Experimental Investigation of Enhancement In Heat Transfer using Nano - Mixed PCM

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***Abstract*— Efficient and reliable thermal storage systems are required for solar applications to overcome their existing discontinuous nature and abrupt change in weather conditions. Thermal storage units that utilize Phase Change Material (PCM) as latent heat storage material have received greater attention in recent years. It has larger heat storage capacity and isothermal nature during charging and discharging process. Besides having high energy density most of the PCMs have an unacceptable low thermal conductivity. To conquer this drawback heat transfer enhancement techniques are required for any Latent Heat Thermal Storage (LHTS) application comprises with PCMs. One of the best suited technique is the addition of nanoparticles into base PCM to enhance its thermal performance.**

In present work, Al_2O_3 nanoparticles were added in 0.5%, 1% and 2% into base PCM to enhance its thermal performance. Solar water heating system is considered as LHTS. Experiments were carried out with both base and nano mixed PCM to ensure the enhancement in heat transfer.

Keywords—Phase Change Material (PCM); LHTS; Nanoparticles.

I. INTRODUCTION

Day by day there are increase in greenhouse gas emissions and rise in fuel prices. These are the main driving forces behind efforts to more effectively utilize various sources of renewable energy [1]. The scientists all over the world have been in search of some new and renewable energy sources since long. It is found that one of the alternatives is to develop energy storage devices, which is having same importance as that of developing novel sources of energy.

Solar energy is a major renewable energy resource which can be used to generate electricity, provide hot water and for air conditioning system etc. It is of intermittent nature and its effective utilization is dependent on efficient and effective energy storage systems. If no energy storage is used in solar systems, the major part of energy demand will be met by the back up or auxiliary energy due to which annual solar load fraction will be very low. The thermal energy can be stored when energy is abundantly available and used when required. Thermal storage has been characterized as a kind of thermal battery; however it is clear that if solar energy becomes an important energy source efficient, economical and reliable solar Thermal Energy Storage (TES) devices and methods will have to be developed.

The storage of thermal energy in the form of sensible and latent heat has become an important aspect of energy management. In order to store the same amount of energy, significantly larger quantities of storage medium are required for Sensible Heat Storage (SHS) in comparison to Latent Heat Storage (LHS) as the phase transition is at constant temperature. Of the two, latent heat thermal energy storage technique has proved to be a better engineering option as it has various advantages like large energy storage for a given volume, uniform energy storage/supply, compactness, etc.

PCMs are the materials in which energy can be stored in the process of charging the aggregate state from solid to liquid and give it back when it required. A good design of latent heat thermal energy storage requires the knowledge of PCM and the latent heat exchange process especially the melting and solidification process [2, 3]. There are many numbers of PCMs at a wide range of temperature making them attractive in number of applications, as it serves as better energy storage device and possesses a nearly isothermal operation. These materials include organic, inorganic and salt eutectics etc.

Solar water heater as LHTS is getting popularity since they are relatively inexpensive and simple to fabricate and maintain. Internationally the market for solar water heaters has expanded significantly since long. Many attempts had been made to incorporate PCMs into the solar water heating system, but it was not so effective due to the poor heat transfer between PCM and water which is because of low heat flux achieved by low thermal conductivity of most PCMs [4]. The effect of the lower value of conductivity is reflected during energy retrieval or withdrawal with an appreciable temperature drop during the process, drastically affects the performance of the system. It will leads to the increasing period of melting and solidification that is the charging and discharging period of system. A larger heat flux can be achieved by enhancing the effective thermal conductivity.

In the present study, paraffin wax is taken as PCM and solar water heating system is considered as LHTS. Al_2O_3 nanoparticles were added into base PCM. Experiments were carried out to verify the enhancement in heat transfer rate of nano mixed PCM.

II PREREQUISITES FOR EXPERIMENTATION

A Selection of PCM and Nanoparticles

As in any other application, the selection of the PCM to be used is a crucial point which will depend on a particular application and its operating temperature. The use of PCMs as latent heat storage material depends upon the desired thermal, physical, chemical properties and economic factors.

In present study domestic solar water heater system is taken as LHTS. Owing to the temperature of water to be stored in hot-water tank is about 55℃, the melting temperature of the PCM should be around 60℃ with maximum amount of latent heat. In the market, different PCMs with this melting temperature can be found. The selected PCM should have the properties mentioned above. Selection of laboratory grade paraffin wax was done as a PCM having melting temperature 58℃ to 60℃ which is suitable for given application. Paraffin waxes are the most commonly used commercial heat storage PCM for LHTS applications. They have large latent heat, good thermal stability and good thermal energy storage density etc. Thermo physical properties of paraffin wax are listed in Table I.

Several investigations of thermal characteristics of pure paraffin waxes during solidification and melting processes have been performed. This shows that no thermal properties degradation occurred after numerous melting/freezing cycles.

Though the selected PCM has high latent heat and suitable melting temperature, it has lower thermal conductivity which limited its ample utilization. The intensification of heat transfer rate is depends on type of application for which the PCM is used. In some cases heat transfer enhancement is required for charging process. However, in solar water heating application, heat transfer enhancement is required mainly for discharging process rather than for charging. This is because heat is available at constant rate for longer period and the same has to be removed at faster rate. Hence, enhancement in heat transfer can be stated as a promising enhancement technique for LHTS system of solar water heaters as producing hot water at faster rate in the required time.

Selection of nanoparticles is based on several parameters such as thermal conductivity, particle size, cost, volume fraction and type of base fluid etc [5]. Particle size is an important parameter because shrinking particles down to nano scale increases the surface area relative to volume and provide better dispersion into the base PCM. Experimental evidence indicates that effective thermal conductivity increases with decrease in particle size. Also, as nanoparticle concentration increases time required for melting at higher nanoparticle concentration is larger than pure PCM and low concentration. This is due to fact that dynamic viscosity increases significantly as nano particle concentration increases. Enhancement in dynamic viscosity may play key role in natural convection dominated melting of nano mixed PCM. As natural convection dominates the heat transfer rate in melting process, higher the viscosity reduces the buoyancy more which in turn slower the melting process.

TABLE I. THERMOPHYSICAL PROPERTIES OF PARAFFIN WAX

Melting temp T_m (^{0}C)	58-60
Specific heat of solid (kJ/kgK)	2
Specific heat of liquid (kJ/kgK)	2.15
Latent heat of melting L (kJ/Kg)	190
Thermal conductivity of solid (W/mK)	0.24
Density of solid (kg/m^3)	910
Density of liquid (kg/m^3)	710
Kinematic viscosity(m^2/s)	5.20×10^{-6}

Based on the literature review and considering all above parameters Al_2O_3 is one of the suitable nanoparticles for the selected application. Al_2O_3 is most common and inexpensive nanoparticles used by many researchers in their experimental investigations.

B. Stabilization of Nano mixed PCM

When nanoparticle was dispersed into the base material, it is observed that there was improper mixing of nanoparticle with PCM and nanoparticle was settled down to the bottom of container. As there was no proper mixing, it was difficult to measure the properties of nano mixed PCM for further procedure. In order to avoid this difficulty several ways are available to create the uniform mixture of two different materials and form the stable mixture. The way which has been chosen to form the stable and uniform mixture of two dissimilar classes of material was to use surfactants, which are unique class of chemical compounds [5]. One of the original and predominant reasons for the ever present use of surfactants is their remarkable ability to influence the properties of surfaces and interfaces [6].

Paraffin wax was selected as PCM, was non-polar in nature. To mix the Al_2O_3 nanoparticle in to it, oil soluble surfactant was preferred which is mostly in non-ionic in nature. The selection of oleic acid was done based on the fact, that it is polar solvent and oil soluble, which was also found suitable for Al_2O_3 nanoparticle and paraffin wax mixture. Methanol was used as the solvent for proper mixture of oleic acid and Al_2O_3 nanoparticles. To test the stability of nano mixed PCM sedimentation photograph method was applied.

C. Characterization of Nano mixed PCM

Characterization of nanomaterials is required to understand the nanoparticle synthesis and its applicability to various applications. It also gives the average particle size and geometrical aspect of the nanoparticle. Differential Scanning Analysis (DSC) is used to check the effect of addition of nanoparticles onto the base material. In present study DSC analysis of paraffin wax and nano mixed paraffin wax were done to measure its properties. The DSC curve is as shown on fig. 1.

Sample of PCM and nano mixed PCM with a mass of 5 mg were taken in pan. The analysis was performed in temperature range of 25℃ to 75℃ with heating rate of 5℃/min, under a constant stream of nitrogen gas having volume flow rate of 100 ml/min. Al_2O_3 was used as material in reference pan for heat capacity determination. From the DSC analysis it was clear that, melting characteristics of paraffin wax does not change though the Al_2O_3 nanoparticle was added into it. Its melting behavior is same which is reflect from the nature of all samples which is tested.

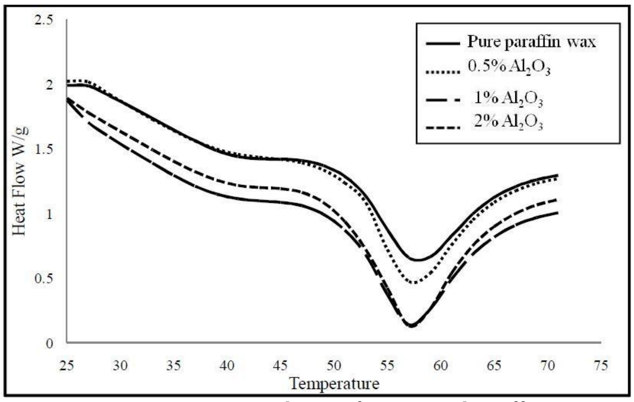

Fig. 1. DSC analysisys of nano mixed paraffin wax

D. Melt Fraction Measuring Technique

The PCMs are commonly encapsulated in spherical containers. The studies on the melting of PCM inside sphere are important for better understanding in the designing of more efficient TES systems [7]. Numerous experimental, analytical and numerical works on melting inside a sphere can be found in the literature. However, very short references are available for measuring the melt fraction within the sphere.

In current work to find out the solid-liquid interface of the PCM inside the sphere, digital images were captured using a digital camera at a particular instant of time. In order to produce solid model from the solid-liquid interface, the coordinates of the PCM phase front must be known. Digital images of the melting phase front during the experiments were taken to determine the solid-liquid coordinates. Using the digitizing software WinDIG version 2.5 the coordinates of the solid-liquid interface are captured from the digital images. The coordinates are then imported into the CAD software like CATIA to create the solid model of the solid PCM. The amount of solid melted inside the sphere can then be estimated and thus the melt fraction at that particular instant of time can be determined.

III. EXPERIMENTAL INVESTIGATION

A. Experimental Set up

An experimental set-up was designed, fabricated and commissioned to collect thermal performance data on the thermal storage tank using multiple spherical capsules. A schematic diagram of the experimental setup is shown in fig. 2. The experiment setup is consists of cylindrical water tank, spherical capsule containing PCM with various percentage of nanoparticles, several K type thermocouples, heater, G.I. Pipes and wattmeter.

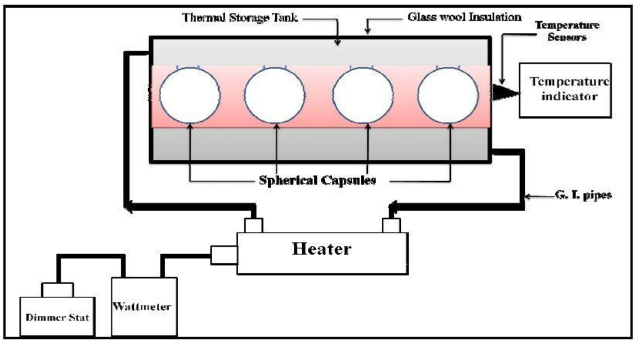

Fig. 2. Schematic of experimental set up

The mild steel storage tank is cylindrical in shape having a length of 500 mm with an inner diameter of 160 mm. The specification of thermal storage tank of 10 liter was designed on the basis of standard specification of 100 liter tank. In experimental setup instead of collector, tube heater was used to generate the heat flux. A slot of dimension 420 mm × 80 mm was made for visualization of melting and image capturing purpose. Acrylic sheet of 6 mm thickness was bended to match with the slot. The dimension of acrylic sheet was slightly greater than the slot for making the bolting arrangement. The gap between slot and acrylic sheet was made leak proof by using rubber gasket and bolts. A gap of 100 mm was made in each ball for smooth circulation of heat transfer fluid that is water in this case. This type of arrangement was so made that pure PCM and nano mixed placed under the same environmental condition that is under the same heat flux.

B. Experimental Trials

Different Tests were carried out on the systems to observe the enhancement in the heat transfer due to the addition of nanoparticles. Observation was also made to check the melting behavior of pure PCM and nano mixed PCM. The tests are classified as pure PCM, forward and backward experiment with addition of nanoparticles in base PCM. In pure PCM experiment, four spherical capsules (balls) having diameter 60 mm were kept in the water tank as shown in fig. 3. In all four balls pure PCM of 85 gm was taken. Generally, the average solar radiation was available for the duration of 5 to 6 hours. Therefore, the wattage of heater adjusts in such a way that the duration of the test is almost in between 5 to 6 hours. Images of each capsule are taken with the help of digital camera for regular interval of time to estimate the melt fraction of PCM at that interval of time.

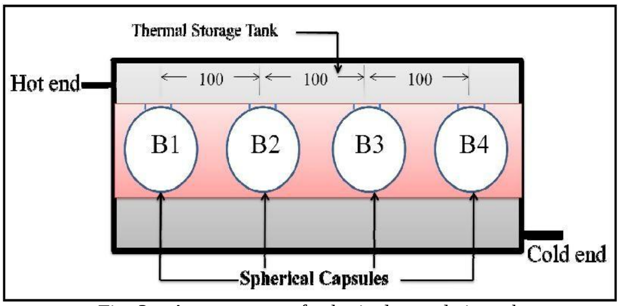

Fig. 3. Arrangement of spherical capsule in tank

In forward experiment, same procedure carried out except the position of the balls. In this arrangement pure PCM was kept at B1 position, PCM with 0.5% of Al_2O_3 was kept at B2 position, PCM with 1% of Al_2O_3 was kept at B3 position and PCM with 2% of Al_2O_3 was kept at B4 position. In backward experiment this order of balls was made reverse. All other conditions were same for the experimentations.

IV. RESULTS AND DISCUSSION

A. *Experimentation on Pure PCM*

In first experiment pure PCM were kept at all the position. Melting behavior of each ball located at different position in the tank clearly visualized from the photographs shown in fig. 4. During observation it was clearly shown that time required for melting of B3 and B4 is less than the melting of ball B1 and B2. This happened due to the setting of natural current from hot end to the cold end of the tank. As time passes, temperature profile is set diagonally and the temperature difference at cold end increases than the hot end junction. From the photograph melt fraction of each ball was calculated with the help of digitizing software WinDIG.

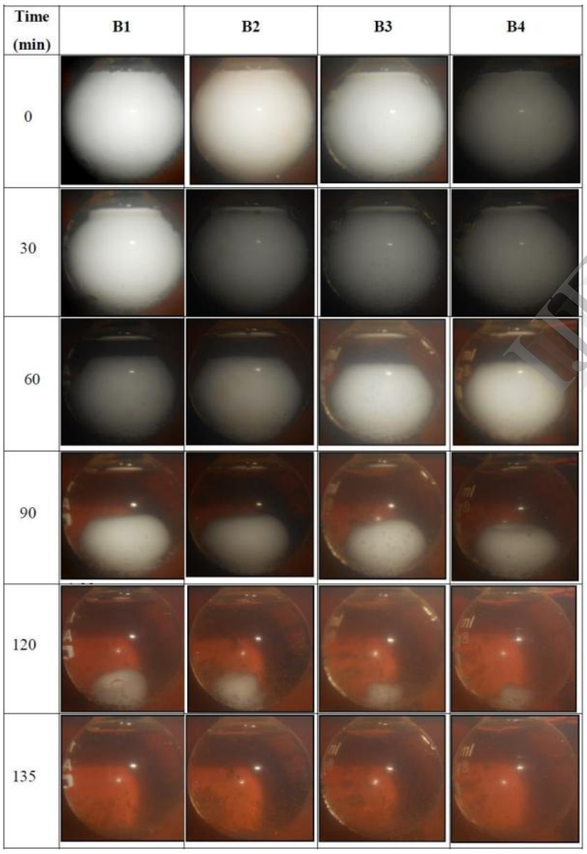

Fig. 4. Photographs of melting of pure PCM

Results are plotted with respect to time as shown in fig. 5. From results it was clear that, initially the melting process was purely due to the conduction phenomenon, as time increases buoyancy driven convection was strengthened due to growth of melt zone. It was also observe that PCM in spherical capsule B3 and B4 melts earlier than the B1 and B2 because of flow setting from hot end to cold end.

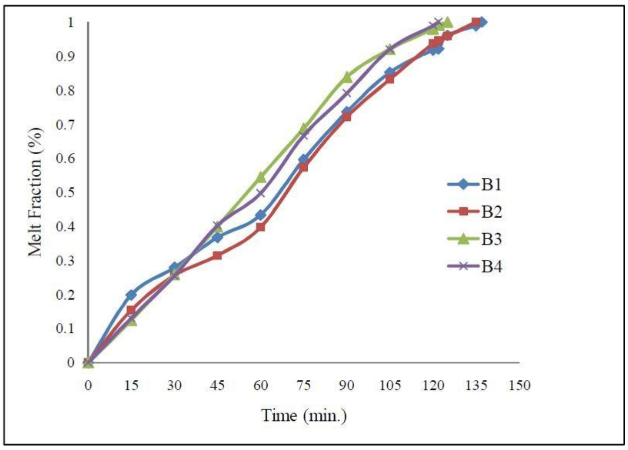

Fig. 5. Melt fraction estimation for pure PCM

B. *Experimentation on Forward Arrangement*

In forward experiment capsule were placed in ascending order of nanoparticles percentage. Other experimental conditions are same for the experimentation. Photograph of melting is as shown in fig. 6.

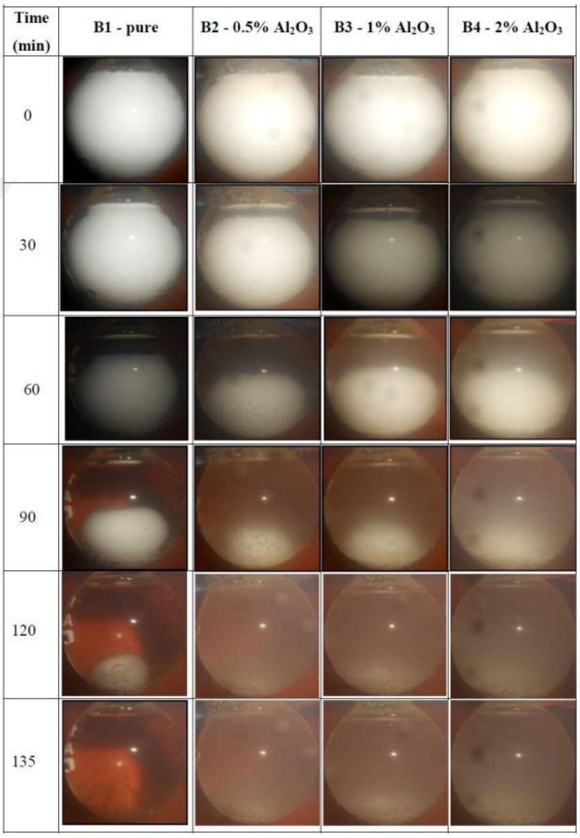

Fig. 6. Photographs of nano mixed PCM in ascending order of nanoparticles percentage

At initial stage of melting heat transfer is mainly due to the conduction and there is no possibility for nanoparticles movement. As time passes melt zone increases and heat transfer through nanoparticles comes into picture. In mid section of graph shown in fig. 7 there is a sudden increment in the melt fraction indicates assistance of suspended nanoparticles in the heat transfer.

It is also found that the melting time reduces due to the addition of nanoparticles. This indicates enhancement in the heat transfer rate for nano mixed PCM. The PCM with 0.5% Al_2O_3 shows the greater enhancement.

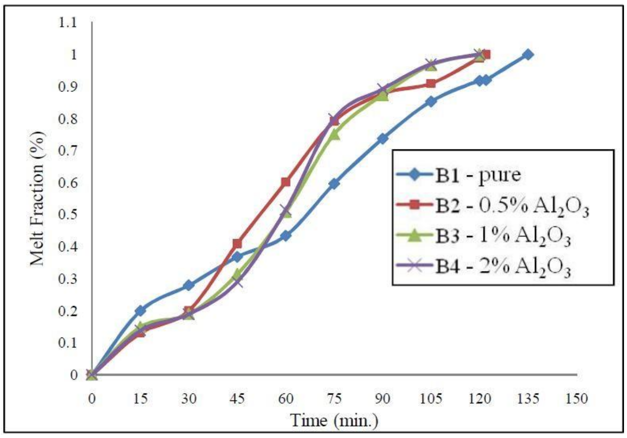

Fig. 7. Melt fraction of nano mixed PCM in ascending order of nanoparticles percentage

C. Experimentation on Backward Arrangement

In backward experiment capsule is placed in descending order of nanoparticles percentage. From photograph study it clear that the PCM from all the balls were melting at same time which is shown in fig. 8.

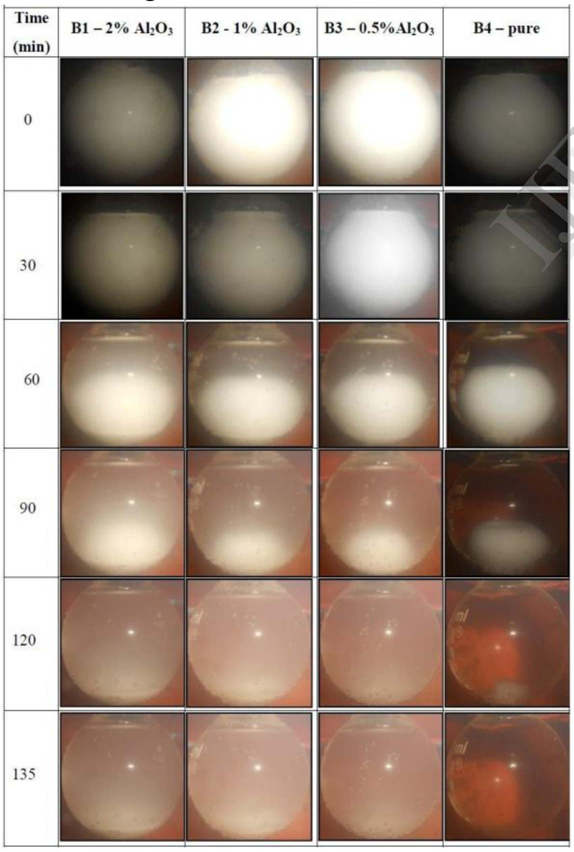

Fig. 8. Photographs of nano mixed PCM in descending order of nanoparticles percentage

At starting condition effect of nanoparticles were not experienced. But nanoparticles assisted in heat transfer after growing of certain amount of melt zone. It is clearly shown in the fig. 9 that at mid section there is abrupt increment in melt fraction with respect to time. This will noticeably shows the enhancement in the PCM by the addition of Al_2O_3 nanoparticles. In pure PCM experiment, there is difference in melting time for each ball is observed.

But in this experiment at the end all the balls were melts nearly at same time. In pure PCM experiment ball B1 requires maximum time, but in this experiment its melting time reduces due to addition of Al_2O_3 nanoparticles. This observation obviously shows the enhancement in the pure PCM with addition of Al_2O_3 nanoparticles.

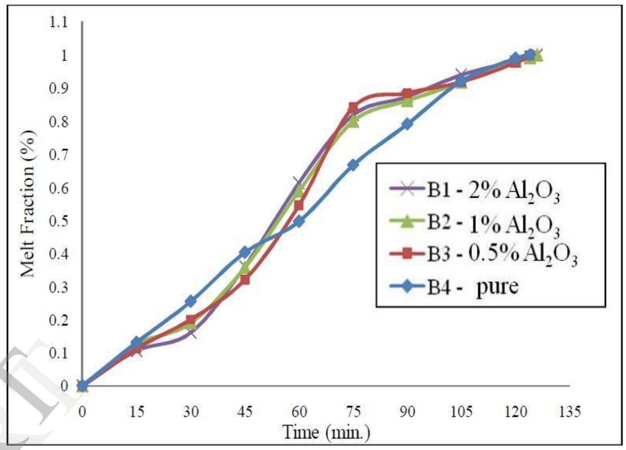

Fig. 9. Melt fraction of nano mixed PCM in descending order of nanoparticles percentage

Thus presence of Al_2O_3 nanoparticles into the paraffin wax enhances its heat transfer rate. This is clearly observed from the reduction of melting time for the nano mixed PCM. Table II shows the melting time in minutes for each ball placed at different position with different percentage of Al_2O_3 nanoparticles. Maximum enhancement in melting time of 10.65% is observed for 0.5% Al_2O_3 when it is placed on B2 position.

TABLE II. MELTING TIME FOR PURE AND NANO MIXED PCM

Percentage	B1	B2	B3	B4
0	137	135	125	122
0.5	-	122	124	-
1	-	125	120	-
2	126	-	-	120

The experiments performed showed that the enhancement in the heat transfer rate is depending on the percentage of nanoparticles and position of the material into the heat transfer fluid tank.

V. CONCLUSIONS

This study has been carried out with the primary goal to ensure the enhancement in pure PCM with the addition of nanoparticles. Tests were carried out with addition of different percentage of nanoparticles. The results are obtained to see the effect of mixing nanoparticles into PCM in different percentage. Significant observations that can be drawn from the experimentations are as follows.

1. From experimental investigation the enhancement is found in heat transfer rate of PCM due to the incorporation of nanoparticles.
2. In experiment of forward experiment with ascending order of Al_2O_3 nanoparticles it is found that at initial condition most of the PCM is in solid state. Because of this there less movement of Al_2O_3 nanoparticles is occurs. As the amount of melt fraction increases the movement of nanoparticles happens which assist in the heat transfer. This clearly shows the enhancement in due to addition of nanoparticles.
3. The enhancement is depends on the percentage of nanoparticles and position of the spherical ball into the tank. Maximum enhancement in melting time of 10.65% is observed for 0.5% Al_2O_3 when it is placed on B2 position in forward experiment.
4. During experiments it is found that ball B3 and B4 melts in advance than the ball B1 and B2. This happens due to setting of temperature profile diagonally from hot end to cold end of the tank.
5. Formation of homogenous mixture of nanoparticles and base PCM is a very critical issue. It clearly affects the performance of nano mixed PCM.

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