

# Performance Comparison of a Thermal Energy System Using PCM Encapsulated With Spherical Capsule

K. THIMMAREDDY<sup>1</sup>, Dr. R. MEENAKSHI REDDY<sup>2</sup>, E. SIVA REDDY<sup>3</sup>, S.NARESH<sup>4</sup>

<sup>1</sup>Student, Mechanical Engineering, G. Pulla Reddy Engineering (Autonomous) College, Kurnool, A.P, India.

<sup>2</sup>Associate professor, Mechanical Engineering, G. Pulla Reddy Engineering (Autonomous) College, Kurnool, A.P,

<sup>3</sup>Assistant Professor, Mechanical Engineering, G. Pulla Reddy Engineering (Autonomous) College, Kurnool, A.P,

<sup>4</sup>Student, Mechanical Engineering, G. Pulla Reddy Engineering (Autonomous) College, Kurnool, A.P, India,

India.

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**Abstract** - Thermal energy storage (TES) systems provide several alternatives for efficient energy use and conservation. Nowadays for solar heating applications, usage of phase change materials (PCM) to store the heat in the form of latent heat is increased, because large quantity of thermal energy is stored in small volume. The present experimental investigation on the thermal energy storage (TES) system is developed using paraffin and stearic acid as PCM. In the present system solar energy is used as heat source to store the thermal energy in the form of sensible heat and latent heat. In the TES system paraffin and stearic acid are stored in the form of spherical capsules of 150 mm diameter.

Sensible heat storage is relatively inexpensive, but its drawbacks are its low energy density and its variable discharging temperature. These issues can be overcome by phase change materials (PCM)-based TES, which enables higher storage capacities and target-oriented discharging temperatures.

**Key Words:** Thermal energy storage(TES)1, Phase change material (PCM)2, Heat transfer fluid (HTF)3.

## 1. INTRODUCTION

Energy is one of the most important inputs for the economic growth of any nation. The continuous increase in the level of utilization of energy and the climb in fuel prices are the main driving forces behind the research toward energy storage. The thermal energy is a main topic in research for last 20 years. Thermal energy can be stored as a change in the internal energy of certain materials as sensible heat, latent heat or both.

### 1.1 Thermal Energy Storage

Thermal energy storage (TES) in general and phase change materials (PCM) in particular, have been an area of researchers for the last two decades. The utilization of TES systems reduces energy consumption and provides an alternative as fossil fuels are getting depleted.

The selection of TES is generally dependent on the storage period required, economic viability and operating conditions. This system finds many applications in domestic, commercial and industrial sectors. It is interesting to note that the combined sensible and latent heat storage system has been successfully introduced in the air-conditioned application also.

### Advantages of Thermal Energy Storage

- Dynamic balancing between energy demand and availability.
- Conservation of primary fuels
- Reduce the equipment size and the initial cost.
- More effective and efficient utilization of equipment.
- Utilization of waste heat recovery
- Maintenance of environmental quality
- Greater flexibility in operation
- Economical energy consumption
- Thermal protection and control of electronic components
- Heating and cooling of buildings and Hot water preparation.

### 1.2 Steric acid properties

PCM plays a very dominant role in the TES system. The selection of the PCM is made based on various parameters like latent heat, melting point, operating temperature range, specific volume, boiling point, availability, cost etc., After the consideration of these factors, Stearic Acid is selected as PCM for present work. The function of the PCM is to absorb the heat energy from the surface of exhaust gas flow type. After gaining the sufficient heat energy it changes its phase from solid to liquid and again converts to solid phase after releasing heat energy.

### 1.3 Paraffin properties

The normal paraffin's of type  $C_nH_{2n+2}$  are a family of saturated hydrocarbons with very similar properties. Paraffin's between C5 and C15 are liquids and the rest are waxy solids. Paraffin waxes the mainly used commercial organic heat storage PCM. Paraffin's have no tendencies to super cool, so nucleating agents are not necessary. Paraffin's are chemically stable. Paraffin waxes show high heats of fusion.

**Table 1: Thermo-physical properties of PCMs**

Phase Change Material		Paraffin Wax	Stearic acid
Melting Temperature °C		61	57
Latent heat of fusion (kJ/kg)		213	198.91
Density (kg/m	Solid	861	960
	Liquid	778	840
Specific heat (J/kg°C)	Solid	1850	1600
	Liquid	2384	2300
Thermal Conductivity (W/m	Solid	0.40	0.3
	Liquid	0.15	0.172

### 1.4 Extended surfaces (Fins)

In the heat transfer study, the surface that extends from an object is known as a fin. This is used to increase the rate of heat dissipation from or to the environment by increasing the rate of convection. The total of convection, conduction, or radiation of an object decides the amount of heat it dissipates. It increases with the difference of temperature between the environment and the object, also increasing the convection coefficient of heat transfer, or increasing the surface area.

## 2. EXPERIMENTAL SETUP AND DESIGN DETAILS

A TES system is intended and evaluated for its thermal performance observance in that the system should be able to supply hot water at an average temperature of 45°C for domestic use in general. The thermal performance of the system is investigated by water with fin. Both charging and discharging experiments are carried out for evaluating the performance of the system. by integrating with constant inlet heat source. In this process the effect of

following variables are studied. by integrating with constant inlet heat source.

In this process the effect of following variables are studied,

#### Phase Change Materials (PCM)

Stearic acid and  
Paraffin wax

#### Mass flow rates of Heat Transfer Fluid (HTF)

2lit/min and  
4 lit/min.

Above variables are studied in two different stages:

1. Charging process.
2. Discharging Process.

### 2.1 Test Rig



Fig1: Experimental Setup

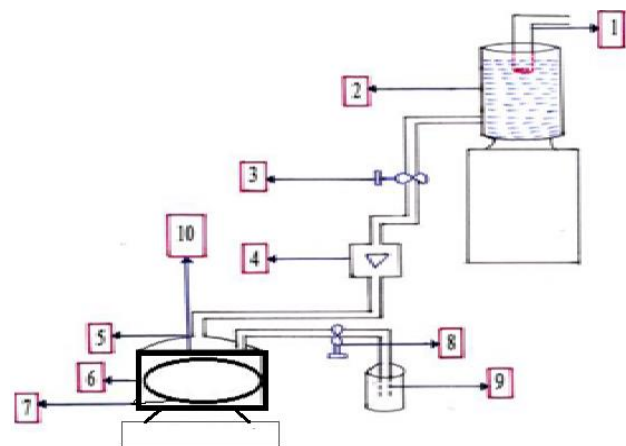


Fig2: line diagram of Experimental Setup

1. Electric heater;
2. Constant temperature bath (water storage tank);
- 3 & 8 Flow control valves;
4. Flow meter;
5. Distributer;
6. TES Tank;
7. PCM capsules;
9. Outlet tank;
10. Digital thermometer.

The above fig. Shows the set-up used in the study of thermal performance of TES system using latent heat and sensible heat of the PCMs. In present system Investigations are carried out to improve the performance of the system, fins are arranged to the PCM storage spherical capsule finally the storage tank is insulated to reduce the heat transfer losses like conduction, convection, radiation losses.

**2.1.1 PCMs storage spherical capsules**



Fig3: Spherical capsule without fin



Fig4: Spherical capsule with fin (circular)

**2.1.2 Storage tank**



Fig5: Insulated with thermocole



Fig6: storage tank with spherical ball

The test rig shows the set-up used in the study of thermal performance of TES system using latent heat and sensible heat of the PCMsthis consists of an insulated TES tank, which contains PCM capsules (spherical capsules), flow meter and water storage tank.

The TES tank has a capacity of 5 liters. The storage tank is insulated with glass wool of 50mm thick and inside of the storage tank is insulated with thermocole of 3 mm thick.

The steric acid and paraffinwax are used as PCMs. Water is used asboth SHS material and HTF.A flow meter with an accuracy of ±2% is used to measure the flow rate of HTF and the flow rate is changedby different tap openings.

The TES tank is incorporated with digital thermometers with an accuracy of ±1°C isplaced above the TES tank to measure the temperatures of HTF and PCM stored inside the capsules.

An electricwater heater is used to maintain the constant temperature in the water storage tank.

## 2.2 Experimental Procedure

### 2.2.1 Charging process

The heat is transferred to or from HTF as it flows on the spherical capsule. During charging the hot HTF is circulated through the tank by the pump employed in the circuit. The PCM inside the capsules absorbs heat and melts. The difference between the mean temperature of HTF and PCM must be sufficient to obtain a satisfactory rate of heat transfer.

During this process at various levels the HTF temperature and PCM temperatures are noted. After the tank is filled, the outlet valve is opened and adjusted such that the water level in the tank is maintained constant.

The circulation of HTF is continued at the given flow rate, till the same temperature is attained by the PCM. The charging experiments are conducted for the HTF at 2lit/min, 4 lit/min. The charging experiments are repeated for the mild steel spherical capsule with fin (circular) and without fin.

### 2.2.2 Discharging process

The process can be by continuous/batch wise process. However, it is reported in the literature that batch wise process is more effective where the requirement is intermittent.

A certain quantity of hot water (5 Lit) is withdrawn from TES tank and the tank is again filled with cold water of quantity equal to the amount of water withdrawn. This fixed quantity of 5 lit of water which is withdrawn from the TES tank to facilitate filling up of fresh cold water is termed as batch. After a time interval of 20 minutes allowing for transfer of energy from PCM, another batch of 5 lit of water is withdrawn from the TES tank. This process is continued until the average temperature of the complete amount of water withdrawn is about 45°C.

## 3 Numerical Studies:

A thermal energy storage system is designed and evaluated for its thermal performance. The thermal performance of the system is evaluated based on the heat energy retrieval from the system. In this the theoretical calculations are carried out for evaluating the performance of the system.

### 3.1 Calculation Procedure

#### 3.1.1 Mass of the stearic acid

Volume of the ball = 1.6 lit

Clearance volume of the ball = 0.2lit

Total volume considered for the

stearic acid = 1.4lit

Mass of the PCM ( $m_{st}$ ) = Density  $\times$  volume  
=  $960 \times 1.4 \times 10^{-3}$

$m_{st} = 1.344 \text{ kg}$

**Total heat of PCM stored in spherical capsule is**

$$Q = (m_{st}c_p\Delta t)_{solid} + (m_{st}L) + (m_{st}c_p\Delta t)_{liquid}$$

Where,

$m_{st}$  = mass of stearic acid

$c_p$  = specific heat of stearic acid

$\Delta t$  = temperature difference

L = Latent heat of fusion

$$Q = 0.0387 + 0.2673 + 0.0710$$

$$Q_{st} = 0.377 \text{ MJ}$$

#### 3.1.2 Mass of the paraffin wax

Volume of the ball = 1.6 lit

Clearance volume of the ball = 0.2lit

Total volume considered for the

Paraffin Wax = 1.4lit

Mass of the PCM ( $m_{pw}$ ) = Density  $\times$  volume  
=  $861 \times 1.4 \times 10^{-3}$

$m_{pw} = 1.205 \text{ kg}$

**Total heat of Paraffin Wax stored in spherical capsule is**

$$Q = (m_{pw}c_p\Delta t)_{solid} + (m_{pw}L) + (m_{pw}c_p\Delta t)_{liquid}$$

Where,

$m_{pw}$  = mass of Paraffin Wax

$c_p$  = specific heat of Paraffin Wax

$\Delta t$  = temperature difference

L = Latent heat of fusion

$$Q = 0.04904 + 0.2566 + 0.0545 = 0.36 \text{ MJ}$$

### 3.1.3 Mass flow rate of HTF

Mass flow rate of water = density of water × flow rate

- **Flow rate of HTF when it is 2lit/min**

$$\text{Mass flow rate} = (1000 \times 2 \times 10^{-3}) \div 60$$

$$m_{\text{htf}} = 0.0333 \text{kg/sec}$$

- **Flow rate of HTF when it is 4lit/min**

$$\text{Mass flow rate} = (1000 \times 4 \times 10^{-3}) \div 60$$

$$m_{\text{htf}} = 0.0666 \text{kg/sec.}$$

### 3.2 Calculation of amount of Heat transfer and Efficiency of TES system

#### 3.2.1 Heat transfer and efficiency of PCM(stearic acid) based TES system with Circular fin by using water as HTF when the flow rate is 2lit/min:

Total time duration for charging process = 140min

$$\text{Mass flow rate of HTF } m_{\text{htf}} = 0.0333 \text{kg/sec}$$

$$\text{Specific heat } c_p = 4.187 \text{kJ/kg k}$$

$$\text{Temperature difference } \Delta t = T_{\text{in}} - T_{\text{out}}$$

$$\text{Heat input of HTF (Q)} = m c_p \Delta t$$

$$Q = 0.0333 \times 4.187 \times 10^3 \times (80 - 79) = 139.427 \text{J/s.}$$

Total heat input of HTF ( $Q_{\text{in}}$ ) = heat input × total time duration

$$Q_{\text{in}} = 139.427 \times 140 \times 60 = 1.171 \text{MJ}$$

Heat output of HTF ( $Q_{\text{out}}$ ) = Total heat input of HTF - Total heat of stearic acid.

$$Q_{\text{out}} = Q_{\text{in}} - Q_{\text{st}} = 1.171 - 0.377$$

$$Q_{\text{out}} = 0.794 \text{MJ}$$

#### Efficiency of the TES system

$$\text{Efficiency of the TES system } (\eta) = (Q_{\text{in}} - Q_{\text{out}}) \div (Q_{\text{in}})$$

$$\eta = (1.171 - 0.794) / 1.171$$

$$\eta = 32.17\%$$

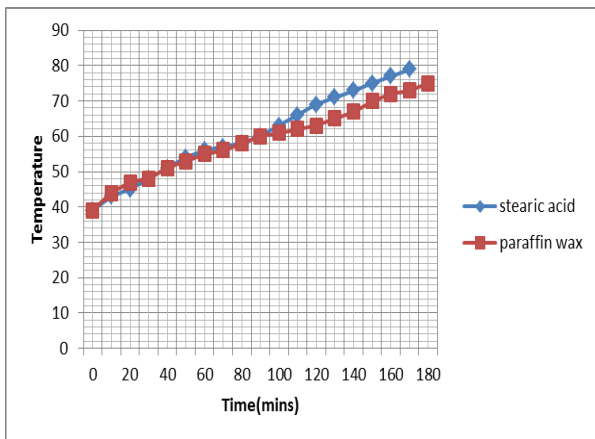
**Table 2: Summary of numerical results and experimental values**

s.no	Types of PCMs	Fin type	Flow rate of HTF (lit/min)	Charging time (mins)	$Q_{\text{in}}$ (MJ)	$Q_{\text{pcm}}$ (MJ)	$Q_{\text{out}}$ (MJ)	$\eta(\%)$
1	Stearic acid	NA	2	170	1.422	0.377	1.045	26.51
2	Stearic acid	circular fin	2	140	1.171	0.377	0.794	32.17
3	Stearic acid	NA	4	80	1.399	0.377	0.962	28.15
4	Stearic acid	circular fin	4	65	1.088	0.377	0.711	34.65
5	Paraffin Wax	NA	2	200	1.673	0.36	1.313	21.51
6	Paraffin Wax	NA	4	95	1.591	0.36	1.231	22.62
7	Paraffin Wax	circular fin	2	170	1.422	0.36	1.062	25.31
8	Paraffin Wax	circular fin	4	80	1.339	0.36	0.979	26.88

## 4. RESULTS AND DISCUSSION

### 4.1 Effect of PCM

The experiment is carried for different PCMs like stearic acid and paraffin wax and the effect of this PCM on heat transfer is illustrated using the graph shown in fig.

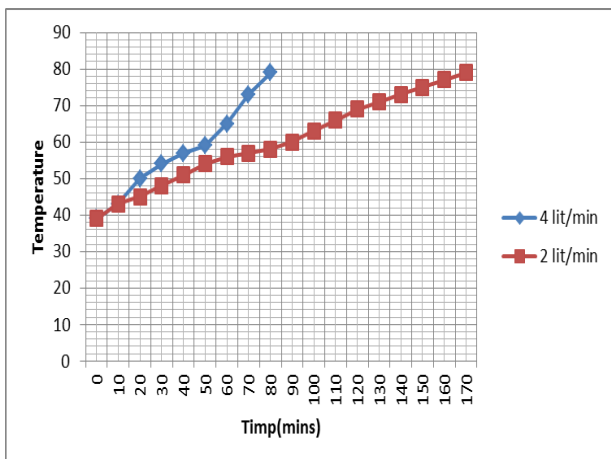


**Graph 1:** Temperature Variation of PCM Spherical capsule without fin and flow rate is 2 lit/min

From the above figures shows the relation between charging time and PCM temperature for paraffin and stearic acid. The charging time of stearic acid is 12% less compared to that of paraffin. This is due to the influence of thermal properties of stearic acid.

#### 4.2 Effect of flow rate

The experiment is carried for different flow rates like 2lit/min , 4 lit/min and the effect of this flow rate on heat transfer is illustrated using the graph shown.

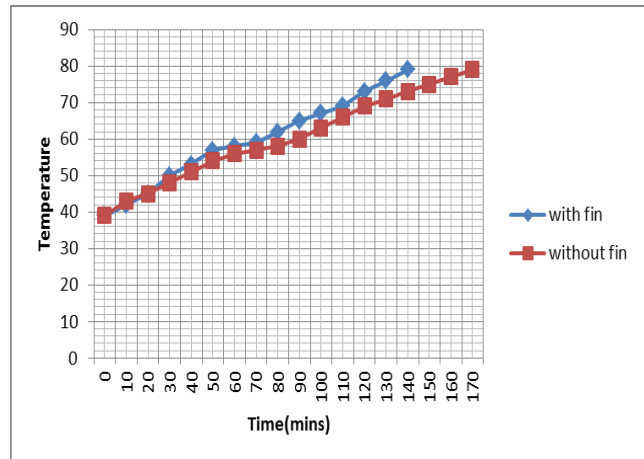


**Graph 2:** Temperature Variation of PCM Spherical capsule without fin PCM as stearic acid

It is observed from the above graphs that the charging time decreases with the increase in mass flow rate from 2 to 4lit/min. This is because as the mass flow rate is increased, the thermal energy supplied to the TES tank through HTF in a given time increases and as there always exists a temperature difference between HTF and PCM. This causes reduction in charging time with increased mass flow rates.

#### 4.3 Effect of Fins

The experiment is carried out to improve the performance of the system by using circular fins for the PCM stored spherical capsules due to this the surface area will be improved and the results are shown by using the graphs.



**Graph 3:** Temperature Variation of PCM Spherical capsule with and without fin and PCM as stearic acid (2lit/min):

It is observed from the above graphs that the charging time decreases by using of extended surfaces i.e., the contact surface area is increases for the spherical capsules so it increase the rate of heat transfer from the system.

It increases with the difference of temperature between the system and the object, also increasing the convection coefficient of heat transfer. This causes reduction in charging time with increased surface area.

#### 5. CONCLUSION

A TES system is developed for the supply of hot water at an average temperature of 45°C for various applications such as water heating, air heating, building applications, printing on the cotton cloths and dyeing the threads and cleaning of utensils etc. Experiments were conducted on the TES unit to study its performance by integrating it with constant heat source.

The variables studied include PCMS, mass flow rate and extended surfaces (FINS), on the performance of TES. From the experimental results it is concluded Out of the two PCMs used in the experiments, stearic acid attains maximum temperature (equal to HTF inlet temperature) faster compared to paraffin. This is due to the phase change temperature and latent heat of stearic acid being less compared to paraffin and by increasing the mass flow rate, the thermal energy supplied to the TES tank through HTF in a given time increases so the charging times can be reduced.

By using extended surfaces the contact surface area is increases for the spherical capsules so it increases the rate of heat transfer from the system. Hence, it is concluded that by charging times can be reduced by using of extended surfaces.

### 5.1 SCOPE OF FUTURE WORK

- In place of PCM being used in the spherical capsules, PCM based nano particles may be employed.
- To increase heat transfer rate in HTF, low density nano particles may be employed, it may give better results.
- To reduce the heat transfer losses perfect insulation provided to the TES system.

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### BIOGRAPHIES



Student, M.Tech in Thermal Sciences and Energy Systems G. Pulla Reddy Engineering College (Autonomous), Kurnool, A.P, India.  
Email:kthimmareddy1@gmail.com



Associate Professor, Mechanical Engineering, G. Pulla Reddy Engineering College (Autonomous), Kurnool, A.P, India.  
Email:rmreddy123@gmail.com



Assistant Professor, Mechanical Engineering, G. Pulla Reddy Engineering College (Autonomous), Kurnool, A.P, India.  
Email:enumulagprec@gmail.com



Student, M.Tech in Thermal Sciences and Energy Systems G. Pulla Reddy Engineering College (Autonomous), Kurnool, A.P, India.  
Email:nareshsandraboina@gmail.com  
Mobile:9985241931