Developments in the Field of Solar Water Heater using Flat Plate Collector - A Review

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Abstract— The development of sustainable energy services like the supply of heating water may face a trade-off with a comfortable quality of life, especially in the winter season where suitable strategies to deliver an effective service are required. Solar energy is becoming an alternative for the limited fossil fuel resources. One of the simplest and most direct applications of this energy is the conversion of solar radiation into heat, which can be used in water heating systems. A commonly used solar collector is the flat-plate. A lot of research has been conducted in order to analyze the flat-plate operation and improve its efficiency. This study investigates the heat transfer process as well as the thermal behavior of a flat plate collector evaluating different configurations of Tubes. Numbers of studies have been carried out on thermal performance of solar water heater and found more increase in the thermal efficiency in comparison to conventional solar water heater. These studies include use of double side absorber plate, honeycomb material, and more efficient coatings. The main objective of this research is to evaluate the performance of solar flat plate collector with tubing arrangement, through the construction, experimentation, theoretical formulation and its simulation of flow and heat transfer. This paper presents an extensive study of the research carried out on solar water heater. In the present study, both experimental and theoretical developments in the field of solar water heater have been reviewed.

Key words: Solar Flat Plate Collector, Heat Transfer Rate, Efficiency, Flow Rate, Outlet Temperature

I. Introduction

Nowadays, renewable energy is considered as the key to a sustainable energy future. It can have a beneficial impact on the environmental, economic, and political issues of the world. Fossil fuel price increase, climate change, adverse environmental impacts – in brief the respect of the Kyoto agreement – makes the exploration for a sustainable way to use energy more important than ever[1].The benefits arising from the installation and operation of renewable energy systems will be energy saving, generation of new working posts, and the decrease of environmental pollution. Solar energy may play an outstanding role to substitute non-renewable energy sources as it may also play an important prerequisite to enhance sustainable development [3]. Solar energy has always been a viable option for the energy problems faced by the world. Solar energy is the radiation resulted by nuclear fusion reactions in the sun. The 30% of the solar power actually reaches the Earth, every 20 minutes the sun produces enough power to supply the earth with its needs for an entire year. This solar radiation can be directly converted into heat. Many different kinds of equipment are available for this conversion. These can help lessen the impact of domestic sector on the environment. Flat plate collectors have been in service for a long time without any significant changes in their design and operational principles [2].

The performance of a solar flat plate collector system is influenced by the product configuration and the local meteorological conditions. Solar flat plate collector can operate as a solar pre-heater in series with a boost tank or as a single-tank system with a boost element incorporated in the solar tank..Solar water heating systems are very common systems, extensively used in many countries with good solar radiation potential, such as in the Mediterranean countries. Solar water heating systems are often viable to replace electricity and fossil fuels used for many home applications [4].In general in a Solar water heating systems, conventional solar flat plate collectors with a metal absorber plate and covers are used to transform solar energy into heat. In solar flat plate collectors, the incident solar radiation is converted into heat and transmitted to a transfer medium such as water [1].

The heat produced by solar collectors can supply energy demand directly or be stored. To match demand and production of energy, the thermal performance of the collector must be evaluated. The instantaneous useful energy collected is the result of an energy balance on the solar collector. The flat plate collector forms the heart of any solar energy collection system designed for operation in the low temperature range, from ambient to 60 °C, to ambient to 100 °C. A well-engineered flat plate collector delivers heat at a relatively low cost for a long duration. The term 'flat plate' is slightly misleading in the sense that surface may not be truly flat—it may be a combination of flat, grooved or of other shapes as the absorbing surface with some kind of heat removal device like tubes or channels. A flat-plate solar collector consists of a waterproof, metal or fiberglass insulated box containing a dark- colored absorber plate, with one or more translucent glazing. Absorber plates are typically made out of metal due to its high thermal conductivity and painted with special selective surface coatings in order to absorb and transfer heat better than regular black paint. The glazing covers reduce the convection and radiation heat losses to the environment. The collector gains energy when the solar radiation travels through the cover both beam and diffuse solar radiation are used during the production of heat.

The greater the transmittance (τ) of the glazing is, the more radiation reaches the absorber plate. Such energy is absorbed in a fraction equal to the absorbitivity (α) of the blackened-metal receiver. In general terms, solar collectors present great heat losses. Although the glazing does not allow infrared- thermal energy (long wavelength) to escape, the temperature difference between the absorber plate and the ambient causes heat losses by convection. A heat-conducting fluid, usually water, glycol, or air, passes through pipes attached to the absorber plate. As the fluid flows through the pipes, its temperature increases. This is the energy to be utilized for productive activities. The amount of the energy taken by the working fluid corresponds to a fraction of the useful energy collected after the heat losses. The instantaneous thermal efficiency corresponds to the fraction from the incoming solar radiation that is actually recovered to be used.Objective of this paper is to presents extensive studies of the research carried out on solar water heater and in this paper both experimental and theoretical developments in the field of solar water heater have been reviewed thoroughly.

II. KEY DEVELOPMENTS IN THE FIELD OF SOLAR FLAT PLATE WATER HEATER

Considering the energy crisis that we find ourselves in these days due to our heavy dependence on fossil fuels, finding alternate ways to provide necessary energy for our expanding society has become crucial to our future generations. With research and public awareness, harnessing solar radiation in locations such as Western India is starting to be regarded as a reliable source of energy and is also becoming a well-supported alternative to fossil fuels for our energy needs. In central Europe, approximately 90% of solar collectors are of the flat plate variety. Only with inspiring curiosity in and promoting education about solar energy, will the widespread implementation of this energy source become a reality [12].The current study is in family with prior researchers including the Alarez et al. (2010), Rodriguez-Hidalgo et al. (2011), Rojas et al. (2008) and Thirugnanasambandam et al. (2010). Comprehensive reviews on solar collectors are given by Kalogirou (2004) while Andersen and Furbo (2009) provide theoretical correlations for solar collectors. A flat plate collector can operate with different heat transfer fluids depending on the application and temperature ranges needed. A concentration of propylene glycol can be used when the environment is known to be colder and the solar collector does not have high exposure to the sun whereas in sunnier places, regular water may be used. Choosing the correct heat transfer fluids and tubing profile is very important because its properties, such as its specific heat Cp, help determine the amount of energy that can be absorbed and transferred to the nearby storage tank in a set amount of time. This amount of useable energy Qu is directly proportional to the difference in temperature and can therefore be calculated by recording the inlet temperature, outlet temperature, and mass flow rate of the heat transfer fluids via the relationship

$$Q_u = mC_p(T_{fo} - T_{fi})$$

Where; T_{fi} denotes the inlet temperature, and T_{fo} denotes the outlet temperature. The useable energy can also be used to find the efficiency of the flat plate collector. There are various efficiencies that can be used to describe a solar collector's performance although some are more descriptive than others. The collector's instantaneous efficiency is inversely proportional to solar irradiation and collector aperture area and will therefore vary over the course of the day. This data would be insufficient in describing the collector and therefore data must be taken throughout the course of a given time in order to take the average efficiency. The following equation describes the relationship mentioned above between useful energy, solar isolation Ic. and aperture area Ac

$$\eta c = Qu/Ic * Ac$$

As the heat transfer fluids flows through the manifold of the flat plate collector, it absorbs energy through conduction and radiation due to the solar irradiation acting incident on the collectors' absorber plate. It then flows into a storage tank that will be used to heat up potable water. This is achieved by using a submerged heat exchanger. The submerged heat exchanger is composed of copper tubing that is wrapped around the storage tank's interior wall. As the fluid enters the submerged heat exchanger, it transfers heat into the storage water as it flows through the coil and exits at a lower temperature. The cooled water will recalculate through a closed loop and the cycle will repeat throughout the day. This process is shown in the Figure 1 below.

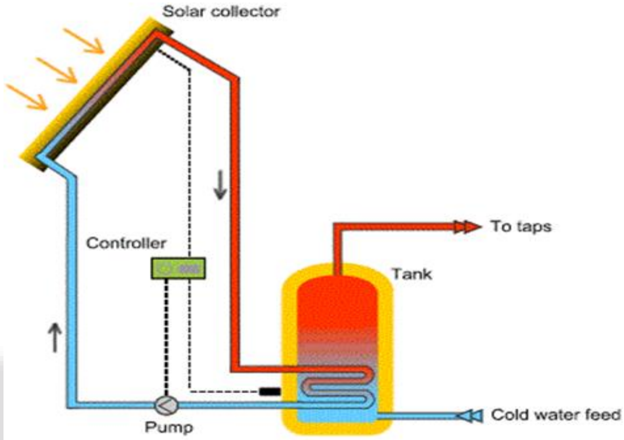

Fig. 1: Depiction of flow process in a closed-loop solar collector system.

Note that the temperature in the storage tank will not be uniform due to the convective cell phenomena. Because of the placement of the submerged heat exchanger, the water will tend to heat up on the bottom of the storage tank first. Recall that as the temperature of water increases, its density will decrease. Therefore, the heated water will tend to flow upwards resulting in a temperature gradient within the storage tank thereby creating a convective cell. This phenomenon also occurs in the air space between the glass cover and absorber plate of the flat plate collector itself, though the temperature gradients caused by it are negligible due to the dominating and highly non-linear nature of radiation acting incident on the absorber plate. In order to maximize the efficiency of the flat plate collector, it must be oriented so that it receives the most sunlight possible, especially since flat plate collector is typically in a fixed position. Due to the Earth's orbit around its own axis, which affects the suns angle with the Earth (also known as the declination angle), the ideal orientation will change according to the geographical location on the Earth. According to Stine and Geyer (1979), this ideal orientation is found to be the latitudinal angle in which it is placed [12].

III. RESULTS AND DISCUSSION

S.N.	Development	Conventional	Effect Of Advancement	Referance

1.	T The collector is of sandwich type. The absorber is made of 2 sheets of GI (1mm) with integrated canals, painted in silica based black paint	A simple flat plate collector consists of an absorber plate in an insulated box covered with transparent sheets.	Efficiency of the new collector is 20.19 that of Efficiency of the flat plate is 24.17%.	Raj Thundil Karuppa, Pavan P. and Reddy. [2]
2	Double side absorber with low emissivity and high reflectance.	Single side absorber plate.	Heat loss 30-70% Lower than conventional system.	N.Groenhout, M. Behnia.[14]
3	Results are presented for the testing of a flat plate solar thermal collector.	The results of the performance testing and characterization of a solar flat plate collector presented herein.	The thermal performance curve is used to determine the air-collector heat removal factor of the device. These results afford a pragmatic baseline for other researchers seeking to benchmark the performance of their solar collectors.	K.R. Anderson, S. Hill, C. Selerberg, E. Guiterez[12]
4	It It is accomplished by employing an alluminnium sheet placed at the base within the system to induce a gradient of heat capacitance.	Domestic V- Through flat plat collector system with a capacity of 100 litters per day.	The experimental result has shown very promising results in both optical efficiency of V-trough reflector and the overall thermal performance of the solar water heater.	Sanjay Kumar Sharma, Dheeraj Joshi.
5	T To test the enhanced solar collector and compare with a standard one, an experimental side-by-side solar collector test bed was designed and constructed.	Enhancement techniques can be applied to flat-plate liquid solar collectors towards more compact and efficient designs.	An experimental side-by-side solar collector test bed was designed and constructed to characterize the thermo-hydraulic behavior of a standard and an enhanced solar collector.	R. Herrero Martín, A. García Pinar , J. Pérez García[19]
6	This paper discuss improving the performance of a flat plate solar energy collector by changing the design parameters of the number of riser tubes and the arrangement of riser tubes in zig-zag pattern.	The existing flat plat collector system	The performance shows that the efficiency is 59.09% when increasing the number of riser tubes and its 62.90% in the zig-zag arrangement of the riser tube	P. Sivakumar, W. Christraj, M. Sridharan and N. Jayamalathi [21]

Table 1: Comparison between developed and conventional FPC (Experimental studies)

Sr.No.	Advancement	Effect Of Advancement	Referance
1.	Increase the Absorptance from 0.95 to 0.97and Decrease in emittance from 0.10 to 0.05	Increase the efficiency apto 6.7%	B. Hellstrom, M. Adsten .[15]
2.	Tube-on-sheet Solar panel with wire coil inserts using TRNSYS simulating tool.	Enhance in thermal efficiency can be possible upto 4.5%	R. H. Martin, J. Perez-Garcia, A. Garcia, F.J. Garcia-Soto, E. Lopez-Galiana. [16]
3.	Indirect force circulation systems using TRNSYS simulation program.	System can provide 83-97% and 30-67% of the hot water demand in summer and winter respectively.	A. Hobbi, K. Siddiqui. [18]
4.	The experimental setup consisted of a commercially available forced circulation domestic scale system fitted with an automated sub-system that controlled hot water draw-offs and the operation of an auxiliary immersion heater	Annual average solar fraction, collector efficiency and system efficiency were 32.2%, 45.6% and 37.8% respectively.The maximum recorded collector fluid outlet temperature was 70.4ºC while the maximum recorded water temperature at the bottom of the hot water tank was 59.9 ºC.	L.M.Ayompe,A.Duffy[22]
5.	Influence Of tube and sheet aspect ratio on the collector.	Collector efficiency increase with increasing collector aspect ratio.	H.M. Yeh, C.D. Ho, C.W. Yeh [17]
6.	A 3D thermo-hydrodynamic model describing the behavior of the heat transfer fluid in a storage tank is introduced considering the continuity, momentum and energy equations,	A good agreement of the numerical results compared with experimental measurements for a new flat-plate, sandwich-like solar collector is obtained	A. Álvarez1, M. Baz, O. Cabeza, J.L. Ferrín, M.C. Muñiz and L.M. Varela. [20]

	complemented with a standard k-ε turbulence model and using the commercial code Fluent to perform the numerical simulations.		

Table 2: Theoretical development and their results

IV. CONCLUSIONS

Based on the review of the literature on solar water heater, it has been found that solar water heater was Widely investigated both analytically and experimentally. A number of studies have been carried out in order to investigate the effect of various parameters on the performance of solar water heater. Several promising advancement are taking place in the field of solar water heating system using flat plate collector. It is quite evident that by improving in solar water heaters it can be used when conditions are not favorable. Optimization of operating parameters like orientation, fluid flow rate can also increase the efficiency and it can be applied to conventional Flat Plate Collector. The information presented here will be beneficial for beginners in this area of research

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