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MODEL DEVELOPMENT AND ANALYSIS OF THE THERMAL PERFORMANCE OF A MODIFIED SOLAR WATER HEATER

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Abstract

A modified design of a Solar Water Heater is proposed in this paper for getting the better thermal performance by making several changes in the existing design. The design modification includes improvement over individual drawbacks of 'Flat plate collector (FPC)' and 'Evacuated tubular collector (ETC)'. A performance study of a solar water heating system with a 1.6 m^2 aperture area of a modified collector has been carried out. The thermal model of the proposed Modified Solar Water Heater (MSWH) has been derived to analyze theoretically the effect of wind velocity and the number of acrylic tubes. The maximum temperature of the collector outlet is found to be 72.24 °C in May 2015. It is observed that on increasing the wind velocity from 0 to 5 m/s, the hot water temperature falls from 72.46 ^oC to 68.60^oC for given input parameters. It has also been found that as the number of acrylic tubes increases, the temperatures of hot and cold water also increase e.g., increasing the number of tubes from 16 to 32, the temperatures of hot water are found 72.24^oC and cold water is 91.45^oC. The outcomes of the experimental analysis are very much useful for the development of a high-performance solar heater.

Keywords- Solar water heater, evacuated tube, flat plate collector, sun light, solar energy, water heater

1. INTRODUCTION

Water heating is a basic requirement of human beings especially in the winter season and cold climatic zones. There are several energy-intensive techniques are used for water heating e.g. Electric Gyser, immersion rods, etc. These techniques put a load on the conventional power plant more for increased power requirement which causes more emission of CO_2 and other harmful gases including greenhouse gases. Therefore, it is desirable to use renewable energy-based water heating systems e.g. Flat plat collectors, Parabolic trough collectors, Biogas based water heating systems, and Evacuated tubular collectors, etc to protect environmental issues and limited resources of fossil fuels. The fluid, carrying the solar energy in form of heat, transmits the heat to water to be hot using direct contact of the fluid tubes or space conditioning equipment. A flat plate collector (FPC) construction is very simple as it consists of an absorber made of metal in a flat rectangular casing and to reduce the thermal losses it is covered by a glass sheet and insulation at the upper and bottom surfaces respectively. The solar radiation absorption and conversion into heat is served by the flat metal plate as a heat exchanger. The collected heat is carried by the fluid or may directly transfer to the water in the storage tank. A heat pipe inside a vacuum-sealed tube is used in the evacuated solar collectors. The heat pipe used in the evacuated solar collector is placed in a vacuum-sealed tube to create a vacuum envelope for saving the convection and conduction losses so that the collectors will be able to operate at higher temperatures than FPC. The evacuated tube collectors [ETC] can collect both direct and diffuse radiation like FPC, and it shows high efficiency at low incidence angles resulted in day-long performance [1]. The thermal performance of an SWH with an area of 4 m^2 of FPC under an active system has been investigated in Dublin, Ireland. It is determined that in May 2009 [2]. The storage of solar energy is very important for the effective use of solar water heating systems due to the fact solar radiation has unsteady features during the day. This problem can be minimized by using phase change material (PCM) [3]. The calculation of the top heat loss coefficient is necessary for analyzing the performance of flat plate collectors. Here is an empirical relationship is proposed for glass cover temperature of a single glazed FPC tilted in range of 60^0-90^0 using the glass cover temperature for top heat loss coefficient. Further the estimation of the top heat loss coefficient U_t is carried out by the analytical model [4-5].

The solar domestic hot water storage tank simulation is carried out by using the two-dimensional computational fluid dynamics (CFD). Then modeling and meshing of the same is done by using Commercial software ICEM (Integrated Computer-aided Engineering and Manufacturing) and final analysis is done by the FLUENT 6.3. The heat transfer, movement, and flow distribution in the storage tank are done by CFD. It has been found that lower laminar velocity helps to develop the temperature profile and to maintain the thermal stratification of the tank. Thermal stratification of tank plays an important role as it was increased the thermal efficiency of the collector was also increased. Therefore, it is desirable that at the inlet and exit of tank velocity

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should be less to minimize the mixing and thermal stratification loss [6-9].

Several energy-intensive techniques are used for water heating e.g. Electric Gyser, immersion rods, etc. These techniques put a load on the conventional power plant more for increased power requirement which causes more emission of CO2 and other harmful gases including greenhouse gases. Therefore, it is desirable to use renewable energy-based water heating systems e.g. Flat plat collectors, Parabolic trough collectors, Biogas based water heating systems, and Evacuated tubular collectors, etc to protect environmental issues and limited resources

The solar heater is normally used in the peak winters, their use is very much uncreased in recent year, so many improveemnts has been cariieidout by the researchers to get the optimized and better design interms of performance and reliability of the system. There are some modeling and some experimental analsysis have been carrriedout to get the desired performance of the system. In a theoretical study of flow investigation for a glass evacuated tube collector, computational fluid dynamics has been employed to investigate the heat transfer and flow structures inside all-glass ETC under variable operating conditions. The collector under the investigation is designed as the horizontal tubes connected to a vertical manifold channel. The tube modeled here are having different dimensions. The analysis of the imposed operating conditions shown that at an optimal inlet flow rate of 0.4–1 kg/min, the shortest tube collector achieved the highest efficiency [12]. Several evacuated tubes (glass-in-glass type, all facing south) have been integrated with the conventional single slope solar still (SS) has been experimentally investigated. These tubes have been joined at the south wall of SS. The water is made to circulate under a natural thermo-siphon effect between SS and these tubes. A thermal model for EISS has been developed and analyze theoretically at different water depths for the winter (January 2010) season of New Delhi. It has been found that IESS is more effective in terms of the amount of distillate over SS [13]. It defines a valid range of the parameter$(T_w - T_a)/I(t)$ and also recommended these as a procedure of thermal testing. A modified solar water heating system has been designed and studied for the parameter of wind velocity and the number of absorber tubes. The proposed model shows better performance in different aspects of consideration.

2. METHODOLOGY

To improve efficiency and to get higher temperatures than the conventional solar water heater. In this paper, a modified solar water heater would be designed and analyzed theoretically. A thermal model has been developed for the analysis of the performance of the SWH. Thermal modeling has been to get a mathematical equation for the evaluation of the temperature of hot water.

The modified design of solar water heater was proposed in this study. The objective of better performance is greatly achived by making some changes in the constructions. The experimental setup was fabricated in MNNIT Alllahabad, on which different analysis have been carried out. On the basis of experimental outcomes, the following conclusion have been made

2.1 Design of Modified Solar Water Heater

The Modified Solar Water Heating (MSWH) system is equipped with a thermal collector and a transparent water storage tank. The thermal collector has an absorbing area of $1.6m^2$ is the combination of flat plate collector and evacuated tube collector. Collector design is in such a way that there is an absorber plate made up of Cu above which several semicircular acrylic tubes in tubes are kept and insulation of FRP sheet is used as the base of collector. These tubes are connected with a modified transparent storage tank of a cuboid shape of 493.6×493.6×800 mm to hold a total water capacity of 200 liters. A detailed photograph of MSWH has been shown in Figure 1.

Figure 1 Pictorial view of fabricated MSWH

It has been designed for the latitude of Allahabad which is 24.45° N. Table 1 shows the design specification of setup. It is clear from the table that the storage tank is having a capacity of 200 l, the length of acrylic tubes is 2 m and the number of tubes is 16. A transparent storage tank is made up of an acrylic sheet as well as fiber reinforcement plastic (FRP). South, top, east and west wall of the tank is made up of a double layer of acrylic sheet, and north and the bottom wall of the tank are made up of FRP with a black coating.

Table 1 Design specification of the experimental setup

Parameter	Values	Parameter	Values
Capacity of storage tank (l)	200	Height of storage tank (m)	0.5
Length of the storage tank (m)	0.86	The thickness of FRP sheet (m)	0.045
Breadth of storage tank (m)	0.5	IT thickness (m)	0.0025
Area of the collector ($m^{2)}$	1.6	Outer tube thickness (m)	0.003
Metal plate thickness (m)	very thin	Tube length (m)	2
Inner radius IT(m)	0.01	Number of tubes	16
Inner radius OT (m)	0.025	Space between tubes (m)	0.0095

The maximum temperature of the collector outlet is found to be 72.24 °C in May 2015. It is observed that on increasing the wind velocity from 0 to 5 m/s, the hot water temperature falls from 72.46 ºC to 68.60ºC for given input parameters. It has also been found that as the number of acrylic tubes increases, the temperatures of hot and cold water also increase e.g., increasing the number of tubes from 16 to 32, the temperatures of hot water are found 72.24ºC and cold water is 91.45ºC. The outcomes of the experimental analysis are very much useful for the development of a high-performance solar heater.

Water heating is a basic requirement of human beings especially in the winter season and cold climatic zones. There are several energy-intensive techniques are used for water heating e.g., Electric Gyser, immersion rods, etc. These techniques put a load on the conventional power plant more for increased power requirement which causes more emission of CO_2 and other harmful gases including greenhouse gases. Therefore, it is desirable to use renewable energy-based water heating systems e.g., Flat plat collectors, Parabolic trough collectors, Biogas based water heating systems, and evacuated tubular collectors, etc to protect environmental issues and limited resources of fossil fuels.

3. RESULTS AND DISCUSSION

There are several energy-intensive techniques are used for water heating e.g., Electric Gyser, immersion rods, etc. These techniques put a load on the conventional power plant more for increased power requirement which causes more emission of CO2 and other harmful gases including greenhouse gases. Therefore, it is desirable to use renewable energy-based water heating systems e.g., Flat plat collectors, Parabolic trough collectors, Biogas based water heating systems, and evacuated tubular collectors, etc to protect environmental issues and limited resources

Table 2 Hourly variations of solar radiation, ambient temperature, and wind velocity

TIME	Va	Ta	It(t)	IE(t)	IW(t)	Itop(t)	IS(t)
(hr)	(m/sec)	°C	(W/m^2)	(W/m^2)	(W/m^2)	(W/m^2)	(W/m^2)
7:00	0.1	28.0	150	100	60	180	50
8:00	0.1	30.0	400	320	80	430	110
9:00	0.1	36.8	650	400	130	690	150
10:00	0.1	38.0	927	636	184	991	310
11:00	0.1	39.0	1081	408	205	1137	350
12:00	0.1	44.0	1125	217	276	1163	358
13:00	0.1	46.0	1118	200	432	1166	360
14:00	0.1	46.5	937	199	730	1017	286
15:00	0.1	40.0	740	146	850	750	220
16:00	0.1	37.0	560	130	946	635	190
17:00	0.1	33.0	450	80	500	250	150
18:00	0.1	30	100	40	150	80	90
19:00	0.1	28	0	0	0	0	0
20:00	0.1	25	0	0	0	0	0
21:00	0.1	25	0	0	0	0	0
22:00	0.1	25	0	0	0	0	0
23:00	0.1	25	0	0	0	0	0
0:00	0.1	25	0	0	0	0	0

of fossil fuels.

Theoretical results for May 2015 have been analyzed in MNNIT Allahabad. The hourly assumed parameters such as solar intensity on (collector tubes and roof, south, east, and west wall of storage tank), ambient temperature, wind velocity, etc have been shown in Table 2. The hot water temperature is calculated by using Microsoft Excel software. The effect of wind velocity and the number of tubes is also analyzed. The analysis is done based on thermal modeling. These are the graphs that are obtained after thermal modeling.

Fig.2 shows the hourly variation of water temperature from 07:00 hr to 0:00 hr. It has been observed that the maximum temperature of hot water is found to be 72.24

°C at 16:00 hr. After that, it decreases due to heat losses and no gain in solar radiation due to off-sunshine hours.

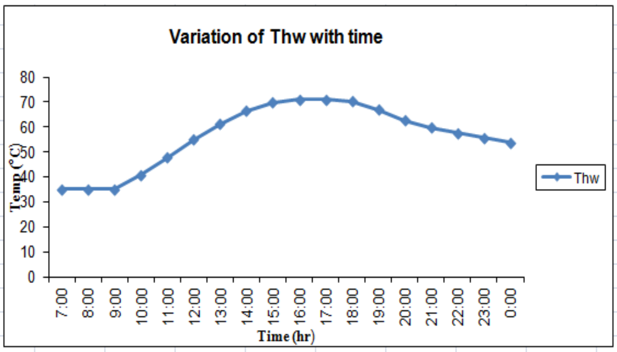

Figure 2 Variation of the temperature of hot water in tubes with time

Fig. 3 shows the hourly variation of water temperature with time with wind velocity from 7:00 hr to 17:00 hr. It has been observed that as wind velocity increases, the temperature of hot water decreases due to increased losses. It is the maximum value of temperature for minimum wind velocity. The maximum recorded value of hot water temperature is 72.24°C for the wind velocity of 0.1 m/sec.

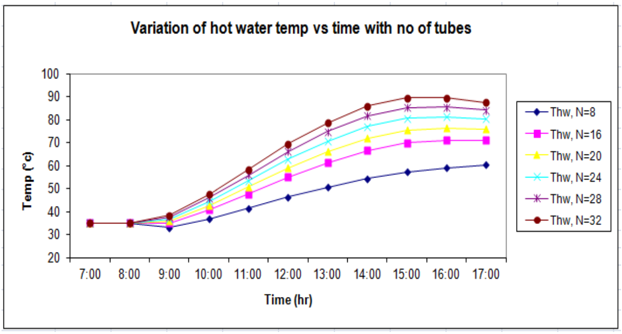

Figure 3 Variation of the temperature of hot water in tubes with time

Figure 4 shows the hourly variation of temperature of the water with time with the number of acrylic tubes from7:00 hr to 17:00 hr. It has been observed that as the number of tubes increases the value of temperature also increases. It is because of the increment in the absorber area. The maximum value of hot water has been recorded for 32 acrylic tubes and the value is 89.45°C at 15:00 hr. And the minimum value of the temperature of hot water in the tube and cold water in the tank is for 8 numbers tubes.

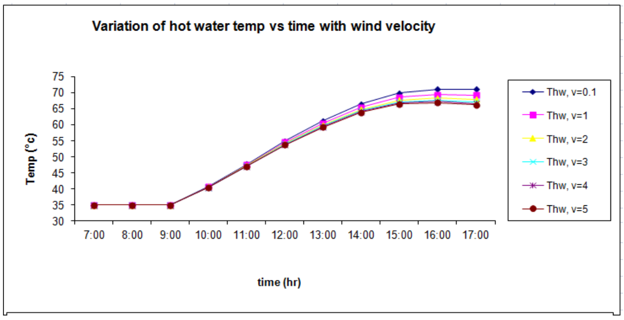

Figure 4 Variation of the temperature of hot water in tubes with time

4. CONCLUSIONS

The modified design of solar water heater was proposed in this study. The objective of better performance is greatly achieved by making some changes in the constructions. The experimental setup was fabricated in MNNIT Allahabad, on which different analysis have been carriedout. On the basis of experimental ourcomesm the following conclusion have been made.

- From the thermal modeling and results, it has been found that this type of SWH is having a higher temperature than conventional ones.
- Designed Modified Solar Water Heating System can overcome drawbacks of flat plate collectors as well as evacuated tube collectors.
- The maximum value of the hot water temperature is 72.24 °C in May 2015.
- From the thermal modeling and results, it was seen that this type of storage tank is having a higher temperature than conventional ones.
- From the results, it is clear that as wind velocity increases, the value of temperature decreases. And as the number of acrylic tubes increases, the value of temperature also increases.

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