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A Review on Performance Improvement in Solar Flat Plate Collector

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Abstract- As non-renewable energy sources like fossil fuels are getting rare; cost of energy production has become higher as well as the involvement of environmental pollution by burning of fossil fuels among the developed and developing nation. Solar energy is most vastly available energy and very effective in terms of energy conversion. Conversion of solar energy into thermal energy is the simple and most used method. The efficiency of solar thermal conversion is around 70%. Solar water heating systems are mostly suited for its simple operation and maintenance. Many research papers acknowledge the improvement on thermal efficiency of solar water heating systems resulted in techniques to improve the convection heat transfer. This review paper summarizes the previous works on solar water heating systems with various heat transfer enhancement techniques contain solar energy collector design, coating of pipes, fluid flow rate, insertion of twisted tapes and dual purpose solar collector (DPSC). This paper also discussed the methods to optimize and simulate the solar water heating systems to understand flow and thermal characteristics in solar collectors that would lead to the improvement of the thermal performance of solar collectors.

Keywords: Solar energy, thermal energy, heat transfer enhancement techniques, solar water heating system, DPSC.

I. INTRODUCTION

India chugging along its self-defined high growth trajectory, to achieve an inclusive and sustainable development, is faced with the several challenges of ensuring energy security, overcoming energy poverty and defining a low carbon development path. To boost up its economic growth, India has traditionally depended on conventional fuel, primarily, which is also likely to keep the mainstay for future development. However, India despite sitting on large coal stock has been recently facing large supply disruptions and domestic coal production has failed to keep pace with the rapid buildup in demand. To add to this, the conventional thermal energy market is going through convulsions world over. Faced with the critical challenges, India has to be careful for and harness alternative energy sources to secure its development objectives. India had large potential for Renewable Energy, an estimated aggregate of over 100,000 MW. In addition, with the scope for power generation and thermal applications using solar energy is huge. Renewable energy potential in India has not been fully assessed or competently tapped, while the India's fossil fuel resources are limited compared to global reserves.

The obvious good choice of a clean energy source, which is abundant and could provide security for the future development and growth, is solar energy. Blessed with 300 sunny days in a year and receiving an average hourly radiation of 200 MW/km^2. India is well placed to overcome its key challenges by harnessing the enormous solar potential. Around 12.5% of India’s land mass could be used for harnessing solar energy. In recent years solar energy has been strongly promoted as a feasible energy source. One of the simplest and most direct applications of this energy is the conversion of solar radiation into heat.

A Solar Water Heating System (SWHS) makes the available thermal energy of the incident solar radiation for use in various applications by heating the water. For industrial and domestic applications hot water is very essential. The SWHS mainly consists of solar thermal collectors, water tanks; inter connecting pipelines, and the water or any other heat carrying liquid, which gets circulated in the system. Figure 1 represents the typical thermosyphon solar water heating system. Solar radiation incident on the collector heats up the tubes, there by transferring the heat energy to water which is flow due to thermosyphon effect.

Fig.1: Passive Solar Water heating system

The thermal performance of SWHS is influenced by inlet water temperature, solar irradiance, flow rate, ambient temperature, inclination of the flat-plate collector, height of the hot water tank, wind speed, relative humidity etc. The storage tank too plays an important role to collect and store the energy obtained from solar collector. The performance of the system largely depends on the collector's efficiency for capturing the incident solar radiation and transferring it to the water.

II. TYPES OF SOLAR COLLECTOR

There are three types of solar collectors that are described below.

A. Flat plate collector

Glazed flat plate collectors are equipped with insulation and weather proofed boxes that contain a dark absorber plate under one or more glass covers. While unglazed flat plate collectors have without a cover or enclosure are typically used for solar pool.

B. Integral collector storage systems

Furthermore, ICS (integral collector storage) or batch systems contain one or more black tanks or tubes in an insulated, glazed box. The water then continues on the conventional backup water heater, providing a steady source of hot water. Generally it should be installed only in the mild freeze climates because the possibility of to freeze the outdoor pipes in the cold weather. Figure 2 shows an integral solar water heater.

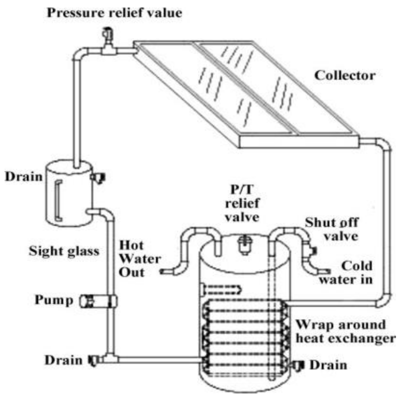

Fig.2: Integral collector storage system

C. Evacuated tube solar collectors

They feature parallel rows of transparent glass tubes. In each Evacuated tube contains a glass outer tube and metal absorber tube attached to a fin. The fin's coating absorbs solar thermal energy but inhibits radioactive heat loss. It is a very popular solar collector is in present time. This is a direct and very effective way to heat the water from the sun, but it is also expensive to set up.

III. HEAT TRANSFER ENHANCEMENT TECHNIQUES IN FLAT PLATE COLLECTOR

Solar water heating systems replace fossil fuels for heating water. Flat plate collector is generally used in domestic and industrial application because it is simple in construction. Hence, the most of the research works have been concentrated on the performance improvement of flat plate collector. The characteristics of a flat plate collector are based on the collector absorber plate and its design, selective coatings, tilt angle of the collector, working fluids and thermal insulation etc. Several designs of solar collectors have been analyzed by the researchers to improve the thermal performance of thermosyphon systems, discussed below.

A. Absorber plate design

Shariah et al. [1] have theoretically studied the effect of the thermal conductivity of the absorber plate. Results were found that the collector efficiency factor and heat removal factor have strong dependence on the thermal conductivity of the absorber plate and almost no advantage in using copper instead of aluminum unless other factors such as problem of corrosion or health hazards could affect the choice of the material for the absorber plate. Yeh et al. [2] investigated theoretically the effect of aspect ratio on the collector efficiency; it is observed that the collector efficiency increases with increasing collector aspect ratio for constant collector area and distance between tubes. Ho C D et al. [3] investigated the effect of double pass sheet and tube with internal fins under various arrayed densities (shown in figure 3). The result found that, collector efficiency increases with suitable designing and operating conditions.

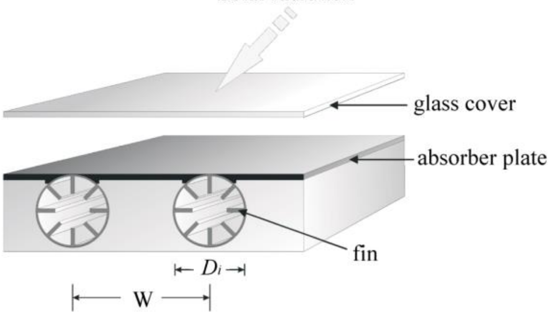

Fig. 3: Sheet-and-tube solar water heater with internal fins

Morrison et al. [4] developed a number of heat extraction methods from all glass evacuated tubes. It has found to be the most successful due to its simplicity in design and low manufacturing cost. Also the factors influencing the operation were discussed and present a numerical study of water circulation through long single-ended thermosyphon tubes.

B. Coatings of pipes

The chrome selective coating increases the performance and the coatings is economically sound investigated by Santamouris et al. [5]. Arif [6] found the, Solchrome solar selective coating fin and tubes; it is increase the thermal efficiency of the collectors by more than 30%, as against the use of black paint or any other coating. Tharamani et al. [7] develop the Cu–Ni alloy coating as a selective surface for solar thermal energy. Ehab [8] investigate the effects of electrolyte concentration and operating parameters on the appearance and studied the optical properties of the coating. Results showed that the coating surfaces had the high absorptance and low emittance rates. Tae June et al. [9] found a transparent glass heater material coated with single-walled carbon nanotube film. The heating systems have an optical transparency above 95% invisible light. Their performance was investigated by measuring the thermal resistance, heating and cooling characteristic. The stability and reliability of the heater were also investigated and the results showed that thermal energy was more efficient that ordinary paint coated surface.

C. Flow analysis in solar water heating systems

The details of experimental observations of temperature and flow distribution in a natural circulation solar water heating system presented by Chuawittayawuth et al. [10] and compare the experimental observation with the theoretical models. The values at the riser tubes near the collector inlet are observe much higher than the other risers on a clear day, while on cloudy days, these temperatures are uniform. The water temperature in the riser depends on its flow rate. Arvind et al. [11] obtained an analytical expression for the water temperature of an integrated photovoltaic thermal solar water heater under constant flow rate of hot water. It is observed that the daily overall thermal efficiency increases with increase constant flow rate and decrease with increase of constant collection temperature. Generally this type of thermal analysis is used to design the hot water systems based on flow rate and number of collectors.

D. Insertion of twisted tapes in solar water heating systems

The twisted tape enhances the heat transfer rate verified by Kumar and Prasad [12] in forced circulation mode for various twist ratios. Also it found that decreasing values of the twist- pitch to tube diameter ratio increase the values of heat transfer rate and the pressure drop as well. Smith et al. [13] studied experimentally by inserting the helical tape in the tube with a view to generate swirl flow which is helps to increase the heat transfer rate of the tube.

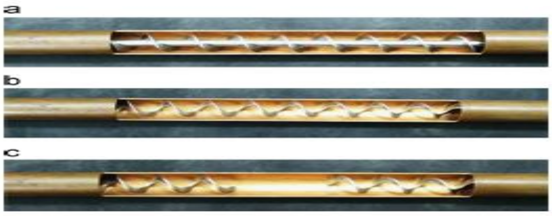

Fig. 4: Helical tape is inserted in the tube.

Kumar and Prasad [14] have developed and tested the modified solar water heater having twisted tape (artificial roughness) inserted inside the tubes along the plain one. The experiments for plain tube with/ without twisted tape insert at constant wall heat flux for different mass flow rates were carried out by Naga et al. [15]. From the experiment it is concluded that reduced width tape inserts is seen to be attractive for enhancing turbulent flow heat transfer in a horizontal circular tube and savings in pumping power and also in tape material cost. Paisarn et al. [16] presented the heat transfer characteristics and friction factor results of the horizontal double tubes with twisted wire brush insert. The effect of inlet fluid temperature, twisted wires density, and significant parameters on heat transfer characteristics and friction factor were considered. Due to the swirl flow, the convective heat transfer obtained to be higher for the plain tube with twisted wires brush insert than the plain tube without twisted wires brush. Dr. Akeel Abdullah [17] has found that by inserting the Conical- ring inside the flow tube with or without twisted tapes could be enhance heat transfer rate by increasing the pressure drop. It was observe that the heat transfer coefficient and friction factor increased with the decrease in twist ratio compared with plain tube. The tube having combined conical-ring and twisted tape insert gave higher heat transfer rates than that tube fitted with conical-ring alone (Figure 5).

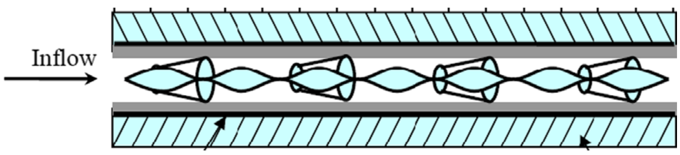

Fig. 5: Test tube fitted with conical-ring and twisted tape insert

E. Dual purpose solar collector [DPSC]

The DPSC is a flat plate collector which is made of two sections, one for water heating and the other for air heating. The basic design of a conventional solar flat plate collector consists of the tubes attached to the absorber plate through which the heated water flows. While in DPSC the conjunction of the air heater which consists of a same absorber plate with a sheet of metals in a V-shaped that is connected to the same absorber plate on the bottom side. This arrangement is shown in Figures.6a and 6b. Assari, M.R [18] designed and made the collector in a way that it can be used for heating the air and water simultaneously.

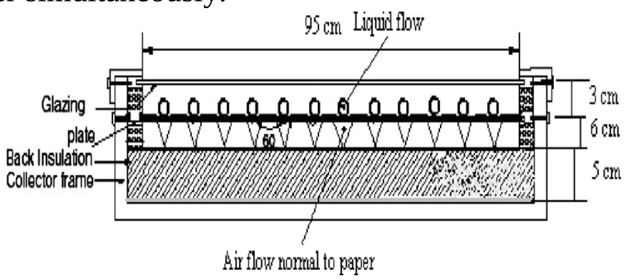

Fig. 6a: Detail configuration of DPSC.

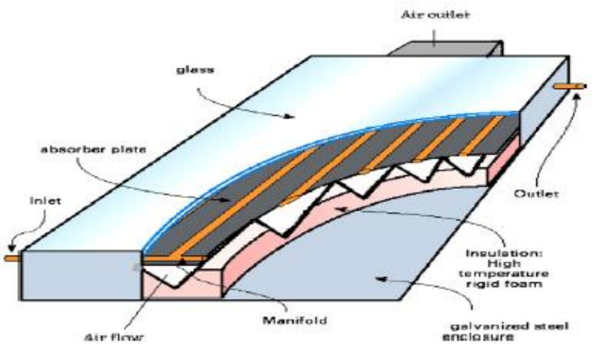

Fig. 6b: Schematic of DPSC

Experiment was carried on DPSC by Assari, M.R [19] Experimental data indicate that high temperature and high performance can be achieved using dual purpose solar collector (DPSC) compared to single water or air heating collector. In the collector water and air this two fluids flow simultaneously. Three different kinds of channels are used to enhance the performance of collector, such as: triangular fin, rectangular fin, and without fin.

Simulation result shown in figure 7. Without fin channel with increase of air flow rate, small changes are seen in heat exchange. In triangular fin channel, up to air flow rate of 0.06 kg/s values of heat exchange decreases slightly and then increases rapidly. In straight fin channel with the increase of air flow rate, values of heat exchange increases in a straight manner. The channels with rectangular fin have better performance compared with others, values of heat exchange effectiveness for straight (rectangular) fin are better than triangular fin. Hence, heat delivery in this situation is higher.

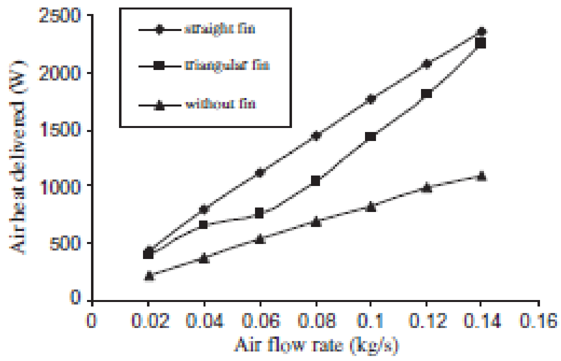

Fig. 7: Air heat delivery in various air flow rate and air channel.

The effect of water inlet temperature and air flow rate on heat delivery by air and water has been investigated. The result shows that with the increase of water inlet temperature, Heat delivery decreases and vice versa.

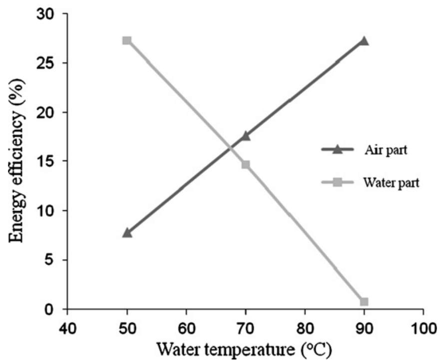

Fig. 8: Results of the performance of DPSC at various water and air inlet temperature.

Figure 8 represents results for the performance of DPSC in various water inlet temperatures and constant air inlet temperature. Overall efficiency of the system decreases with the increase of water inlet temperature and correspondingly the efficiency of air part increases. For the case of water inlet temperature of 90 ^{0}C, the efficiency of air part is up to 27.3%. This result is obtained for minimum air flow rate and can be increased with the increase of air flow rate. Thus, air section at higher water inlet temperature can absorb part of energy that water cannot deliver. Hence, with DPSC high temperature and high efficiency can be obtained

Drying process is of high importance in food industries. One of the best methods of food drying is using solar dryers. The DPSC is a hybrid system which facilitates a dryer system and provides consumptive hot water. The system designed and experiment carried by Alireza Mohajer et al. [20]. In this study, the same DPSC collector which was designed by Assari et al. was investigated to analyze its performance as a simultaneous solar dryer and solar water heater shown in figure 9.

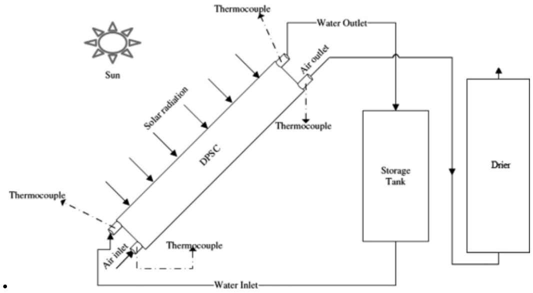

Fig. 9: Hybrid Solar Drier and Water Heater System

IV. CONCLUSION

The critical outcomes from this study are summarized below:

- The paper gives the view of the developments in the areas of technologies to improve the performance SWH and also to design a new system.
- The collector efficiency increases with, 1) Increase in thermal conductivity of absorber plate, 2) Increase in collector aspect ratio and distance between tubes, 3) Use of internal fins 4) Chrome selective coating on pipes 5) Solchrome solar selective on fin and tube 6) Increase in constant flow rate of water 7) Decrease in constant collection temperature 8) The use of twisted tape in tube.
- Because of more cost effective and simplicity, more number of research works must be initiated to analyze the performance of thermosyphon solar water heating system to improve better performance.
- The more study on DPSC is required in upcoming era.

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