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Study of PCM for Improving Efficiency of Solar Water Heaters

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Abstract:- *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. 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. This is very energy efficient but provides problems of peak energy network loading and the inability to effectively access the solar energy. Hot water systems that use solar contribution must necessarily use energy storage when the loads are to be drawn beyond the solar day. The aim of the paper is to study the heat exchanger for PCM heat storage for the certain amount of water requiring at certain temperature at output which develop a thermal storage heat exchanger which can be useful in heating the water during night or non-sunshine period by the use of Phase change material. Due to this not only the utility time of setup is increased but the efficiency of system also increases. The advantages and disadvantages are also discussed in the context*

Keywords- *Green House Gas, PCM, Charging Process, Discharging Process*

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. 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.

In particular solar energy, being nonpolluting, clear and in exhaustible. An important factor is that solar energy is time dependent energy source with the intermittent character. Hence some form of Thermal Energy Storage (TES) is necessary for the most effective utilization of this energy source. 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.

However many domestic water heaters do not use thermal storage. They heat water when and where it is required. This is very energy efficient but provides problems of peak energy network loading and the inability to effectively access the solar energy. Hot water systems that use solar contribution must necessarily use energy storage when the loads are to be drawn beyond the solar day. This is typical of domestic hot water loads. Traditionally, water based storage is used and this provides the great majority of thermal storage in domestic hot water system around the world.

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 (LHS) 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. Solar energy is available only during the day, and hence, its application requires an efficient. Thermal energy storage so that the excess heat collected during sunshine hours may be stored for later use during the night.

II. OBJECTIVE

The primary objective of this paper is to study a tube, phase change material (PCM) based heat exchanger, which can act as a thermal energy storage device, and hence can be used in solar water heater. The thermal energy storage device will act as a short term energy storage device. From background it is observed that there is good scope of work in phase change material. The objective of the present work is to study a prototype model of thermal energy storage shell & tube type heat exchanger. To experimentally investigation of the thermal behaviour and feasibility of phase change material as a latent heat thermal energy storage unit will be carried out later.

Here we are studying the heat exchanger and storage tanks for the water capacity of 40 liters and we require the temperature of water as 75°C at output. Note that we have already available cylindrical receiver of 8 liters capacity and two storage tanks and heat exchanger as the remaining components of above circuit.

III. PROPERTIES OFPCM

A change of phase of material refers to change of state of a material between the phases of solid, liquid and gas. The heat absorbed or released as a result of phase change is referred to as latent heat and the change of phase occurs at constant temperature in an ideal material.

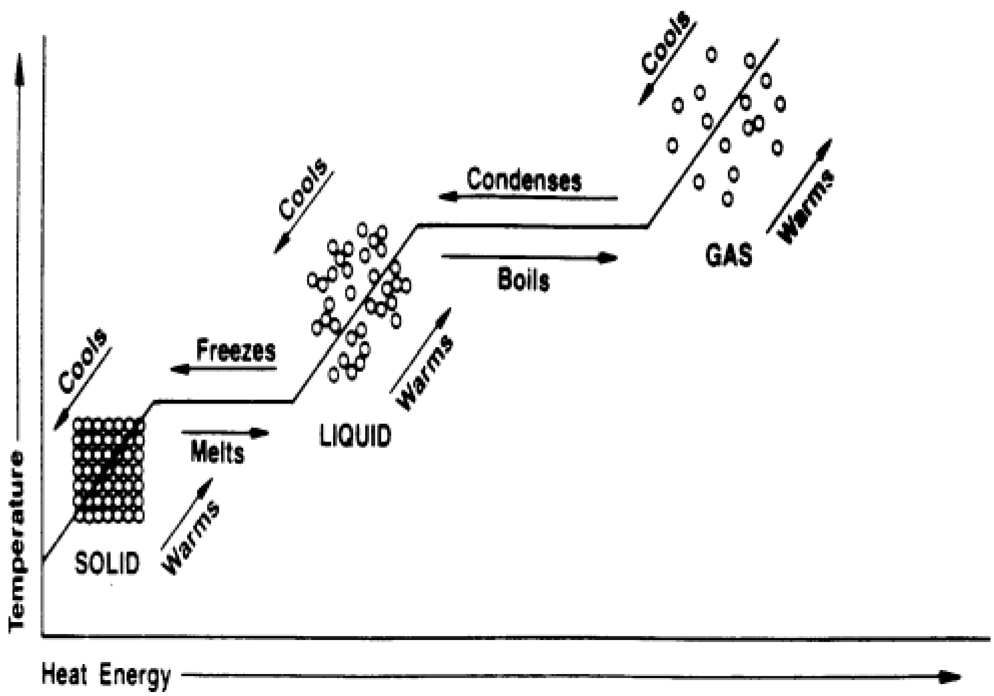

Figure 3. Graph of Phase change & energy input from solid state to Gas state

The change of phase process is referred to as melting, freezing, boiling and condensing. Some uncommon changes of state may occur e.g. solid to gas (sublimation) and to solid to solid. Considerable exchange of heat is involved in the change of material's phase. Typical latent heats of phase change are illustrated in given table.

It is important to note that phase change materials have sensible heat exchange when operated other than their melting and boiling points and this heat should be included when comparing storage densities to water. When the liquid/gas phase change is used, the boiling point of material is influenced by working pressure and hence some flexibility may be gained in the operating state of the system.

The use of phase change material is indicated in the given figure. Once the melting temperature of phase change material is reached, considerable additional heat is absorbed by the material with little rise in its temperature. This means that heat losses from a store using PCM will decrease for the equivalent energy storage with water.

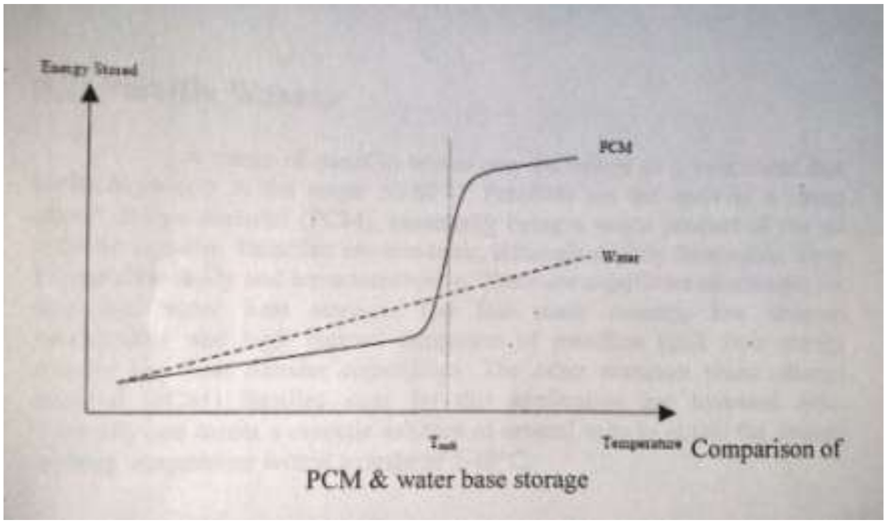

Figure 4. Comparison of PCM & Water based storage

While materials undergo phase change at a wide range of temperature, this study will only consider those useful to hot water services. To be useful, the material must undergo a phase change at the hot water service outlet temperature. Furthermore changes of phase from liquid to gas involves large change in volume of the material and so are difficult to make practical in closed domestic hot water system. Indeed, there are no attempts to use liquid/gas phase change for phase change material storage in literature. This study now focuses on solid/liquid phase change materials that have characteristics melting temperature in the range of 50-65^o C.

There are two widely used classes of phase change material (PCM) for water heating.

1. Paraffin Waxes - A range of paraffin waxes may be mixed to give a blend that melts anywhere in the range of 50-65^o C. Paraffin's are the basis of cheap phase change material essentially being a waste product of the oil refining industry. Paraffin's are the non-toxic, non- corrosive although slightly flammable. These are significant advantages for domestic water heat storage. The low mass density, low thermal conductivity and high thermal expansion of paraffin's limit their energy density and heat transfer capabilities. The other common phase change material families used for this application are hydrated salts. Typically one mixes a eutectic solution of several salts to obtain the desired melting temperature within of 5-10^o C/

2. Eutectic mixtures of Hydrated Salts - Hydrated salts are also non-toxic, non-flammable and cheap but can be corrosive due to their electrical conductivity. They have better thermal conductivity and mass density than paraffin's. There is some doubt over the long term stability of some salts and additives are often added as preservatives and to promote consistent nucleation of the material during the crystallization (freezing) process.

IV. PERFORMANCE BEHAVIOUR OF PCM

4.1 Charging process –

1. Effect of flow rate of HTF - The effect of varying the mass flow rate of heat transfer fluid during the charging of the storage tank. Increase in the mass flow rate has large influence on the phase transition process of phase change material. As the flow rate increases the time required for one complete charging process becomes smaller.

2. Effect of varying the porosity - Porosity determines the quantity of thermal energy that can be stored and the surface area of heat transfer between the particle and fluid per unit volume. For a given volume of the storage tank and size of the tubes, changing the number of phase change material capsules in the storage tank varies porosity. The charging time of PCM tubes reduces for the higher porosities as the phase change material (PCM) mass reduces with increase in porosity.

3. Instantaneous Heat Stored – The instantaneous heat is stored in the storage tank during the charging process of phase change material (PCM). It is observed that during the initial period of charging process the heat stored is high, but decreases there on end. During the phase change period of PCM, the drop in heat stored is less drastic, almost a constant. This is a major advantage of latent heat of thermal storage system (LHTES) where a uniform rate of charging and discharging is possible for a longer period, which will be useful for practical applications.

4. System Efficiency – System efficiency is defined as the ratio of the amount of energy stored by the thermal energy storage (TES) tank to the heat energy available from solar radiation. It is seen that the system efficiency decreases with time during the sensible heating of the solid PCM, remains nearly constant during phase change period and then further decreases during sensible heating of liquid PCM. The decreasing efficiency can be accredited to decreasing temperature differences between phase changes.

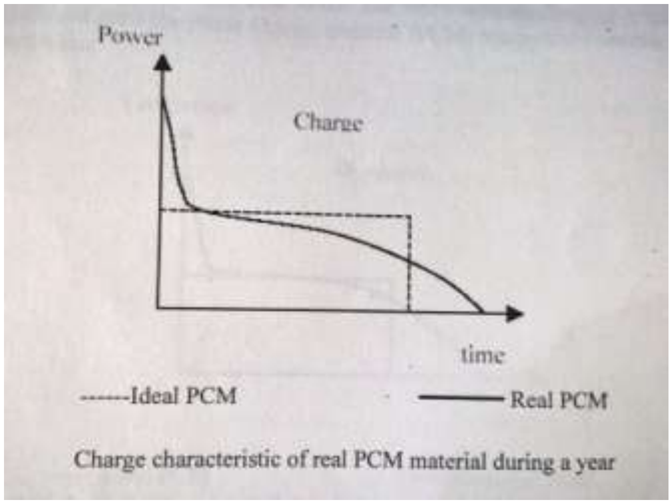

Figure 5. Charge Characteristics of PCM

Material (PCM) and heat transfer fluid (HTF) during charging, which lowers the amount of heat transferred to the TES tank. Also, the increase in HTF temperature at the inlet of solar collector in turn decreases the heat absorption rate from the collector. A further drop in system efficiency arises due to increasing heat losses from the TES tank as the heat transfer (HTF) temperature increases over time.

Transition temperature	40^0C to 50^0C
Latent heat capacity	206 kJ/kg
Density	789 kg/m3

Table 3. Properties of Paraffin Wax

5.2 Discharging process

The present work is an effort to evaluate the feasibility of applying latent heat thermal energy storage system (LHTES) for domestic water heating purposes. Thus, we confine ourselves to the study of the discharge characteristics of the HTF alone.

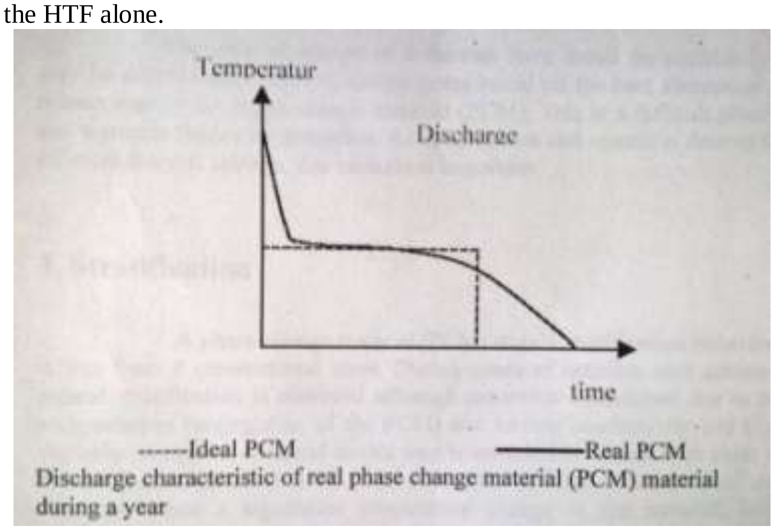

Figure 6. Discharge Characteristics of PCM

Application

Solar water heating using phase change material provides continuous flow of water, whether sunlight is present or not. It has found large application in domestic as well as in the industrial sector.

It is widely used in houses, apartments, guesthouses, hotels, restaurants, hostels, laundries, hospitals, milk industries, sugar factories, boilers, processing plants, etc.

Advantages

1. PCM based solar thermal energy storage system which uses latent heat storage principle can store heat for approximately 45% more time than conventional solar water heating system which uses sensible heat storage principle only.
2. Delivers hot water during non-sunshine period.
3. Pollution free.
4. Less maintenance required as compared to conventional solar water heating system.

Disadvantages

1. Initial cost is high.
2. Problem of leakage of PCM material.
3. Complex in construction.

V. CONCLUSION

1. Solar thermal energy storage system can store heat for 45% more time than conventional solar heat storage system which uses sensible heat storage principle only.
2. Paraffin wax is better than other phase change materials because of its high latent heat capacity. Also, it is non-corrosive and non-toxic in nature.
3. It can be concluded that solar water heater using phase change material increases the utility of the setup. Latent heat thermal energy storage system is a commercially viable option for solar heat energy storage with further research in this area.
4. Further modifications can be done by increasing the porosity of the phase change material. This can be done by encapsulating the PCM into small spherical shells instead of tubes. As a result of which more surface of PCM is in contact with hot water and time required for charging is less. Also discharging can be done very quickly so as to get hot water when sunlight is not present.

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