International Journal of Research in Advent Technology, Special Issue, December 2018
International Conference on Mechanical and Civil Engineering (ICOMACE-2018)
E-ISSN: 2321-9637
Available online at www.ijrat.org

Design and Analysis of a Flat Plate Solar Collector

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Abstract- Renewable energy is accepted as a key source for the future, not only for Saudi Arabia, but also for the world. Saudi Arabia has abundant potential for exploiting solar energy, which is renewable, clean, and freely available. The average annual solar radiation falling on the Arabian Peninsula is about 7900 MJ/m2. The utilization of solar energy could cover a significant part of the energy demand in the country. If a major breakthrough is achieved in the field of solar-energy conversion, Saudi Arabia can be a leading producer and exporter of solar energy in the form of electricity. The geographical location of the country, its widespread unused desert land, and year-round clear skies, all make it an excellent place of study for research.Flat-plate collectors are in wide use for domestic household hot-water heating and for space heating, where the demand temperature is low. Many excellent models of flat-plate collectors are available commercially to the solar designer. A real time application of flat-plate collectors is included here because of its use in house-hold heating systems either to supply low-temperature demands or to preheat the heat transfer fluid before entering a field of higher-temperature concentrating, collectors.The emphasis of this work is to develop an understanding of both the attributes of different design features and the performance characteristics of this class of collector (Flat Plate). The results will permit the system designer to evaluate whether flat-plate collectors should be considered in a system design.The assembly is done by combining the frames, the glass cover, the tubes and flow controls and the temperature controls as a single unit fabricated as designed. The position of collector face is due south and it is tilted above the ground surface with reference to its latitude. Cold water tank and hot water tank are placed separately with proper insulation to pipes and tank of hot water to avoid heat transfer losses during night time and a valve is used to avoid reverse flow of water from cold tank to hot tank. Efficiency is calculated using the relations available and the system is modelled in a commercial package to find the temperature relations and other parameters.

Keywords- Solar Collector, Performance, Design and Analysis.

1. INTRODUCTION

1.1 Solar Water Heating (Hot water supply system):

The basic elements of a solar water heater are

(i) Flat Plate Collector
(ii) Storage tanks
(iii) Circulation system and auxiliary heating systems
(iv) Control of the system

The use of solar energy for heating water in many respects quits similar to its use for heating buildings. There are however, several aspects of solar water heating,that make it potentially better investment of energy, money and effort than solar building heating. The demand for hot water is relatively constant throughout the year.

Thus the collector and the other parts of the solar water heater will be working harder and longer to produce the savings in fuel that eventually must pay for higher initial cost of the system. The solar building heating system on the other hand, fully operational only during the coldest months of the heating seasons.

The simplest type of solar water heater is that working on thermo-siphon system. Some typically designs of solar water heaters are:

(a) Natural Circulation solar water heater (Pressurized)
(b) Natural Circulation solar water heater (Non-Pressurized)
(c) Forced Circulation solar water heater

2. LITERATURE SURVEY

Rajesh, Chaurasiya [4] gave brief insight on various techniques used to analyse the effects and various designs has also been presented with the development methodology. Some analytical studies and CFD models have also been mentioned which can be carried out in the direction of heat transfer from solar flat plate collectors. D Gunjo, Mahanta [5] observed that the thermal efficiency of the solar water heating system increases with ambient temperature, solar insolation, and mass flow rate of water. However, thermal efficiency decreases as inlet water temperature increases. Numerical simulations were carried out using a 3-dimensional computational fluid dynamics (CFD) to predict the outlet water and absorber plate temperatures using the experimental values of solar insolation, ambient temperature and inlet water temperature within one hour interval. The CFD results were validated with the experimental result ZSheng [7] In their study used Cu–H2O nanofluids with different mass fraction and size were prepared through two-step method. Its thermal conductivities and the effect of Cu–H2O nanofluids on the efficiency of a flat-plate solar collector was investigated experimentally.

3. DESCRIPTION

The present work is based on the design of the naturally circulated solar water heater. It consists of a collector facing South, with transparent cover Glass, two separate highly insulated water storage tanks and well insulated pipes connecting the two tanks. There is no auxiliary energy required to circulate the water through it. Circulation occurs through the natural convection or the thermo-siphoning action. i.e as the water is heated in its passage through the collector,its density decreases and hence it raises and flows into the top of the storage tank(Hot water tank), Colder water from the bottom of the tank has a higher density and so tends to sink and enter the lower heater of the collector for further heating. The density difference between the hot water and cold water thus provides the driving force (Convection) for the circulation of the water through the collector and the storage tank. Hot water is drawn off from the top of the tank as required and is replaced by the cold water from the service system. As long as the sun shines the water will quietly circulate, getting warmer. After sunset, a thermo-siphon system can reverse its flo direction and loss heat to the environment during the night. To avoid reverse flow, the top heater of the absorber is kept above 0.3 to 0.5 meter below the cold leg fitting on the storage tank. To Provide heat during long, cloudy periods and electrical immersion heater can be used as a backup for the system. A non freezing fluid may be used in the collector circuit like Ethelene Glycol. The Thermo-siphon system is one of the least expensive solar hot-water systems and can be used whenever desired. Thermosiphon systems are passive and do not require a mechanical pump to circulate the water. Such heaters can be used in rural areas, where electricity is not available and there is a little danger of freezing.

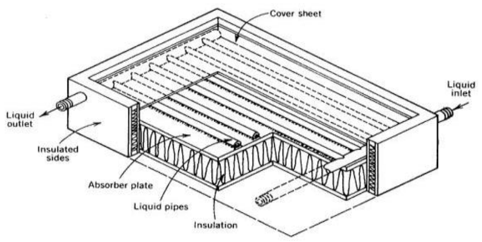

Fig.1 Cross Sectional View of a Flat Plate Solar Collector

The Energy balance equation on the whole collector can be written as:

$$A_c\,[\,H.R\,(\tau.\,\alpha)_b - H.R\,(\tau.\,\alpha)_d] = Q_u+Q_l+Q_s$$

Q_l = Rate of energy loss from the collector to the surrounding by re-radiation, convection and by conduction through supports for the absorber plate and so on.

Q_s= rate of energy stored in the collector. Collector efficiency η_C is the performance of the collector and is defined as the ratio of useful gain over any time period to incident solar energy over the same period.

The Performance of the flat plate solar collector is the ratio of the amount of heat transferred from absorber through convection to water and the solar radiation intensity considering radiation on the reference surface.

= Useful energy to water, = Factor F_R x (Stored energy – Convection Loss to water)

$$Q_u = mC_p(\,T_{fo}- T_{fi}) = A_cF_R[\,S- U_L(T_{fi}- T_a]\qquad \text{Eq.(2)}$$

Efficiency of Flat-Plate Collector, η = Eq.(1)

Where

F_R =Heat removal factor = Eq(3)

and we can take G = /

m is the amount of water and A_c is the area of the collector, The Stored energy due to beam radiation intensity per unit length is given as ‘S’ = H_bR_b<τ. α>, where <τ. α> is the transmissivity absorptivity product. H_b = beam radiation intensity depending on the Global radiation at various latitudes, R_b= Beam incident factor depends on position of collector.

The Variation of collector efficiency for various flow rates and surface fluxes is shown below

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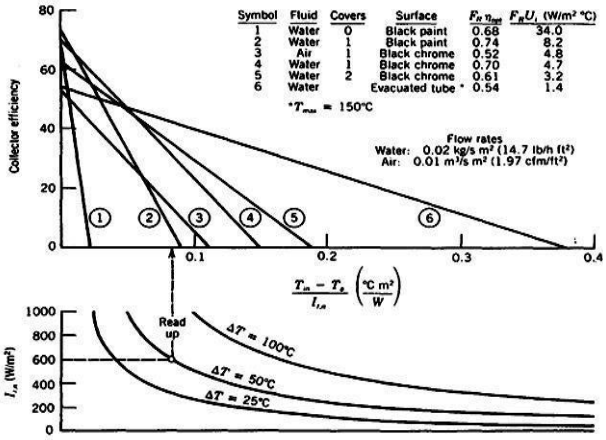


Fig.2 Variation of Collector Efficiency, Surface fluxes with flow rates

4.1 Long-term daily mean values of sunshine duration and Global Solar Radiation:

City	Lat (Deg.)	Lon (Deg.)	Alt (m)	Sun light (Hrs)	Global Solar Radiation W/ m^2
Riyadh	24.57	46.72	564	9.2	5,123
Shaqra	25.25	45.25	730	9.2	6,055
Dawdami	24.48	44.37	0	8.8	5,945

4. FLAT PLATE COLLECTOR DESIGN

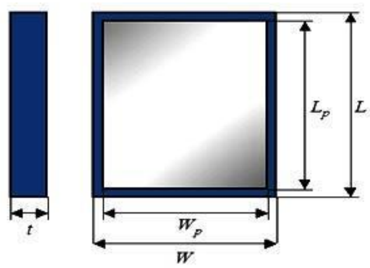
Design and Fabrication process of the proposed flat plate collector is shown below:

Fig. 3 Flat Plate Solar Collector Assembly

Fig.4 Frame for Absorber/tubes assembly

Fig. 6 Cu tubes fabricated and assembled in the Collector frame.

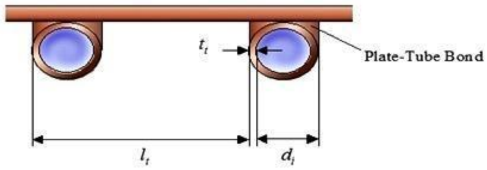
Collector Dimensions:



Overall Dimensions	Length	L	0.8	[m]
	Width	W	0.4	[m]
	Thickness	t	0.1	[m]
Absorber Dimensions	Length	L_p	0.5	[m]
	Width	W_p	0.25	[m]

Fig. 7 Collector specifications in the Solver Tubes and Fluid:

Fig. 5 Flat plate Collector panel

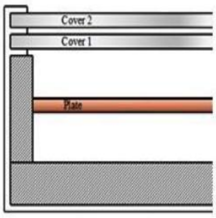


Tube	Number of Tubes	N_t	7
	Inner Diameter	d_i	1.6 [cm]
	Outer Diameter	d_o	1.8 [cm]
	Tube-to-tube spacing	l_t	????
Fluid	Material		Water
	Percent Composition*		50 [%]
	Volumetric flow rate	$\dot{V}$	5 [L/min]
	Inlet pressure	P_{in}	1.013 [kPa]
Plate-tube bond conductance		k_b	250 [W/m-K]

*for propylene glycol and ethylene-glycol solutions

Fig.8 Tubes and Fluid Data in the solver

Cover and Plate:



Number of covers			N_{cov}	1
Cover 2	Cover Material			Glass
	Properties of cover material			
	Solar spectrum	Refractive index	n	1.526
		Transmittance	$\tau_{c,s}$	0.891
	Long-wave	Absorptance	ε_c	0.88
		Transmittance	$\tau_{c,IR}$	0
Cover 1	Cover Material			Glass
	Properties of cover material			
	Solar spectrum	Refractive index	n	1.526
		Transmittance	$\tau_{c,s}$	0.891
	Long-wave	Absorptance	ε_c	0.88
		Transmittance	$\tau_{c,IR}$	0
Cover-plate air spacing			d_{cp}	1.8 [cm]
Cover 1 - cover 2 air spacing			d_{c1c2}	0.5 [cm]
Plate	Plate Material			Copper
	User-defined Conductivity		k_{pl}	380 [W/m-K]
	Thickness		t_p	0.02 [cm]
	Solar spectrum	Absorptance	α_n	0.88
	Long-wave	Emittance	ε_{pl}	0.15

Fig.9 Glass specifications

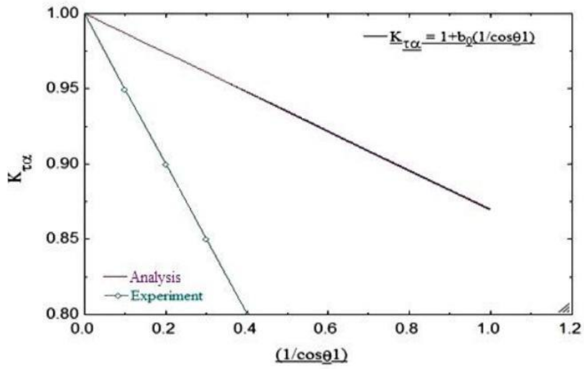
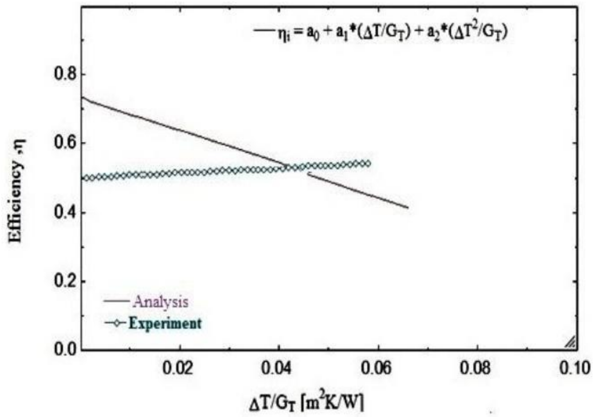


Fig.10 Variation of the Incident energy with the Loss coefficient Instantaneous efficiency of the Collector:

Test Conditions:

- **Incident Solar Radiation :** $G_T = \boxed{5945}$ [W/m^2]
- **Diffuse Radiation Proportion :** $G_d/G_T = \boxed{15}$ [%]
- **Incident Angle of Beam Radiation :** $\theta = \boxed{40}$ [deg]
- **Collector Slope :** $\beta = \boxed{15}$ [deg]
- **Ambient Temperature :** $T_{amb} = \boxed{21}$ [C]
- **Wind Speed :** $V_{wind} = \boxed{5}$ [m/s]
- **Relative Humidity :** $R = \boxed{55}$ [%]
- **Efficiency curves based on temperature difference :** $T_i - T_a$



5. RESULTS AND DISCUSSIONS

The stored energy due to direct solar radiation through sun, with the beam intensity is 'S' = $H_bR_b\langle\tau.\ \alpha\rangle$
H_b = 660 w/m^{2}hr; Rb= 1.25 (for this collector position); $\langle\tau.\ \alpha\rangle$ = 0.9
S = 742.5 W/m^2
Useful gain $Q_u = F_R\ [S - U_L\ (T_{fi} - T_{fo})]$
F_R = Heat removal factor = 0.65 (approximately),
U_L = 6.8 W/m^2 C; T_{fi} = 20,22,23,24,25
T_{fo} = 45, 50,55,60,63.
Q_u = 430 W/m^2
69%, 72%, 66%, 54% [approximately for different values of i/o]

The experimental and analytical results obtained is now compared with the data obtained from the design solver. The design is done as per the dimensions of the collector in a solver. The variation of the efficiencies with the flow rates, temperature flux, incident angles etc can be visualized in the graphs obtained in the solver.

Efficiency of the Collector, $\eta = \underline{\qquad} = \frac{430}{660\ \ 1.25} = 52\%$,

Fig.11 Instantaneous efficiency vs Temperature Flux The results shows a good deal between the calculated values of the collector efficiency and the values obtained from the solver program, which shows the actual variation of efficiency with the temperature flux.

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