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EXPERIMENTAL ANALYSIS OF EVACUATED TUBE COLLECTOR WITH PARABOLIC AND FLAT REFLECTORS.

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Abstract-In this study an integrated model of solar water heater with all glass solar evacuated tubes with different reflector is studied in natural convection mode. Various factors suchas temp difference, Efficiency, energy and exergy are analysis, studied along with their comparison. In this setup parabolic reflector has been compared with flat reflector. Construction of this setup is been done in hisar, with latitude 29.8'15'' NL and longitude 75.45'20'' EL. The tilt angle of ETC tube is 30∘with horizontal.

It was observed that shape of reflector effect the efficiency of the system. After experimental analysis it was found that ETC tube with flat reflector has more efficiency than without any reflector. And ETC tube with parabolic reflector has more efficiency than with flat reflector. So mathematically we can Wright

$$\eta wr < \eta f < \eta p$$

keywords: parabolic reflector, evacuated tube, solar water heater, flat reflector.

I. INTRODUCTION

India is blessed with solar energy in abundance at Zero cost. India is having high solar insolation of 46.5 KWh/sq.m/day for an average of 280 sunny days and most of that resource has been left untapped. The most popular cost-effective devices that harness the solar energy is Solar Water Heating System (SWHS). SWHS heating system is a commercially viable and technologically mature product, is existing in country for many years with enormous potential.

most of the rays of sun Of all the sunlight that passes through the atmosphere annually, only 51 % is available at the Earth's surface to do work. This energy is used to heat the Earth's surface and lower atmosphere, melt and evaporate water, and run photosynthesis in plants. Of the other 49 %, 4 % is reflected back to space by the Earth's surface, 26 % is scattered or reflected to space by clouds and atmospheric particles, and 19 % is absorbed by atmospheric gases, particles, and clouds

The solar thermal collectors are used to absorb the solar energy to heat up the running water through the system. Different types of solar thermal collectors are used according to the requirement of the system. But the main type collectors are Evacuated tube solar thermal system, Flat plate panel solar thermal system, Thermodynamic solar panels and Solar thermal bowl.

II. LITERATURE REVIEW

Chow[1] classified evacuated tubes on base of flow i.e. Single phase thermosyphon flow or two phase thermosyphon flow, having straight/U-shaped tubes.

Morrison[2] Found Evacuated tube collector has better efficiency than flat plate collectors and water in glass tube collectors is preferable to household applications because of ease in production and lower cost.

E Zambolin[3] Conducted comparative tests between flat plate and ETC and found that ETC has better efficiency that flat plate collector because efficiency losses are reduced in ETC also ETC can collect more radiation than flat plate due to its shape.

Dabra1[4] Studied the thermal performance of the individual glass evacuated tube solar collector by one-dimensional analytical method. The results show that influence of the thermal resistance of air layer on the heat efficiency is large. Also to evaluate the thermal performance of the glass evacuated tube solar collector, not only should the heat efficiency be considered, but also the surface temperature of the absorbing coating is an important parameter. And the efficiency increases with increase of solar radiation intensity, but it reaches gradually to a constant.

H Zheng[5] Studied the effect of receivers black surface emissivity on heat loss of the evacuated solar tubes and found that receivers black surface emissivity plays major role in heat losses especially at higher temp. it was also observed that by increasing the receiver's black surface emissivity can increase the heat loss of the ETC and reduce the efficiency, which is very helpful for preventing the occurrence of overheating problem at higher temperature, specially at high latitudes in summer.

E Dikmen[6] Conducted evaluation of thermal performance of evacuated tube collector by ANN (artificial neural network) and ANFIS(Adaptive neuro fuzzy inference system) models and compared results with experimental results factors taken in consideration were collector tilt-angle, ambient temperature, solar radiation, mean storage tank temperature and found both models give satisfactory results. However ANN model gives more satisfactory results

R Liang[7] Purposed theoretical model and validated it with experiments for comparing the performance of filled U shaped evacuated tube and evacuated u shaped tube. He found that theoretical model suggests the optimum thermal conductivity of the filled layer is 10 when thermal conductivity reaches to 10, its performance is equal to copper tubes and at hundred, productivity will be 12% higher than the evacuated not filled U shaped tubes.

Y Gao[8] Prepared a mathematical model for predicting thermal performance of evacuated solar tube and validated it with experimental data and following results were obtained

1. Increasing the length will not always result in increase in thermal efficiency.
2. Thermal efficiency mainly depends on local solar irradiance.
3. Absorber having lower heat loss coefficient are best suited for cold condition

In order to avoid mounting problems it is necessary to study the effect of inclination angle of productivity of evacuated tubes.

Runsheng Tang[09] Studied the thermal performance of evacuated tubes and results revealed that the collector tilt-angle of solar water heaters had significant influences on the daily collectible radiation and daily solar heat gain of a system, but insignificant on the heat removal from solar tubes to the water storage tank and the daily solar thermal conversion efficiency. Results also showed that the daily thermal efficiency of SWHs was almost independent of the climatic conditions as a result of lower heat loss from solar tubes to the ambient air.

R Tang[10] Prepare a mathematical model for determining optimal tilt angle for evacuated solar tubes and found that tilt angle should be kept generally less than site latitude to maximize solar gain. It was also found that T-type collectors are more efficient than H-type collectors and use of diffuse ray reflector increases the productivity especially for H-type collectors.

III. LITERATURE GAP AND PROBLEM FORMULATION

During Literature survey it is observed that various factors effects the performance of solar water heater.

Nemours research have been done on different parameters such as

- Effect of angle of tilt on the performance of evacuated solar tube
- Evacuated tube collectors have better efficiency than flat plate collectors.
- The efficiency increases with increase of solar radiation intensity.
- Studied the effect of receivers black surface emissivity on heat loss of the evacuated solar tubes.
- ANN and ANFIS Models compared with experimental results.
- Absorber having lower heat loss coefficient are best suited for cold condition.
- Increasing the length will not always result in increase in thermal efficiency.
- Tilt angle should be kept generally less than site latitude to maximize solar gain.

During literature survey no study was done on comparison of solar water heater combined with ETC with different type reflectors.

Problem formulation-

- Design of solar water heater with ETC and different type of reflector.
- To study the efficiency of solar water heater with ETC.
- To study the efficiency of SWH with ETC combines with flat and parabolic reflector.
- Compare different efficiency of SWH
- Exergy and energy analysis of setup
- To calculate various heat transfer coefficient with various design.

IV. EXPERIMENTAL SETUP

An experimental analysis on all glass evacuated solar tubes water heater with parabolic, flat and without reflectors is investigated in this study. In this setup three conditions of all glass evacuated tubes are going to be compare. 1stwith parabolic reflectors and Flat reflector, 2nd with flat vs. without reflector and 3rd with parabolic vs. without reflector. Construction of this setup is been done in hisar with latitude 29.8’15’’ NL and longitude 75.45’20’’ EL.

Integrated Model of all Glass Evacuated Solar tubes with parabolic reflector, flat reflector and without reflector is shown in fig. 1.

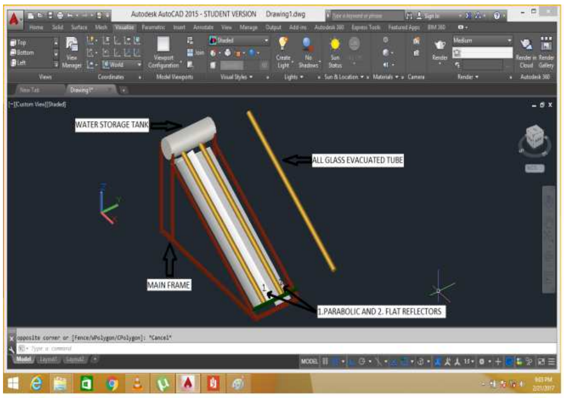

FIG.1. INTEGRATED MODEL OF SETUP

The pictures of experimental setup are shown in fig 2. There are two insulated separate tanks in the setup, one for each ETC tube. Setup has 178 cm length and 95 cm height .The tilt angle of tube is 30° with horizontal. Because in setup there is no force circulation, So Thermosyphon circulation is used. In literature review we found that for Thermosyphon circulation, 30° angle of all glass evacuated tube is more efficient than 45.

FIG.**2**. PICTURE OF EXPERIMENTAL SETUP

A PT-100 (3 wire type) thermocouples are used for temp measurement.PT 100 thermocouples have measuring range of -199.9 to 199.9°C. Temp indicator (Fig 3) is used to show temp was recorded manually with 60 minutes gap. Five pencil type thermocouples are used in this setup. Temp indicator has 10 channel out of which 5 is used. One for ambient temp, one for each all glass evacuated tube and one for each tank section. Pencil type thermocouple and temp indicator is shown in fig. 3.

FIG. 3. PENCIL TYPE THERMOCOUPLE AND TEMP. INDICATOR

Parabolic reflector is made of reflective foil with thickness of 11 micron and 29.5 mm width. It is used from its bright side with reflectivity of 88%.The length of parabolic reflector is 164 cm and width is 29.5 cm.
The reflective foil is paste on a hard paper sheet. The parabolic curve is made on the formula base $y=ax^2$

Where "a" shows the focal length of reflector and it can be any number. I.e. if we want focal length 1 than "a" will be 1/4.this is shown by fig no 4.

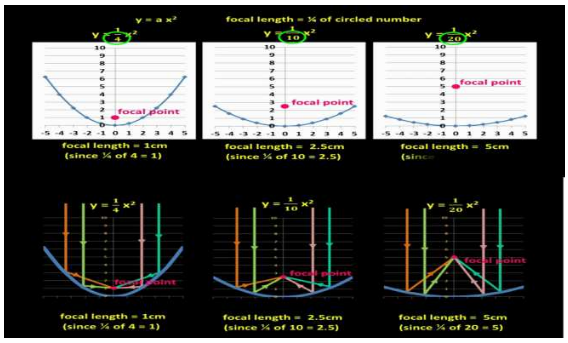

FIG. 4. FOCAL LENGTH PRINCIPLE

V. EXPERIMENTAL PROCEDURE

The each experiment is conducted in one day, during which the following measurements had been recorded:

- The flow of water is by thermosyphon or natural circulation.
- The temperature of all glass evacuated tube, ambient and storage tank are measured.
- The experimental data are collected in interval of 60 minutes, starting from about 10 A.M. up to the 4 pm.

VI. THERMAL MODELING

The natural circulation of the water to the all glass evacuated tube is directly proportional to heat input. More the heat input, more the natural circulation of water. This is done due to viscosity effect. As the temperature increase the viscosity of water decrease. This decrease in viscosity, decrease the shear resistance between the adjacent layers of the water. Also the diff. in temp between tank and ETC effect the natural circulation of water. Higher the difference more the flow, hence more heat is transmitted to water and better efficiency can be achieved.

Another factor that affects the efficiency of setup is density difference. More the difference of density better natural flow can be achieved and hence efficiency can be improved for achieving more density difference. We have to prevent heat loss from setup, for that tank is properly insulated by thermocol.

VII. EXERGY AND ENERGY ANALYSIS

Exergy is defined as the maximum amount of work which can be produce by a system or a flow of matter. After the system and surrounding reach equilibrium, the exergy is zero.

Exergy from collector to storage tank (W)

$$E_{x0} = \dot{m}c_p(T_{f0} - T_0) - \dot{m}T_0c_pL_n\frac{T_{f0}}{T_0}$$

The solar collector thermal efficiency can be defines as a ratio of the actual useful energy collected(Q_u) to the solar energy intercepted by the collector gross area (A_{scol}). This can calculated as follow

$$\eta_{scol} = \frac{\dot{Q}_u}{A_{scol}I_T}$$

The usable energy (Q_u) can be calculated by this formula

$$\dot{Q}_u = \dot{m}_w C_{p,w}(T_{w,out} - T_{w,in})$$

VIII. RESULT AND DISCUSSION

The data was recorded for 4 days, on date 27th February to 2nd March 2017, in various conditions from 10:00 am to 4:00 pm. There are two all glass evacuated tubes with their separate storage tank. All these data is taken in the environment of hisar.

There are three conditions which was study

1. Both all glass evacuated tube with reflector, one with flat and another with parabolic on 27 and 28 Feb.
2. One all glass evacuated tube without reflector and another with parabolic reflector on 1st March.
3. One all glass evacuated tube with flat reflector and another without reflector on 2nd March.

In this process we neglect the air flow effect on setup. The storage tank has insulation with thermocol.

On 27th and 28th February the data was taken with flat reflector and parabolic reflector. Or in other words one ETC with flat reflector and other with parabolic reflector. The data taken on 27 Feb. is shown in table 1 and its graphical representation is shown in fig.6.

As there is no water pump used in the setup, so water flow is done by thermosyphon. From table 1, we found that ETC with parabolic reflector gain more temperature than ETC with flat reflector.

On the basis of table 1st,We calculated table 2. We find that ETC with parabolic reflector gives more efficiency and exergy than ETC with flat reflector. As we can see with parabolic reflector max efficiency is 22.5% but with flat reflector it is 20.73%.

The graphical representation of table 2 is shown by fig. 7

Like this, the reading was taken on other three days with different condition.

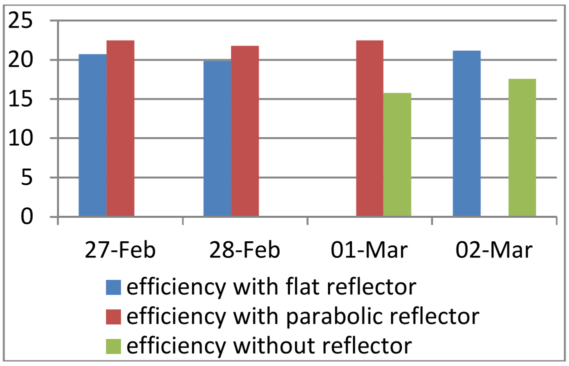

FIG. 5.EFFICIENCY OF SWH WITH ETC WITH DIFFERENT REFLECTOR ON 27TH FEB TO 2ND MARCH 2017.

Overall efficiency of system is shown in fig.5.

ABLE 1.DATA RECORDED FOR VARIOUS PARAMETERS ON 27 FEBRUARY 2017

TIME	ETC WITH FLAT REFLECTOR		AMBIENT TEMP	ETC WITH PARABOLIC REFLECTOR		SOLAR RADIATION W/m^2
	T_{tu}	T_{ta}	T_a	T_{tu}	T_{ta}	
10	31.7	31.8	32.0	31.3	31.1	620
11	38.3	39.2	36.7	42.2	41.1	779
12	43.0	44.4	37.3	51.2	50.4	896
13	46.8	47.9	38.6	56.0	56.1	925
14	53.5	53.6	37.7	59.9	60.2	841
15	56.1	56.2	35.4	59.7	59.9	760
16	56.3	56.6	33.1	58.3	58.6	520

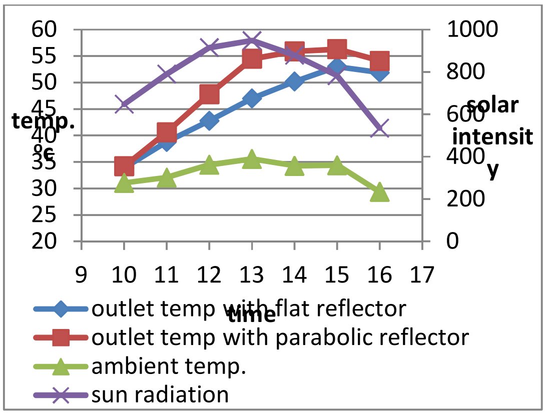

FIG. 6. GRAPHICAL REPRESANTATION OF TABLE 2

TABLE 2.DATA RECORDED FOR VARIOUS PARAMETERS ON 27 FEBRUARY 2017

Time	h_f	E_{xof}	h_p	E_{xop}	m	I
10	0.000	0.000313	0.79424	0.00643	0.496	620
11	2.2062189	0.051026	3.882945	0.153077	0.6232	779
12	6.2656617	0.432676	11.56059	1.349121	0.7168	896
13	8.2071343	0.719663	15.44353	2.281743	0.74	925
14	14.031552	1.780871	19.85597	3.28341	0.6728	841
15	18.355741	2.711762	21.62095	3.593435	0.608	760
16	20.738458	2.400889	22.50343	2.756499	0.416	520

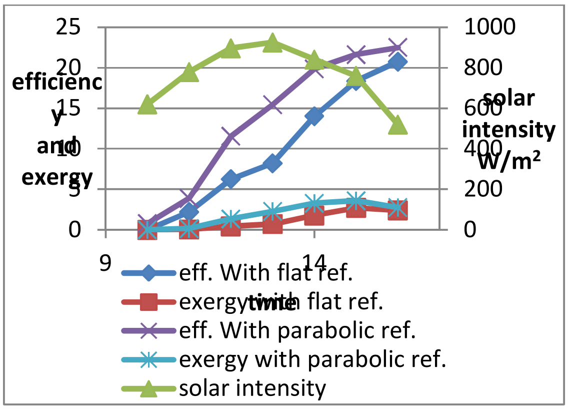

FIG. 7. GRAPHICAL REPRESANTATION OF TABLE 2

CONCLUSION

Following points can be concluded from the experimental analysis.

1. First and second experiment was conducted on 27 and 28 February with 1stcondition (one ETC tube with flat and other with parabolic reflector) to find various parameters with 32 liter water (each section had 16 liter water). Experiments were continued for 2 days. Maximum temp with flat reflector obtained was 56.6°C on 1st day and 51.9°C on 2nd day. Maximum temp with parabolic reflector obtained was 60.2°C on 1st day and 56.3°C on 2nd day. Ambient temp varied between [29-38] °C during experiment. Solar Intensity varied between 620-948 W/m^2.
2. It was observed that shape of reflector effect the efficiency of the system. After experimental analysis on 27 and 28 February it was found that ETC tube with flat reflector has max 20.71 % efficiency and 2.7 W exergy and with parabolic reflector has max 22.53 % efficiency and 3.6 W. So from here we can conclude that parabolic reflector has higher efficiency than flat.
3. 3rd experiment was conducted with 2nd condition (One ETC tube is without any reflector and other with parabolic.). Maximum temp of ETC without

reflector obtained was 52.4°C and with parabolic reflector 59.5°C on 1st march. Ambient temp varied between [27-39] °C during experiment. Solar Intensity varied between 589-981 W/m^2.

4. After experimental analysis on 1st march it was found that ETC tube without any reflector has max 15.7 % efficiency and 2.25 W exergy. And ETC with parabolic reflector has max 22.50 % efficiency and 4.31W exergy. So from here we can conclude that ETC with parabolic reflector has higher efficiency than ETC without any reflector.
5. 4th experiment was conducted with 3rd condition (One ETC tube with flat reflector and other without any reflector.). Maximum temp of ETC with flat reflector obtained was 57.5°C and without any reflector 53.9°C on 2ndmarch. Ambient temp varied between [23-39] °C during experiment. Solar Intensity varied between 563-963 W/m^2.
6. After experimental analysis on 2ndmarch it was found that ETC tube with flat reflector has max 21.17 % efficiency and 2.67 W exergy. And ETC without any reflector has max 17.56 % efficiency and 1.93W exergy. So from here we can conclude that ETC with flat reflector has higher efficiency than ETC without any reflector.

So overall conclusion is that ETC with parabolic reflector has higher efficiency than flat reflector. And ETC with flat reflector has higher efficiency than ETC without any reflector.

LIST OF SYMBOLS AND ABBREVIATIONS

ETC- Eevacuated tube collector
E_{xo}- Exergy from collector to storage tank (W)
m - Mass flow of water (kg/s)
C_p- Specific heat of water (J/(kg ^{o}C)
T_{fo}- Outlet temperature of water fromcollector to storage tank (K)
T_o - Ambient temperature (K)
Q_u - Net heat energy absorbed by working fluid, W
A_{scol}- Collector gross area (m$^{2)}$
I_T - Solar intensity w/m^2
M - Mass flow rate in kg/s
C_P - Specific heat of water (J/(kg ^{o}C)
T_{tu} - Inside temperature of tube (^{o}C)
T_{ta} - Inside temperature of storage tank (^{o}C)
T_a - Ambient temperature (^{o}C)
h_f - Effieciency of system with flat reflector
h_p - Effieciency of system with parabolic reflector
h_{wr} - Effieciency of system without reflector
E_{xof} - Exergy of system with flat reflector (W)
E_{xop} - Exergy of system with parabolic reflector (W)
E_{xowr} - Exergy of system without reflector (W)

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