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Experimental Investigation for Enhancement of Thermal Energy Storage using Heat Pipe

[#1]Mr. Siddhartha Shandilya, [#2]C.L.Ladekar

[1]sshandilya42@gmail.com
[2]kishore.ladekar@pccoepune.org

[#1]P.G. Student, Department of Mechanical Engineering, Savitribai Phule Pune University, Maharashtra, India,

[#2]Professor, Department of Mechanical Engineering, Savitribai Phule Pune University, Maharashtra, India,

ABSTRACT: With the continuous depletion of fossil fuels all across the globe, solar energy along with other non-conventional energy resources has gained renowned attention in 21st century. This work emphasizes on the study and analysis of the feasibility of solar energy using thermal energy storage with different Phase Change Materials (PCMs) utilizing Heat pipes. The energy which is getting stored can be utilized post sunset and when there is low solar radiation. This leads to hot water being available all throughout the day. This work comprises on a system having two heat-absorbing units. First being a solar flat plate collector and other is Two Thermal energy storage tanks, one embedded with heat pipes and the other with copper pipes, PCM (paraffin) being their heat storage unity. The solar water heater supplies hot water only during the day when the weather is not very cloudy. The TES tanks stores the heat in PCMs effectively which is supported by Heat pipes and can supply hot water at night. Initially, water is circulated between the heating panel (Solar collector) and the PCMs. The absorbed heat is then transferred to the PCM which changes its phase by absorbing latent heat and the excess heat is stored as sensible heat. In this work, the heat transfer rate shall be compared of heat pipe and copper pipe when different Phase change materials, namely PCM 50, 55 and 58 are employed. This latent heat thermal energy storage can be utilized for domestic applications. The results, based on the Temperatures obtained at a particular mass flow rate of inlet water are compared and elaborated

Key words: Thermal Energy Storage, Latent Heat, Phase Changing Materials, Heat pipes.

I. INTRODUCTION

Conservation of energy is one of the key challenges our society is facing. Our life style is dependent on energy. However, resources of energy are finite. Besides, this is leading to a continuous rise in the cost of energy concerned. A large hotel or hospital spends lakhs of rupees for energy each year. These are places of enormous energy consumption. There is a wide gap between energy and demand that many researchers have tried to fill by exploring different energy resources. Also, consumption of energy is continuously depleting our environment as majority of them are non-renewable and not environment friendly. Fossil fuel, when used, emits carbon dioxide into the atmosphere which accelerates the greenhouse effect. Air conditioning system releases CFC gas which is slowly destroying the earth's ozone layer. Thus, consumption of Energy reduces not only the fuels, but also a spectrum of other resources.

A fundamental challenge for scientific community today is to develop and enhance existing technologies for conservation of energy. Increased consumption of energy, shrinking resources and continuously rising energy costs will have a huge impact on standard of living for us as well as our future generations. Thus, it’s an evitable time for the development of alternative, cost effective sources of energy for domestic and industrial purposes alike. Scientists all over the world are in search of new and renewable energy sources. One such option is to develop energy storage devices, which by all means shall prove important as developing or finding new sources of energy. Solar thermal power generation, being non renewable in nature is quite feasible as a source of solar power generation in hot and humid countries, but due to its intermittent and variable nature, an energy storage system is required. Thermal Energy storage (TES) is an effective technology that stacks or collects thermal energy by heating or cooling medium so that the stored energy can be used at a later time for heating and cooling applications and power generation. TES systems can be used in buildings and for domestic purposes.

The three forms of TES are

Sensible Heat Thermal Energy Storage (SHTES): There is no change of phase of the material. The working fluid remains in same state, only it temperature varies.

Latent Heat Thermal Energy Storage (LHTES): When there is phase change for working fluid in TES, we refer it to as Latent Heat Thermal Energy Storage.
Chemical Storage: When the fluid undergoes chemical reactions during the storage of the heat, it is referred as chemical heat.

Thermal energy storage systems are an essential feature which makes an efficient use of solar energy due to intermittence of this energy source and can be used for this particular disadvantage of the latter. It allows making use of thermal energy which is accumulated during hours of high solar radiation in moments of low or no solar radiation and reduces the mismatch between the supply and demand of the energy. As stated above, in sensible heat Thermal energy storage (SHTES), energy is stored in the manner such that the temperature of the storage material varies with the amount of energy stored. Water or rock can be the best examples. Alternatively, thermal energy can be stored as latent heat in which energy is stored when a substance changes its phase either by melting or by freezing. The temperature of the substance remains constant during the phase change. Comparing the two, latent heat thermal energy storage (LHTES) 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 and compactness. Apparently, it has been receiving considerable attention in the past decade and two, yielding promising results. Previous research on LHTES and SHTES systems pertained to the study

of the performance characteristics of both systems, theoretically and experimentally. In this study, incorporation of heat pipes with LHTES is studied experimentally.
When LHTES functions, a phase change material is used which changes its phase from solid to liquid and vice versa, which accepts heat and liquefies and gives off heat when solidification. The above two processes are termed as charging and discharging respectively. Apparently, charging occurs when thermal energy is being supplied and needs to be stored and discharging occurs when this stored needs to be used or availed by the user for practical purposes. Thus for LHTES systems in solar energy resource conservation, charging of PCM occurs during day time and discharging occurs post sunset. Generally paraffin wax of varying melting points is incorporated in LHTES systems as PCM. Their nomenclature is usually on based on their melting point like PCM 50 means it’s a phase change material having 50 0C as its melting point. In this work, PCM 50, 55 and 58 has been tested. The paraffin wax is a good material to be used as Phase change material considering their melting point is well within reach using solar panel heaters. However, their thermal conductivity is low which lead to not so good heat transfer among the PCM particles when the heat from Heat Transfer Fluid (HTF) coming from panel reaches them. To overcome this, heat pipes are incorporated for effective heat transfer phenomenon within the PCM and are embedded in TES system to transfer heat from water or other HTF to the wax material

Heat pipe is a heat-transfer device that employs the principles of both thermal as well as phase transition so as to yield efficient heat transfer between two sections which are not in thermal equilibrium with each other. Heat pipes are devices used for efficient transport of heat over large distances. The heat transfer system is based on the simultaneous occurrences of evaporation and condensation processes. When heat is applied to the outer area of the tube on its one side termed as evaporator section, the liquid inside the tube boils and vaporizes into a gas that moves through the tube towards a cooler location where it condenses, giving off its latent heat. For gravity-assisted heat pipes, the liquid is condensed back to the evaporator section with the help of gravity, for other types of heat pipes, wick structure is used which employs capillary action . Heat pipes requires no mechanical intervention or external electricity for its operation and generally requires very less or no maintenance, although the non- condensable gases which diffuses through the pipe's walls, resulting from breakdown of the working fluid or as impurities extant in the material, may eventually reduce the pipe's effectiveness at transferring heat. Hence, these gases need to e removed from time to time. The functioning of Heat pipes are based on a closed-loop heat transfer cycle without requiring external electricity for its operation, thus making it a very viable option when continuous transfer of heat is needed between two media

II. LITERATURE SURVEY

Many researchers have carried out the experiments related Thermal energy Storage particularly in areas with fewer natural resources. Solar energy is bestowed us from nature and can be renewed again and again. However, the demerit is that solar energy is intermittent in nature, unpredictable, and available only during the day. Hence, its application requires efficient thermal energy storage so that the surplus heat collected during sunshine hours may be stored for later use during the night. In cases of heat recovery systems, where the waste heat availability and its period utilization are different, requires efficient technology of thermal energy storage. In thermal energy storage, the useful energy from the collector is transferred to the storage medium where it is transformed into an internal energy. This internal energy can be used when we have low or no sunshine. The internal energy stored as sensible or latent heat in TES tanks. The latent thermal energy storage requires an effective phase changing material so that latent heat can be stored for latter and it loses or gains heat isothermally which leads to efficient storage and fewer losses. The PCM have low values of thermal conductivity. This decreases the heat transfer rate among the PCM materials once it starts gaining heat from HTF.

Several techniques have been proposed by researchers to overcome this drawback which includes the utilization of extended surface or fins, packing PCM with high thermal conductivity porous medium, or blending PCM with high thermal conductivity particles. However, the approach that is highly gang interest and is proving viable is a integrating a two-phase heat transfer device which is a heat pipe in a thermal energy storage unit thatincreases the effective heat transfer rate in PCM particles if it is properly embedded in the latter. Salunkhe et al found that Shell material’s thermal conductivity has a very significant impact on the heat exchange between the PCM and heat transfer fluid (HTF). They also studied the solidification and melting characteristics of the PCM and the effect of various encapsulation parameters on the phase change behavior. Also, a strikethrough point was that conduction and natural convection are the dominant modes of heat transfer during solidification and melting process respectively.[1]

Nithyanadam et al examined latent heat thermal energy storage (LHTES) system embedded with gravity-assisted heat pipes. They did an economic evaluation of same and concluded that storage cost less than $15/kWh, round-trip exergetic efficiencyto be greater than 95% and charge time less than 6 h for a minimum discharge period of 6 h. Overall, this study illustrated an efficient methodology for design and optimization of LHTES with embedded gravity assisted heat pipes for a Concentrated Solar Plant CSP plant operation.[2]

Rouault et al did experimental investigation on PCM and took into account the close-contact exchange between the PCM and tube surface since the PCM's density decreases as it goes on melting and the corresponding buoyancy effect. They showed that there are some modelling uncertainties while modelling of PCM numerically due to the estimation of the heat exchange coefficients between air and tube walls, and the turbulences created by the shape of the exchanger at the inlet of air.[3]

Jmal et al did numerical study of PCM solidification. They conclude that under the availability of fins, rate of energy extraction from PCM to airflow occurs is faster, which leads to lower discharge time and increase in the outlet air temperature [4].

Wang et al studied parametric effect of phase change thermal energy storage. The major findings were that the energy efficiency ratio and the heat storage rate are more susceptible to the outer tube diameter. The performance of phase change thermal energy storage unit using circular finned tube proved to be best when water was used as the heat transfer fluid (HTF). [5]

Tardy et al did a thermal analysis using heat pipe comparing its mathematical and numerical models. Ice was used as phase change material and different thermal resistances were considered in numerical study. They found it be very close to experimental results at different inlet conditions which thus proved the validity of numerical model [6]

Peyghambarzadeh et al studied the performance of different working fluids for a heat pipe for same set of temperature ranges and found that water is best working fluid in comparison to ethanol and methanol. Also showed that increasing heat flux increases the evaporator heat transfer coefficient. [7]

Nithyanandam et al did a study to overcome problem of low thermal conductivity for phase change material when used for TES system. They inserted thermosyphons and found that it is beneficial as different arrangements improved the heat transfer rate b different amounts. However, when condenser section is above evaporator section, thermosyphons or heat pipes acts as fins when direction of heat transfer is same as gravity and in those cases heat gets transferred by conduction only through the walls of thermosyphons [8].

Nithyanandam et al analyzed LHTES systems with embedded heat pipes and concluded that increase in the HTF mass flow rate, module length and tube radius reduced the effectiveness of the heat pipes while increase in the length of the condenser section, the length of the evaporator section and the vapor core radius enhanced its effectiveness. The discharging effectiveness was noted to decrease with increase in the HTF mass flow rate due to the significant improvement of the heat transfer rate between the vertical heat pipes and HTF [9].

III.EXPERIMENTAL DETAILS

Experimental setup for carrying out this work is made by using a Flat Plate collector having 100 LPD capacities. Two Latent Heat Thermal Energy Storage Tanks are assembled of dimension 300mm by 550mm, one having place for storing Phase changing material PCM, Paraffin with heat pipe embedded in it and other having PCM with Copper(Cu)t pipes. There are 7 heat pipes and copper pipes welded in the two tanks respectively Also, a third tank is manufactured and installed for storing sensible heat when extra hot water is in supply of the dimensions 300mm by 275mm.The outlet water of Solar Flat plate collector is supplied to the inlet of one of the tanks and is then circulated to other two tanks. The TES tanks made of stainless steel has capacity of about 36 liters, out of which 18 liters is stored with wax and the remaining half is stored with water with the help of a copper plate partition in between the two. The dimensions of tanks are: diameter 300mm and height 550mm, it has in it the PCM above the partition which allows the heat transfer between PCM and water. The arrangement done in the other tank is same, except that it is having Copper pipes in place of heat pipes for comparison purpose. The dimensions of Heat pipes are 500mm length and 16mm diameter, same being for copper pipes. The copper material has very high thermal conductivity; hence their performance of heat transfer is compared with heat pipes made of copper. The copper plate partition is of 10mm thickness and 300mm diameter so as to make 2 compartments for PCM and water. Thus, as stated above PCM which is on the upper portion of the tank does not come in contact with the water i.e. the HTF. As per literature study, the heat energy always try to give its maximum possible heat to the upper portion as its density goes on decreasing, hence PCM is placed on upper side of copper plate and HTF below .This also allows heat pipes to be a gravity assisted one as its evaporator section lies below condenser sections. The insulation of tanks is done with the help of 50mm of glass wool, and is also equipped with an aluminium cladding. RTDs are assembled at four different locations of the storage tank and PCM temperature in both the tanks and temperature of water in these two tanks are recorded simultaneously by connecting the 4 RTDs to a temperature indicator.

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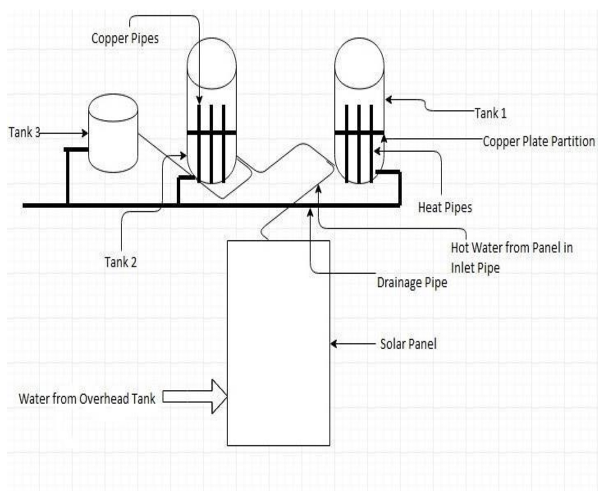

Fig.1:- Schematic of Experimental Setup

Figure 1 shows the schematic diagram of thermal energy storage tanks with equipment used for experimental work. These three arrangements of tanks are having same stand to avoid disturbance of flexible fittings. The orientation of the flat plate collector is towards south-west direction. The inlet or the supply of water to the Flat plate collector is done from pipe which connects overhead tank at terrace where setup is done to the collector. Figure 2 shows the actual photograph of the experimental setup assembled. Figure 3 shows top view of tank after it was welded with 7 heat pipe and copper plate partition in between it. Below the plate, hot water is supplied at from the solar panel at different mass flow rates being controlled through rotameter set in. The 3 different PCM used for testing are placed in the Tank one after the other after completion of tests on one particular PCM. The PCM used are granulated paraffin wax with melting point temperatures of 50, 55 and 58 ^{0}C respectively. The temperatures of the PCM and the HTF (water) are recorded in both the tanks using the 4 RTDs.
Table 1 shows the thermos physical properties of PCM 50. The values of PCM 55 and PCM 58 are slightly different with their melting point being 55 and 58 ^{0}C respectively.

Table 1: Themophysical properties of PCM 50

Properties	***Value***
PCM Density (Liquid Phase)	775kg/
PCM Density (Solid Phase)	833.60kg/
Specific heat of PCM(Solid Phase)	2.384kJ/kg^{0}C
Specific heat of PCM(Liquid Phase)	2.44kJ/kg^{0}C
Latent heat of Fusion	184.48kJ/kg
Thermal conductivity	0.15W/mk
Kinematic viscosity	8.31×10^{-5}

Fig.2:- Actual Experimental setup of TES Tanks with Solar Panel

IV.METHODOLOGY

During the charging process on a bright sunny day, the HTF i.e. water is circulated through the solar collector unit and the TES tanks at a particular mass flow rate regulated through rotameter. The HTF absorbs solar energy sensibly in solar panel thereby increasing its temperature and reaches the tanks and gets stored below copper plate partition and exchanges this heat with the PCM which is initially at room temperature at about 30^{0}C in its solid form. The PCM slowly gets heated; first sensibly; thereby temperature rises and reaches its melting point i.e. 50^{0}C for the first PCM undergoing tests viz. PCM 50. As the charging proceeds, energy getting stored as Latent heat is achieved as the Paraffin wax starts to melt at a constant temperature of 50 ^{0}C. The charging process continues till the time when the

PCM and the HTF attain thermal equilibrium with each other which implies hot water from panel is supplied till that point of time.

Figure 4 shows charging process in process during the day while figure 5 shows the photograph of discharging after PCM gets melted which results in hot water being obtained from the tank in the night which can’t be obtained from the solar panel after sunset.

Fig. 3:- Photograph of Heat Pipe embedded Tank (from top)

The discharging process is just the opposite of charging process. Hence, the heat transfer too takes place in opposite direction in this process. In this method, a certain quantity of water at normal ambient temperature is supplied to the TES tank and the charged PCM starts losing out its heat and giving its heat to water thereby increasing its temperature making it hot and PCM gradually solidifies itself reaching the temperature it was a ambient condition i.e. before the process of charging started.

Fig. 5:- Photograph of PCM being discharged (evening)

The temperature of water rises in both the tanks and is subsequently withdrawn so that extra water can be placed in the tank for it to become hot during discharging. The temperature distributions of HTF and the PCM s are recorded during charging and discharging processes. The discharging process is continued till the PCM gets fully solidified so that Maximum heat is gained by water. The very same process is carried out for testing (charging and discharging) of PCM 55 and PCM 58 at same mass flow rate after subsequently removing the PCMs from both the tanks once their testing is completed.

The heat stored inside PCM includes 3 processes. The first process is sensible where increase in temperature inside the tank of solid PCM takes place because of incoming heat transferred by heat pipes and copper pipes from hot water from panel, second process is melting of PCM which occurs at a constant temperature i.e. at melting point of respective PCM's and third phase will be again change in temperature of liquid PCM i.e. sensible phase.

Heat absorbed by PCM (Q) = Sensible Heat of PCM (Heat of solid medium) + Latent Heat of PCM + Sensible Heat of PCM (Heat of liquid medium)

$$Q = mC_p\Delta T + ma_m \cdot h_m + mC_p$$

$$Q = [mC_{sp}(T_m - T_i) + a_m \cdot L_{pcm} + C_{lp}(T_f - T_m)]$$

where,
C_{sp} = specific heat of solid medium [KJ/kgK]
C_{lp} = specific heat of liquid medium [KJ/kgK]
a_m = melting fraction of PCM
h_m = Latent heat of fusion [KJ/kg]
L_{pcm} = Latent heat of PCM [KJ/kg]

Considering melting of PCM as Lumped System, since temperature remains constant over specific period of time. During a differential time interval dt, the temperature of the paraffin (PCM) rises by a differential amount dT. An Energy balance of the solid for the time interval dt can be expressed as,

The following equation gives the rate of heat transfer through heat pipe which occurs in tank 1,

$$Q_{max} = m_{max} \cdot L_{pcm}$$

Where, m_{max} is the maximum liquid flow rate in the wick.

In copper pipe, there is no vapour flow inside the pipe. Hence it acts as a fin to enhance heat transfer area. The following equation gives the rate of heat transfer through copper pipe which occurs in tank 2,

$$Q = \sqrt{(hpKA)(T_i} - T_f)\tanh(ml)$$

Where,
h is heat transfer coefficient of water
p is perimeter of pipe = $\pi \times d$, d is diameter of pipe
K is thermal conductivity of copper material A is heat transfer area

T_i and T_f are initial and final temperatures

V.RESULTS AND DISCUSSION

The results obtained from the experimental work carried out on both the TES tanks employing different PCMs presented in this section. Various graphs are plotted to study the variation throughout the day during charging as well as discharging.

During charging, the following variations temperatures were obtained at a mass flow rate of 2 LPM (Liters per minute) which was controlled by a rotameter placed at inlet section of both the tanks.

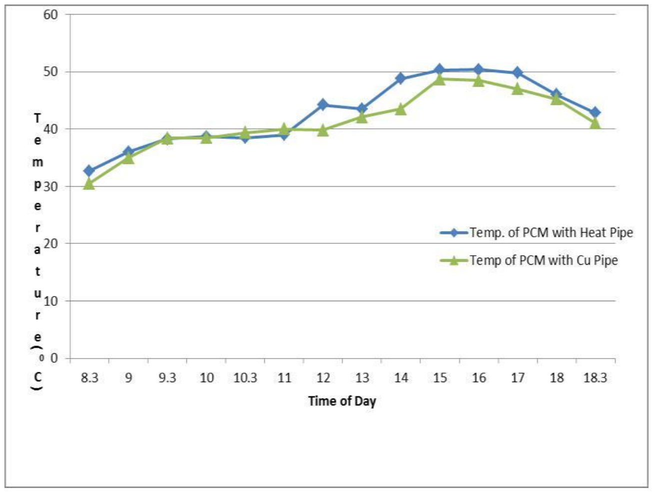

Fig.6:- Variation of Temp. of PCM 50 in Both Tanks

Figure 6 shows the variation of Variation of Temp. of PCM 50 in Both Tanks all throughout the day from morning to evening on 1st of April, 2016. A maximum of 50.4 ^{0}C was reached during the day in the tank in which heat pipe is installed while in tank containing Cu pipe, a maximum of 48.7 ^{0}C is obtained at 3'o clock in the afternoon.

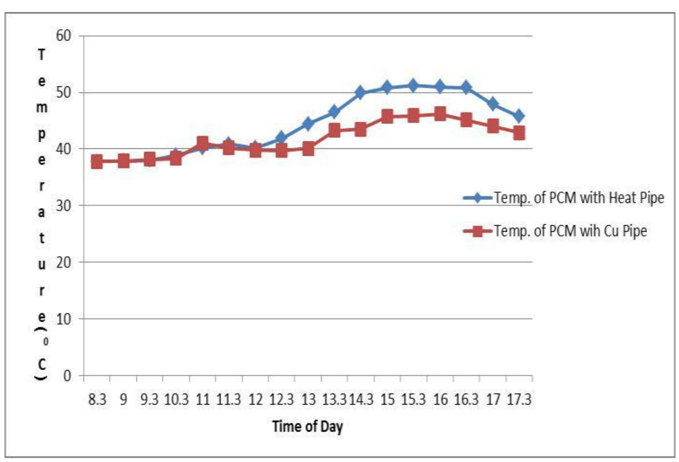

Fig.7:- Variation of Temp. of PCM 55 in Both Tanks

Figure 7 shows the variation of PCM 55 in both the tanks on 11th of April, 2016. As we observe, the peak of blue line is much higher than thive heat tranfer e red line which shows effective heat transfer phenemenon in heat pipe in comparison to Copper pipe.

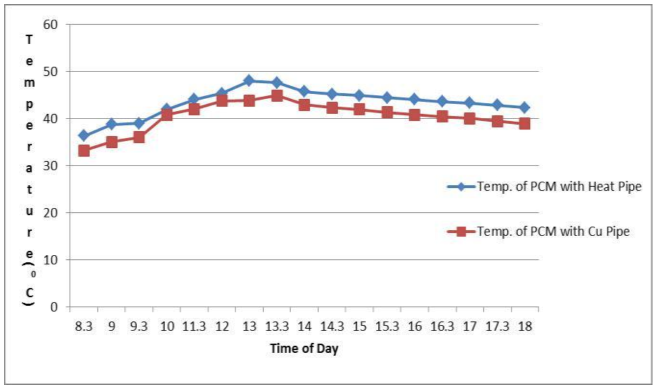

Fig.8:- Variation of Temp. of PCM 55 in Both Tanks

Figure 8 depicts the charging phenomenon in both the pipes for PCM 58 on 21st of April, 2016. Coming to discharging, which is solidification of PCM during night time, gave hot water after sunset. Following graphs were obtained from the readings.

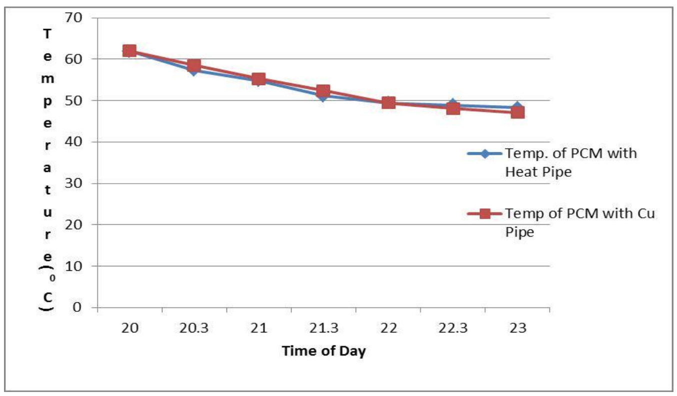

Fig.9:- Discharging of PCM 58 in Both Tanks

From figure 9 we observe initial sharp reduction in temperatures as PCM got solidified from its liquid state from a maximum of 620C. The reduction in temperatures for tanks with heat pipes and Cu pipes are fairly as red and blue curves almost coincide with each other. As a result we are getting hot water in both the tanks which was initially at room temperature as 8 P.M. in the evening when it was supplied at same mass flow rates to the tanks. The graphs comes out in accordance with Nithyandam's et al paper which says when condenser section is in heated region , the pipes acts as fins to enhance heat transfer rate and there is no vapour flow within the heat pipes. The subsequent water temperature readings are taken on same water till 11P.M. in the night at an interval of half an hour. The same readings are depicted in figure 10.

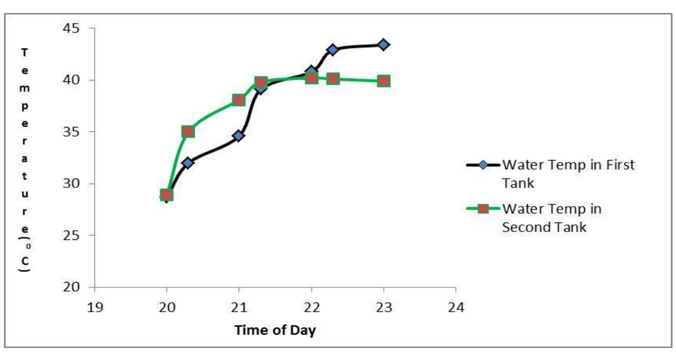

Fig. 10:- Temperature of Water at Night

VI. Conclusion

1. At a mass flow rate of 2 LPM, charging of PCM occurs all throughout a sunny day with a maximum of 51.2^{0}C
2. Heat Pipe performs much better then Copper pipe as peak of First tank temperature is much higher than second tank in all the 3 PCMs tested.
3. Comparing the performance of 3 PCMs, PCM 50 got charged the most in one single day. However, we get maximum temperature in PCM 55, which was 51.2^{0}C
4. Discharging occurs quite sharply from 8 to 11 PM in the evening with plots being reasonably same for PCM with heat Pipe to that of PCM with Cu Pipe.
5. Water temperature rises sharply in evening when PCM solidifies to a maximum of 43.4^{0}C from normal room temperature at 11 PM in evening which shows LHTES with PCM is a viable concept, if PCM is properly charged during the day time

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