RESEARCH ARTICLE OPEN ACCESS

Solar Thermal Power Generation: Performance Characteristics of an Evacuated Flat Plate Collector

Gulnar Perveen*, S. K. Singh**
*(Solar Energy Centre, Ministry of New and Renewable Energy, Delhi-110003, India)
** (Solar Energy Centre, Ministry of New and Renewable Energy, Delhi-110003, India)

ABSTRACT
In the present study, an Evacuated Flat Plate Collector technology is used for research purposes. This paper is about the comparative simulative study of the performance of an Evacuated FPC based on the specifications, and its characterization based on radiation/weather data in different climatic conditions across India. An Evacuated Flat Plate Collector consists of a glass cover, an absorber, a serpentine tube, an aluminium frame and the inner gas used is a noble gas. The absorber plate collects sun energy and transfers the heat into the pipes which run through the absorber plate. The fluid runs through pipes under the absorber plate and the heat from the sunlight is transferred via the absorber to the fluid as it flows through the pipes. In this paper, maintaining 55% Efficiency throughout the year, as per Performance Specifications of an Evacuated Flat Plate Collector, and its characterization based on the annual average analysis of Radiation data, the Mean Desired Temperature is calculated month wise, and also annual average Energy Gain is realized for different locations across India.
Keywords – absorber, Evacuated Flat plate Collector, serpentine tube.

I. Introduction

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 need for an entire year. This solar radiation can be directly converted into heat. The utilization of solar energy require its detailed analysis including modeling, neural networks estimation, sunshine hours, and average analysis of diffuse radiation, DNI, Global Radiation.

Research articles are there on High efficiency Evacuated Flat Plate Collector [6-7] however, no information yet is available on operating temperature conditions in different climatic conditions. However, in this research article, maintaining 55% efficiency throughout the year, as per the performance specification of an Evacuated Flat Plate Collector, installed at Solar Energy Centre as shown in Figure 2, the mean desired temperature and average Energy Gain is calculated month-wise based on the analysis of the radiation data in different climatic conditions.

II. Evacuated Flat Plate Collector

An Evacuated Flat plate collector consists of an absorber plate in an insulated box covered with transparent sheets. The fluid used for heat transfer generally flows through a metallic pipe, which is connected to the absorber strip. The outer casing which provides mechanical strength to the equipment is insulated to reduce the heat losses from back and sides of the collector. The absorber is usually made of metallic materials such as copper, steel or aluminium. The collector housing is highly insulated at the back and sides to reduce the heat losses.

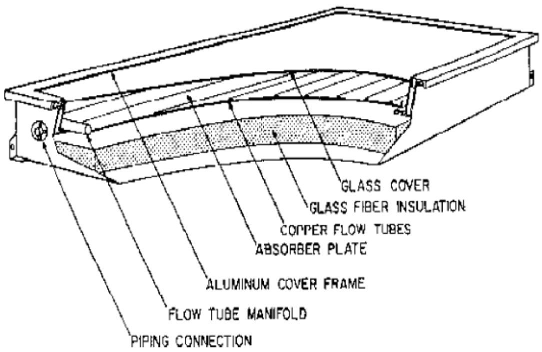

Fig. 1 Schematic of Solar Evacuated Flat Plate Collector

These collectors work best when the angle of the sun is at an optimum angle to the absorber area, and their performance drops off with lesser incidental angles.

III. Specification of an Evacuated Flat Plate Collector

Specification given by TVP Solar
Energy Performance:-
Thermal output@180^{0}C – 550 W/m^2, 1877 BTU/h (1000 W/m^2, T_{amb} – 30^{0}C).
Operating Conditions:-
Stagnation temperature- 325^{0}C, 617^{0}F
Maximum Operating Pressure -15 bar.

Calculated Figures

Optical Efficiency or zero loss Efficiency η_o= 70%
First order Heat Loss Coefficient a_1 (W/m^{2}K) = 0.333
Second order Heat Loss Coefficient a_2 (W/m^{2}K^2) = 0.0088

Fig. 2 Experimental Demonstration of an Evacuated FPC at Solar Energy Centre

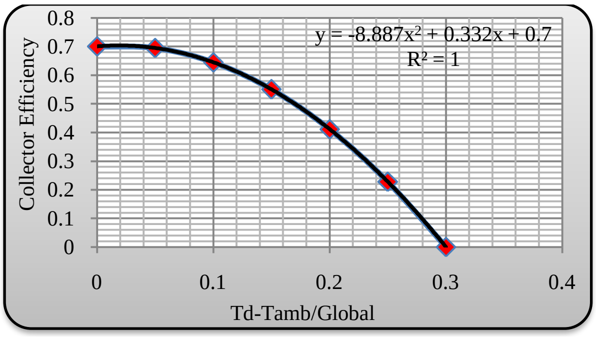

Fig. 3 Performance Characteristics Curve of an Evacuated FPC installed at SEC

IV. Results and Discussions

4.1 Annual analysis of Radiation data for different locations

4.2 Performance Characterization of an Evacuated Flat Plate Collector at 55% Efficiency

At 55% Efficiency of the Performance Characteristics of an Evacuated Flat Plate Collector, the average monthly and annual Energy Gain in KWh per meter square received is realized for different locations across India and the corresponding Mean Desired Temperature is calculated as shown in the Figure [4-8].

4.2.1 At Haryana_SEC: Performance Characterization of an Evacuated Flat Plate Collector at 55% Efficiency

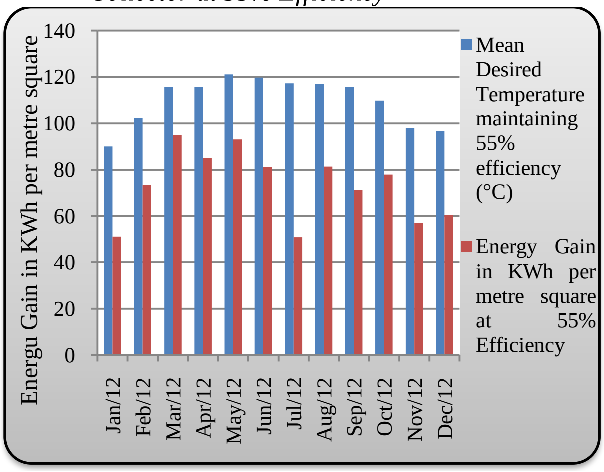

Fig. 4 Maintaining 55% efficiency, Mean Desired Operating Temperature and Month wise average Energy Gain in KWh per meter square at Haryana_SEC

4.2.2 At Gujarat_Gandhinagar: Performance Characterization of an Evacuated Flat Plate Collector at 55% Efficiency

Table 1 Annual average analysis of Radiation/Weather data at different locations

Stations covered in India	Air Temp (^{0}C)	Global Hori-zontal Rad. (Avg.) W/ m^2	Diffuse Rad. (Avg.) W/m^2	DNI (Avg.) W/m^2	Global Tilted Rad. (Avg.) W/m^2	Energy Gain (annual) in KWh per meter square (Global Horizontal Rad.)	Energy Gain (annual) in KWh per meter square (Diffused Rad.)	Energy Gain (annual) in KWh per meter square (DNI)	Energy Gain (annual) in KWh per meter square (Global Tilted Rad.)
Haryana_SEC	27.39	517	246	392	548	1516	715	1144	1592
Gujarat_ Gandhinagar	28.20	543	253	437	568	1402	576	1219	1477
Leh_Ladakh	8.75	544	203	627	622	1432	519	1653	1578
Rajasthan_ Jodhpur	2.80	536	282	481	561	1617	791	1527	1666
Chennai	30.70	562	254	442	575	1477	655	1186	1477

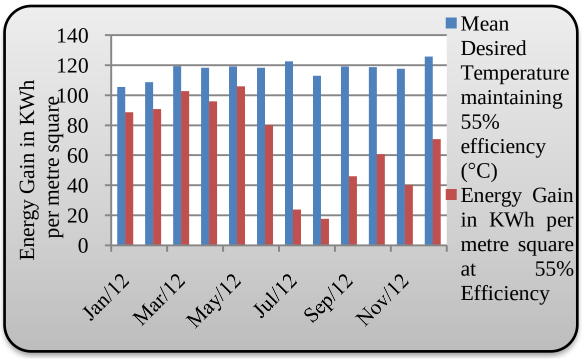

Fig. 5 Maintaining 55% efficiency, Mean Desired Temperature range and Month wise average Energy Gain in KWh per meter square at Gujarat_Gandhinagar

4.2.3 At Leh_Ladakh: Performance Characterization of an Evacuated Flat Plate Collector at 55% Efficiency

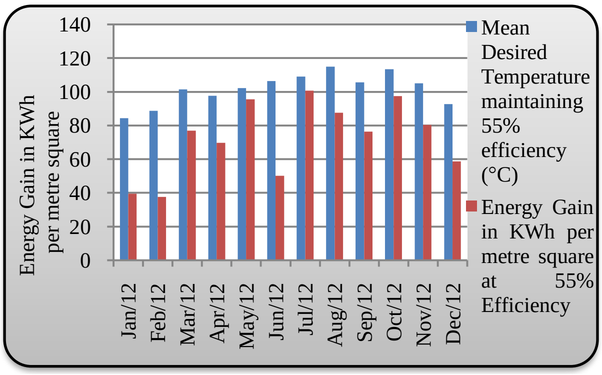

Fig. 6 Maintaining 55% efficiency, Mean Desired Temperature range and Month wise average Energy Gain in KWh per meter square at Leh_Ladakh

4.2.4 At Rajasthan_Jodhpur : Performance Characterization of an Evacuated Flat Plate Collector at 55% Efficiency

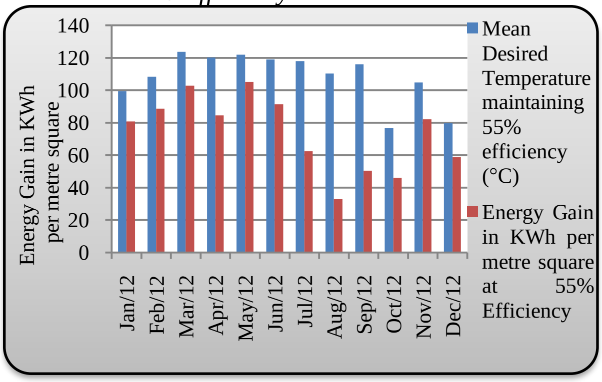

Fig. 7 Maintaining 55% efficiency, Mean Desired Temperature range and Month wise average Energy Gain in KWh per meter square at Rajasthan_Jodhpur

4.2.5 At Chennai: Performance Characterization of an Evacuated Flat Plate Collector at 55% Efficiency

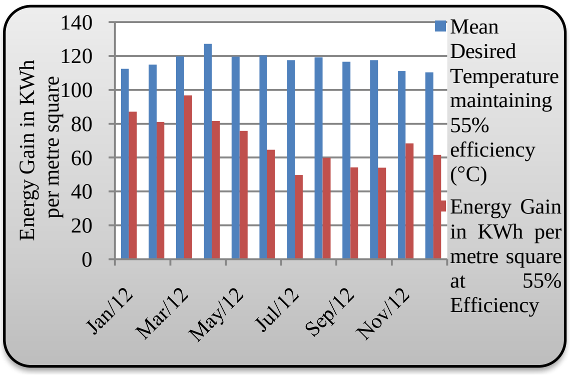

Fig. 8 Maintaining 55% efficiency, Mean Desired Temperature range and Month wise average Energy Gain in KWh per meter square at Chennai

Table 2 Calculated Mean Desired Temperature, at Haryana_SEC, maintaining 55% Efficiency

Month	Energy Gain in KWh per meter square at 55% Efficiency	Mean Desired Temperature maintaining 55% Efficiency(^{0}C)	Energy Gain in KWh per meter square at half of Global Radiation	Mean Desired Temperature at half of Global Radiation(^{0}C)
Jan	51	89	46	99
Feb	73	102	66	113
Mar	94	115	86	127
Apr	84	115	77	127
May	93	121	84	132
Jun	81	119	73	130
Jul	50	117	46	128
Aug	81	116	73	128
Sep	71	115	64	127
Oct	77	109	70	120
Nov	57	97	51	107
Dec	60	96	54	107

Table 3 Calculated Mean Desired Temperature, at Gujarat_Gandhinagar, maintaining 55% Efficiency

Month	Energy Gain in KWh per meter square at 55% Efficiency	Mean Desired Temperature maintaining 55% Efficiency (^{0}C)	Energy Gain in KWh per meter square at half of Global Radiation	Mean Desired Temperature at half of Global Radiation (^{0}C)
Jan	88	105	80	116
Feb	90	108	82	119
Mar	102	119	93	131
Apr	95	118	87	129
May	105	119	96	130
Jun	80	118	72	129
Jul	23	122	21	134
Aug	17	112	16	123
Sep	45	119	41	131
Oct	60	118	55	130
Nov	40	117	36	129
Dec	70	125	64	138

Table 4 Calculated Mean Desired Temperature, at Leh_Ladakh, maintaining 55% Efficiency

Month	Energy Gain in KWh per meter square at 55% Efficiency	Mean Desired Temperature maintaining 55% Efficiency (^{0}C)	Energy Gain in KWh per meter square at half of Global Radiation	Mean Desired Temperature at half of Global Radiation (^{0}C)
Jan	39	84	35	97
Feb	37	88	34	100
Mar	76	101	69	114
Apr	69	97	63	109
May	95	102	86	114
Jun	50	106	45	118
Jul	100	109	91	120
Aug	87	115	79	127
Sep	76	105	69	117
Oct	97	113	88	127
Nov	80	105	72	118
Dec	58	92	53	105

Table 5 Calculated Mean Desired Temperature, at Rajasthan_Jodhpur, maintaining 55% Efficiency

Month	Energy Gain in KWh per meter square at 55% Efficiency	Mean Desired Temperature maintaining 55% Efficiency (^{0}C)	Energy Gain in KWh per meter square at half of Global Radiation	Mean Desired Temperature at half of Global Radiation (^{0}C)
Jan	80	99	73	110
Feb	88	108	80	119
Mar	102	123	93	136
Apr	84	120	78	289
May	105	121	106	281
Jun	91	118	93	280
Jul	62	117	62	278
Aug	32	110	31	263
Sep	50	115	50	283
Oct	46	76	33	156
Nov	82	104	74	115
Dec	58	79	53	87

Table 6 Calculated Mean Desired Temperature, at Chennai, maintaining 55% Efficiency

Month	Energy Gain in KWh per meter square at 55% Efficiency	Mean Desired Temperature maintaining 55% Efficiency (^{0}C)	Energy Gain in KWh per meter square at half of Global Radiation	Mean Desired Temperature at half of Global Radiation (^{0}C)
Jan	87	112	79	123
Feb	80	114	73	126
Mar	96	119	87	131
Apr	81	127	74	139
May	75	119	68	130
Jun	64	120	58	131
Jul	49	117	45	128
Aug	59	119	54	130
Sep	54	116	49	127
Oct	54	117	49	129
Nov	68	111	62	121
Dec	61	110	56	121

V. Conclusion

As per the design specifications of the performance characteristics of an Evacuated FPC, the system can deliver 55% efficiency at 180^{0}C of mean desired temperature. However, the simulative study reveals that, maintaining 55% efficiency throughout the year, the temperature range varies across different locations as concluded below based on the month-wise average analysis of Weather/Radiation data for the year 2012.

5.1 At Haryana_SEC,

The mean desired temperature to be maintained, ranges from 89^{0}C (Jan) to 121^{0}C (May), also an annual Energy Gain of 872 KWh per meter square is realized as shown in Table 2.

5.2 At Gujarat_Gandhinagar,

The mean desired temperature range to be maintained is from 105^0C (January) to 125^0C (December) and an annual Energy Gain of 815 KWh per meter square is realized as shown in Table 3.

.

5.3 At Leh_Ladakh,

The mean desired temperature ranges from 84^0C (January) to 115^0C (August) and an annual Energy Gain of 864 KWh per meter square is realized as shown in Table 4.

5.4 At Rajasthan_ Jodhpur,

The mean desired temperature range to be maintained is from 76^0C (October) to 123^0C (March) and an annual Energy Gain of 880 KWh per meter square is realized as shown in Table 5.

5.5 At Chennai,

The mean desired temperature range is maintained from 110^0C (December) to 127^0C (April) and an annual Energy Gain of 828 KWh per meter square is realized as shown in Table 6.

VI. Acknowledgement

Ms. Gulnar Perveen acknowledges Mr. S. K. Singh, Director & Scientist "F" for his meticulous support, guidance and technical advice. The author pays special thanks to her parents Mrs. & Mr. Ahmed for their warmth encouragement & blessings. This work was done at Solar Energy Centre, MNRE that has provided support for doing current research work.

References

[1] Dimas Firmanda Al Riza, Syed Ihtsham ul Haq Gilani, and Mohd. Shiraz Aris, Hourly Solar Radiation Estimation Using Ambient temperature and Relative Humidity Data, *International Journal of Environment Science and Development 2(3),* 2011, 188-193.

[2] M. Maroof Khan and M. Jamil Ahmad, Estimation of global solar radiation using clear sky radiation in Yemen, *Journal of Engineering Science and Technology Review 5(2),* 2012, 12-19.

[3] Zarzo Manuel, Marti Pau, Modelling the variability of solar radiation data among weather stations by means of principal components analysis, *International Journal of Applied Energy 88(8),* 2011, 2775-2784.

[4] Janjai, S. & Pankaew, P. & laksanaboonsong, J., A model for calculating hourly global solar radiation from satellite data in the tropics, *International Journal of Applied Energy 86(9),* 2009, 1450-1457.

[5] Sukhatme, S. P. Solar Energy, 2nd edition, Tata McGraw-Hill. New Delhi; India; 1996, p. 234–248.

[6] N. Benz, T. Beikircher, High efficiency Evacuated Flat plate solar collector for process steam production, *International Journal of Solar Energy 65(2)*,1999, 111-118.

[7] M.C. Rodriguez-Hidalgo, P.A. Rodriguez-Aumente, A. Lecuona, G.L. Gutierrez-Urueta, R.Ventas, Flat Plate thermal collectors efficiency: Transient behaviour under working conditions part II: Model application and design contributions, *International Journal on Applied Thermal Engineering 31*, 2011, 2385-2393.

[8] Smyth, M. & Eames, P.C. & Norton, B. Integrated collector storage solar water heaters, *International Journal on Renewable and Sustainable Energy Reviews 10(6),* 2006, 503-538.

[9] F.F. Mammadov, Estimation of Flat Plate Collector productivity, *International Journal on Technical and Physical problems of Engineering 4(10),* 2012, 35-40.

[10] Zondag, H.A., Flat Plate PV-Thermal Collectors and systems: A review, *International Journal of Renewable and Sustainable Energy review 12(4),* 2008, 891-959.

[11] Dan Nchelatebe Nkwetta, Mervyn Smyth, Agglelos zacharopoulos, Trevor Hyde, Experimental Performance analysis of and optimization of medium temperature solar thermal collectors with silicon oil as a heat transfer fluid, *International Journal of Energy Research 37,* 2013, 570-581.

[12] Hossain, M.S. & Saidur R. & Fayaz, H. Rahim, N.A. & islam, M.R. & Ahamed, J.U. & rahman, M.M. Review on solar water heater collector and thermal energy performance of circulating pipe, *International Journal on Renewable and Sustainable Energy Reviews 15(8),* 2011, 3801-3812.

[13] Daryl R. Myers. Solar Radiation Modeling and measurements for renewable energy applications: data and model quality, *International Journal of Applied Energy,* 2005, 1517-1531.

[14] Ampratwum, David B. & Dorvlo, Atsu S. S., Estimation of solar radiation from the number of sunshine hours, *International Journal of Applied Energy 63(3),* 1999, 161-167.

[15] Khatib, Tamer & Mohamed, Azah & Sopian, k. A review of solar energy modeling techniques, *International Journal of Energy and renewable Reviews 16(5),* 2012, 2864-2869.