CFD Study of an Integrated Collector – Storage Type Flat Plate Solar Water Heater Without and with Fins, Dimples and V-grooves in Absorber Surface

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Abstract— Flat Plate Solar Water Heaters are extensively used all over the world to utilize the natural source of solar energy from sun. In order to utilize the solar energy during off sunshine hours it is inevitable to store and retain solar thermal energy as long as possible. For effective gain and retention of solar thermal energy a fins are provided. Depth of fins immersed in water, V-grooved and dimpled absorber surface in a solar thermal collector are important geometric parameters that influence the maximum temperature rise during peak solar irradiation and hence the losses. CFD studies show an improved heat transfer with increase in depth of fin.

Index Term— Solar Water Heater, Movable absorber plate, Integrated Collector storage, Sensible heat gain, CFD, fins.

I. INTRODUCTION

Solar Water Heating is a technology used to harness the energy available in abundance in nature. It can be utilized for both residential and industrial applications and can help to conserve our fuel reserves. Conventional Solar water heater consists of a separate solar collector and storage device. Actual energy output and overall system efficiency will depend upon installation location, climate, insulation, system configuration and many other factors. On rainy or heavily overcast days, energy output will be greatly reduced. In compact solar water, since the storage device is underneath the collector as a single unit, space and material are reduced, and hence cost. There is a lot of scope for performance enhancement of solar water heaters by optimizing surface geometry design of the absorber concerned with it.

Mousa S. Mohsen et al. [1] conducted experiments on compact solar water heater for water depths of 5, 10 and 15 cm and concluded 10 cm as optimum water depth. Single glazing showed better water temperature rise and double glazing retained heat better [1].

Sridhar et al. [2] conducted experiments on Cuboidal Solar Integrated Collector-Storage system for depths of 2, 5, 8 and 12 cm and inclination angles of 10°, 20°, 30°, and 50°. Average heat transfer coefficient at the bottom surface of absorber plate is 20% higher for depth of 12 cm as compared to the 2 cm depth of cuboidal section, after 2 hours of heating.

Agbo et al. [3] concluded that the loss coefficient decreases with increase in the gap between the absorber plate and the glass cover. A gap width >= 5 cm is recommended for optimum loss coefficient.

H.P. Garg et al. [4] reported that the storage potential of built-in-storage type solar water heater with transparent insulation is higher than that of a system with moveable insulation. The decrease in transmittance of the transparent insulation more than offsets its better insulating property during the sunshine hours.

Rakesh kumar et al. [5] reported that more solar energy was converted into useful heat with corrugated absorber surface, but this modification reduced the efficiency of the system marginally.

R.P. Sharma [6] proposed that Agitator in the raiser tubes enhanced heat transfer while Pebbles and stainless steel chips enhanced the retention period of heat. The internal dimensions of the collector were 1.2m x 0.6m x 0.18m. Agitator using curling coper wire inside the raiser tubes in the form of helix was used to increase the heat transfer coefficient. Pebbles and stainless steel chips were used to cover the absorber surface to enhance heat transfer and retention.

Domenico Borello et al. [7] proposed a cuboidal collector with inbult cylindrical storage and showed that the vertical structures developing downstream from the inlet section maintain steady for a very short collector length, then they become unsteady and warp demonstrating mixing of thermal boundary layer is mainly related to convective motion.

Souliotis M. et al. [8] designed three ICS experimental models consisting of one cylindrical tank horizontally mounted in a stationary symmetrical Compound Parabolic Concentrating (CPC) reflector trough with the objective to achieve a low depth, in order to be easily installed on horizontal and inclined roofs, but night time operation is still limited.

Souliotis M. et al. [9] designed one cylindrical tank with asymmetrical CPC reflectors and the annulus between the cylinders partially evacuated with outer surface partially exposed and remaining insulated to improve heat retention. The thermal loss coefficient during night time is similar to that of thermosyphon FPSWH.

K.P. Gertzos et al. [10] validated a model with indirect heating of the service hot water, through a heat exchanger incorporated into front and back major surfaces of the ICSSFPSWH, but the design was not optimized.

K.P. Gertzos et al. [11] optimized the position and size of the recirculation ports, and the arrangement and size of the
interconnecting fins to maximize the velocity flow field of an ICSMFPSWH by 65 %.

Mehrooz M. Ziapour [12] proposed an ICSMFPSWH system which is divided by two trapezoids cross section volumes and the efficiency of the system maximised for top volume to bottom volume ratio greater than or equal to four.

David Faiman et al. [13] provided a reverse thermo-siphon prevention valve that prevents flow reversal and hence losses in an ICSMFPSWH.

Malhotra A et al. [14] has discussed the equations for heat loss calculation of flat plate solar collectors.

Raj Thundil Karuppa R et al. [15] tested with the absorber made of 2 sheets of GI (1 mm) with integrated canals, painted in silica based black paint solar water heater and small pump for forced circulation. It can be concluded there is little difference between the output temperatures while using copper and GI different collectors. Efficiency of the flat plate collector for copper is 24.17% and GI is 20.19%.

Madhukeshwara. N. et al. [16] used three different coatings Sol chrome, Matt black and Black chrome for solar flat plate collectors and water temperatures in the storage tank were recorded. Maximum temperature of hot water in the storage tank was obtained for black chrome coating when compared to other two coatings.

Narasimhe Gowda et al. [17] studied the heat transfer phenomena in the collector system were calculated by using theoretical model. To improve the thermal efficiency of the solar collector system, inlet water temperature should be as low as possible. The efficiency increases more or less linearly with ambient temperature. Increasing the thickness of insulation beyond 5 cm is worthless. Efficiency will decrease with increase of wind speed. Transmission ratio of glass cover should be more than 0.95 in order to obtain higher thermal efficiency. Higher the ambient temperature higher is the efficiency because of less heat loss to the surrounding.

A comprehensive study is necessary to explore the performance of an Integrated Collector storage type Flat Plate solar water Heater for different depths of extended surfaces from absorber surface, V-grooves, and dimpled surface to compare and evolve optimum surface geometry for maximum heat gain and retention. Hence a CFD model of transient heat transfer in an Integrated Collector Storage type movable flat plate solar water heater (ICSMFPSWH) models were developed to analyse the variation of temperature in 24 hours.

II. EXPERIMENTAL SETUP

A Schematic diagram of the CFD Model of ICSMFPSWH setup is shown in Fig. 1. The compact solar water heater model is of dimension 0.5 m x 0.5 m x 0.15 m made of steel sheet, filled with water to a depth desired. The insulation provided is Polyurethane of 0.05 m thickness with an outer layer of 0.017 m thick layer of plywood to minimize convection heat losses to the surrounding. The glass cover is one in number and of 0.004 m thickness. The glazing cover is at a distance from the absorber plate. The distance between the absorber plate and the glazing cover varies with depth of water. The absorber plate is made of Aluminium in the shape of a square tray of dimension a little smaller than 0.5 m x 0.5 m x 0.03 m with clearance to move, of thickness 0.001 m and thermal conductivity 200 Wm⁻¹K⁻¹. The absorber plate is in 100 % contact with the entire water surface. The emissivity and absorptivity of the glazing cover are taken as 0.1 and transmissibility of the glazing cover is taken as 0.9. The emissivity of the absorber plate is taken as 0.8 and emissivity for re-radiation is 0.18.

Figures 2, 3, 4, and 5 show the isometric view of ICSMFPSWH without fins, with fins, with V-grooves of 25 mm depth and 50 mm spacing and with dimpled absorber surface respectively. Fins pitch is 100 mm with 5 fins. V-grooves have 25 mm depth and 50 mm spacing. Dimples are of 25 mm diameter, 5 mm depth and 50 mm pitch.
III. COMPUTATIONAL SIMULATION OF TRANSIENT HEAT TRANSFER IN AN INTEGRATED COLLECTOR STORAGE TYPE MOVABLE FLAT PLATE SOLAR WATER HEATER (ICSMFPSWH)

A transient heat transfer analysis was done with an assumed fair weather radiation data on a particular day in June for different ICSMFPSWH models as described in the setup given in Fig. 2 to Fig. 6. 16 mm square mesh size was selected in water zone and suitable finer mesh size near the plate boundary and in air zone were selected as shown in Fig. 6. Grid independence test was performed to test the convergence of solution with a finer mesh size of 8 mm near the absorber surface for water side and 4 mm mesh size near the glass and absorber surface for air side and the average variation percentage is found to be less than 0.17 and hence the grid convergence is confirmed to be satisfactory.

The full geometry and computational mesh for CFD simulations were created in the Solid works software, which is used as a pre-processor for the CFD solver and Cosmosexpress V 2014 is used for post-processor. The computational domain has been solved as a steady state conjugate heat transfer problem and the solution process is performed until convergence and an accurate balance of mass and energy are achieved. The solution process is iterative and each of the iteration in the steady state problem is treated as a

 Fig. 4. ICSMFPSWH with V-grooves

 Fig. 5. ICSMFPSWH with dimpled surface

 WITHOUT FIN

 20MM FIN

 40 MM FIN

 60MM FIN

 ROUND DIMPLE

 V GROOVE

 Fig. 6. Mesh details of ICSMFPSWH models
pseudo-time step. In the iterative scheme, all the equations are solved iteratively, for a given time step, until the convergence criteria are met.

The calculations are repeated for every minute of 24 hours period, with solar insolation, ambient temperature as recorded on 05-06-2014 at Tiruchirapalli, India. The initial water temperature is assumed as 26 Deg.C and water depth as 10 cm. initial water temperature and depth as input data. Heat loss coefficient is assumed to be a minimum of 5 W/m²K from the outer surfaces.

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A cross over in temperature was observed in the graphs after 2 AM where the temperature for V-groove absorber surface starts dropping below that of other models.

At 6:00 AM next day morning, \( T_{\text{without fin}} > T_{20 \text{ mm fin}} = T_{40 \text{ mm fin}} = T_{60 \text{ mm fin}} > T_{\text{dimple}} > T_{V-\text{groove}} \). The temperature of water with that of a flat absorber surface is maximum when compared to other models and that of V-groove is minimum.

Fig. 7a shows the variation of ambient temperature which well agrees with the variation in solar radiation data shown in Fig. 7b. A short span of cloud cover and shower as reflected by a drop in radiation data for a short span of time rapidly increased the ambient temperature and humidity of the locality and hence a higher temperature was observed thereafter.

IV. RESULTS AND DISCUSSION

Fig. 7c, and Fig.8 show the variation of average water temperatures for different surface geometry. At 6:00 PM, the temperature of water ‘T’ in various absorber surface models is: \( T_{\text{dimple}} < T_{\text{without fin}} < T_{20 \text{ mm fin}} < T_{40 \text{ mm fin}} < T_{60 \text{ mm fin}} < T_{V-\text{groove}} \). The temperature of water with that of V-groove absorber surface is maximum when compared to other models and that of dimpled surface is minimum.

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Fig. 9 shows the variation of water temperature within the ICSMFPSWH models at 6:00 PM. It was observed in V-groove absorber surface, the temperature near the absorber surface is very high when compared to other models and also maximum temperature gradient was observed with depth of water which indicates maximum heat gain. Dimpled absorber surface showed next better temperature gradient with depth of water although better heat gain was not reflected from water temperature view point since the absorber temperature was the least.
Fig. 8 Variation of water temperature at 6:00 PM within ICSMFPSWH for different absorber surface configuration.

Fig. 9 shows the variation of water temperature within the ICSMFPSWH models at 6:00 AM next day morning. It was again observed in V-groove absorber surface, the temperature near the absorber surface is low when compared to other models and also maximum temperature gradient was observed with depth of water which indicates maximum heat loss. Dimpled absorber surface showed next better temperature gradient with depth of water and hence next maximum heat loss.

V. CONCLUSIONS
CFD Studies were carried out to design a batch type flat plate solar water heater model to improve the temperature gain in the evening and heat retention next day morning. In this regard, absorber surfaces with different dimensions of fins
and V-groove fins were studied. Among all these models, the model with V-groove is advantageous for hot water usage in the evening, because it gains maximum heat and hence temperature when compared with other fins. But heat retention in the next day morning is least because of increased surface area.

REFERENCES


