Research Paper

COMPARATIVE STUDY OF SOLAR WATER HEATER WITH AND WITHOUT LATENT HEAT STORAGE SYSTEM

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ABSTRACT

The effective use of solar energy is hindered by the intermittent nature of its availability, limiting the use and effectiveness in domestic application. Sensible heat storing system required large storage capacity in order to cover a minimum of a couple of days with intermittent usage. Storage of solar energy as a sensible energy is cheap but inefficient, due to intermittent nature of solar energy (5 to 7 hours/day with 4 to 7 $Kw/h.m^2$), Low specific heat of Heat Transfer fluid (0.24), Varying atmospheric condition of inlet temperature of Heat Transfer fluid, Wind speed etc.

The present work has been undertaken to study the feasibility of storing solar energy using Phase Change Materials (PCMs) and utilizing this energy to heat water for domestic purposes. The system consists of two simultaneously functioning heat-absorbing units. One of them is a solar water heater sensible heat storing unit and the other a latent heat storage unit consisting of Phase Change Materials (Paraffin Wax).The storage unit stores the heat in Phase Change Materials, during (charging) the days time and supplies hot water, when solar radiation is not available. The performance of this PCM based thermal energy storage system is compared with, conventional sensible heat storage system and the conclusions drawn from them are presented here.

KEYWORDS: Heat transfer fluid,thermal energy storage,latent heat storage,sensible heat storage,phase change matrial

INTRODUCTION:

Direct solar radiation is considered to be one of the most prospective sources of energy. 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 challenge to the scientist. 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 energy conservation. It leads to save premium fuels and makes the system more cost effective by reducing the wastage of energy. One of prospective techniques of storing thermal energy is the application of phase change materials (PCMs), prior to the large-scale practical application of this technology, it is necessary to resolve various problems at the research and development stage.

TYPES OF THERMAL ENERGY STORAGE:

The thermal energy storage system can be sensible or latent heat storage system or combination of the two. In sensible heat storage the temperature of the storage material increases as the energy is stored while the latent heat storage makes use of the energy stored when a substance changes from one phase to another. Following are the types of thermal energy storage system .

Sensible heat storage:

Sensible heat storage is affected by raising the temperature of the storage medium. The storage capacity of material depends on specific capacity of value. Thus it is desirable for the storage medium to have high specific capacity. Sensible heat storage may be classified on the basis of heat storage media as liquid media storage (like water oil based fluids. Molten salts etc)and solid media storage (like rocks, bricks metals and others) some of sensible storage systems are explained in following section Heat storage liquids are plentiful and economically competitive. They can be sub classified into storage in water, storage in salty water and storage in other fluids.

Water is generally preferred for storing thermal energy at low temperature because of its higher specific heat, low cost and wide availability. If the water is at atmospheric pressure the temperature is limited from 0 to 100°C. It is possible to store water temperature at above 100°C by using pressurized tank. However due to its high pressure it requires costly insulation and pressure withstanding containment for high temperature application. Water can be used as storage and transport medium of energy in solar energy system. Consequently it is most widely used storage medium today for solar base warm water and space heating application.

Solid materials such as rocks, concrete, sand, bricks etc. can be used for wide temperature range. The difficulties of the high vapor pressure of water and the limitation of the liquids can be avoided by storing thermal energy as sensible heat in solids.

Latent heat storage materials:

Phase change materials (PCM) are Latent heat storage materials. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid, this is called a change in state, or Phase. Initially, these solid–liquid PCMs perform like conventional storage materials & their temperature rises as they absorb heat. Unlike conventional (sensible) storage materials, PCM absorbs and release heat at a nearly constant temperature. They store 5–14 times more heat per unit volume than sensible storage materials such as water, masonry or rock. A large number of PCMs are known to melt with a heat of fusion in any required range. However, for their employment as latent heat storage materials these materials must exhibit certain desirable thermodynamic, kinetic and chemical properties. Moreover, economic considerations and easy availability of these materials has to be kept in mind.

The PCM to be used in the design of thermal-storage systems should possess desirable thermo physical, kinetics and chemical properties which are as follows.

LITERATURE SURVEY:

A very good literature is available on the solar water heating system. Here a focused literature review on the phase change material used in solar water heating system. Latent heat storage has been receiving considerable attention only over the last two decades, yielding promising results. Previous research on

LHTES and SHS systems has pertained to the study of the performance characteristics of these systems, theoretically and experimentally, predominantly using artificial heat sources. The majority of the literature research on the LHTES system has been performed for shell and tube arrangement, and more recently for spherical shells.

Research problem:

A vast range of PCM and technology is available for the development and use of solar water heaters. This will help in designing a suitable heat exchange mechanism with latent heat thermal energy storage for solar water heaters. Potential materials used by researchers are potential PCMs in solar water heaters were described still the designs were of preliminary in nature and no commercial design and system is available in the market. An inbuilt (L.H.S.) thermal storage can be an alternative to the present day solar water heater with less complicated design and cost effectiveness.

Phase Change Materials for Energy Storage Devices:

A PCM is a substance with a high latent heat (also called the heat of fusion if the phase change is from solid to liquid) which is capable of storing and releasing large amounts of energy at a certain temperature. A PCM stores heat in the form of latent heat of fusion which is about 100 times more than the sensible heat. For example, latent heat of fusion of water is about 334kJ/kg whereas sensible heat at 25°C is about 4.18kJ/kg. PCM will then release thermal energy at a freezing point during solidification process. Two widely used PCMs by many of us are water and wax. Think how water requires significant amount of energy when it changes from solid phase to liquid phase at 0°Cor how wax extends the burning time of a candle. Moreover, the cycle of the melting and solidification can be repeated many times.

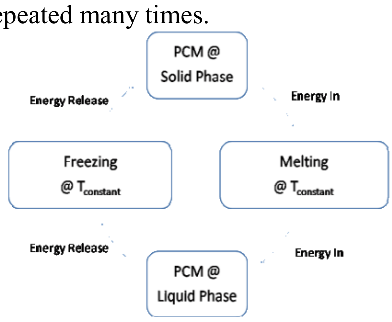

Figure 1: Phase Change of a PCM

There are large numbers of PCMs that melt and solidify at a wide range of temperatures, making them attractive in a number of applications in the development of the energy storage systems. Materials that have been studied include hydrated salts, paraffin waxes, fatty acids and eutectics of organic and non-organic compounds therefore, the selection of a PCM with a suitable phase transition temperature should be part of the design of a thermal storage system. Also it should be good at heat transfer and have high latent heat of transition, the melting point temperature should lie in the range of the operation, Chemically stable, Low in cost, Non-corrosive and Nontoxic.

The PCM tanks have two groups by the construction:

I. PCM tanks with inner core (cylindrical form).
II. PCM tanks with inner balls (spherical ball).

The benefit of the tanks supplied with the inner core (cylindrical form) is easy for putting of the phase change material. The disadvantage of the inner core is the small surface. The phase change materials have small coefficient of thermal conductivity, so if the core has too big diameter the process of the melting and the solidification will be slow by the thicker and thicker solid layer on the inner surface of the core.

In the other type of the tanks the balls are filled with the phase change material. The diameter of the balls is very small for the diameter of the tank. The balls are not fixed to the tank. It results a bigger heat exchange surface area between the water and the phase change material. The biggest disadvantage of this construction is the requirement of special devices for making, filling and closing of the balls.

In this experiment tank with inner tubes filled with PCM-material. This construction has bigger heat exchanging surface, and the manufacturing is simple.

EXPERIMENTAL SET-UP:

Figure 2: Experimental set up

Figure 3: Aluminum tubes filled with PCM

This setup consists of an insulated cylindrical Thermal Energy Storage tank, which contains Phase Change Martial encapsulated Aluminum cylindrical tube, solar flat plate collector of 2m^2, The stainless steel thermal energy storage tank has a capacity of 52 Liters (400 mm Diameter and 420 mm Height) to supply hot heat transfer fluid. The storage tank is insulated with glass wool of 50 mm thickness.

The diameter of Aluminum cylindrical tube is 50 mm and it is made of Aluminum with a wall thickness of 1 mm. Each cylinder contains 420gm of phase change material. The total number of Aluminum cylindrical tube in the thermal energy storage tank is 31 for the case with porosity (ε) of 0.43824.The Aluminum cylindrical tube are uniformly packed in four layers and each layer is supported by aluminum plate of 4mm thick. (Figure 3).The paraffin is used as phase change martial that has a melting temperature of 59^{0}c and latent heat of fusion of 190 kJ/kg. Heat transfer fluid is used as both sensible heat storage material and heat transfer fluid. The phase change material slowly gets heated, sensibly at first, until it reaches its melting point temperature. As the charging proceeds, energy storage as latent heat is achieved as the Paraffin wax melts at constant temperature (59 ±1°C).After complete melting is achieved, further heat addition from the heat transfer fluid causes the phase change material to superheat, thereby again storing heat sensibly. The charging process continues till the phase change material and the heat transfer fluid attain thermal equilibrium. The heat transfer fluid circulates through the storage tank due to thermosyphon action. The thermal energy storage tank is divided into four segments along its axial direction and the RTDs with an accuracy of ±0. 1^{o}C are placed at the inlet, outlet and four segments of the thermal energy storage tank to measure the temperatures of heat transfer fluid. Another four numbers of RTDs are inserted into the phase change martial capsules and they are placed at four segments of the thermal energy storage tank to measure the temperatures of phase change material. The temperatures of the phase change material and the heat transfer fluid are continuously recorded at different locations (10 RTD inputs). The RTDs are connected to a temperature indicator, which provides instantaneous digital outputs.

EXPERIMENTAL PROCEDURE:

Experimental analysis of solar water heating system without P.C.M. for charging

During the experiments, heat transfer fluid inlet temperature varies in accordance with the solar isolation. During the charging process (storing of heat energy) the heat transfer fluid is circulated through the thermal energy storage tank continuously. The heat transfer fluid exchanges its energy to heat transfer fluid and energy stored as sensible heat during the charging process, the temperature of the heat transfer fluid is 28^0C at beginning. As the charging process proceeds, energy storage is achieved by increase in temperature of heat transfer fluid.

Temperatures of the heat transfer fluid at different locations of the thermal energy storage tank at inlet to storage tank, outlet from storage tank and at four different location in storage are recorded at an interval of 10 minute thermal energy storage. The charging process is continued until the temperature reaches the value of 71^0C.

Experimental analysis of solar water heating system with P.C.M. for charging

During the experiments, heat transfer fluid inlet temperature varies in accordance with the solar isolation. During the charging process (storing of heat energy) the heat transfer fluid is circulated through the thermal energy storage tank continuously. The heat transfer fluid exchanges its energy to phase change material placed in Aluminum cylindrical tube and at the beginning of the charging process, the temperature of the phase change material (T_{pi}) inside the packed bed capsules is 28^0C, which is lower than the melting temperature. Initially the energy is stored inside the capsules as latent heat until the phase change material reaches its melting temperature. As the charging process proceeds, energy storage is achieved by melting the phase change material at a constant temperature. The energy is then stored as sensible heat in liquid phase change material. Temperatures of the phase change material and heat transfer fluid at different locations of the thermal energy storage tank are recorded at an interval of 10 minute thermal energy storage. The charging process is continued until the phase change material temperature reaches the value of 67^0C.

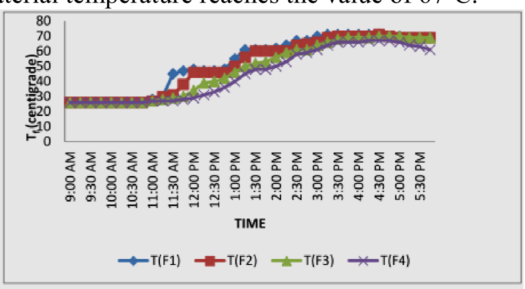

Figure 4: Temperature Distribution of H.T.F. (without P.C.M.)During charging

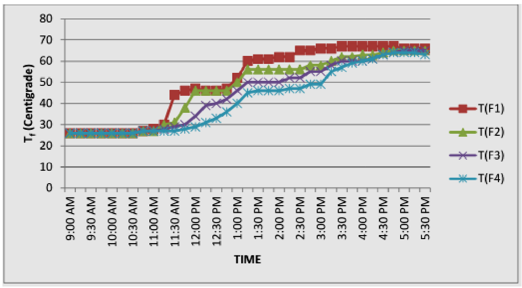

Figure 5: Temprature Distribution of H.T.F. (with P.C.M.)During charging.

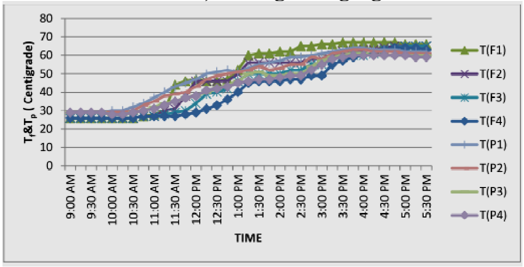

Figure 6: Temprature Distribution of H.T.F. &P.C.M. (with P.C.M.)During charging.

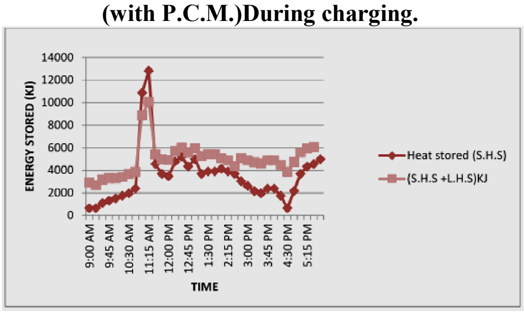

Figure7: Comparison of Energy Storage in S.H.S and S.H.S + L.H.S.

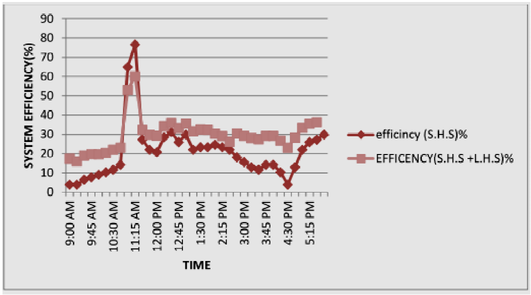

Figure 8: Comparison of System Efficiency (S.H.S Vs L.H.S +S.H.S)

CONCLUSIONS

- In S.H.S (Charging without PCM) heat storage system heat transfer fluid circulates continuously through system and temperature rises gradually till it's temperature reaches 70 ° C and remain constant for 45 to 50 minutes.
- During combined heat storage system i.e. SHS and LHS (charging with PCM) heat transfer fluid is circulated continuously and gradually reaches up to 62 to 63 °C and remain constant for period more than conventional system i.e. 60 to 70 minutes. Since temperature reaches 9 to 10 degree less, temperature loosed in sensible form is stored in latent heat form.
- During initial period of charging heat storage is high and then it is decreasing in temperature due to decreases in temperature differences between HTF and temperature of storage tank.
- In combined heat storage system uniform rate of charging and discharging of HTF for

long period result in more heat storage throughout the cycle but in SHS system initially heat storage is more and reduces as temperature differences between inlet HTF and outlet HTF of storage tank reduces.

- System efficiency of combine heat storage system decreases with time during sensible heating of solid PCM, remain constant during phase change period and then further decreases during sensible heating of liquid PCM .The decreasing efficiency can be accredited to decreasing temperature difference between PCM and HTF during charging.
- In system efficiency of S.H.S. & S.H.S. +L.H.S., the combine system is remaining constant and more effective than S.H.S. system.
- Since temperature of paraffin wax (63°C) and heat transfer fluid (69°C) is not exceeding melting point of paraffin wax (59°C) so the phase change is from solid to liquid only, the heat transfers only in conduction and convection mode.

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