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Study and investigation of Solar water heating system using Phase change material (PCM)-Review

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ABSTRACT— In order to utilize the solar energy from the sun at all times energy should be stored and used when needed. Phase change material is a viable for storing thermal energy in solar water heating system and has the advantages of its isothermal behaviour during the charging and discharging processes and high energy storage density. They store 5 to 15 times more amount of heat per unit volume than sensible storage materials. The application of PCM in heating and cooling systems is to improve overall efficiency of system and reduce electrical power consumption and greenhouse gas emission. Review paper summarizes works on solar water heating system with thermal energy storage material and compatibility between HTF, heat exchanger and/ or storage material. Heat storage in phase change materials is an advantage of compactness of system and heat supply at constant temperature in heating and cooling applications. Thermal energy loss by the system can be reduce by different type of systems integrate with PCM into solar collector, hot water tank, duct, heat exchanger technology and due to system efficiency increases. This study helps to develop new advance experimental setup of solar water heating system with PCM.

KEYWORDS- Solar water heating system, Latent heat storage materials, Hot water tank, and solar collector.

I. INTRODUCTION

Due to electricity deregulation and anxiety over energy security are contributing to growing attention being paid to more solar energy utilization. However, because of intermittent supply and low concentration of solar energy which varies, depending on geographical location, the need for more research such as this continues to exist. The imminent energy shortage and the high cost of energy and new power plants has been a scientific concern over the last three decades. Central to the problem is the need to store excess energy that would otherwise be wasted and also to bridge the gap between energy generation and consumption. Solar water heater by using a phase change material (PCMs) in storage tank is the effective way of storing the thermal energy. Within the past decade uses of PCMs for heating and cooling applications for buildings, space heating and for water heating have been investigated. Review is carried out for the investigation and study of thermal energy storage incorporating with PCM for use in solar water heaters. Storing solar energy with the help of phase Change materials (PCMs) and utilizing this energy to heat water for domestic purposes during the night time. The system consist of two absorbing unit one of them is solar water heater other a heat storage unit consisting of PCM. During the day time the solar collector absorb the heat from sun and the water is heated with the help of solar radiation. The heated water transfer it heat to phase change material (PCMs). The phase change material absorbed the sensible heat and the excess heat is stored in the form of sensible heat. PCM as phase change material as absorbing heat unit we can get the hot water during night, with increase in the performance of solar collector efficiency is also increases. Latent heat thermal energy storage is particularly attractive technique because it provides a high-energy storage density. When compared to conventional sensible heat energy

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storage systems, latent heat energy storage system requires a smaller weight and volume of material for a given amount of energy. In addition latent heat storage has the capacity to store heat of fusion at a constant or near constant temperature which corresponds to the phase transition temperature of the phase change material (PCM).

1.1 Energy storage methods

1. Mechanical energy storage
2. Electrical storage
3. Thermal energy storage
4. Thermo chemical energy storage

1.2 Classification of thermal energy storage system

a) Thermal energy storage

1) Sensible solid

i) Liquid

ii) Solid

2) Latent heat

i) solid-solid

ii) solid-liquid

iii) liquid- gaseous

b) Chemical energy storage

i. Thermal Chemical Pipe Line

ii. Heat of Reaction

iii. Heat Pump

1.3 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 material, their temperature rises as they absorb heat. Unlike conventional (sensible) storage materials, PCM absorbs and release heat at a nearly constant temperature. Phase change temperatures ranging from 100 to 897 oC, and latent heat ranging from 124 to 560 kJ/kg. They store 5 to 15 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 main disadvantage of latent heat storage is its low thermal conductivities, which mostly fall into the range of 0.2 W/ (m K) to 0.7 W/(m K), and therefore relative heat transfer enhancement technologies must be adopted

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

a) Thermal properties

1) Suitable phase-transition temperature

2) High latent heat of transition.

3) Good heat transfer.

Property	Organic Paraffin	Organic Non-Paraffin	Inorganic Salt Hydrate	Inorganic Metal Eutectic
h_f (kJ/kg)	230 - 290	120 - 240	170 - 340	30 - 90
h_{fv} ([J/m^3] x 10^6)	190 - 240	140 - 430	250 - 660	300 - 800
ρ (kg/m^3)	~ 810	900 - 1800	900 - 2200	~ 8000
k(W/m°C)	~ 0.25	~ 0.2	0.6 - 1.2	~ 20
Thermal Expansion	High	Moderate	Low	Low
Congruent Melt	Yes	Some Do	Most Do Not	Yes
Supercool	No	No	Most Do	No
Corrosion	Low	Some Are	Highly	Some Are
Toxicity	No	Some Are	Highly	Some Are

Table.1 Thermal Properties of the different material

b) Physical properties

1) Favorable phase equilibrium

2) High density.

3) Small volume change.

4) Low vapour pressure.

c) Kinetic properties

1) No super cooling.

2) Sufficient crystallization rate.

d) Chemical properties

1) Long-term chemical stability.

2) Compatibility with materials of construction.

3) No toxicity.

PCM can suffer from degradation by loss of water of hydration, chemical decomposition or incompatibility with materials of construction. PCMs should be non-toxic, non-flammable and non-explosive for safety.

II. LITERATURE SURVEY

2.1 Literature Review:-

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1. A comparative study of solar energy storage systems based on the latent heat and sensible heat technique has been carried out to preserve the solar heated hot water for night duration by Chaurasia [1]. He used paraffin wax as PCM for solar water heating. For this purpose, two identical storage units were used; one unit contained 17.5 kg paraffin wax melting temperature 54o C as the storage material packed in a heat exchanger made of the aluminum tubes and another unit simply contained the water as a storage material in a galvanized tank. Both units were separately charged during the day with the help of flat plate solar collectors having same absorbing area. This study revealed that the latent heat storage system comparatively yields more hot water on the next day morning as compared to sensible storage system.
2. Bajnoczy [2] studied the two-grade heat storage system (60–30 oC and 30–20 oC) based on calcium chloride hexahydrate and calcium chloride tetrahydrate. They also studied the storage capacity changes during the cycles and possible use of a solar energy storage system for domestic water heating system
3. Kaygusuz [3] conducted an experimental and theoretical study to determine the performance of phase change energy storage materials for solar water heating systems with CaCl2_6H2O as phase change material. They also compared the performance of PCM, water and rock based storage system. Whenever solar energy is available, it is collected and transferred to the energy storage tank that is filled by 1500 kg encapsulated PCM. It consisted of a vessel packed in the horizontal direction with cylindrical tubes. The energy storage material (CaCl2_6H2O) is inside the tubes made of PVC plastic and heat transfer fluid (water) flow parallel to them.
4. Boy et al. [4] proposed an integrated collector storage systems based on a salt hydrate phase change materials as an appliance for providing hot water instantaneously. They demonstrated that the thermal efficiency of such systems could be improved significantly by incorporating an appropriate PCM device. However, in their system the salt hydrate PCM was encapsulated in a special corrugated fin heat exchanger, which increased the cost of the system.
5. The thermal performances of hydrated salt-PCMs such as Na2S2O3_5H2O, Zn (NO3)2_6H2O, Na2HPO4_12H2O, CaCl2_6H2O and Na2SO4_10H2O were examined theoretically. The size and shape of the vessel have a significant effect on the collection of solar radiation. The greater the exposed surface area to volume ratio the less time will be required for insolation to heat up the water store. For example, for a shallow rectangular vessel with a high surface area/volume ratio, the incident insolation has a small depth of water to heat up. However, a store with a large exposed surface area will also lose substantial amounts of heat by convection and long-wave radiation during normal conditions and will cool down significantly by radiative losses to the night sky. The importance of the surface area–volume ratio was realised by Haskell [5] who patented an 'improved' integrated collector storage solar water heater design that used a shallow rectangular tank having an inherently higher surface area to volume ratio than cylindrical vessels.
6. Khalifa et al. [6] compared the thermal performance of a DHW system with PCM and those of a conventional DHW system. In this study, the solar collector that acts as the PCM thermal storage medium consists of six 80mm diameter copper pipes that are connected in series and are integrated with a back container of paraffin wax. The performance of the integrated thermal storage collector device is compared with that of the conventional device in terms of parameters such as the temperature difference across the collector, instantaneous efficiency, heat removal, and overall heat loss coefficient. The results indicated that the temperature difference in the storage- collector is 66% higher than that in the

conventional one. Furthermore, the instantaneous efficiency of the storage-collector was 41.7% to 55.1% higher than that in the conventional one.

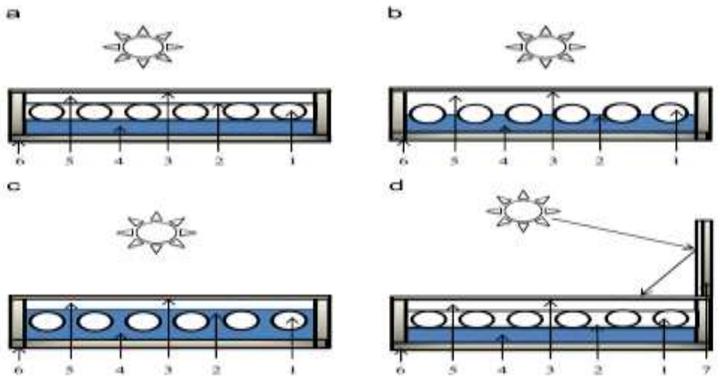

Fig. 1 Schematic of a flat plate solar collector with PCM technologies (a)below tubes, (b)half perimeters of the tubes, (d)immersed tubes, (d)with reflector, (1)tubes, (2)absorber, 3) glass cover, (4)PCM, (5)air layer, (6)insulation, (7)reflector.

7. Haillot et al. [7] evaluated the performance of the DHW system with PCM. In this system, PCM was inserted into a flat plate solar collector to replace the collector absorber. There researchers applied four types of PCMs (sodium acetate trihydrate, RT65 paraffin, stearic acid, and penta glycerin) to optimize PCM integration in the solar collector. Furthermore, they analyzed and synthesized the different physical properties of the PCMs, including thermal conductivity, absorptivity, storage capacity, and PCM life time. The results suggested that the characteristics of three of the four composites were suitable for integration into the solar collector, with the exception of sodium acetatetrihydrate
8. Ibáñez et al. [10] numerically studied the incorporation of two cylindrical PCM capsules into the solar storage tank of a DHW system. They produced a new TRNSYS component based on previously developed components to simulate and validate the water temperature in the tank. The predicted results agreed with those of the experiment. Padovan and Manzan [8] generated an optimization tool for PCM thermal energy storage in a DHW system to enhance energy saving and to reduce the volume/space required by the system. They analyzed different designing para- meters, such as tank dimensions, PCM melting temperature point, and insulation thickness. The findings indicated that the effects of tank geometry and insulation thickness on energy saving in thermal storage are limited. Kousksouetal. [9] Numerically analyzed the benefits of PCM in a DHW system and made recommendations to improve the thermal performance of the PCM storage system. The DHW system consists of a storage tank, PCM capsule, solar collector, pump, controller, and an auxiliary heater as shown in Fig. 2. As per the results, the utilization of PCM in DHW system may not be considerably beneficial. Thus, an optimization tool must be established during the early stages of design because PCM integration into DHW may be enhanced by selecting proper design parameters, such as PCM melting temperature point.

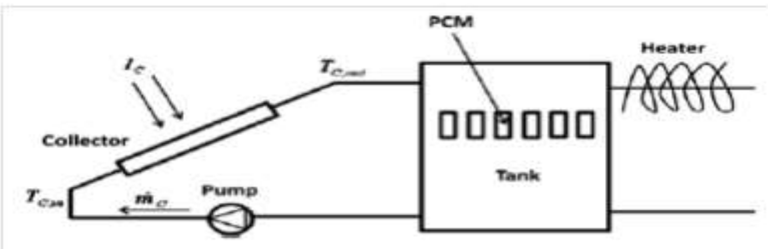

Fig. 2 Schematic layout of domestic hot water system.

9. To increase the heat capacity of thermal storage, researchers typically incorporate PCM into the hot water storage tank. In this process, cylindrical or spherical capsules are inserted into the tank. Al-Hinti et al. [11] introduced two levels of PCM into a conventional hot water storage tank that contains a total of 38 thin walled and cylindrical, aluminum containers. This tank is filled with 38.0 kg of paraffin wax and is located at the Hashemite University campus in Jordan, as presented in Fig. 8. The galvanized steel storage tank length is 675 mm with an inner diameter of 450 mm and a volume of 107.4l, insulated with 75-mm thick layer of rock wool insulation. The total volume of the PCM containers is 49.4l, with water occupying the remaining 58l in the storage tank. PCM storage was investigated under controlled energy with an electrical heater and flat plate collectors in a closed-loop system. This system operated under both forced and natural circulation. For the conventional flat plate solar technology, the water temperature of the water-PCM storage system was maintained at over 45 0C under all operational and climatic conditions.
10. Nkwetta et al. [12] numerically studied the performance of a DHW tank integrated with different PCM types in various this models was validated experimentally and used to determine the effect of PCM location on the thermal performance of the tank given three actual profiles of hot water consumption. The results indicated that the discharge times were consistent at the different draw-off intervals between predictions. The stored energy increased with the increase in PCM. Hence, the integration of PCM in hot water tanks improves storage capacity. Furthermore, it may provide energy, shift, and/or smooth peak power demand. Moreover, the PCM composed of sodium acetate trihydrate + 10% graphite displayed the highest storage potential at a shorter charging time compared with industrial-grade granulated paraffin wax and RT58-Rubitherm.
11. Jinjia Wei et al. [13] studied four different capsules (sphere, cylinder, plate and tube) for investigating the effects of geometrical configurations. The effects of the capsule diameter and shell thickness and the void fraction on the performance of the heat storage system were also investigated. The experiment was conducted by using a commercial plate heat exchanger as the heat storage tank. It was found that the spherical capsule showed the best heat release performance among the four types of investigation capsules.

III. PROBLEM DEFINITION

3.1 Remarks from Literature Review:-

1. The latent heat thermal energy systems are a commercially viable option for solar heat energy storage with further research in this area.
2. Even though theoretical and experimental studies area vailable to find out the performance of solar water heating systems, detailed experimental studies showing the temperature profiles are few
3. The thermal performance of the PCM incorporation into storage tanks or solar collectors significantly enhanced in relation to energy capacity, operation time under a temperature range that is acceptable for application, and low DHW system volume/space.
4. Solar energy is sporadic, fluctuant, and available only during the day. Hence, its applications require active thermal energy storage so that the overabundant heat collected during sunshine hours may be stored for later use during the night.

3.2 Objective of the Project:-

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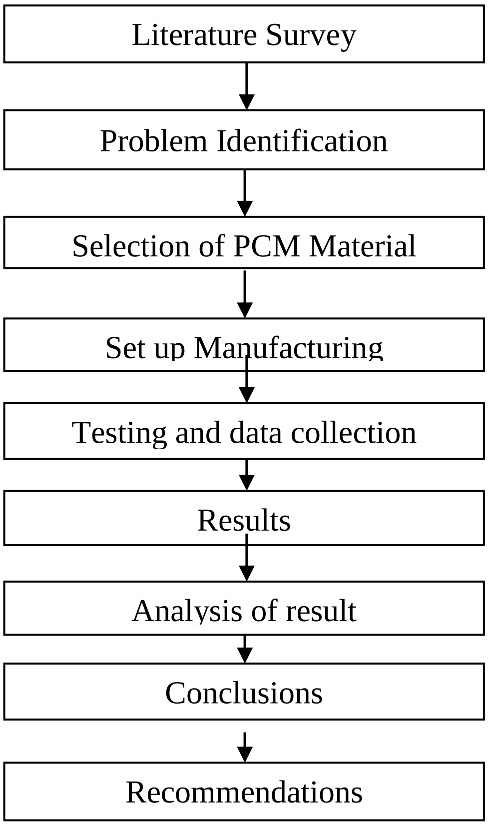
1. Learn the general concept of Phase Change Materials (PCM)
2. Understand the applications and uses of PCM for heating and cooling systems
3. To reduce heat loss from SWHS System by using PCM
4. To develop more compact system by using PCM in SWHS.
5. An optimization SWHS by selecting proper design parameters such, as PCM melting temperature point, PCM capsule size, storage capacity, and PCM life time.

3.3 Scheme of Implementation / Methodology



Flowchart for methodology

IV. PROPOSED SOLUTION

A) Theoretical Work:

i) To Study the theoretical concepts of solar water heating system with PCM

ii) To carry out literature review of solar water heating system with PCM

B) Experimental Work:

i) To develop experimental setup of solar water heating system with suitable PCM

ii) The objective of the present work is to predict the optimum size of capsules for better efficiency of a sensible and latent heat thermal energy storage unit integrated with a varying (solar) heat source.

iii) To predict effect of the flow rate of HTF on PCM.

iv) Evaluate the feasibility of applying LHTES systems for solar water heating system

v) To understand design criteria of a solar thermal energy storage system.

V. EXPECTED RESULTS

1. Design solar water heating systems with high heat transfer, efficiency and complicated design.
2. Improve the thermal performance of solar collectors by using PCM.
3. Reduced dimensions and weights, bringing lower installation costs.
4. High heat transfer and efficiency.

VI. CONCLUSION

Solar water heating system is used with environmentally compatible PCM.

1. Although interesting possibilities of innovation exists by using this kind of storage, further research is needed for the design of the storage system and heat exchanger
2. Various types of thermal energy storage systems are review, in terms of design criteria, material selection and heat transfer enhancement technologies involved.
3. The latest developments and advances in solar thermal applications are reviewed.

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