



## INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

### HEAT TRANSFER ENHANCEMENT IN LATENT HEAT THERMAL STORAGE SYSTEMS USING DIFFERENT GEOMETRY AND COMPOSITE MATERIALS

**S. Venkatraman\*, J. Davidrathnaraj, P. Jidhesh**

\*PG Student, Department of mechanical engineering, Sri Ramakrishna Engineering College,  
Coimbatore, Tamil Nadu, India

Professor, Department of mechanical engineering, Sri Ramakrishna Engineering College, Coimbatore,  
Tamil Nadu, India

Assistant Professor Department of mechanical engineering, Sri Ramakrishna Engineering College,  
Coimbatore, Tamil Nadu, India

DOI: 10.5281/zenodo.573557

#### ABSTRACT

This paper presents an analysis of the storage/release of thermal heat during melting and solidification of paraffin wax PCM (phase change material) with different composite of materials. In this composite material, the paraffin wax is characterized by high phase change latent heat and serves as the heat capacity promoter. Since the low thermal conductivity of PCM makes charging and discharging those system challenging on enhance the heat transfer and latent heat storage. In different geometric design used to enhance the heat transfer for addition of fins, use of straight tube, shell tube and encapsulation in this configuration mostly used for thermal storage system. Finally this paper discusses about heat transfer enhancement study using PCM at there different geometry and composites materials in an heat exchanger.

**KEYWORDS:** Paraffin wax, latent heat, phase change material, heat transfer.

#### INTRODUCTION

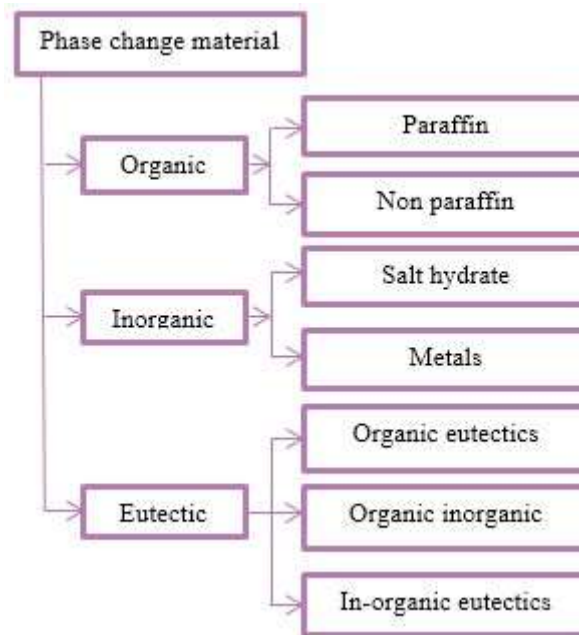
Thermal energy storage is inevitable for effective use of renewable energy source due to their intermittent nature, particularly solar energy, which is the most prospective energy source. In phase change materials (PCMs) for thermal latent heat storage has received a great interest in efficient use of thermal energy in nowadays. It is widely used to applied in many fields, such as solar power generation, industrial waste heat recovering, active and passive cooling of electronic devices. The choice of the most appropriate PCM is based on a number of factors including low cost, high latent and sensible heat, high thermal conductivity in both solid and liquid phases, high specific heat capacity promoters in suitable for phase change temperature. Water is widely used as the PCM thermal storage because of such major advantages as high latent heat of melting, stability, easy available, and cheaper cost no environmental pollution concern and compatibility with the material of air-conditioning and refrigeration equipment. Not withstanding, there zone few detriments with the utilization of water as PCM. A standout amongst the most difficult issues is the supercooling wonder that happens during the time spent cementing water amid charging of the cold storage. This paper assessed various heat storage materials, geometry and performance of heat storage units. Sensible heat storage units found to be having huge size as compared to latent heat storage units. Various kinds of different composites with improved thermal properties were investigated for optimum latent storage of heat. These materials enhanced the amount of heat stored by the system at small volumes. Geometrical designs of different heat storage units were reviewed to find out the suitable geometric design for optimum transfer of heat as will as the different composite materials. The major disadvantage associated with phase change materials is their poor thermal conductivity hence various modification have been tried to enhance the material properties using composites prepared from phase change materials and materials with high thermal conductivity

#### Phase change material

A phase-change material (PCM) is a substance with a high heat of fusion which, melting and solidification at a certain temperature, is capable of heat storing and releasing large amounts of energy.

### Classification of PCM

Details on the classifications of the PCM are available in the literature and are summarized in Fig. 1. The choice of any material for latent heat storage lies on the different application as the materials exhibits different characteristic properties in the PCM. However, certain desirable properties of PCMs that include thermodynamic, physical, and chemical properties as well as economic viability and availability must be taken into account for proper selection of the good materials.



**Fig: 1 Phase change material**

The paper presents a state of the previous review on heat transfer enhancement in phase change material that possesses all the desirable properties highlighted above and as such, the PCMs exhibit some undesirable properties and behaviours that hinder their performance in LHTES (Latent Heat Thermal Energy Storage) systems.

### Phase change material used for latent heat storage

Selection of right phase change material for thermal storage application is an important part where range of parameters need to be investigated. These parameters include a desired melting point depending on the type of application, desired latent heat of fusion vaporization, thermal conductivity and stability of material towards thermal cycling. The important criterion for choosing a phase change material is that its melting point should lie in the range for desired application. Organic phase change materials have low melting temperature range and employed for low temperature thermal energy storage systems. PCM with melting point 10<sup>0</sup>C inside the tubes of thermal storage unit coupled with ice based system and found that about 13.5% energy recovered by the system which was further enhanced by heat transfer optimization. Similarly inorganic phase change materials lie in the high temperature melting point range and used for high temperature thermal storage like in CSP (Concentrated Solar Plant), thermocline storage material etc. Table 1 represents thermal properties of some organic and inorganic PCM are used in different applications for latent heat storage. Eutectic mixtures of organic and inorganic materials is again matter of interest for past research programs to develop mixtures with desirable melting point, high thermal capacity.

**Table: 1 Phase change material used for latent heat storage**

PCMs	Type	Melting point (°C)	Heat of fusion (kJ/kg)	Thermal conductivity (W/mK)
Paraffinwax (C13eC18)	Organic	32	251	0.214
Polyglycol E600	Organic	22	127.2	0.189

Vinyl stearate	Organic	29	122	0.25
Butyl stearate	Organic	19	140	0.21
Caprylic acid	Organic	16	148	0.149
KNO <sub>3</sub> /NaNO <sub>3</sub>	Inorganic	220	100.7	0.56
LiNO <sub>3</sub> /CaNO <sub>3</sub> With solar salts NaNO <sub>3</sub> and KNO <sub>3</sub>	Inorganic	130	276	0.56
KNO <sub>3</sub> /NaNO <sub>3</sub> (30%/70%)	Inorganic Non eutectic mixture	260	305	0.54
Polymethyl methacrylate (PMMA)/ capric-stearic acid mixture	Organic eutectic mixture	21.37	116.25	0.15

### Composites of phase change material

Although phase change materials have been used in wide range of applications to trap heat but they have poor thermal conductivity. Combination of phase change materials with materials of high thermal conductivity attracted the interest of the researchers to use them for various applications. Table 2 shows different composites prepared from organic phase change materials. The materials used to enhance the thermal conductivity of PCMs should have high thermal conductivity, resistant to chemical reaction and should be compatible both with phase change material and material of the container. Thermal conductivity of pure paraffin is 0.216 W/mK which increases its melting time and increases the charging time of thermal storage system which can be improved further by adding materials of high thermal conductivity to the paraffin wax. Ref. [1] added Nano magnetite/ nanoparticles of magnetite with high thermal conductivity 9.1W/mK to enhance the thermal conductivity of paraffin by providing metallic surface area for heat transfer and it is a costlier component which also adds weight to the system. TiO<sub>2</sub> nanoparticles (Harikrishnan *et al.*, 2013) were used with paraffin wax as well as stearic acid to enhance their thermal conductivity. Aluminium foam (218 W/mK) was also used to enhance thermal conductivity of paraffin [2]. Enhanced thermal conductivity was due to conduction through the aluminum foam as compared to the natural convection. Addition of metal foams or their nano forms will enhance the thermal conductivity but they also added weight to the system and increased the cost of the thermal storage system. Table 3 listed various composites of inorganic PCM, their eutectic and non-eutectic materials.

*Table: 2 Composites of organic phase change materials*

S.No	Organic Composite	Thermal conductivity (W/mK)	Observation
1	Paraffin wax (80% wt.) with nano magnetite (20% wt.)	0.40	Addition of 20% nanomagnetite enhanced the thermal conductivity of paraffin by 67%. Use of 10% nanomagnetite increased the cost of composite by 20%.
2	1.Liquid paraffin/aluminium foam 2.Solid paraffin/aluminum foam	1. 46.04 2. 46.12	Thermal conductivity of PCM composite increased up to 218 times more as compared to the pure paraffin with 26% drop in heat fluxes.
3	Paraffin wax (80% wt.)/graphite (20% wt.in form of foam, fibers and fins	0.972	Heat flow much rapidly in porous graphite foam as compared to fin and fiber configuration. More temperature was enhanced using fin configuration as compared to foam and fibers for the same time.

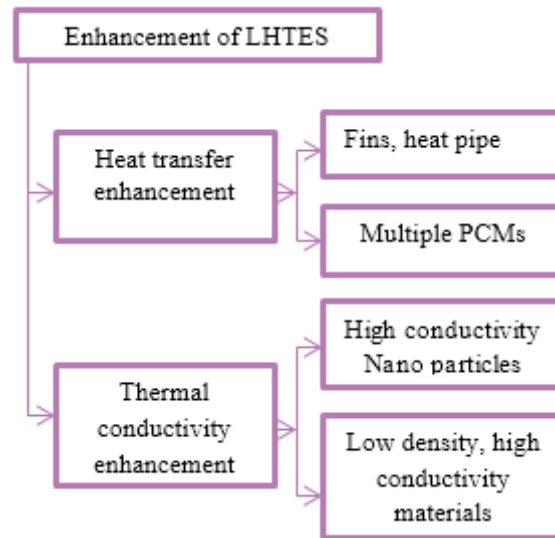
4	1.Paraffin wax (80% wt.)/waste graphite (20% wt.) 2.Paraffin wax (80% wt.)/SFG75 (Timrex powder) (20% wt.)	1. 0.428 2. 0.906	91% enhancement in thermal conductivity of paraffin was observed with waste graphite as compared to 300% enhancement by fresh graphite
5	1.Paraffin wax (90% wt.)/expanded graphite (10% wt.) 2 .Paraffin wax (90% wt.)/graphite (10% wt.)	1. 0.938 2. 0.561	Expanded graphite enhanced thermal conductivity of paraffin by 300% while graphite enhanced the thermal conductivity by 150% as compared to pure paraffin.
6	Paraffin with expanded graphite (2% wt., 4% wt., 7% wt. and 10% wt)	0.29, 0.51, 0.68, 0.81 respectively	Thermal conductivity of paraffin increased with increase in graphite content with no leakage up to 10% wt. of graphite.
7	Paraffin with TiO <sub>2</sub> (1%-4% wt.)	0.7	With increase in TiO <sub>2</sub> loading phase change temperature increases with decrease in latent heat capacity. Thermal conductivity of composite increases with increase in TiO <sub>2</sub> loading upto 3%.

**Table: 3 Composites of inorganic phase change materials.**

S.No	Inorganic composite	Thermal conductivity (W/mK)	Observation
1	KNO <sub>3</sub> /NaNO <sub>3</sub> -graphite composite (80% wt./20% wt.)	20	Molten salts also having low conductivity. Thermal conductivity is 20 W/m.K.
2	Non eutectic mixture KNO <sub>3</sub> (30% wt.)/NaNO <sub>3</sub> (70%)	0.5	Salt mixture provide wide range of temperature range between 220 and 260 <sup>0</sup> C for melting and freezing cycle
3	Lithium carbonate and sodium carbonate/ceramic/ carbon materials (10%)	4.3	Using eutectic mixture of sodium and lithium carbonate on skeleton on magnesium carbonate
4	Na <sub>2</sub> CO <sub>3</sub> /MgO composite with added multiwall carbon nanotubes (0.5% wt.)	1.13	Material without added carbon nanotubes showed good thermal stability but poor thermal conductivity.
5	Cylindrical model of paraffin and porous graphite matrix were studied.	Radial 27.3 Axial 5.3	Increased in graphite content directly proportional to thermal conductivity of composite.
6	LiNO <sub>3</sub> /KCl (70% wt.)- expanded graphite	15	Presence of EG decrease the latent heat of the composite. Composite with higher density increases the thermal conductivity of the composite.

### Latent heat thermal energy storage

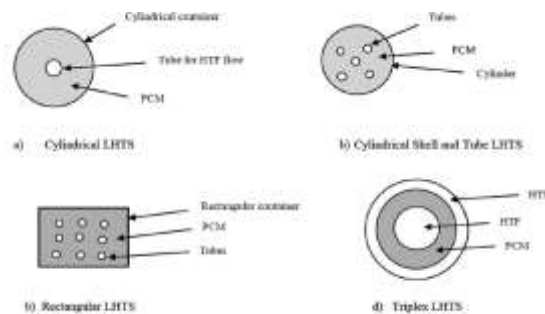
A large number of researchers have conducted significant work including theoretical and experimental studies on heat transfer enhancement in LHTES. However, based on the literature survey there is limited number of review articles focusing on heat transfer enhancement of LHTES, dealing with the problem of poor thermal performance due to low thermal conductivity. With ever increasing research interest on LHTES heat transfer enhancement. The paper presents a state of the art review on heat transfer enhancement in LHTES systems, covering the techniques summarized in Fig. 2



*Fig: 2 Techniques of Heat transfer enhancement in LHTES systems*

### Geometry of thermal storage systems

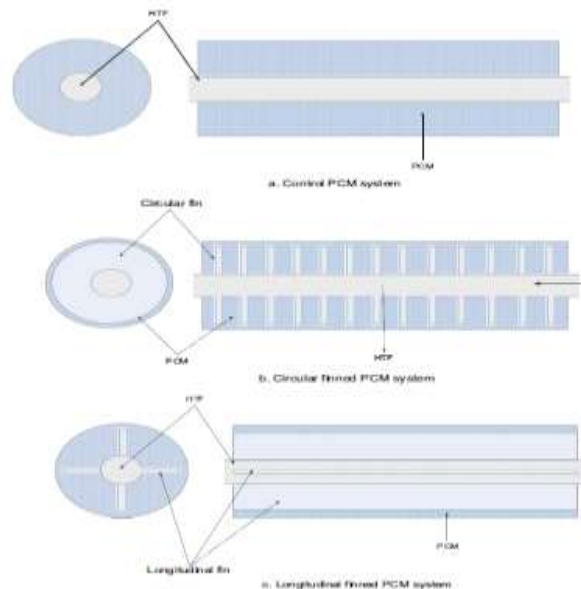
For optimum heat storage system selection of PCM and geometry of heat storage unit plays crucial part. Type of PCM for a particular heat storage unit is based on its melting point while geometry of heat storage system drives the heat transfer. Different geometrical designs of thermal storage unit studied are shown in Fig. 3 which includes cylindrical/rectangular heat storage unit with HTF (Heat Transfer Fluid) passing through single tube, multiple tubes and triplex tube heat transfer unit with HTF flowing through center and outer of phase change material. In some geometrical arrangements fins were integrated with the tubes to provide more surface area for heat transfer. However addition of fins reduces the amount of PCM in the storage unit and hence reduced overall heat capacity of the system. Material used for PCM container should be well insulated from outside and it should not show any reaction with the phase change material filled inside the container.



*Fig: 3 Geometry of thermal storage systems*

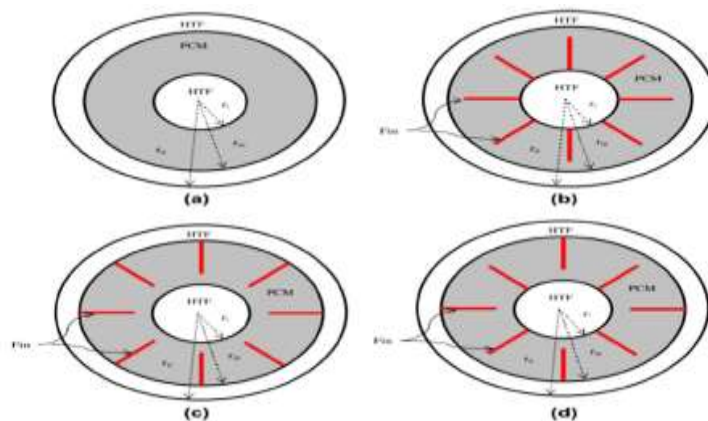
### Heat transfer enhancement with fins

Fins are generally employed to increase the heat transfer area between PCM and HTF and consequently improve the thermal performance of LHTES system. Selection of the fin material depends on its thermal conductivity, density, cost and corrosion potential. Some relevant properties and cost of common fin materials are given in Table 2. Graphite foil appears to have the advantage of low density, while aluminium has the advantage of relatively high thermal con- Fig. 2. Techniques for heat transfer enhancement of LHTES systems thermal conductivity, low cost and medium density as compared with other materials. Many researchers reported the use of fins of various shapes and configurations in LHTES systems. The common configurations of LHTES investigated so far are of two kinds: (i) System that involves heat storage and retrieval through hot/cold HTF, such as the one used in solar air or water heaters. (ii) System that serves as a heat sink reservoir through hot/cold boundary wall, for example, the ones used in electronic cooling. In heat sink based-LHTES systems, which do not involve HTF, the fins are located within the PCM. However, the fins location in LHTES with HTF is generally on the side with lower relative thermal conductivity, which in most cases is the PCM.



**Fig: 4 Three horizontal concentric tubes storage units**

Agyenim et al. [3] considered three horizontal concentric tubes storage units: one unfinned (control PCM unit) and the other two with circular and longitudinal fins, as shown in Fig 4. The authors compared the thermal performance of the three configurations experimentally and the results showed that the system with the longitudinal fins provided the best thermal response during melting. Abidi et al. [4] investigated PCM solidification in a TTHX numerically with and without internal and external fins considering both pure conduction and natural convection. The results indicate that the effect of fin thickness was smaller as compared to that of the fin length. In addition, the total solidification time for TTHX geometry with the highest number of fins was decreased by 35%. Mat et al. [5] studied the melting process in a TTHX system considering inside tube heating, outside tube heating, and both sides heating methods for charging. They considered three configurations, namely, a TTHX with internal fin, a TTHX with external fin, and a TTHX with internal–external fin as shown in Fig.5. Comparative analysis showed that there was no significant difference among the three configurations in terms of PCM melting rate. The use of internal–external fin reduced the time for complete melting of the PCM by 43.3% as compared with that of TTHX without fins. As stated earlier, one common LHTES application is heat sinking or rejection usually employed for cooling electronics and PV cells [6]. PCM-based heat sinks can absorb dissipated heat from a component and cool its surface passively and effectively without any mechanical input [7]. In heat sink systems, there is no HTF, and the PCM or its container is in contact with the surface to be cooled and therefore, heat is transferred from the surface to the PCM. Fins are usually inserted into the PCM in such systems to enhance the heat transfer process.



**Fig: 5 (a) TTHX without fin, (b) TTHX with internal fins, (c) TTHX with external fin, (d) TTHX with internal–external fin**



## CONCLUSIONS

There are various types of sensible and latent heat systems, their heat storage materials and their geometrical designs are available. Sensible heat storage systems were simple in designs, easy to maintain but bigger in size. Latent heat systems were found to be more suitable for thermal storage due to their high energy storage density and quasi thermal nature of storage. The low melting point of organic PCMs made them suitable for low temperature applications like solar water heating, cold storage, as building material etc. While inorganic PCMs due to their high melting point were more suitable for high temperature storage application like concentrated solar plant. Broadly, the study revealed that enhancement in heat transfer can be accomplished either by increasing the heat transfer area of the storage system or by increasing the thermal conductivity of the storage material (PCM). Extended surfaces such as fins and heat pipe are usually employed to increase the heat transfer area while high conductive materials/particles are used to increase the heat transfer of the LHTES systems.

## REFERENCES

- [1] N. S, ahan, M. Fois, Halime Paksoy, Improving thermal conductivity phase change materials study of paraffin nanomagnetite composites, *Sol. Energy Mater. Solar Cells* (2015).
- [2] Z.Wang, Z. Zhang, L. Jia, L. Yang, Paraffin and paraffin/aluminum foam composite phase change material heat storage experimental study based on thermal management of Li-ion battery, *Applied Thermal Eng* (2015).
- [3] Agyenim F, Eames P, Smyth M. A comparison of heat transfer enhancement in a medium temperature thermal energy storage heat exchanger using fins. *Sol Energy* (2009)
- [4] Al-Abidi AA, Mat S, Sopian K, Sulaiman MY, Mohammad AT. Numerical study of PCM solidification in a triplex tube heat exchanger with internal and external fins. *Int J Heat Mass Transfer* (2013).
- [5] Mat S, Al-Abidi AA, Sopian K, Sulaiman MY, Mohammad AT. Enhance heat transfer for PCM melting in triplex tube with internal-external fins. *Energy Convers Manag* (2013).
- [6] Ma T, Yang H, Zhang Y, Lu L, Wang X. Using phase change materials in photovoltaic systems for thermal regulation and electrical efficiency improvement: a review and outlook. *Renew Sustain Energy Rev* (2015).
- [7] Kandasamy R, Wang X-Q, Mujumdar AS. Transient cooling of electronics using phase change material (PCM)-based heat sinks. *Applied Thermal Engg* (2008).
- [8] Nasiru I. Ibrahim, Fahad A. Al-Sulaiman, Saidur Rahman , Bekir S. Yilbas , Ahmet
- [9] Z. Sahin. Heat transfer enhancement of phase change materials for thermal energy storage applications. *Renewable and Sustainable Energy Reviews* (2017).
- [10] Abhay Dinker, Madhu Agarwal, G.D. Agarwal. Heat storage materials, geometry and applications. *Journal of the Energy Institute* (2015).
- [11] Guruprasad Alva, Lingkun Liu, Xiang Huang, Guiyin Fang. Thermal energy storage materials and systems for solar energy applications. *Renewable and Sustainable Energy Reviews* (2017).
- [12] A. Reyes, L. Henríquez-Vargas, J. Rivera, F. Sepúlveda. Theoretical and experimental study of aluminum foils and paraffin wax mixtures as thermal energy storage material. *Renewable Energy* (2017).
- [13] Jose Pereira da Cunha, Philip Eames. Thermal energy storage for low and medium temperature applications using phase change materials *Applied Energy* (2016).

## CITE AN ARTICLE

Venkatraman, S., Davidrathnaraj, J., & Jidhesh, P. (2017). HEAT TRANSFER ENHANCEMENT IN LATENT HEAT THERMAL STORAGE SYSTEMS USING DIFFERENT GEOMETRY AND COMPOSITE MATERIALS. *INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY*, 6(5), 384-390. doi:10.5281/zenodo.573557