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Analysis of solar water heater with aerogel-based thermal energy storage medium

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ABSTRACT

Solar water heating systems are emerging technology and requirement of today's industry and domestic user in order to achieve renewable and sustainable goals. This work is devoted to analyze the water heating system designs with thermal energy storage. Comparison of exergy of both with and without thermal storage water heating system is done in this paper. Also, analysis of various thermal storage material based on sensible heat storage and latent heat storage carried out. It is found that latent heat storage is more appealing in terms of efficiency and more potential to dominate conventional water heating system.

Key words: Solar Water heating, flat plate collector, aerogel-based collector, latent heat, sensible heat, PCM.

Introduction

As we are talking about different methods of harnessing the solar energy to overcome the issues of fuel saving, environmental impacts and a sustainable energy harnessing which never get exhausted [1]. In today's date we are harnessing the solar power by the means of photovoltaic cells, solar water heaters, solar cookers, solar dryers etc. but yet it is not up to the mark as we can replace the total energy generation by means of it [2]. India is endowed with rich solar energy resource. The average intensity of solar radiation received on India is 200MW/km sq. with geographical area of 3.287 million km square, this amount to 657.4 million MW [3].
Solar power in India is fastest developing industry. Solar water heaters also impact in great way and expected to grow rapidly [4]. Bangalore has the largest deployment of solar water heaters in India with 200 MW of energy generation and now it's mandatory also in new structures in the city. Broadly the solar water heating systems are of two categories which are open loop system and closed loop system. Further on the basis of collectors they are of two types [5]. They are flat plate collector and evacuated tube type collector. Wide spread use of solar water heaters reduces the use of conventional fuels and conventional heating systems significantly used for domestic purposes, industrial purposes, other commercial and institutional establishments [6].

Salient features of Solar Water Heating System [7]

- Temperature about 60 deg.-80 deg. Can be attained depending upon the solar radiations received.
- Only soft and potable water is suitable for the system for good efficiency.
- A 100 litres capacity system can save 1500 units of electricity annually.

- A solar water heater of 100 litres capacity can prevent emission of 1.5 tonnes of carbon-dioxide per year.

In recent years solar water heating systems seen a rapid growth but yet they are not proved to be such efficient as there are some drawbacks such as weather, undistributed solar power throughout the world, unavailability of solar power in nights etc. [8]. In such conditions we need a modification in solar water heating systems that increase their efficiency and affordability too. This problem can be alleviated by storing the solar thermal energy and using whenever it required. Solar water heaters with thermal storage are proved to be an efficient way nowadays [9]. Thermal energy storage plays an important role in energy conservation [10]. This has high potential in solar thermal applications such as water heating, air conditioning, waste heat recovery etc. Thermal energy can be stored either in the form of sensible heat or in form of latent heat. Sensible heat of a substance allows store of thermal energy by raising its temperature up to the phase change and afterwards during the phase change the thermal energy stored in the form of latent heat which is also more prior than the sensible heat as it has high storage capacity [6].

The amount of sensible heat storage of a medium depends upon specific heat of medium, temperature change and mass of storage material given by equation

$$Q = mc_p\Delta T$$

Some of the sensible heat storage materials are rock, glass wool, water, sand etc.

The amount of latent heat storage can be determined by the equation

$$Q = m\Delta h$$

Typical examples of such materials are paraffin compounds, fatty acids salt hydrates and eutectics.

Latent Thermal Heat Storage System

The thermal heat storage in the form of latent heat is more feasible and efficient than the sensible thermal heat storage. Thermal energy stored in the material during its phase change is the Latent Thermal Heat. Thermal energy stored and released with changes in material phase which is stored by the phase change materials (PCMs). Phase change materials store the energy initially in the form of sensible heat and during phase change it stores the energy in form of latent heat. They release energy with the drop of temperature and regain its physical state as earlier. To store the thermal energy we need good insulation to the heat storage tanks to get the best performance or say to maintain the energy storage for longer duration. The insulation reduces the heat losses from the tank. There are many Super Insulation Materials (SIMs) also like Vacuum Insulation Panels (VIPs) and Aerogel Based Products (ABPs), have a 5-10 times lower thermal conductivity compared to the traditional insulating materials.

Types of solar water heating systems

Sun is the largest energy source for the earth receives the solar energy 885 million TWh per year which is 6200 times commercial energy use by human kind in 2008

Solar Cooling Systems

Solar cooling system most applicable at areas of humid and warm environment, regions includes are south Asia.

Solar heating systems

Solar heating have application in both areas space heating for cold environment & winter conditions and industrial heating [9].

Integrated solar heating and cooling systems

As most of the system requires heating and cooling systems simultaneously integrated solar heating and cooling systems have huge applications.

Designs of Solar heating and cooling systems

There are number of designs proposed by various researchers some of them are presented and analyzed in this section.

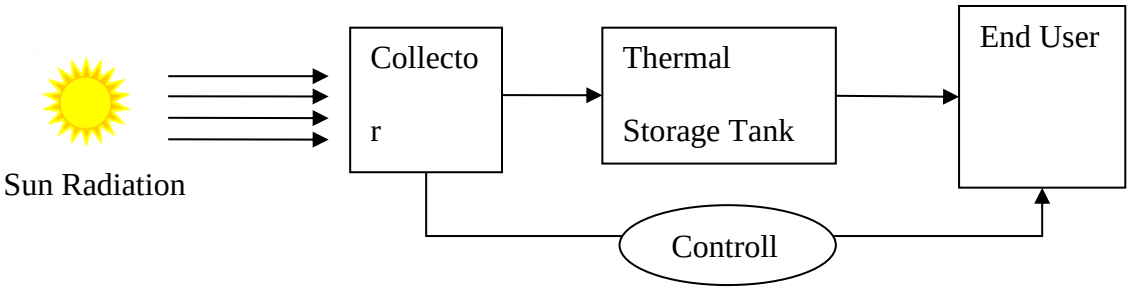

Figure 1: Proposed system design of solar water heating system

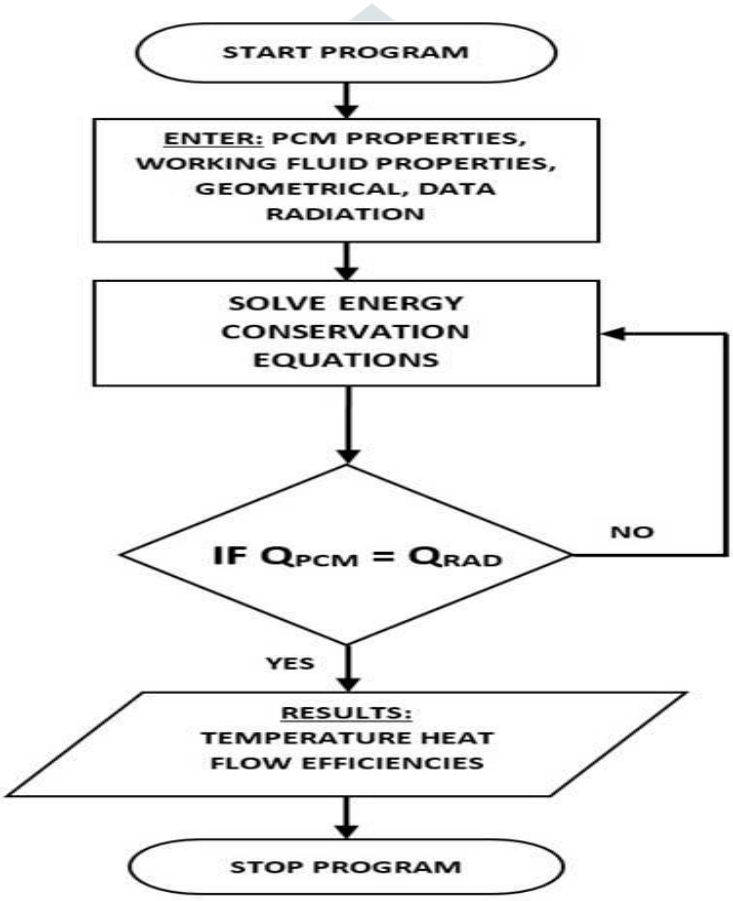

Figure 2: Flow chart of heat

Analysis of solar water heater with thermal energy storage

Heat transfer analysis of thermal storage tank:

For 100 litre capacity per day

Average Solar flux at Jaipur = 1000W/m^2

PCM material Paraffin Wax (suitable for water heat storage i.e. 80°C) Properties:

Melting point = 80°C

Latent heat of fusion = 200 kJ/kg

Heat require for 100 ltr water to increase temp from 5°C to 35°C

$Q = mc_p\Delta T = 100 \times 4.18 \times 30$ = 12540 KJ

Requirement of PCM

12540 KJ = m × 200

m = 62.7 kg

Price of paraffin wax = 62.7×60 = Rs. 3760

Container Design

Density of paraffin wax = 900kg/m^3

Volume of tank required (Heat Exchanger) = 62.7/900= 0.07 m^3

With 10 % space given to pipes, total volume of tank = 0.077 m^3 ≅ 0.08 m^3

Volume of cylinder with radius 'r' and height 'h'=πr^2h=0.08 m^3

$$h=0.08/\pi r^2$$

and By considering cylindrical container (for minimum area) = $\frac{\partial(2\pi rh)}{\partial x} + \frac{\partial(2\pi r^2)}{\partial x} = 0$

by solving the equations we get, r≅23.36 cm or 0.2336 m

And, h≅46.71 cm or 0.4671 m

Considering metal foam as an insulating material with 10 pore per inch (PPI).

Density of polyurethane foam =30 kg/m^3

Thermal conductivity of foam is (avg.) = 0.025W/mk

Interfacial heat exchange coefficient between paraffin wax and metal foam is(avg.) = 275 W/m^2k

Interfacial heat exchange coefficient between metal foam and air is (avg.) = 5 W/m^2k [9]

$$R_{total} = \frac{1}{A_i h_i} + 2\frac{L_f}{kA} + \frac{ln\frac{r_2}{r_1}}{2\pi kh} + \frac{1}{A_o h_o}$$

Taking foam thickness = 2 cm

Neglecting metal sheet thickness and heat resistance,

Pipe surface area, we have [11]

Internal Surface Area (A_i) =1.0277 m^2

Outer Surface Area (A_o) = 1.1476 m^2

So, R_{total} = 0.8749 m^2K/W

Total heat loss in night time condition [12]

$$Case\ I: Winter\ Condition (70°C\ Temp\ Diff, 15\ hrs) \quad Q = \frac{\Delta T}{R}t = 80.009 * 15 * 3600 = 4320.49\ kJ$$

$$Case\ I: Summer\ Condition (50°C\ Temp\ Diff, 12\ hrs) \quad Q = \frac{\Delta T}{R}t = 57.147 * 12 * 3600 = 2468.79\ kJ$$

Conclusion:

It can be concluded that solar water heating with the help of latent heat storage is more appealing and shows that a significant amount can be stored throughout night time in both summer and winter conditions.
Some key point of analysis is:

- There is loss of 4320 kJ during winter night against 12540 kJ heat stored.
- In summer condition only loss of heat is 2468 kJ.
- Summer condition hot water can be use for applications like washing, Vapor absorption refrigeration system etc.
- Using thin and rigid foam insulation proves more effective thermal resistance than the thick and soft foam.
- It is recommended that container design should contain PCM only which reduces the exposed area in air, which further reduce the heat loss.

Because the amount of heat storage material required in the latent heat storage is less than the sensible heat storage and higher storage capacity, however cost may be high. It is that solar water heating systems are emerging technology and need to increases utilization factor, for that heat storage for loner time required. As per analysis and design proposed 24 hours latent heat can be easily stored with the help of paraffin wax and at rate of loss of 100 Watt at winter night time. Further it can be suggested that countries with hot summer can integrated these solar water heaters with solar refrigeration system that can again enhances utilization factor throughout the year.

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