Performance Improvement of Energy Storage System with nano-additives in HTF

N Beemkumar*, A Karthikeyan, Saravanakumar B, Jayaprabakar J
School of Mechanical Engineering, Sathyabama University, Chennai, India
E-mail: beem4u@gmail.com

Abstract. This paper is intended to improve the heat transfer rate of thermal energy storage system with copper oxide (CuO) as nano-additives in heat transfer fluid (HTF) by varying encapsulation materials. The experimentation is done with different encapsulating materials like copper, brass and aluminium. The results are analysed for their thermal performance characteristics during charging and discharging processes. D-Sorbitol and therminol-66 with CuO is used as PCM and HTF respectively. A comparison was made between the different encapsulations and it was found that copper encapsulation has higher efficient, storing and recovering energy. However, its high thermal conductivity promotes larger heat losses and its cost is also high on other side. So the economical use of encapsulation material is aluminium compared to other two materials.

1. Introduction
Thermal energy storage can be defined as the storage of thermal energy of any temperature (i.e., either high or low) for temporary purposes. Thermal energy are basically stored in three different methods which include sensible heat storage, latent heat storage and some physiochemical reactions results in the thermal storage [1-4]. Sensible heat storage is the storage systems in which the heat is stored directly without the changing the phase of the material. Heat transfer fluids are used for sensible heat storage. Energy storage usually increases reliability and stabilize the energy supply which improves the performance of energy systems [5-6]. A storage system improves the performance of the power generated by levelling of load; the higher efficiency leads to energy conservation and improves the cost effectiveness.

The nanoparticles when dispersed in heat transfer fluid enhance the heat transfer in the fluids. Solid metallic particles show high thermal conductivity than non-metallic solids and metallic & non-metallic liquids. Copper particles show high thermal conductivity than Aluminium particles [7]. Nanofluids tend to deteriorate heat transfer at supercritical pressures because deposition of the nanoparticle smoothens the wall roughness and presents an additional thermal resistance [8-9]. Effective thermal conductivity of nanofluids increases with the volume fraction of nanoparticles as well as with temperature.In addition of nanoparticles gives a better enhancement with temperature for low volume fraction of particles. Many researches have been done on the improvement of heat transfer in thermal storage system but no or very minimal researches have been done to include nanoparticles in the HTF to improve the heat transfer in thermal storage system. It is decided to have CuO as a nanoparticle which is been mixed with therminol-66 oil and used as a HTF. The PCM selected is D-sorbitol which as high stability during phase transformation.
2. Experimental Setup and Methodology

The experimental set up consists of three PCM storage tanks, a storage tank, a heater and a circulating pump. The storage tank consists of both, the PCM and the HTF. Each tank has a diameter of 25.6 cm and 30 cm length made of 0.6 cm thick MS plate. The storage tank is well insulated with glass wool of 10 cm thickness and pipe lines are also insulated with same material. A total quantity of 50 L of Therminol-66 with an additive CuO is charged in the storage tank and also in the piping circuit, and it has been ensured that there is no leak in the oil flow path. An additional tank is also fabricated to house the heaters which will be used to provide the required heat energy. For circulating HTF gear pump is used with 0.5 HP motor. Valves are present at regular intervals to control the amount of HTF flow. The selection of PCM is depends on the required temperature range. The PCM chosen is D-sorbitol, due to its stability. The HTF is Therminol-66 with nano additives of CuO. Therminol-66 is very stable and higher melting point around 390°C and CuO have higher thermal conductivity around 409 w/mk. A gear pump maintains the HTF flow in the circuit, through the heater and storage tank during charging process in which the heated oil transfers heat to the PCM. The PCM is encapsulated in spherical balls of copper, aluminium and brass and the experimentation was done by changing different encapsulating material. Totally six K-Type thermocouples are used to measure the temperature at different locations with a sensitivity of approximately 41μV/°C. The experimentation has been done by two modes of operation, charging and discharging. The experimental layout and the actual PCM tank setup is shown in the figure 1 and 2 respectively.

![Figure 1. Experimental layout](image1.jpg)

![Figure 2. PCM tank.](image2.jpg)
2.1. Charging mode
During the charging mode the HTF is circulated through the heater tank, PCM tank and process unit. The heated oil passing through the PCM tank, the PCM absorbs heat energy present in the oil and then the less energy oil is made pass through the process unit (retrieval of heat energy present in the oil) then it is circulated back to the heater tank. This cyclic process is continued until PCM changes its phase from solid to liquid state. During this process the temperature oil is noted at every 10 minutes interval.

2.2. Discharging mode
During the discharging mode, the heater tank is switched off and the oil temperature gradually decreases. The oil is made pass through the PCM tank; the PCM loses energy to the oil and the temperature of oil increases. The PCM releases heat to the HTF and changes its phase from liquid to solid. This process maintains the temperature of the fluid constant for a longer time. This process continues until the HTF reaches the temperature of 30°C (ambient temperature). This process is continued around 100 cycles. The temperature of oil observed at the interval of 10 minutes during discharge mode.

3. Results and Discussion
Figure 3 shows the charging and discharging process in the second tank. It was observed that the temperature in the second tank is slightly less than that in the first tank. The heat transferred increases initially and then varies within the specific range during charging. The heat recovered in the beginning during the discharging process varies largely. It can be interpreted that the average heat transfer rate during charging is around 9.562 kW and while discharging, the heat transfer is found to be 2.34 kW. Comparing charging and discharging, the heat transfer rate is very low in discharging process.

Figure 3. Charging and discharging of copper encapsulation.
Figure 4. Charging and discharging of aluminium encapsulation.

Figure 5 shows the charging and discharging process in the second tank. It was observed that the temperature in the second tank is slightly less than that in the first tank. The heat transferred increases initially and then varies within the specific range during charging. The heat recovered in the beginning during the discharging process varies largely. The heat stored increases sharply in the middle of the process because of a high change in temperature of the HTF during the heating process. Towards the end of the process, heat stored decreases. For the discharging process, the heat recovered decreases initially and then remains constant throughout the process. The process continues for a longer period because of the slow discharge of heat from the phase changing material. A comparison is made between heat transfer rates of three tanks. It can be interpreted that the total heat transfer rate during charging for is 2.09 kW. During discharging is 11.21 kW.

Figure 5. Charging and discharging of brass encapsulation.

4. Conclusion
A comparison of the heat stored and recovered in brass, copper, aluminium encapsulations while using therminol-66 with a nano additive of CuO as HTF. The results show that the copper encapsulated PCM balls stores the more heat energy while brass stores the least during charging mode. The same is observed during heat recovery i.e., discharging mode. But at the same time, the heat loss (difference between heat stored and recovered) is the highest in copper encapsulation followed by aluminium encapsulation and the least in brass encapsulation. This can be attributed to the high thermal conductivity of copper and a relatively low thermal conductivity for brass. Comparing three materials copper has more heat gain while charging and heat recovery while discharging. But according to economical usage the aluminium encapsulated PCM is best in all.
References

[1] Aceves-Saborio SS, Nakamura HH and Reistad GM 1994 Optimum efficiencies and phase change temperatures in latent heat storage systems ASME Journal of Energy Resources Technology 116(1) pp 79-86.

[2] Antony Aroul Raj and R Velraj 2011 Heat transfer and pressure drop studies on a PCM-heat exchanger module for free cooling applications International Journal of Thermal Sciences 50 pp 1573-1582.

[3] Antony Farell, Brain Norton and David M Kennedy 2006 Corrosive effects of salt hydrated phase change materials used with copper and aluminium Journal of Material Processing and Technology 175 pp 198-205.

[4] Atilla Biyikoglu 2002 Optimization of a sensible heat cascade energy storage by lumped model Energy Conversion and Management 43 pp 617–637.

[5] Felix Regin, S.C. Solanki and J.S. Saini 2006 Latent heat thermal energy storage using cylindrical capsule: Numerical and experimental investigations Renewable Energy 31 pp 2025–2041.

[6] Jinjia Wei, Yasuo Kawaguchi, Satoshi Hirano and Hiromi Takeuchi 2005 Study on a PCM heat storage system for rapid heat supply Journal of Applied Thermal Energy 25 pp 2903 – 2920.

[7] Horst Michels and Robert Pitz-Paal 2007 Cascaded latent heat storage for parabolic trough solar power plants Solar Energy 81 pp 829–837.

[8] Govindaraj Kumaresan, Rahulram Sridhar and Ramalingom Velraj 2012 Performance studies of a solar parabolic trough collector with a thermal energy storage system Energy 47 (1) pp 395–402.

[9] Mohamed M Abdulgalil, Franc F Kosi, Mohamed H Musbah and Mirko S Komatina 2014 Effect of thermal energy storage in energy consumption required for air conditioning system in office building under the african mediterranean climate Thermal Science 18(1) pp S201-S212.

[10] Beemkumar N and Karthikeyan A 2016 Experimental analysis of heat transfer characteristics of solar energy Materials today: Proceedings 3 pp 2475 – 2482.