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# REVIEW ON SOLAR WATER HEATERS USING PCM (PHASE CHANGE MATERIALS) IN TES (THERMAL ENERGY STORAGE) SYSTEMS

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**ABSTRACT**

*The fast growing problem of the depletion of the available non renewable energy resources has focused the world's attention on the need of proper use and harvesting of the renewable energy resources. One of the important renewable energy resources is solar energy. In recent times the use of PCM (phase change materials) for storage of thermal energy in solar water heaters has come forward as an efficient way for trapping and storing solar energy. This paper is a summary of the analysis made on how efficiently thermal energy can be stored using PCM in thermal energy storage systems of solar water heaters. The solar water heater is so constructed that it is a combination of two working systems, the first of the two absorbing systems is the solar water heater and the second is TES (thermal energy storage system). TES systems which have paraffin as the PCM are under study here. These systems trap and store the solar energy during daytime with the help of PCM (paraffin) which can later be used during night time to heat water. This heated water can then be used for domestic as well as industrial purposes. TES with PCM has been termed as an effective way to store thermal energy on the basis of the recent experimental studies highly due to their large heat trapping capacity and also because of their isothermal characteristics. These systems are examined properly to check their efficiency.*

***Keywords*: Isothermal, PCM(Phase Change Material), Solar Water Heater, TES (Thermal Energy Storage) Unit, Thermal Efficiency**

## I. INTRODUCTION

Each and every human activity demands energy in some form or other. Our requirement for energy is increasing day by day with every advancement in the various fields. This ever increasing need of energy has put a lot of stress on the non renewable resources which are limited in quantity. Hence it has now become a need to find alternative sources of energy and this need of alternative source of energy can very well be fulfilled by the renewable sources of energy if utilized properly. The main drawback of renewable energy resources is that they are dependent on time, considering the case of solar energy; the availability is restricted only to day time. So it becomes necessary to find ways to trap and store solar energy for its easy utilization during night time or during overcast conditions.

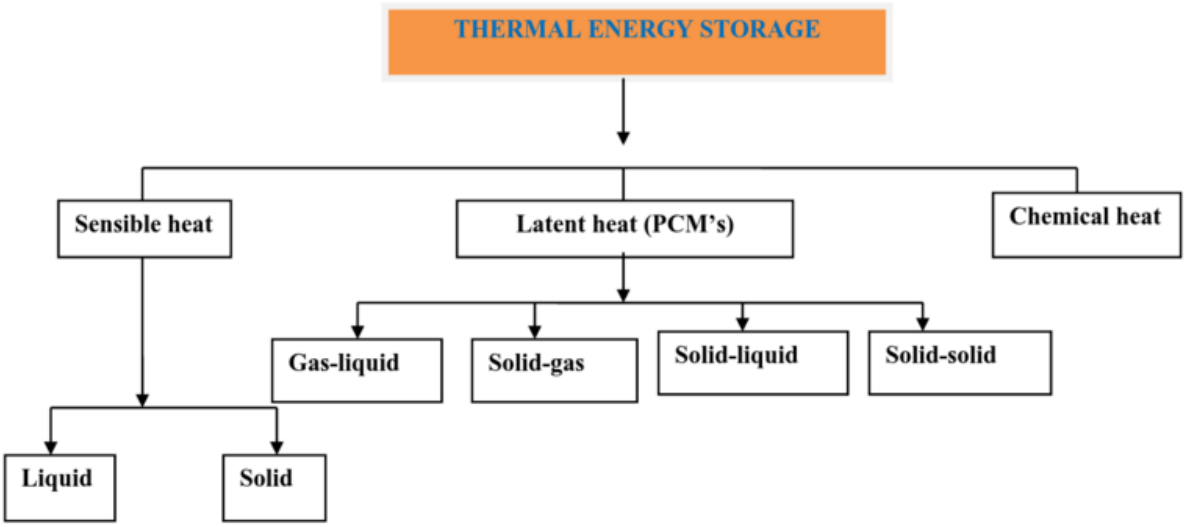
There are different ways in which solar energy can be stored; use of PCM is one of the important methods for effective storage of solar energy. The results of the experiments carried out it was observed that by the use of PCM in TES systems, thermal energy storage increases by almost 2 to 3.5 times as compared to that what was stored without the use of PCM.

### 1.1 Energy Storage Methods

There are various forms of energy available. Energy can neither be created nor be destroyed it can only be converted from one form of energy to another useful form of energy. (According to the law of conservation of energy).

Different forms of energies require specific techniques for their proper storage purpose. These techniques are judged on the factors such as cost (economy), time for which energy can be stored, amount of energy that can be stored through a particular method etc.

Different methods to store energy are as follows:




### 1.2 TES (Thermal Energy Storage) Systems

A latent heat thermal energy storage system comprises mainly of the following three components

- A PCM that would be effective to work in the systems desired range of temperatures.
- Encapsulation of PCM (mostly cylindrical aluminum containers are used with proper insulation or even shell and tube type arrangements are there).
- Surface for heat exchange which would transfer the heat from the surrounding to PCM.

### 1.3 PCM (Phase Change Materials)

Certain materials have the capacity to melt and solidify at certain temperatures and because of this they are capable of storing or releasing large quantity of energy, such materials with inherent capacity to store or release energy at constant temperature by undergoing a phase change are called PCM (phase change materials).

As compared to sensible heat storage materials PCM have considerably higher heat storage capacity (almost 5-14 times more heat per unit volume). The selection of a PCM for a particular application should be based on a careful study of the properties of the substances, since there is no such material present which has all the properties to become an ideal PCM.

Easy availability of these phase change materials is also a factor to be considered. From the point of view of reduction in the total cost for storing thermal energy, we should also consider the fact that as the energy density of PCM increases the necessary storage volume for a given application decreases. Hence because of this the total area required for storage can be lowered and also required amount of heat can be stored at a comparatively cheaper rate.

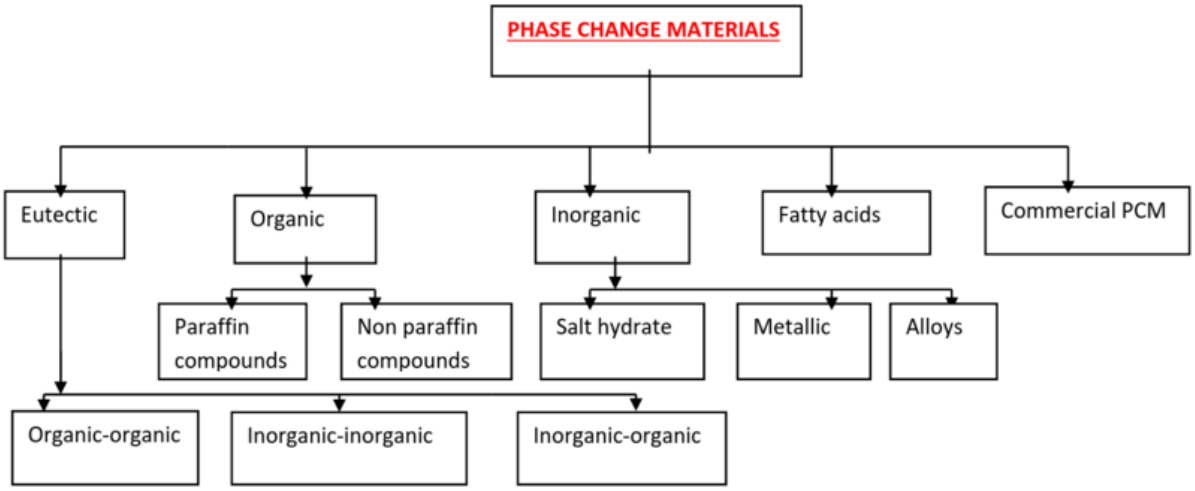
PCM now have become an important thermal energy trapping and storing component and is being under use in various thermal storage devices. However there is still scope of development in the characteristics of PCM's so that they come even closer of being an ideal thermal energy trapping materials. PCM's due to their stability at high working temperatures and also because of their high heat storing capacity these materials are high useful and will find even more application in future in the field of solar energy harvesting and storage.

The properties that PCM in thermal energy storage system should posses so that it can work effectively are as follows

- **General Properties that a Phase Change Material Should Posses**

| Thermodynamic properties | Physical properties | Chemical properties | Kinetic properties | Thermal properties | Economic properties |
|---|---|---|---|---|---|
| 1)High latent heat of fusion, specific heat and thermal conductivity | 1) marginal or almost zero supercooling during freezing | 1) should be stable | 1) to avoid supercooling of liquid nucleation rate should be high | 1) heat transfer rate should be appreciable | 1) should be easily available |
| 2)during phase transformation volume change should be marginal | 2) variation in density should be less during phase change | 2)non-poisonous, non-inflammable and non-explosive | 2) crystal growth rate should be high | 2) in the solid and the liquid phase the thermal conductivity should be high | 2) Initial cost of these materials should be less, materials should be inexpensive. |
| 3)to reduce the containment problem there should be small vapor pressures at operating temperature | 3) phase equilibrium should be favorable | 3) should not undergo any chemical reaction with the container material | | 3) latent heat of transition and specific heat should be high | |
| 4) melting should be continuous (congruent) | 4) material should be of high density | 4) crystallization rate should satisfactory | | 4) high latent heat per unit mass | |

**Classification of PCM**




### 1.3.1 Examples of PCM

| ORGANIC PCM | INORGANIC PCM | FATTY ACIDS | COMMERCIAL PCM |
|---|---|---|---|
| 1-dudecanol | $Na_2SO_4.10H_2O$ | Vinyl stearate | R T25 |
| Paraffin $C_{13}$ | $Zn(NO_3)_2.4H_2O$ | 34% mistiric acid+ 66% capric acid | S27 |
| Paraffin wax | $Na_2SO_2O_3.5H_2O$ | Lauric acid | TH29 |
| 1-Tetradecanol | $LiNO_3.3H_2O$ | Palmitic acid | R T50 |

The PCM which we are concentrating our attention on during this analytical study is paraffin.

### 1.4 Paraffin

One of the most reliable phase change materials which are being extensively used nowadays as heat storage material in most of the thermal storage units is paraffin. Paraffin is popularly used because of its properties such as large latent heat and thermal characteristics. The thermal characteristics of paraffin are varied phase change temperature, low vapor pressure in the molten state, negligible super cooling, appreciable thermal and chemical stability and also self nucleating behavior. A long freeze melt cycle is experienced by the systems which use paraffin as the phase change material in their thermal energy storage unit. Paraffin is made of a mixture of long chain of n-alkanes [$CH_3$-($CH_2$)-$CH_3$ ]. Properties such as latent heat of fusion and melting point increases as the length of chain is increased. Availability in large temperature ranges is an important advantage of paraffin and hence is used as heat of fusion storage material. Eg:-hexadecane, pentadecane, tetradecane etc

- **Advantages and disadvantages of Paraffin**

| Advantages | Disadvantages |
|---|---|
| 1)Freezing action with much undercooling | 1) In solid state thermal conductivity is low |
| 2)Segregation is absent | 2) during freezing cycle high heat transfer rates are required |
| 3)They can be recycled | 3) They are flammable |

| | |
|---|---|
| 4)Heat of fusion is high | 4)Special contaminants are required to raise their burning temperatures |
| 5)Very stable chemically | 5) use of essential paraffin mixtures raise the overall price of energy storage |
| 6)Self nucleation | 6) low volumetric latent heat storage capacity |

- **Some Paraffin and their properties**

| Paraffin | Freezing point ($^0$C) | Heat of fusion (KJ/Kg) |
|---|---|---|
| 5838 | 47-50 | 189 |
| 6499 | 66-68 | 189 |
| P116 | 45-48 | 210 |
| 6403 | 62-64 | 189 |

## II. REVIEW ON SOME EXPERIMENTS

**2.1 M.H. Mahfuz et al [1]** :- the researcher made a complete study of how actually a thermal energy storage unit of a solar water heater works and made conclusions accordingly. The use of PCM in solar water heater and the benefits that these materials give by their use is explained in this extract.

### 2.1.1 Analysis of the TES of solar water heater

In this first experimental study only the thermal energy unit was under consideration

#### 2.1.1.1 System Description

The system under study consists of three units

- a solar collector unit
- a double pipe thermal energy storage
- well insulated water storage tank

#### 2.1.1.2 Procedure

i) Charging process is carried out only during the day time when the solar radiations are available.

ii) For the charging purpose valve 1 is kept open and valve 2 is closed and cold water is allowed to pass through the solar collector.

iii) Water takes up the heat and part of this heated water is made to flow through the heat storage unit for charging the PCM and the remaining part of the heated water is passed on to the water storage tank.

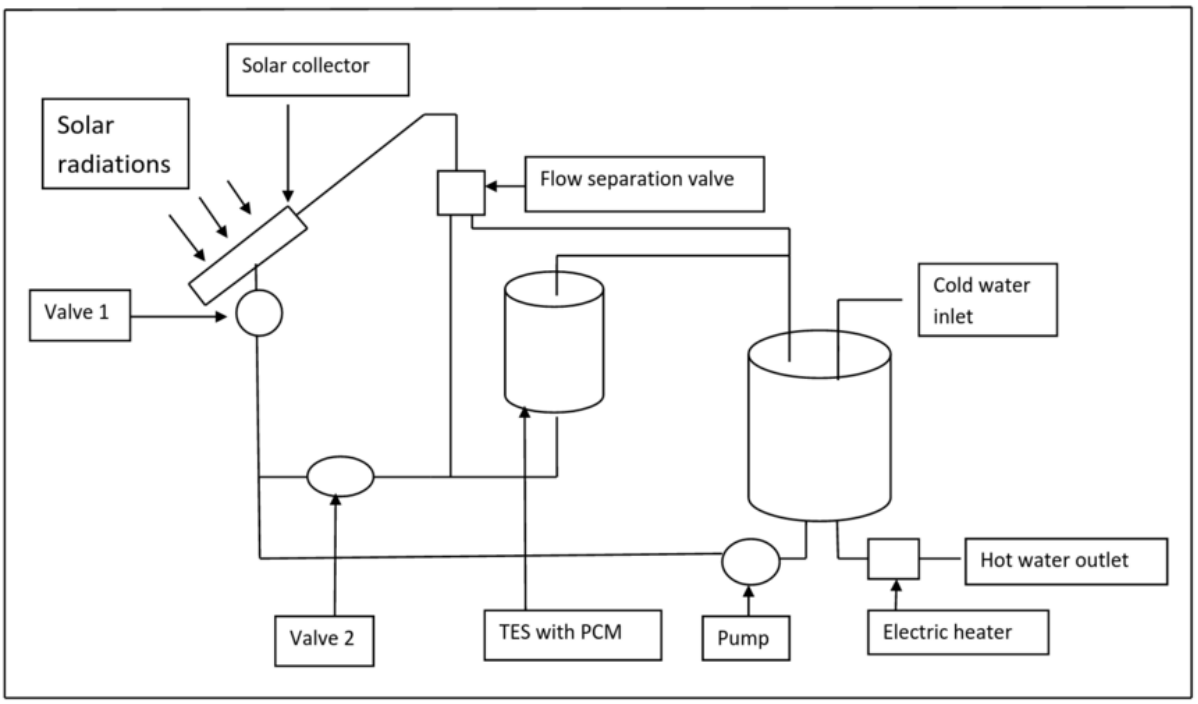
iv) During the night time discharge takes place when solar radiations are absent, valve 1 is kept closed and valve 2 is opened to allow the flow of cold water through the thermal energy storage system.

v) Discharge of heat to the cold water takes place and the PCM starts to solidify simultaneously and being fully solidified the PCM can be used for charging again.

vi) This process continues till the end of PCM thermal life cycle.

vii) To maintain a constant output temperature in the desired range, electric heater is also attached to the water storage tank.

viii) Using a thermostat in the system enables to axis control over both power consumption and heating.




**Block Diagram Representation of Solar Water Heater**

### 2.1.2 In the Second Part the Vertical System of Latent Heat TES was Studied

- The annular space between the copper tube and the outer shell was filled completely with paraffin wax (PCM)
- Thermal bath is provided and the temperature at the input is set as 90 degree
- This is the same output from the solar connector system
- The charging period of thermal storage is enhanced by this overall setup
- Till the PCM's heat capacity is reached the charging process continues to ensure constant difference between input and output temperatures
- After discharge hot water is taken out and bath is filled up with fresh water for heating. The discharge cycle begins with flow of water at 25 degree temperature
- The state where the output temperature is equivalent to environmental temperature marks the end of discharge cycle

#### 2.1.2.1 Result

1) Experimental examination of shell and tube thermal energy storage was made.
2) The lost energy costs were decreasing with increase of flow rate.
3) Material cost was constant for all flow rates.
4) Exergy efficiency decreases with increase of flow rate.

#### 2.1.2.2 Conclusion

1) This experiment gives an effective way to store thermal energy which can be used for heating water in the absence of solar radiation.
2) Use of PCM (paraffin) enhances the thermal energy storage capacity of the system and increases its efficiency.

3) Energy efficiency increases with increase in flow rate of fluid (water in the experiment under consideration).

### 2.2 Zhangyuan Wang et al [2]

The researchers did a complete investigation and analysis of how PCM's can affect the heat storing capacity of a solar water heater and explained the applications of solar water heaters with PCM's. A complete study of PCM's was made which included analysis of their properties, structure and also their heat storage capacities. Performance comparison of solar collectors with and without PCM materials was made. Three types of paraffin with different melting temperatures were used to be filled in the vertical tubes in TES systems. PCM's are thermally effective and technically feasible for use as heat storage materials in solar water heaters but certain improvements in the characteristics of PCM to fit in the application in the solar water heating unit is essential. The study was done in two parts 1) Structural characteristics study which involved components of SHW being integrated with PCM. 2) Research methodology which included a study of properties, performance simulation and cost evaluation.

#### 2.2.1 Material Specification

- Three types of paraffin as PCM with different melting temperatures
- TES system (Tube type)
- Solar collector unit first with PCM and second without PCM

#### 2.2.2 Conclusion

1) Increase in energy storage density and efficiency by the use of PCM.
2) There is scope for further improvement in these systems to enhance the heat storage capacity.

### 2.3 Hussain H. Al-Kayiem et al [3]

During the experimental session the device that was used was an in house design and fabricated system. Sophisticated instruments were used for the laboratory experiment purpose. Experiment measurement program continued for almost a year where data collection and analysis was done on a regular basis.

8 months:- PCM used for thermal storage

4 months:- PCM enhanced with nano particles

were used for storage

Paraffin wax is the primary PCM used in this study. System was tested at three inclination angles ( $10^0$, $20^0$, $30^0$). The flow rate at which the experiment was carried out was 0.5 Kg/min. The system evaluation was being made according to the full day cycle.

Three cases were tested:

1) Without TES material
2) With PCM
3) With nano composite

#### 2.3.1 Material Specification

- PCM integrated solar collectors
- Flat plate collectors in one single unit with 23 thermocouples attached to the collector
- Absorber plates, 9 riser tubes, 37 fins

- PCM or nano PCM (paraffin 26 kg and for nano PCM added amount of copper) along with insulation and casting to the system

**2.3.2 Result**

The use of nano composite (1% wt Cu+ Paraffin wax) gives better efficiency and thermal storage capacity. (Additional 1% wt fraction means an additional 280 g of copper with the original 26kg of paraffin).

**2.3.3 Conclusion**

1) As compared to the pure wax the thermal conductivity of the nano composites was 24% increased.
2) Optimum performance of the system was observed at an inclination angle of $10^0$.
3) Efficiency was enhanced by 8.4% when Cu-PCM nano composite was used with the PCM

## 2.4 M. Rezaei et al [4]

In this extract the researcher has given special attention towards performance and the cost analysis of phase change materials. Phase change materials with different melting temperatures are tested. General study is made on PCM irrespective of them being used in a solar water heater or any other thermal energy storage device. The effect of different melting temperatures of PCM on the exergy efficiency and the cost of the overall heat storage cycle is properly analyzed. Heat exchanger system for transfer of thermal energy with integrated solar collectors is the experimental setup for this study. Heat exchangers are so designed that they would be able to acquire a energy efficiency value of 0.97 (97%). Mass flow rate is calculated for this value of energy gain. On the basis of the value of different results of mass flow rates and the temperatures the final conclusions are drawn.

**2.4.1Material specification**

- Heat exchangers with PCM collectors
- Solar collectors designed to collect energy for almost 6hrs
- PCM (specific PCM is used, price equal to 6.5$/Kg)

**2.4.1 Result**

Share of different factors in the total life cycle cost

- Average lost exergy price- 70.49%
- Average lost energy price- 29.45%
- PCM price - 0.06%

**2.4.2 Conclusion**

1) For having an optimum design exergy of the system should be considered as it has an important and major share in the total life cycle cost
2) For higher melting temperature amount of total life cycle cost along with exergy lost price is decreasing

## 2.5 Monia Chaabane et al[5]

Different types of solar water heaters are used today for water heating and thermal energy storage purpose. In this study we have been given complete information about how the use of PCM has enhanced the thermal efficiency of an integrated collector storage solar water heater with phase change materials. All this experimental setup and study was been carried out in order to check the systems performance with and without the use of PCM. The study aimed at bringing in ideas to reduce thermal losses at night. The experimenter integrated a PCM directly surrounding the storage tank (receiver tube) and studied the effect of such an

alignment of PCM on this operating solar system. For this study different radius of the PCM which was directly wrapped around the receiver tube were selected and tested. The effects of these different radiuses on the thermal energy losses were checked. Also description about the mesh characteristics of this type of solar water heater with and without the use of PCM is given. The PCM's used in this study are RT42-graphite and myristic acid.

**2.5.1 Material specifications**

- Integrated collector storage solar water heater
- Receiver tube (storage tank)
- PCM's (RT42-graphite and myristic acid)

**2.5.2 Assumptions made**

- An incompressible fluid is used.
- Climate has an effect when it comes to testing of solar water heaters so climatic conditions are assumed to be favorable during study.
- Fluid properties are constant except for density that changes with temperature

**2.5.3 Result**

- Use of PCM's enhanced the systems performance during night time
- Reduction in systems night thermal losses coefficient
- More the PCM radius lesser the night thermal losses
- A comparative study between the two PCM's shows that the use of myristic acid as PCM proved to be more beneficial

**2.5.4 Conclusion**

1) A successful attempt of reducing the night thermal losses is made
2) Use of PCM has a great affect on the system
3) PCM reduce the thermal losses and enhance the heat storage value
4) Mayristic acid gives the same temperature reduction as compared to RT42-graphite but with the advantage of higher values during the PCM melting temperature hence myristic acid proved to be better.

## III. REVIEW TABLE

| Sr no | Name of researcher | Materials used | Conclusion |
|---|---|---|---|
| 1 | M.H. Mahfuz | Paraffin wax as PCM | Use of PCM (paraffin) enhances the thermal energy storage capacity of the system and increases its efficiency. |
| 2 | Zhangyuan Wang | 3 PCM with different melting temperatures | Increase in energy storage density and efficiency by the use of PCM. |
| 3 | Hussain H. Al-Kayiem | Only PCM and PCM with nano composites | The use of nano composite (1% wt Cu+ Paraffin wax) gives better efficiency and thermal storage capacity |

| | | | |
|---|---|---|---|
| 4 | M. Rezaei | Specific PCM(6.5$/Kg) | For higher melting temperatures of PCM amount of total life cycle cost along with exergy lost price is decreasing |
| 5 | Monia Chaabane | RT42-graphite and myristic acid as PCM | PCM reduce the thermal losses and enhance the heat storage value |

## IV. CONCLUSION

In this review paper the complete focus was given on the study about how the use of PCM enhances the thermal energy storage and all the various applications. There is tremendous progress in the field of thermal energy storage but still there is scope of further advancement in this field.

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