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Thermal Analysis of a Solar Flat Plate Collector

M. R. RAGHUNATH[1], Mr.N.SRINIVASA RAJNEESH[2], G.VINOD KUMAR[3]
[1]*Student, M.Tech – Thermal Engineering, MREC (Autonomous) - Hyderabad, Telangana.*
[2]*Associate Professor, Mechanical Engineering Dep.t, MREC(Autonomous) - Hyderabad, Telangana.*
[3]*Assistant Professor, Mechanical Engineering Department, KITS, Warangal, Telangana.*
Corresponding Author[1]: raghunath.hyd@gmail.com

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ABSTRACT: In present world as the natural resources are depleting focus is towards the alternate energy sources and Solar Energy being the most promising resource. The solar collector is a device which absorbs solar energy and converts it to useful form of energy i.e. thermal energy by means of heat transfer fluids (water or air). Solar flat plate collector is simple, cheap and most widely used for various applications such as textile industries, agricultural, desalination and space heating. This paper aims at presenting the thermal analysis of a Solar Flat Plate Collector. Performance analysis includes Energy and Exergy analysis of collector. The performance of solar collectors depends on many factors such as working fluid, ambient temperature & temperature of fluid, mass flow rate, solar irradiation etc.

KEYWORDS: Solar Energy, Solar Collectors, Performance of SFPC, Exergy Analysis

I. INTRODUCTION

The increase in depletion of energy resources required for generation of energy and a drastic increase in demand for energy gives rise to the global revolution for Renewable Energy (RE) production. The energy obtained from Sunlight, Geothermal, Tidal, Wind, Heat etc… constitute resources for Renewable Energy. These forms of Energy are renewable and may last forever/longer periods.

1.1 RENEWABLE ENERGY (RE)

RE is the source which exists naturally, like Energy from solar, wind, geothermal and hydroelectric. Energy from biomass is also classified under renewable.

1.2 SOLAR ENERGY

The energy obtained from the sun is called Solar energy. Through a process termed as thermonuclear process the sun produces its energy. In this process heat and electromagnetic radiation is generated which is utilized further for power generation.

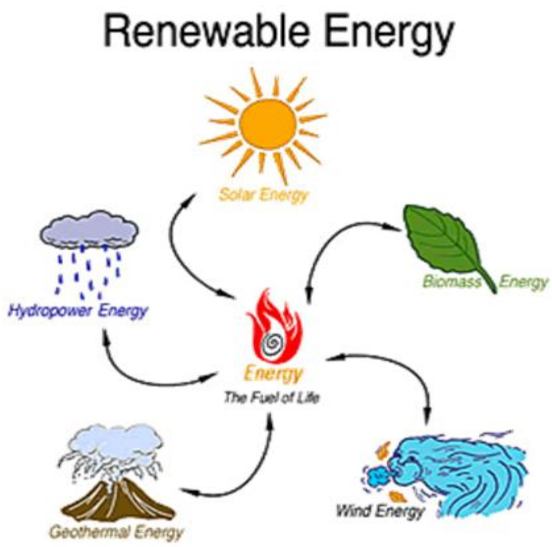

Figure 1.1: RE Sources

Solar Heating, Solar Photovoltaic Cells, Solar thermal electricity, Solar Architecture and Artificial Photosynthesis are a range of technologies which have evolved by harnessing Solar energy.

Mainly the power obtained from the sun is defined as converting sunlight into heat/electricity. The devices used for conversion are known as Solar Collectors. The solar collectors are very much helpful for trapping of solar energy and converting the particular energy into the required energies such as heat energy or thermal energy. Various devices are designed which works with the help of solar energy. They include solar heaters, re-feed generators, solar cookers, solar air conditioners, solar lights, solar vehicles etc.. The solar flat plate collector is an important equipment majorly utilized for trapping solar energy.

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1.3 SOLAR FLAT PLATE COLLECTOR (SFPC):

Flat plate collectors absorb both direct and diffuse solar radiation and convert it in to useful energy. SFPC's are mostly utilized for water/space heating, power production etc.

The components of SFPC's are absorber plate, glazing sheets and pipes for heating. The pipes & absorber plates are coated with high absorptive material through which the fluid flowing through them gains the heat. The flow of fluid may be either by natural or forced circulation through the collector pipes. SFPC's are mainly classified on medium of heat transfer viz; Liquid heaters and Air heaters.

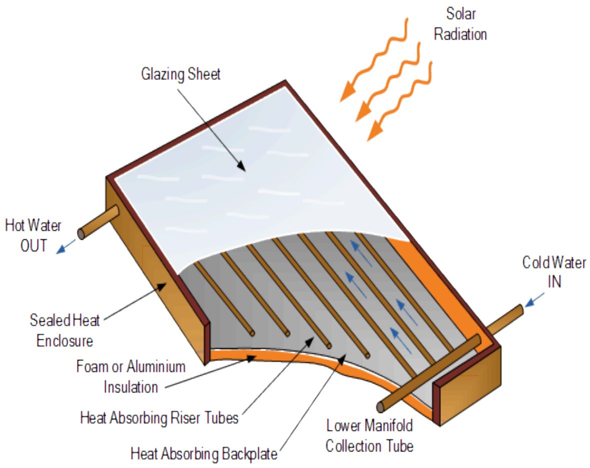

Figure 1.2: Solar flat plate collector

II. INVESTIGATIONS

The experimental investigations include the study of the apparatus used. The Solar Collector consists of the below components:

1. SFPC
2. Inlet and outlet ducts
3. Blower at inlet
4. Anemometer
5. Fluid Regulator (Mass flow)
6. Thermocouples

2.1 INSTALLATION OF THE SETUP

Finally the setup is installed at an inclination of 18^o due North and the plate is installed at an inclination of 24.5^o with the horizontal. The device used for setting the direction is the magnetometer. The 18^o is meant for the latitude. The latitude of Warangal is 18^o.

III. EXPERIMENTATION

The main objective here is to determine the useful energy delivered, energy efficiency, useful exergy & exergy efficiency for a constant input of solar radiation.

The experiments are conducted for thermal analysis of SFPC with different working fluids.

3.1 EXPERIMENT ON SFPC WITH WATER

In this, the experiment is carried on simple flat plate collector. Water is allowed to flow through the collector from an overhead tank and comes out of the collector due to natural convection process. The inlet and outlet temperatures are recorded w.r.t time as furnished in table-1

S NO.	TIME	Inlet Fluid temp. T_1 ^{0} C	Outlet Fluid temp. T_2 ^{0} C
1	10:30	30.00	69.80
2	11:00	31.00	75.50
3	11:30	33.00	79.00
4	12:00	34.00	85.40
5	12:30	35.00	90.00
6	1:00	35.00	87.80
7	1:30	36.00	87.20
8	2:00	37.00	85.63
9	2:30	36.00	83.50
10	3:00	35.00	76.60
11	3:30	35.00	73.20
12	4:00	34.00	65.20
13	4:30	34.00	62.30

Table-1 Temperature recordings w.r.t time for SFPC with water as working fluid

IV. THEORITICAL ANALYSIS

4.1 ENERGY ANALYSIS

The rate of useful energy extracted by the collector (Q_u) is expressed as collectors heat extraction rate (or) it may also be measured by means of the amount of heat carried away by the fluid passing through Solar Collector.

$$Q_u = \dot{m}\, C_p\, (T_2 - T_1) \text{ Watts}$$

The performance (η) of Flat plate collector is defined as ratio of useful energy gain (Q_u) to that of solar energy incident over flat plat collector.

$$\eta = \frac{\dot{m}C_p\,(T_2 - T_1)}{I_t * A_c}$$

4.2 ANALYSIS OF EXERGY

In a specific environment at a given state from a system, the maximum useful work that is obtainable is defined as Exergy. In Using exergy analysis to determine solar energy system performance, calculation of exergy of solar radiation and maximum work produceable are two important factors.

Exergy of solar radiation

$\psi_{sr,\,max} = 1 + \frac{1}{3}(\frac{Ta}{Ts})^4 - (\frac{4}{3}\frac{Ta}{Ts})$

Where
Ts = Solar radiation temperature is taken as 5273K in exergetic evaluation of a solar flat plat collector

Exergy of solar collector
$Ex_{s,col} = I_t * A_C * \psi_{sr,max}$ Watts

Useful Exergy (Ex_u)

$Exu = m' Cp[(T_2 - T_1) - Ta\left(Ln\frac{T_2}{T_1}\right)]$

The solar collectors instantaneous exergy efficiency ($\varepsilon_{s,col}$) is defined as ratio of the increased water exergy to that of the solar radiation exergy (or) is also defined as ratio of useful delivered exergy (Ex_u) to that of absorbed exergy by solar collector ($Ex_{s,col}$).

Solar collectors Exergy efficiency ($\varepsilon_{s,col}$) $= \frac{Ex\,u}{Ex\,s,col}$

V. EXPERIMENTAL RESULTS AND DISCUSSIONS

Experiments are conducted for thermal analysis of SFPC with different working fluids and output parameters viz. Useful energy delivered, energy efficiency, useful exergy & exergy efficiency are determined for a constant input of solar radiation and time.

Considerations for experimentation:
- solar radiation temperature Ts (K)= 5273
- $\psi_{sr,max}$ = 0.92

5.1 Performance Analysis on Simple SFPC with water

S.No	TIME	T1 (^{0} C)	T2 (^{0} C)	m' (kg/sec)	Intensity (W/m^2)	Ambient Temp Ta (K)	$Ex_{s,col}$ (W)	Ex_{uww} (W)	$\varepsilon_{s,col}$ (%)	$Q_{u,ww}$ (W)	η_{ww} (%)
1	10:30	30.00	69.80	0.00576	761	303.00	1405.44	7.35	0.52	958.26	62.96
2	11:00	31.00	75.50	0.00576	866	304.00	1598.82	7.39	0.46	1071.42	61.86
3	11:30	33.00	79.00	0.00576	920	306.00	1698.37	7.44	0.44	1107.53	60.17
4	12:00	34.00	85.40	0.00576	1018	307.00	1877.77	7.48	0.40	1237.55	60.79
5	12:30	35.00	90.00	0.00576	1021	308.00	1882.20	7.52	0.40	1324.22	64.88
6	1:00	35.00	87.80	0.00576	1010	308.00	1862.02	7.51	0.40	1271.26	62.96
7	1:30	36.00	87.20	0.00576	995	309.00	1834.72	7.53	0.41	1232.73	61.94
8	2:00	37.00	85.63	0.00576	973	310.00	1793.48	7.55	0.42	1170.85	60.17
9	2:30	36.00	83.50	0.00576	941	309.00	1735.16	7.52	0.43	1143.65	60.76
10	3:00	35.00	76.60	0.00576	896	308.00	1651.81	7.48	0.45	1001.59	55.91
11	3:30	35.00	73.20	0.00576	830	308.00	1530.99	7.47	0.49	919.73	55.40
12	4:00	34.00	65.20	0.00576	733	307.00	1351.60	7.43	0.55	751.20	51.26
13	4:30	34.00	62.30	0.00576	580	307.00	1070.03	7.42	0.69	681.37	58.73

Table- 6.1 Energy Efficiency & Exergy Efficiency of Simple SFPC with water

Comparative statements of the output parameters obtained from the experimentation data are represented hereunder:

5.2 Intensity Vs Useful Energy for both the working fluids.

The table-2 shown below gives the energy gained by the working fluids at different intensities of solar radiation

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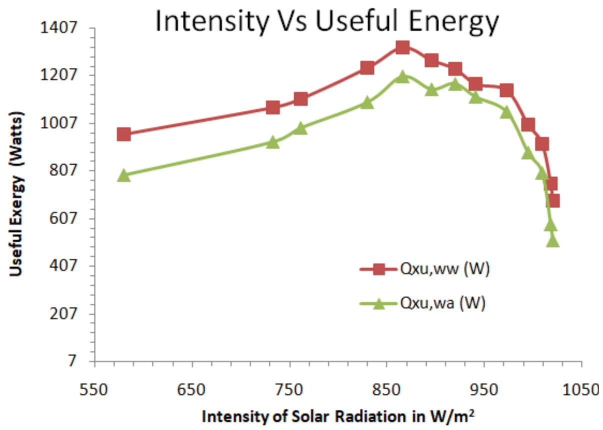
S.No	Intensity (W/m^2)	Qu,ww (W)	Qu,wa (W)
1.	580	958.26	789.72
2.	733	1071.42	926.96
3.	761	1107.53	987.15
4.	830	1237.55	1093.09
5.	866	1324.22	1203.84
6.	896	1271.26	1150.87
7.	920	1232.73	1172.54
8.	941	1170.85	1115.48
9.	973	1143.65	1052.16
10.	995	1001.59	881.21
11.	1010	919.73	799.35
12.	1018	751.20	582.66
13.	1021	681.37	512.84

Table - 2 Intensity Vs Useful Energy for Water and Air

The graph-1 shown below gives the comparison of energy gained between water and air for different intensities of solar radiation.

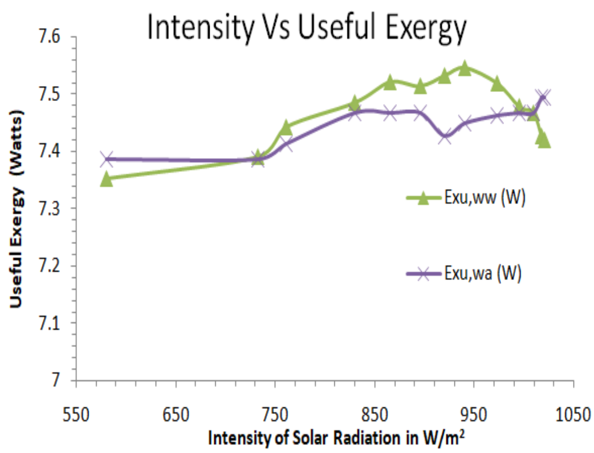


Graph- 1 Intensity Vs Useful Energy for Water and Air

From the above table-2 & graph-1 the maximum useful energy gain for both the working fluids is at an intensity of 866 W/m^2.

Similarly the other output parameters like useful exergy, energy efficiency and exergy efficiency are also evaluated for working fluids at different intensities of solar radiation and presented in the form of graphs below

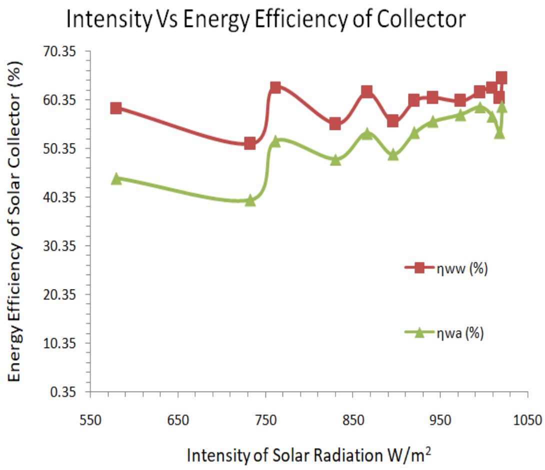
5.3 Intensity Vs Useful Exergy for both the working fluids.



Graph-2 Intensity Vs Useful Exergy for Water and Air

From the above graph-2 maximum useful exergy for water is at an intensity of $941W/m^2$ and for air it is at an intensity of $1021W/m^2$.

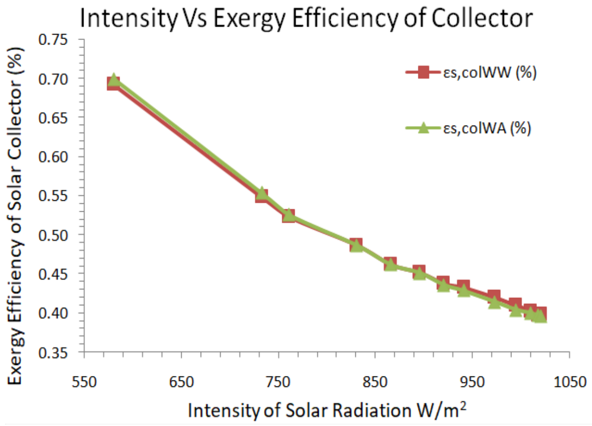
5.4 Intensity Vs Energy Efficiency of Collector



Graph-3 Intensity Vs Energy Efficiency for Water and Air

From the above graph-3 the path traced by both the fluids is observed to be same and the maximum efficiency of SFPC with air and water is observed at $1021W/m^2$.

5.5 Intensity Vs Exergy Efficiency of Collector



Graph-4 Intensity Vs Exergy Efficiency for Water and Air

The Graph-4 reveals that the System (SFPC) efficiency at any intensity is nearly same for both the fluids.

VI. CONCLUSIONS

- The performance of flat plate collector is evaluated using thermal analysis which includes energy analysis and exergy analysis. From the energy analysis we can conclude the maximum useful energy and energy efficiency of SFPC. From the exergy analysis the maximum energy that can be extractable can be concluded.
- From energy and exergy analysis, the exergy analysis plays a significant role. It explains the possibility of extracting maximum possible energy from unavailable/lost energy by adapting technical modifications in terms of design or operating parameters.
- Significant experimental conclusions:
  - From table-2 & graph-1 the maximum useful energy gain for both the working fluids is at an intensity of 866 W/m^2.
  - From the graph-2 maximum useful exergy for water is at an intensity of 941W/m^2 and for air it is at an intensity of 1021W/m^2.
  - From graph-3 & graph-4 a little variation in the exergy efficiency is found for both the working fluids when compared with energy efficiency at same Solar intensities.
- From the experimental results it is envisaged that the efficiency can be improved using high thermal conducting fluid in the SFPC.

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Email id: ijaem.paper@gmail.com