Int. J. Chem. Sci.: 14(4), 2016, 2349-2357
ISSN 0972-768X
www.sadgurupublications.com

EFFECT OF CONTAINER SIZE ON THERMAL PERFORMANCE OF SUGAR ALCOHOL (D-MANNITOL) IN CONCENTRATED SOLAR RECEIVER

RAMALINGAM SENTHIL[*] and MARIMUTHU CHERALATHAN

Department of Mechanical Engineering, SRM University,
KATTANKULATHUR – 603203 (T.N.) INDIA

ABSTRACT

Phase change material (PCM) employed inside the solar receiver increases the usability. The geometry of PCM container is an important factor for the phase change of PCM. The influence of size of the container on phase change process of PCM was investigated with nanoparticles. The enhanced melting and solidification characteristics were reported for the optimized size.

Key words: Solar receiver, PCM geometry, Nanoparticle dispersion, Phase change materials.

INTRODUCTION

Thermal energy storage (TES) materials are integrated into the storage of solar collectors to reduce heat losses. The parabolic dish collector (PDC) with integrated storage in the receiver is numerically studied by Tao et al.[1] Effect of nanoparticle in binary salt was also investigated[2]. Mawire and Taole[3] found the energy and the exergy efficiency vary according to the outlet receiver temperature in a PDC. Padilla et al.[4] analyzed exergy of a trough collector. Senthil and Cheralathan[5] determined the temperature distribution on receiver in a PDC. The solar irradiation is utilized for reducing dye concentration with titanium dioxide[6]. Wick solar stills improved the productivity by 14% to 34%.[7] The desalination of water using solar energy was investigated the solar still with pond improved the daily overall efficiency from 42% to 52%.[8,9] The effect of thermal performance enhancers in PCM was reviewed by Senthil and Cheralathan[10,11]. TES modules were integrated into solar water heater to improve thermal performance[12]. The integration of PCM on external wall is used to reduce the heat flux entry the building[13]. The sugar alcohols are promising PCMs for medium temperature. D-Mannitol is an excellent PCM for TES in

[*]Author for correspondence; E-mail: senthil.r@ktr.srmuniv.ac.in

medium temperature applications where temperature requirement is about 160-185^{o}C. The PCM and nanoparticles in a TES enhanced the thermal performance. The graphite nanoparticles have the good ability to increase the efficiency of the PCM.

EXPERIMENTAL

Materials and methods

Parabolic dish collector (PDC) is used for industrial applications. The output from the system is unaffected by sunlight, but in the absence of the sun's radiation; the performanceis affected. The storage enhances the system's ability. It also increases the receiver absorption efficiency.The objective of the study is to provide uniform heat transfer to the heat transfer fluid (HTF) inside the receiver.

Table 1: PCM container sizes

PCM container	Length (mm)	Diameter (mm)
1	50	12.5
2	50	25
3	50	50
4	75	12.5
5	75	25
6	75	50
7	100	12.5
8	100	25
9	100	50

Thermal performance of the PCM was studied with respect to length and diameter of container (Table 1) under similar heat input (isothermal wall temperature of 200ºC) from the base. The dispersion of graphite nanoparticles in PCM is also to enhance the heat flux distribution in PCM. The measurable outcomes are useful heat gain and thermal efficiency. Fig. 1 shows the PCM containers.

A temperature controlled electric heater of 1 kW was used for heat input from one of the base of the cylindrical container. The different diameter and length copper tubes were used in the experiment. The mass of the PCM, container and nanoparticles were measured using a digital weighing balance with an accuracy of ± 1%. The properties of D-Mannitol are given in

Table 2. The thermal conductivity of the PCMs increases with increasing the concentrations of MWCNT, Graphite nanoparticles. Fig. 2 shows the SEM image of graphite particles.

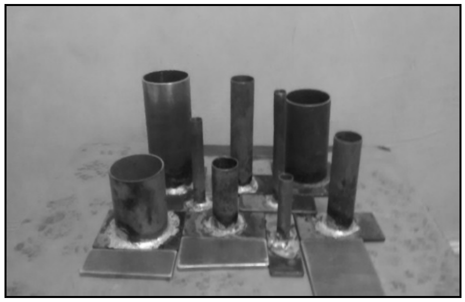
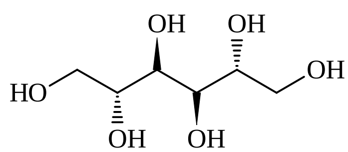


Fig. 1: PCM containers

Table 2: Properties of D-Mannitol

Chemical formula	$C_6H_{14}O_6$
Molecular weight	182.15
Melting point	166 °C
Density (solid)	1520 kg/m^3
Latent heat	316 kJ/kg
Thermal conductivity	0.12 W/mK
Chemical structure	

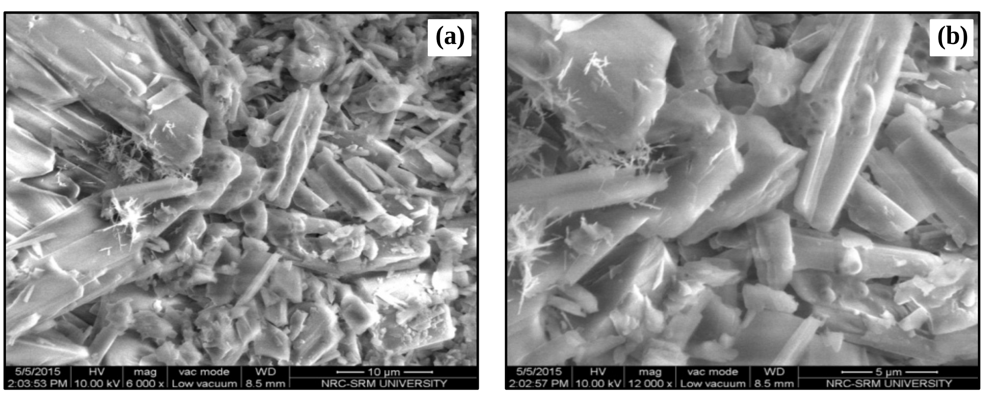


Fig. 2: SEM images of graphite nanoparticles with different magnifications

RESULTS AND DISCUSSION

The effect of geometry od PCM container and nanoparticle concentration are studied. The thermal behavior of PCM was observed for the copper containers with 0.75 kg mass of PCM. The copper containers were subjected to heating from the bottom plate and temperature trends in PCM (Fig. 3) and free convective cooling at air through the lateral surfaces of PCM container (Fig. 4). The experiments are repeated for a particular diameter (25 mm) and three lengths.

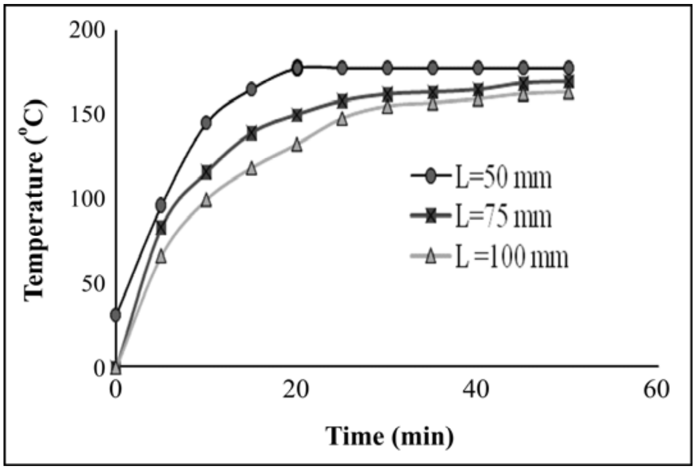


Fig. 3: Melting of PCM in various lengths with same diameter

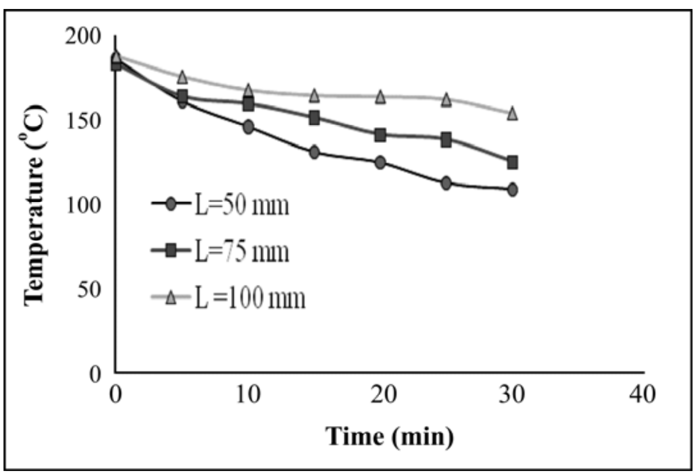


Fig. 4: Freezing of PCM in various lengths with same diameter

The melting and solidification trends are shown in Figs. 5 and 6. It is concluded that the 50 mm height and 12.5 mm diameter is proved the most efficient. The faster and complete melting occurred in the shorter length or diameter without any thermal performance enhancement techniques. However, the dimensions are to be optimum to compensate the energy stored as well as retrieval.

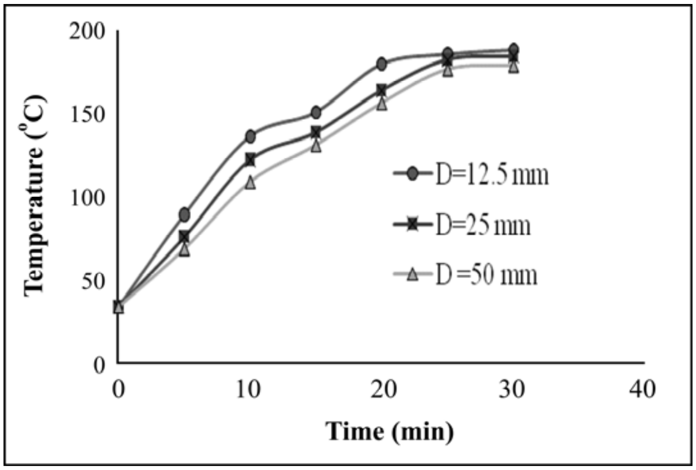


Fig. 5: Melting of PCM in various diameters at the constant length

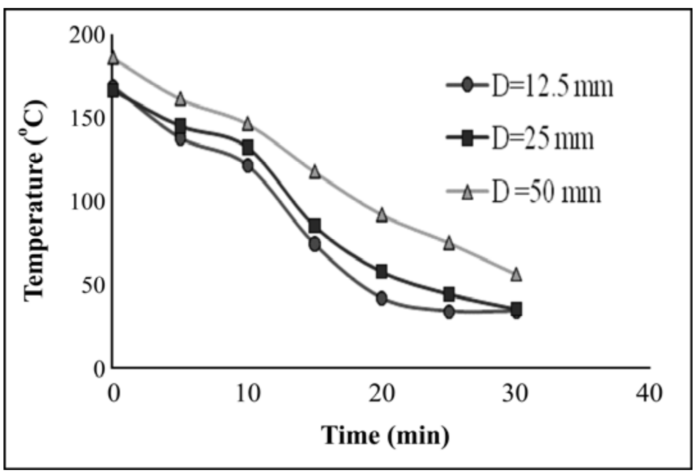


Fig. 6: Solidification of PCM in various diameters at the constant length

The lengths used are 50 mm, 75 mm and 100 mm. The diameters used are 12.5 mm, 25 mm and 50 mm. The 25 mm long container is observed with slightly faster melting than 50 mm diameter. However, the 50 mm diameter PCM was observed with longer solidification duration. Regarding the length of the containers, 50 mm length was better in phase change aspects.

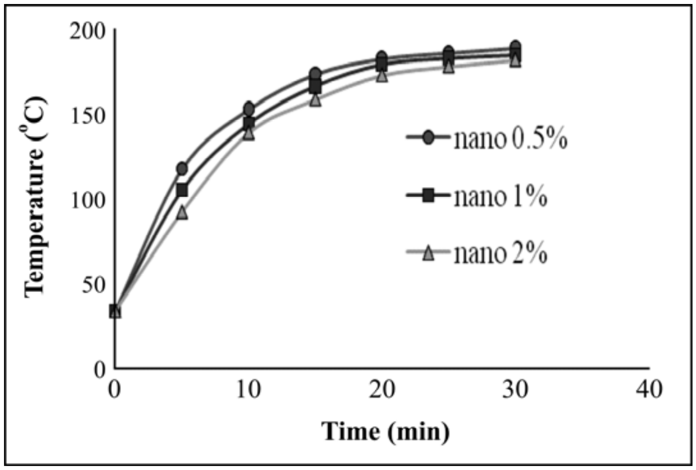


Fig. 7: Melting of PCM with concentrations of nanoparticles

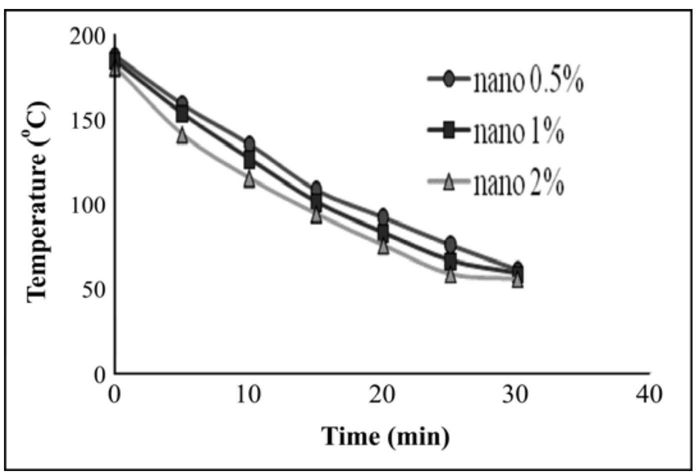


Fig. 8: Solidification of PCM with concentrations of nanoparticles

Figs. 7 and 8 illustrate the charging and discharging behavior of PCM with 0.5%, 1% and 2% concentrations. The lower nanoparticle concentration in PCM was observed with faster melting due to more uniform dispersion. The complete melting time is considered as the performance parameter during melting. The temperature at three equal distance was measured and the mean temperature was shown in the graphs.

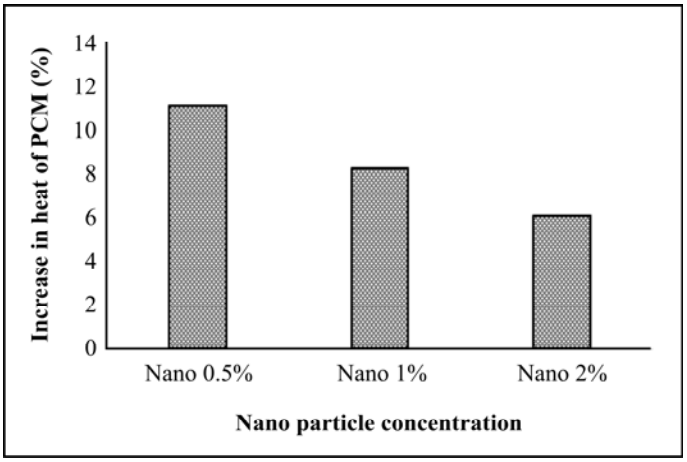


Fig. 9: Effect of nanoparticle on melting time of PCM

The increase in the percentage of nanoparticles leads to agglomerate deposits at the bottom of the container at high temperatures and results in ineffectiveness. From the studied different concentrations of nanoparticles, 0.5% concentrations in a container of 25 mm diameter and 50 mm length is proved as the most efficient container size. The increase in nanoparticle concentrations also weakens the latent heat of PCM. The effect of nanoparticle in PCM is illustrated in Fig. 9. There is 11% increased heat content for 0.5% of nanoparticle dispersion. The increase in nanoparticle concentration decreases the heat stored in the PCM. Lower concentration showed a considerable enhancement due to a uniform distribution. The temperature was measured using K-type thermocouples (accuracy ± 1%), mass of PCM was measured using a digital balance (accuracy ± 1%). The measurement uncertainty was determined with a value well below 3%.

CONCLUSION

An experimental study was conducted to observe the characteristics of PCM for the length, diameter of the PCM container and the concentration of the nanoparticles. The smaller than 50 mm size (length or diameter) containers were shown the enhanced heat transfer inside the PCM. The most efficient dimension of copper tube for encapsulation is less than 25 mm diameter or length of 50 mm with 0.5% concentration of nanoparticles. The thermal performance of PCM increases with decrease in diameter and length of the PCM container during axial flow of heat inside the container. These containers will be attached to the receiver surfaces and act as the finned storage. The outdoor testing of PCM integrated receiver at PDC is an undergoing work of the authors.

REFERENCES

1. R. W. Tao, Y. L. He, F. Q. Cui and C. H. Lin, Numerical Study on Coupling Phase Change Heat Transfer Performance of Solar Dish Collector, Solar Energy, **90**, 84-93 (2013).
2. B. Dudda and D. Shin, Effect of Nanoparticle Dispersion on Specific Heat Capacity of a Binary Nitrate Salt Eutectic for Concentrated Solar Power Applications, Int. J. Ther. Sci., **60**, 37-42 (2013).
3. A. Mawire and H. Simeon Taole, Experimental Energy and Exergy Performance of a Solar Receiver for a Domestic Parabolic Dish Concentrator for Teaching Purposes, Energy for Sustainable Development, **19**,162-169 (2014).
4. R. Vasquez Padilla, A. Fontalvo, G. Demirkaya, A. Martinez and Arturo Gonzalez Quiroga, Exergy Analysis of Parabolic Trough Solar Receiver, Appl. Ther. Engg., **67**, 579-586 (2014).
5. R. Senthil and M. Cheralathan, Effect of Non-Uniform Temperature Distribution on Surface Absorption Receiver in Parabolic Dish Solar Concentrator, Thermal Science, doi: 10.2298/ TSCI150609169S (2015).
6. A. J. Lafta, A. M. Odeh, H. A. Abidalameer, H. A. Esmael, I. J. Mubark and F. S. A. Alameer, Photocatalytic Removal of Some Textile Dyes over Suspension of Titanium Dioxide and Irradiation with Solar Radiation, Int. J. Chem. Sci., **13(4**), 1755-1764 (2015).
7. K. Udhayabharathi, P. Baskar, S. Mohhammed Shafee and R. Sathish Babu, Performance Analysis of Wick Type Solar Stills **–** A Review, Int. J. Chem. Sci., **13(3)**, 1109-1122 (2015).
8. S. Kaliappan, M. D. Rajkamal, V. G. Ganesan and P. Manikandan, Experimental Investigation on Single Basin and Double Basin Solar Desalination, Int. J. Chem. Sci., **14(2)**, 1121-1132 (2016).
9. S. Joe Patrick Gnanaraj and S. Ramachandran, Design and Fabrication of Modified Single Slope Solar Still with Solar Pond, Int. J. Chem. Sci., **14(S2)** 615-624 (2016).
10. R. Senthil, M. Cheralathan, Natural Heat Transfer Enhancement Methods in Phase Change Material Based Thermal Energy Storage, Int. J. ChemTech. Res., **9**(**5)**, 563-570 (2016).

11. R. Senthil, M. Cheralathan, Effect of the PCM in a Solar Receiver on Thermal Performance of Parabolic Dish Collector, Thermal Science, doi: 10.2298/ TSCI150730007S (2016).

12. G. Suganya and B. R. Ramesh Bapu, Experimental Studies on Performance of Latent Heat Thermal Energy Storage Unit Integrated with Solar Water Heater, Int. J. Chem. Sci., **14 (2)**, 1165-1171 (2016).

13. D. Rajesh, K. Abdul Rahim, T. S. Senthil and D. Kumaresh, Passive Solar Heating or Cooling for Residential Building Using PCM, Int. J. Chem. Sci., **14(S2)**, 502-512 (2016).

Revised : 20.08.2016 *Accepted : 21.08.2016*