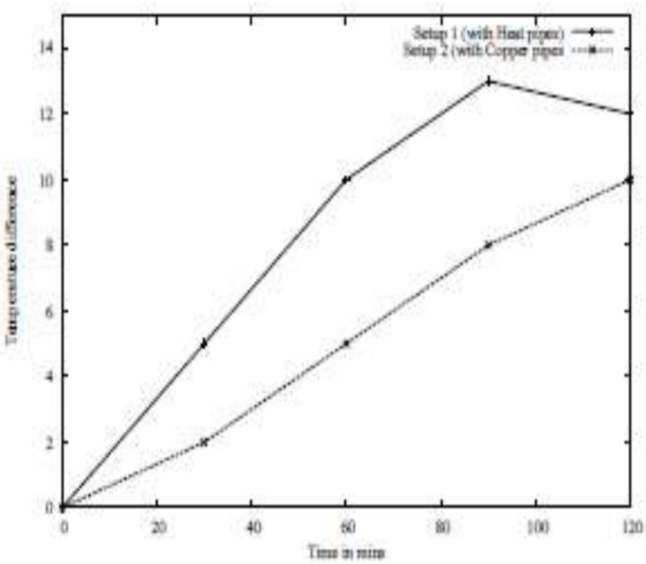

Fig.no 7 Temperature difference vs. in charging at 6Lit/min Flow rate

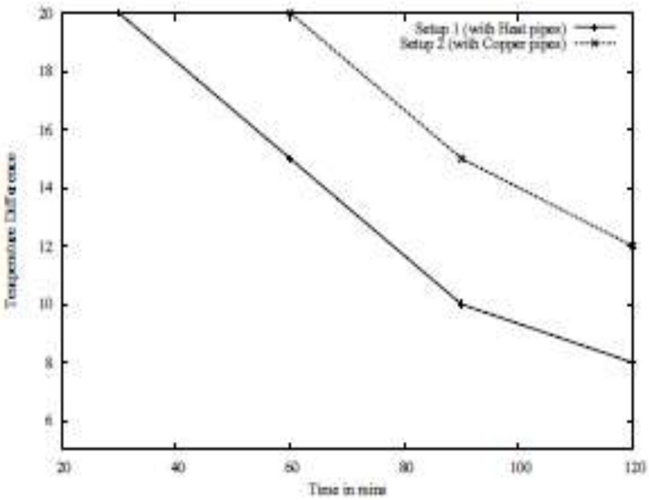

Fig no.8 Temperature difference vs. discharging at 6Lit/min Flow rate

The Discharging process shows that when the inlet temp is about 90°C, the Outlet Temp is 70°C,the temperature difference being 20°C. This means that at times of lower solar radiation when the temp will be as low as about atmospheric temp, the outlet temp still goes on increasing due to the storage method employed. This is what is needed. The discharging process though shows increase in outlet temp, though the inlet temp is less, the enhancement is not as good as in Setup1.Thus heat pipe effectiveness is justified. The Discharging for 10Lit/min can be evaluated from graph shown below.

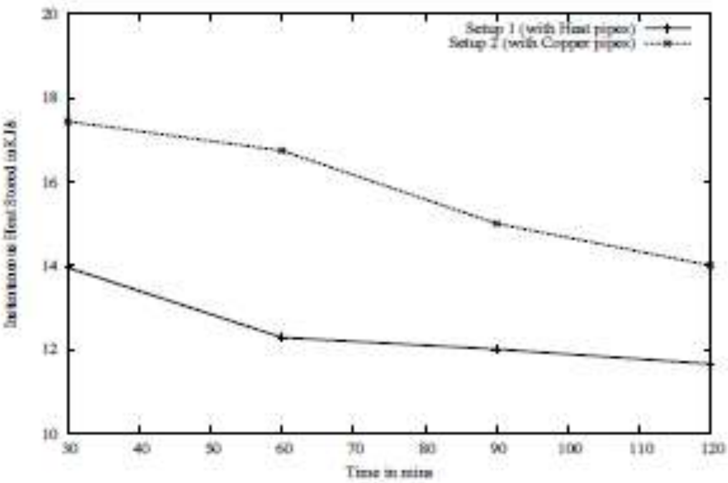

Fig no.9 Temperature difference vs. discharging at 10Lit/min Flow rate

V.CONCLUSIONS

The following conclusions can be extracted

1) From the temperature histories of PCM and HTF, it can be seen that, for the present system, the heat transfer rate possible from the HTF to PCM in the storage tank is higher than the solar heating rate of the HTF from the solar collector.
3) Heat source orientation and gravity have less effect on sintered powder metal heat pipes due to the fact that the sintered powder metal wick has the strongest capillary action.
4) We can see that the Setup1(with heat pipes) having tanks with Phase changing material and PCM on the half side is giving better performance in terms of greater temperatures as compared to Setup 2 (with copper pipes) having tanks with PCM and copper pipes even though copper has a high thermal conductivity. Hence heat pipes can be selected as better thermal conductor.
5) The Experimental results show that the feasibility of using PCM with Heat pipes is a better option than any good thermal conductivity material (Copper Pipes here)

6) When the flow rate is higher the heat storage capacity is increased. Experiment with flow rate of 10lit/min showed better results than 6lit/min.

VI. ACKNOWLEDGMENT

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