Heat Transfer Enhancement during Charging and Discharging of Pure Paraffin Wax with Dispersion of Nanomaterial

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ABSTRACT— Phase change material (PCM) has capacity to store energy and release it. In present work, paraffin wax use as phase change material (PCM) but it has lower heat transfer rates during charging/discharging due to its low thermal conductivity. Nanoparticles are added in PCM to increase heat transfer rate. Experiments are carried out with dispersion of nanomaterial CuO in pure PCM to ensure the enhancement in heat transfer. These experiments are conducted by adding nanoparticles in different percentage into base PCM to enhance its thermal performance. Comparative study of both pure PCM and nano mixed PCM is conducted. Solar water heating system is considered as latent heat storage system.

***Keywords*:**Latent heat, Thermal storage, Phase change material, Paraffin wax, Heat transfer fluid

I. INTRODUCTION

Energy is the backbone of all human activities on the earth. Development of efficient and inexpensive energy storage devices is as important as development of new sources of energy. The thermal energy storage (TES) can be defined as the temporary storage of thermal energy at high or low temperatures. The TES is not a new concept, and it has been used for centuries. Energy storage reduce the time or rate mismatch between energy supply and energy demand. It plays an important role in energy conservation. Energy storage improves performance of energy systems by smoothing supply and increasing reliability. For example, storage can improve the performance of a power generating plant by load leveling. The higher efficiency would lead to energy conservation and improve cost effectiveness. Some of the renewable energy sources onlyprovide energy intermittently.

Energy storage store energy during the time when excess energy available in order to be used later. In other words, energy storage uses to correct the mismatch between the time of energy supply and energy demand. There are main two types of thermal energy storage system. Sensible heat storage and latent heat storage. Latent thermal energy storage requires less volume than sensible thermal energy storage. In addition, latent thermal energy storage can store a huge amount of thermal energy with a small change in temperature, however, latent thermal energy storage still facing many problems due to the materials used to perform the storage process such as high cost, low thermal conductivity and stability of thermo physical properties after many cycling.

Thermal energy stored as latent heat in which energy stored when a substance changes from one phase to another by either melting or freezing. In latent heat storage the principle is that when heat is applied to the material it changes its phase from solid to liquid by storing the heat as latent heat of fusion or from liquid to vapor as latent heat of vaporization. When the stored heat is extracted by the load, the material will again change its phase from liquid to solid or from vapor to liquid. The latent heat of transformation from one solid phase into another is small. The solid-liquid transformations involve relatively small changes in volume. Such materials are available in a range of transition temperatures.

The PCM used in the design of thermal-storage systems should passes desirable thermo physical, kinetics and chemical properties. There are different types of PCM. These are organic, inorganic and eutectic. Paraffin wax have been widely used for latent heat thermal energy storage system applications due to large latent heat and desirable thermal characteristics such as little or no super cooling, varied phase change temperature, low vapour pressure in the melt, good thermal and chemical stability. Paraffin wax has lower heat transfer rates during melting/freezing processes due to its inherent low thermal conductivity. In order to enhance the effective thermal conductivity usually highly conducting materials are added into paraffin wax.

V .S. Hajare1 et.al [1] has presented experimental study of nanoparticle TiO2 was added in phase change material (PCM) paraffin wax in different percentage. Also concentrated experimentally study on forward and backward arrangement of PCM in spherical ball. In forward system arrange ascending order of nanoparticles percentage in the capsule and exactly opposite arrangement in backward system. Melting and solidification phenomenon for single spherical capsule has been investigated for nano- mixed PCM. Result shows that heat transfer rate is depending on the percentage of nanoparticles and position of the material into the heat transfer fluid tank. It clearly observed that reduction in melting time. Maximum enhancement in melting time of 5.92% observed for 0.05% TiO_2 when it was placed on B2 backward experiment.

A. Val an Aras et.al [2, 8] investigated numerical analysis of natural convection dominates melting in two dimensional rectangular cavities has been widely studied. Present work concentrated on the melting performance of a PCM in a square enclosure is numerically studied and compared between the vertical side wall heating and horizontal bottom wall heating for paraffin wax as PCM. Numerical study was created using pre- processor software GAMBIT.

Agus P. Sasmitob [3] numerically investigation of nanoparticles Al2O3 and CuO added in PCM and analyzed the effect of nanoparticles volume fraction on both the melting and solidification rates of paraffin wax and compared for Al2O3 and CuO nanoparticles. Also studied natural convection effect. Only upper half is modeled for numerical analysis. The enthalpy porosity technique is used in FLUENT for modeling the melting and solidification process. The mushy zone is the region where porosity increases from 0 to 1 as the PCM melts. When the region is complete solid the porosity is zero. The result shows that dispersing nanomaterial in.Smaller volumetric fractions increase the heat transfer rate. The heat transfer enhancement of paraffin wax is greater for Al2O3 compared with CuO nanoparticles.

Yanbin Cui [4] studied experimentally thermal properties of carbon nanofiber (CNF) and carbon nanotube (CNT) filled phase change material (soy wax and paraffin wax) to improve their thermal conductivity. CNF has a strong resistance to corrosion and chemical attack also it has high thermal conductivity and less density. CNT is another nanomaterial which has high thermal conductivity and light in weight. Soy wax is petroleum product which is more environments friendly and sustainable. By stirring of CNF and CNT the composite phase change material were prepared in liquid at 600c with CNF and CNT dopping levels of 1, 2, 5 and 10% weight. The result show that CNF can be considered as an additive to effectively improve the temperature response and thermal conductivity of PCM composites without reducing its latent heat storage capacity. Thermal conductivity of CNF is greater than CNT.

Mehran Abolghasemibizaki et.al [5] presented the thermal energy storage system consist of two concentric cylinders. These are internal cylinder and annulus cylinder. Internal cylinders consist of working fluid and annulus cylinder filled with phase change material. The system carries cyclic operation; each cycle consists of two processes. In charging process hot water enters in internal cylinder as working fluid to transfer heat to PCM. In discharging process cold water enters in internal cylinder to absorb heat from PCM. From these process differential governing equation obtained. There is compared study between numerical and experimental results. Numerical calculation shows that using nano-mixed PCM reduces charging period of the thermal storage. Calculation indicates that nanoparticles have major effect on entropy reduction and minor effect on stored energy reduction.

A V Wag mare et.al [6] experimental investigation has been carried out that the performance enhancement of paraffin wax by adding nanomaterial alumina (Al2O3) in mass fraction 1, 2, 3, 4 and 5% in latent heat storage system. The comparative result indicates that charging rate of thermal energy can be enhanced using nano- mixed PCM. Increasing temperature of HTF from 80^0C TO 90^0C then decreases total melting time.

Francis Agyenim et.al [7] detail studied theoretical, numerical and experimental on various phase change materials, different PCM geometries and different enhancement techniques. It have been concluded that phase change problem occur at temperature range 0^0c – 60^0c. Current studies have concentrated on method of heat transfer enhancement using mostly fins, insertion/dispersion of high thermal conductivity materials, multitudes and micro or macro-n encapsulation. Yvan Dutil et.al [9] review will present models based on the first and second law of thermodynamics. Overall stresses need to match experimental investigation with recent numerical analysis

Present study aims to investigate the heat transfer enhancement due to dispersion of nanomaterials in paraffin wax. The storage system contains commercially available paraffin wax as PCM which is employ to store thermal energy. Limitation of paraffin wax in LHTES system is its low thermal conductivity. To improve thermal performance of LHTES system it is essential to implement some heat transfer enhancement technique, so that thermal conductivity of paraffin wax should increase. Aim of present work is to study the heat transfer enhancement during melting (charging) and solidification (discharging) of the pure paraffin wax with dispersion of nanomaterials by mass concentration.

1. PCM and Nanoparticle

A. Selection of PCM

All materials are phase change materials. The most important difference between these materials is the phase change temperature.Each materialmakes its phase change at different temperature. In addition, each material has different value of latent heat and thermal conductivity. The main drawback of most of phase change materials is their low thermal conductivity that decreases the heat transfer rate. The most important feature for the selected phase change material is to have its phase change temperature fitted with the application temperature range. Indeed, there is no specific material that is called as an ideal material to be used as a phase change material; each material has its advantages and disadvantages.

Table 1. Groups of phase change materials

Organic substances	Inorganic substances	Fatty acids	Commercial PCMs
Paraffin C13	Mn(NO3)2-6H2O	Caprice–lauric acid (45-55%)	RT25
1-Dodecanol	CaCl2-6H2O	Vinyl stearate	STL27
1-Tetradecanol	Na2SO4-10H2O	Lauric acid	RT30
Paraffin C18	LiNO3-3H2O	Capric acid	S27
Paraffin	Na2CO3-	Myristic	TH29

C16–28	10H2O	acid	
Paraffin wax	CaBr2-6H2O	Palmitic acid	RT40
	Na2HPO4-12H2O	Stearic acid	RT50
	K3PO4-7H2O		TH58

Selection of PCM depends upon on a particular application. Use of PCMs as latent heat storage material depends upon the desired physical, chemical, thermal properties and economic factors. In present work solar water heater system as LHTS. The temperature of water to be stored in hot water tank is about 55^0C, so the melting temperature of the PCM should be around 60^0C with maximum amount of latent heat. Selection of laboratory grade paraffin wax is as PCM which having melting temperature 58^0C to 60^0C which is suitable for given application. They have large latent heat, good thermal stability and good thermal energy storage density etc. thermophysical properties of paraffin wax are listed in table2.

Table2.Thermophysical properties of paraffin wax

Melting temp Tm(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
Kinematic viscosity (m/s^2)	5.20×10^{-6}
Density of liquid (kg/m^3)	710

B. Selection of nanoparticle

Selection of nanoparticles depends upon several parameters such as thermal conductivity, cost, particle size, volume fraction and type of base fluid. Particlesize was important parameter because shrinking particles down to nano scale increase the surface area relative to volume and provide better dispersion into base PCM. Results indicated that thermal conductivity increases with decrease in particle size. Nanoparticle concentration was also important parameter. At high concentration time required for melting was high and at low concentration time required for melting was low. Based on the all basic things and considering all above parameters CuO is most common and inexpensive nanoparticles used by many researchers in their experimental investigation.

C. Stabilization of nanomixed PCM

To provide better performance using nanofluids, they are expected to possess long-term stability which should be noted during preparation and synthesis of nanofluids. Indeed, to utilization of nanofluids in practice, stability may be one key issue. Therefore, reasons for fast sedimentation of nanoparticles or nanotubes should be recognized and dispelled. Therefore, in preparation both issues should be taken into account to make a balance between stability and thermal conductivity, whichhave a stable thermal conductive nanofluid. When nanoparticles aredispersed into base material, it observed that there was improper mixing of nanoparticles with PCM and nanoparticles was settling down to the bottom of container. If there was no proper mixing then it was difficult to measure properties of nanomixed PCM with procedure. This problem solved by different methods such as addition of surfactant, PH control and ultrasonic vibration.

Paraffin wax selected as PCM which is non-polar in nature. In the first dispersion step, the CuO were added in the molten paraffin wax with desirable weight percentage of paraffin wax. The Nano suspensions were prepared using an ultrasonic vibrator generating ultrasonic pulses of 100 W at 36±3 kHz. Surfactants were not used as they influence the thermal conductivity value and the effect of nanoparticle addition alone cannot be isolated [4]. To ensure stability and homogeneity, intense sonification was done for a period of 6 hours. The mixture was kept in the liquid state throughout the process by maintaining a constant temperature of 750C. No settling was observed, ensured that the prepared composites were stable.

II. EXPERIMENTAL METHOD

Experimentation is in order to get performance of latent heat thermal energy storage (LHTES) during charging and discharging. Trial extended for addition of CuO in by mass concentration 1, 3 and 5% by mass fraction of paraffin wax which is used as a phase change material in LHTES**.**

A. Experimental set up

The schematic of experimental set- up is shown in Fig1. Temperature sensors with their axial and radial positions are given in Table 3. As shown in Figures, the test unit has a vertical concentric double pipe configuration. There are the heat transfer fluid (HTF) pipe introduced into the PCM in the annular space. The inner and the outer pipes are made of Copper and SS-304 respectively. The HTF isflowing through form bottom to the top of the HTF pipe. Temperatures probes of PCM are Pt100 have measuring accuracy of 0.1^0c. In the heat storage unit, four temperature probes are set up in longitudinal from the bottom (at the positions of 100, 200, 300, 400mm), and radial direction (at the positions of 21.5 34.5, 43) from the outer wall of the HTF pipe toward the inner wall of the PCM container in order to measure the temperature field in the PCM. Additional measurements include the temperatures of the inlet and outlet HTF temperatures. Insulation of asbestos rope is wounded to prevent heat loss from the system to the surroundings. The mass flow rate of HTF measured by a calibrated flow meter with a measuring accuracy of 0.01 kg/s.

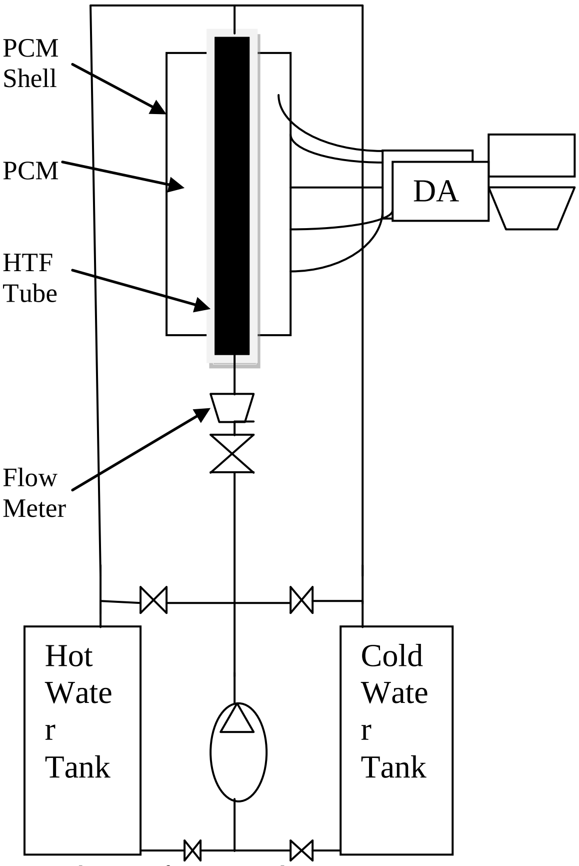

Fig 1. Schematic of experimental set up

Insulatedhot Water tank with temperature controller to provide HTF to the test unit. Cold water tank of the same size provided as well. Two industrial heaters are in combination with temperature controller are fixed in hot water tank. One pumps to circulate hot water and cold water in the test unit along with necessary piping. Data acquisition is an integral part of the system.

Table 3: Temperature sensors positions

Temperature sensor	**Axial position from bottom, mm**	**Radial position, mm**
T1	100	21.5
T2	200	21.5
T3	300	21.5
T4	400	21.5
T5	100	34.5
T6	200	34.5
T7	300	34.5
T8	400	34.5
T9	100	43
T10	200	43
T11	300	43
T12	400	43

B.Experimental procedure:

Operation of the system for the first time involve loading of solid chunks of the PCM inthe PCM container. The system heated to a high temperature of 90^0C to allow for melting of solid pieces. The melting run started at room temperature, where the PCM was in the solid phase. Throughout melting run, the hot HTF with a constant mass flow rate and temperature over the melting range of the PCM passed into the HTF pipe. The melting process process finished as soon as all the radial temperatures were above the melting temperature range. Temperature data are recorded intervals of 1min. the solidification period was initiated directly by passing the cold HTF into the HTF pipe at a constant mass flow rate and temperature below the solidification range after completing the melting process. Temperature distributions in the PCM and the inlet and outlet temperatures of the HTF were measured and recorded in the same way as in the melting period. Melting and solidification processes of the PCM were repeated at different initial HTF temperatures and mass flow rates.

The experimental procedure parameters are as shown in Table 4.

Table 4: Experimental procedure parameters

Case	Process	Mass	Flow Rate	Heat transfer fluid (HTF)
PCM	Charging Discharging	- -	Constant Constant	Variable T Variable T
PCM+ Nano I	Charging Discharging	1,3,5% 1,3,5%	Constant Constant	Variable T Variable T

Next study will concentrate on computational analysis of PCM as well as nanomixed PCM melting and solidification process. For the analysis process ANSYS software will be used. By using this software time rate of melting and solidification of PCM and nanomixed PCM will receive.Also focused on comparative study on thermal energy storage by using only PCM and dispersion of nanomaterial CuO in PCM.

III. CONCLUSION

In present work theoretical and experimental study carried out.

1. This review pays attention towards LHTES using PCM. This technology is very beneficial for thermal energy storage and its conservation.
2. Shell and tube type heat exchanger is the most promising device as a latent heat thermal energy storage system.
3. Most of the experiment shows that PCM has moderate thermal energy storage density, good thermal and chemical stability and low cost but the major drawback is lower thermal conductivity. Low value of thermal conductivity of the PCMs can be improved by using nanomaterials.
4. Very few researches have studied the LHTES system using PCM by inserting metal structures.
5. Less research was directed towards experimental investigation of heat transfer enhancement in LHTES system by using nanomaterial's with different wt. %.

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