To Develop a Device to Store Thermal Energy using Phase Change Material

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Abstract— The use of a latent heat storage system using phase change materials is an effective way of storing thermal energy and has the advantages of high-energy storage density and the isothermal nature of the storage process. In this project a PCM based tube in tube heat exchanger is developed. The study focuses on the temperature distribution pattern of the phase change material during the process of charging and discharging. Also the distribution is studied at different mass flow rates of the heat transfer fluid. The results are obtained by experimentally carrying out the charging and discharging process at different mass flow rates. Paraffin wax has been used as the phase change material. This type of thermal energy storage system has a good potential of acting as a thermal storage device and can be used in solar water heating application.

Key words: Phase Change Material, Temperature Distribution, Heat Transfer, Thermal Energy Storage

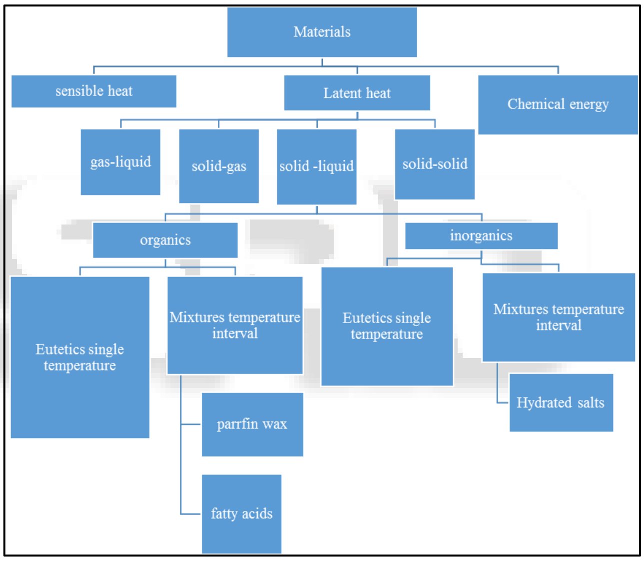
I. INTRODUCTION

The continuous increase in the level of greenhouse gas emissions and the increase in fuel prices are the main driving forces behind efforts to more effectively utilize various sources of renewable energy. In many parts of the world, direct solar radiation is considered to be one of the most prospective sources of energy. The scientists all over the world are in search of new and renewable energy sources. One of the options is to develop energy storage devices, which are as important as developing new sources of energy. The storage of energy in suitable forms, which can conventionally be converted into the required form, is a present day challenge to the technologists. Energy storage not only reduces the mismatch between supply and demand but also improves the performance and reliability of energy systems and plays an important role in conserving the energy. It leads to saving of premium fuels and makes the system more cost effective by reducing the wastage of energy and capital cost. For example, storage would improve the performance of a power generation plant by load levelling and higher efficiency would lead to energy conservation and lesser generation cost. One of prospective techniques of storing thermal energy is the application of phase change materials (PCMs). The use of a latent heat storage system using phase change materials (PCMs) is an effective way of storing thermal energy and has the advantages of high energy storage density and the isothermal nature of the storage process. PCMs have been widely used in latent heat thermal storage systems for heat pumps, solar engineering, and spacecraft thermal control applications. The uses of PCMs for heating and cooling applications for buildings have been investigated within the past decade. There are large numbers of PCMs that melt and solidify at a wide range of temperatures, making them attractive in a number of applications

A. *Phase Change Material:*

A phase change material (PCM) is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa; thus, PCMs are classified as latent heat storage units. Three types of phase changes can happen in a material, solid liquid phase change, solid gas phase change, liquid gas phase change. Generally solid gas phase change and liquid gas phase change involve large amount of volume change, hence solid liquid phase change is the most preferred mode of latent heat storage.

B. *Classification of PCM*



C. *Selection of Suitable Phase Change Material*

Selection of a suitable phase change material is very important and is the fundamental requirement of our project. The following are desirable characteristics of a good phase change material:

1) It should possess high latent heat storage density.
2) Thermal conductivity of the PCM should be good.
3) The phase transition temperature should be suitable as per requirements of the system.
4) Small volume change should happen during phase change.
5) It should be chemically stable, less toxic and should be compatible with the components.
6) It should be available and economical.

According to our requirements, paraffin wax is best suitable material to use in our project because it has high latent heat capacity of 206 kJ/kg. The phase transition temperature of the wax is 40°C to 50°C, which is suitable for our requirement. The change in volume of wax from solid to liquid is negligible. The wax is chemically stable and does not affect any component of the heat exchanger. Above all, wax is available at low cost.

D. Thermal Properties of Paraffin Wax

Transition temperature 40^0C to 50^0C
Latent heat capacity 206 kJ/kg
Density 789 kg/m^3

E. Experimental Setup and Procedure

During sunshine period, valve 1 is kept open and valve 2 is kept closed. The cold water from the storage tank goes through the flat plate solar collector, absorbing heat energy from the solar radiations. It then passes through the PCM heat exchanger, where it loses its heat to the phase change material. It then goes back to the storage tank. In this way, the PCM gains heat energy which will then be used to heat water during non-sunshine period. During non-sunshine period, valve 1 is kept closed and valve 2 is kept open. The cold water from the storage tank goes through the PCM heat exchanger, absorbing heat energy from the heat stored in the phase change material. It then goes back to the storage tank. By this way cold water is heated with the help of heat stored in PCM.

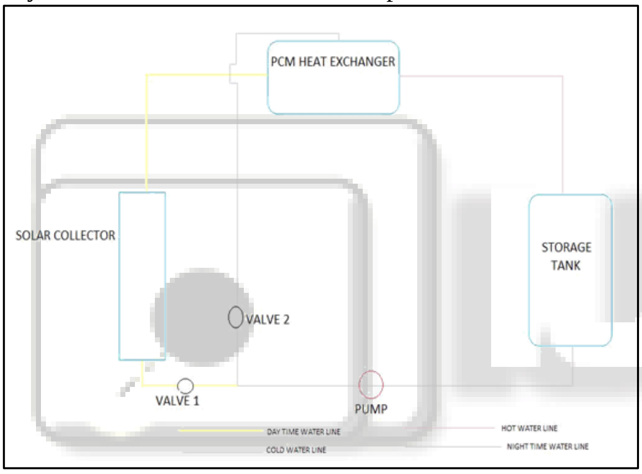


Fig. 3.1: Outline of thermal energy storage with solar water heater

F. Basic Components:

The above setup consists of following components:

1) Solar Collector:

A solar collector consists of an opaque body, a thermal heat transfer fluid, thermal insulations and a transparent cover on top. A flat plate solar collector is the most important type of solar collector, since it does not require a lot of maintenance.

2) Storage Tank:

A storage tank is used to store both cold and hot water. Cold water is extracted from below and hot water from collector is released in tank from top.

3) Pump:

Since we will be using a forced circulation, we need to incorporate a pump to maintain flow in the system.

4) Valves:

Valves will be used to isolate the daytime water line and night time water line, with each other.

5) PCM Heat Exchanger:

PCM heat exchanger is the most important component of our system and is the system which is under study.

6) Phase Change Material:

PCM will be incorporated in the heat exchanger for thermal energy storage. This will be discussed in detail later. PCM is the backbone of this project.

G. Selection Criteria for suitable heat exchanger.

The calculation for the PCM based heat exchanger is done in the following steps:

1) Amount of hot water required during non-sunshine period is estimated. Accordingly, amount of energy needs to be stored is estimated.
2) A suitable type of heat exchanger is selected.
3) A suitable phase change material is selected.
4) Dimensional parameters of heat exchanger are then calculated.

H. Amount of hot water required

Usually, in a typical household, during non-sunshine period, requirement of water is around 3 buckets. Taking volume of each bucket as 20 liters, total requirement will amount to 60 liters. However for our experimental purpose we consider designing of a heat exchanger to heat 7 kg of water. The same approach may be adopted to design a system of higher requirement.

I. Amount of heat energy to be stored

During winter season, the average temperature at which the water is available in the tanks is around 15-20°C. Temperature of water required for comfortable bathing during winter season is around 40°C. Hence the amount of temperature difference we need to attain for comfortable bathing is 20-25°C.

Initial temperature of water, Ti = 15°C
Final (desired) temperature of water, Tf = 40°C
Tf – Ti = 25°C
Heat capacity of water, Cv = 4.187 kJ/kg
Hence, amount of heat required to carry out the above transition = Q
Q = mass of water x (Tf – Ti) x Cv
i.e. Q =7x 25 x 4.187 = 732.72 kJ
Hence, amount of energy needs to be stored = 732.72kJ.

J. Estimation of amount of PCM

The amount of PCM to be incorporated in estimated as follows:
Amount of energy to be stored = Q = 1046.75 kJ
Hence mass of PCM to be incorporated =Q/(Latent heat) = 732.73/206 approximately 3.5 kg of PCM needs to be incorporated in the heat exchanger.

K. Calculation of dimensional parameters of heat exchanger.

Volume of PCM to be used = Mpcm/ῥ
i.e. Vpcm = 3.5/ 789
= 0.004436m3
Hence, the cross sectional area of outer portion of heat exchanger
A2 = V/L = 0.004436/0.3
= 0.0147866m2
= 147.866 cm2

Assuming a suitable diameter for the internalspipe.
We select a standard diameter of copper pipe = 1.4 cm
Hence, cross sectional area of the internal pipe = A1 = 1.5393 cm2
Diameter of outer tube = 147.866*4/π = d2
d = 13.72 cm

L. Actual Test Rig.

M. Charging Method

The water of storage tank is heated to the range of 80-85oC, using the heating arrangement.
The flow control valve is adjusted to a suitable mass flow rate of heat transfer fluid.
The initial readings of the temperature indicator are recorded.
The pump is switched on to initiate the flow in the circuit.
The readings of temperature indicator i.e. temperature at the predetermined points are then taken at an interval of 2 minutes, for around 40 to 60 minutes.

N. Discharging Method

The heating arrangement of the storage tank is kept off.
The initial readings of the temperature are recorded.
The water in the storage tank at ambient temperature is circulated using the pump.
The readings of temperature indicator i.e. the readings of temperature indicator temperature at predetermined points are taken at an interval of 2 minutes for around 40 to 60 minutes
The variation of temperature at each point in the wax then plotted against the time elapsed.
The charging and discharging procedure is repeated again for different mass flow rates of heat transfer fluid, and thus temperature variation plots are obtained for different mass flow rates

II. RESULTS &CONCLUSION

The temperature distribution of the phase change material, during charging and discharging was taken at three different mass flow rates at 15, 11 and 7 kg/min. For each mass flow rate, curve was plotted for variation of temperature at each point in the wax against time elapsed to get melting curve in case of charging and solidification curve in case of discharging.

The melting and solidification curves at all the three mass flow rates, shows similar behaviour.

A. Melting curve

The variation of temperature of the phase change material is almost linear. The temperature variation curve of wax nearer to the inner tube shows more nonlinear behaviour than those at the outermost layer.
Also it can be seen that the melting is more accelerated at the top, compared to that at the bottom.

B. Solidification curve

At the beginning of the solidification process, the temperature of the paraffin wax decreases rapidly, as sensible heat stored in the wax is transferred to the flowing heat transfer fluid. In this case also, the wax nearer to the inner tube looses its heat energy faster than those at the periphery. The wax at the periphery looses their heat more uniformly than nearer to the inner tube.

III. CONCLUSION

Based on the experimental work carried out, following conclusion could be drawn:

Paraffin wax is a good PCM for energy storage in latent heat storage system. It has a suitable transition temperature range of 45-55°C and a relatively high latent heat of 206 kJ/kg. In addition, it does not exhibit any sub-cooling. A simple tube-in-tube heat exchanger system can be used for energy storage with reasonable charging and discharging times. The melting was more at the top and nearer to the inner tube. The solidification was rapid at the point which was nearer to the inner tube carrying heat transfer fluid. The given arrangement can be used to store thermal energy in solar water heating application. The cost to incorporate the system is also very economical

IV. FUTURE SCOPE

The project includes testing of a small heat exchanger, in order to establish the effectiveness of using paraffin wax as a suitable phase change material. The paraffin wax is incorporated in the heat exchanger, which acts as thermal energy storage device. This device will then be tested on a test rig for water heating and other applications.

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