CFD Investigation of Heat Transfer Enhancement in Flat Plate Solar Collector using Various Cross Sectional Inserts

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Abstract— The performance of solar water heater can be improved to perform a certain heat transfer duty by heat transfer enhancement techniques. In general, these techniques can be divided into two groups: active and passive techniques. The active techniques require external forces, e.g. electric field, acoustic or surface vibration, etc. The passive techniques require fluid additives or special surface geometries. Curved tapes have been used as one of the passive heat transfer enhancement techniques and are the most widely used techniques in several heat transfer applications. The main categories of heat transfer augmentation involves insetting curved tapes, helically coiled tapes, spirally coiled rods, other coiled tubes and also using fins are studied and analyzed to determine the optimum technique for a solar water heater by improving the convective heat transfer between the circular pipe and water medium. Simulations were carried out using commercial CFD software ANSYS FLUENT 14.0.

Keywords: Solar Water Heater, Solar Energy, Twisted Tapes, Helical Tubes, CFD, Fluent, Heat Augmentation.

I. INTRODUCTION

Solar water heating (SWH) or solar hot water (SHW) systems comprise several innovations and many mature renewable energy technologies that have been well established for many years. SWH has been widely used in Australia, Austria, China, Cyprus, Greece, India, Israel, Japan, Jordan, Nepal, Spain and Turkey. In a "close-coupled" SWH system the storage tank is horizontally mounted immediately above the solar collectors on the roof. No pumping is required as the hot water naturally rises into the tank through thermosyphon flow. In a "pump-circulated" system the storage tank is ground or floor mounted and is below the level of the collectors; a circulating pump moves water or heat transfer fluid between the tank and the collectors. SWH systems are designed to deliver hot water for most of the year. However, in winter there sometimes may not be sufficient solar heat gain to deliver sufficient hot water. In this case a gas or electric booster is used to heat the water.

Freeze protection measures prevent damage to the system due to the expansion of freezing transfer fluid. Drain back systems drain the transfer fluid from the system when the pump stops. Many indirect systems use antifreeze (e.g. Propylene glycol) in the heat transfer fluid. In some direct systems, the collectors can be manually drained when freezing is expected. This approach is common in climates where freezing temperatures do not occur often, but is somewhat unreliable since the operator can forget to drain the system. Other direct systems use freeze-tolerant collectors made with flexible polymers such as silicone rubber. A third type of freeze protection is freeze-tolerance, where low pressure polymer water channels made of silicone rubber simply expands on freezing. One such collector now has European Solar Key mark accreditation, following extra durability testing.

When no hot water has been used for a day or two, the fluid in the collectors and storage can reach very high temperatures in all systems except for those of the drain back variety. When the storage tank in a drain back system reaches its desired temperature, the pumps are shut off, putting an end to the heating process and thus preventing the storage tank from overheating. One method of providing over heat protection is to dump the heat into a hot tub. Some active systems deliberately cool the water in the storage tank by circulating hot water through the collector at times when there is little sunlight or at night, causing increased heat loss. This is most effective in direct or thermal store plumbing and is virtually ineffective in systems that use evacuated tube collectors, due to their superior insulation. No matter the collector type, however, they may still overheat. High pressured sealed solar thermal systems versions ultimately rely on the operation of temperature and pressure relief valves. Low pressure, open vented ones have simpler, more reliable safety controls, typically an open vent.

II. FLAT PLATE COLLECTOR

Flat plate collectors, developed by Hottel and Whillier in the 1950s, are the most common type. They consist of

(1) a dark flat plate absorber,
(2) a transparent cover that reduces heat losses,
(3) a heat transport fluid (air, antifreeze or water) to remove heat from the absorber, and
(4) a heat insulating backing.

The absorber consists of a thin absorber sheet (of thermally stable polymers, aluminum, steel or copper, to which a matte black or selective coating is applied) often backed by a grid or coil of fluid tubing placed in an insulated casing with a glass or polycarbonate cover. In water heat panels, fluid is usually circulated through tubing to transfer heat from the absorber to an insulated water tank. This may be achieved directly or through a heat exchanger. Most air heat fabricators and some water heat manufacturers have a completely flooded absorber consisting of two sheets of metal which the fluid passes between. Because the heat exchange area is greater they may be marginally more efficient than traditional absorbers. (1)

Sunlight passes through (3) the glazing and strikes the absorber plate, which heats up, changing solar energy into heat energy. The heat is transferred to liquid passing through pipes attached to the absorber plate. Absorber plates are commonly painted with "selective coatings," which absorb and retain heat better than ordinary black paint. Absorber plates are usually made of metal—typically copper or aluminum—because the metal is a good heat conductor.

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Copper is more expensive, but is a better conductor and less prone to corrosion than aluminum. In locations with average available solar energy, flat plate collectors are sized approximately one-half to one square foot per gallon of one day's hot water use. Absorber piping configurations include:

- Harp – traditional design with bottom pipe risers and top collection pipe, used in low pressure thermosyphon and pumped systems;
- Serpentine – one continuous S that maximizes temperature but not total energy yield in variable flow systems, used in compact solar domestic hot water only systems (no space heating role);
- Flooded absorber consisting of two sheets of metal stamped to produce a circulation zone;
- Boundary layer absorber collectors consisting of several layers of transparent and opaque sheets that enable absorption in a boundary layer. Because the energy is absorbed in the boundary layer, heat conversion may be more efficient than for collectors where absorbed heat is conducted through a material before the heat is accumulated in a circulating liquid.

III. PERFORMANCE ISSUE

The current solar water heater system's efficiency can be improved by various methods from changing cross sections (passive) to using pump (active). The problem in using pumps i.e. active technique it consume more energy but passive techniques does not requires external energy. By using passive technique the convective heat transfer can be improved between the inside surface of the pipe and the water medium. The effective convection in solar water heater can be achieved by introducing various cross sections inside the pipe.

IV. MODELING

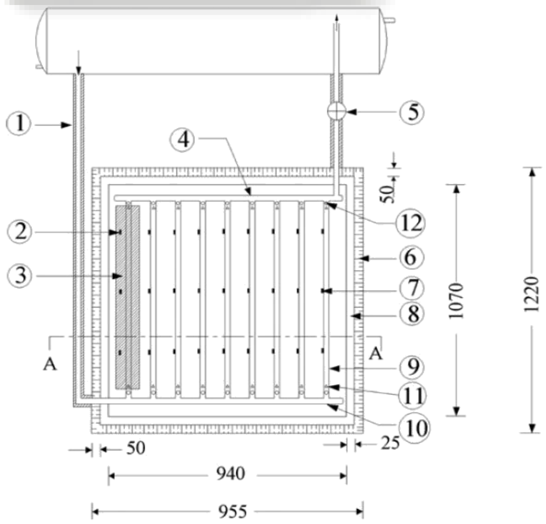

Fig. 1: Autocad 2D Image of Whole Model

The Modeling is done using CREO Parametric 2.0, but when modeling for a CFD analysis it is to be considered developing a separate part model for the fluid, this can only done using Boolean operation. For the purpose of performing Boolean operation we are using ANSYS Design Modeler which was inbuilt modeling platform in ANSYS 14.0. The Riser tube only taken in account for modeling because all other parameters can be assumed and can be assigned to match the real time environment, the dimensions of the tube are exactly the same used in traditional solar water heater, the below shown model Fig.1 is modeled in CREO Parametric 2.0.

1) Water inlet to collector.
2) Absorber plate temperature.
3) Absorber plate.
4) Upper header.
5) Magnetic flow meter.
6) Glass wool supported by aluminum frame.
7) Riser tube temperature.
8) Wooden sides.
9) Riser tube.
10) Lower header.
11) Taps for measuring pressure drop inlet and outlet.
12) Taps for measuring pressure water inlet and outlet.

S. No	Design materials / Parameters	Specifications
Collector		
1	Tilt Angle	18° (Default)
2	Aperture area Ac	$1m^2$
3	Collector glazing	Single transparent glass of 3 mm thickness
4	Lower header	ID 25.4 mm
5	Upper header	ID 25.4 mm
6	Riser tubes	OD 12.5 mm, ID 11 mm, length 1000 mm
7	Absorber plate	Width 120 mm, length 1000 mm
8	Bottom insulation	100 mm glass wool
9	Side insulation	50 mm glass wool covered by aluminum frame
10	Absorber plate coating absorptivity	0.92
11	Transmittance of glazing	0.91
12	Number of riser tubes	9
Storage tank and piping		
13	Tank type	Horizontal
14	Tank volume	100 L
15	Tank wall thickness	4 mm
16	Tank insulation thickness	50 mm
17	Connecting pipe size	ID 25.4 mm
18	Pipe insulation thickness	20 mm

Table 1: Parameters of Solar Hot Water Systems

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V. HEAT AUGMENTATION INSERTS

This paper compares the various passive heat augmentation technique that are to be analyzed using CFD such as,

(1) Twisted tapes
- With various twist ratios (Twist ratio 4)
- With holes drilled
- With rectangular cut

(2) Spiral rod
(3) Fins (Varying length)
(4) Pattern & Wick structure.

These structures are modeled and inserted into the pipe for analyzing. These sections are simulated in the same environment and boundary condition.

VI. COMPUTATIONAL FLUID DYNAMIC ANALYSIS

The solar heat flux is applied on the riser tubes, only half tubes are exposed to sunlight, so the imprint of the half pipe section is taken as wall and the inlet and outlet is shown in the in Fig.2

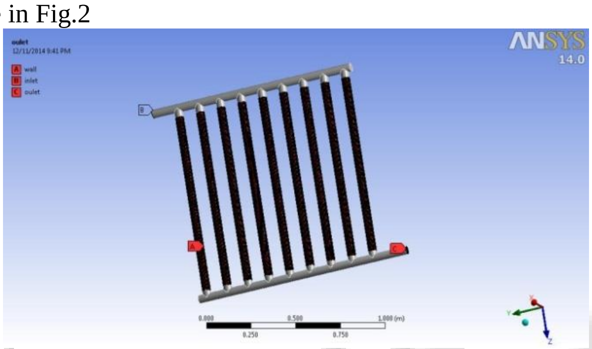

Fig. 2: Boundary Conditions

Materials and Medium used

Riser tubes: Copper (Cu)
Fluid medium: Water (H_2O)

VII. RESULTS AND DISCUSSION

The six sections of the riser tube are analyzed with the same boundary condition as mentioned in the previous chapter. The weather and the sunlight exposure is not a transient but taken as static at a particular time as the weather matching south India at 13.00 Indian standard time (8). The results are satisfactory. The results obtained in the analysis are shown in the below Table 2.

Heat transfer augmentations	Outlet temperature
Twisted tape of twist ratio 3	58
Twisted tape of twist ratio 4	63
Twisted tapes with hole	61
Twisted tapes with rectangular cuts	60
Spiral rod inserts	51
Fins	50
Pattern	48

Table 2: Results of Outlet Temperature from Analysis

The riser tube in a solar water heater is analyzed with various heat augmentation inserts and found that the riser tube with the twisted tapes gave good results in the outlet temperature. The spiral rod gave the second satisfying results compared to fins and pattern, both pattern and fins may be suitable for heat convection for higher velocity flows but not in case of solar water heating application. Twisted tapes have various geometries, in this particular analysis four of them are used and found twisted tape twist ratio higher gave good results (outlet temperature).

VIII. CONCLUSION

CFD investigation of convection heat transfer and characteristics of thermosyphon solar water heater with uniform twist ratio 3, 4 and different twist geometry (Rectangular cut and Spiral rod inserts) are performed and presented. The analysis data for different raiser tube sections are compared with the each other. The heat enhancement in twisted tape is found to be better than the plain tube collector. While comparing the twisted tape twist ratio 3 for the same twist ratio 4 has higher heat transfer and thermal performance are obtained. The increases in heat transfer for twisted tapes are higher than Plain tube collector respectively. It is clear from the above studies that the use of twisted tape in solar water heater enhances the heat transfer and overall thermal performance.

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