Performance analysis and comparison of heat transfer for flat plate and plate with fins by using forced convection in rectangular duct

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Abstract- *Given the geographical location, India has enormous scope for usage of solar energy. India is a peculiar to the tropics and due to this here we receive solar radiation all around the year, which is around 3,100 hours of the sunshine which is almost equivalent to the 5,100 trillion kWh. Approximately. This present work deals with the energy as well as energy analysis of solar-air heater which is having absorber flat plate with the force convection.*

Keywords- Blower, Anemometer, K-type thermocouple, Acrylic glass, Aluminium plate

I. INTRODUCTION

Energy is the strength & vitality required for sustained physical & mental activity. It is the property of matter & radiation that is manifest as a capacity to perform work. Two types of energy resources are available: conventional and non-conventional. Conventional energy resources such as fossil fuel (coal, crude oil and natural gas) are limited in amount. Total energy in recoverable conventional energy resources is estimated to be around 32- 35Q (1Q=1018k) while the worldwide rate of energy usage is roughly 0.4-0.5Q/year. Hence conventional energy resources are roughly estimated to last for 75-85years. This awareness of the limited nature of conventional energy resources gave rise to the search of alternative energy resources. Solar energy has the extent potential among all the sources of energy which is not used up when used and even a small amount of this renewable source of energy is sufficient to meet the total energy demand of the world.

Most solar air heating systems are wall mounted, this allows them to capture a optimum amount of solar emission of energy in the winter. They are also fully building integrated and typically reduced between 21% to 51% of conventional energy used for heating buildings.

For a workable solar energy system, one should understand how the solar energy traversed the earth and also how this energy varies accordingly throughout the time of year. The peak climatic conditions for solar heating are based on bright sunlight on the coldest days of the year. A solar collector is then able to gather plenty of energy when is needed most. Surprising is the amount of energy available even on cloudy days, which also tend to be not as cold. Cloud work as a covering or blanket over the earth which results in preventing some of its energy from radiating away. Solar radiation reaches solar panels in three patterns: direct, diffuse, and reflected radiation. There are three types of radiations are as mention below:

- Direct radiation consists of parallel rays coming straight from the sun. This type of radiation a slight squint shadows on clear days.
- Spread out over a large area radiation is sparsely, converging energy rays. This type of radiation makes the sky blue on clear days.

II. PROBLEM STATEMENT

Many experiments are done previously on solar air heater, but many of them uses only flat plate in the absence of blower because of that they get lower efficiency. Now we are going to use both flat plate as well as blower so that we will get maximum efficiency.

Although solar-air heater has vast potential, it has not received much attention like the solar liquid collectors. Air type solar collectors have two problems, low thermal capacity of air and low absorber to air heat transfer coefficient, at the same time the most essential parameter of solar air collector design is the heat transfer factor sandwiched absorber-plate and the hanging air since the collector efficiency is highly affected due to this parameter, which is turn is dependent on collector type and operating conditions..

III. PROJECT DETAILS

A) Future Scope

The present study of artificial convection of high temperature from horizontal rectangular passage can be extended to study further in future

- Future studies should be consider the consequence of the gap during the absorber plate and the cover.
- By changing shape and orientation of fins used in plate with fin, performance can be better than this.
- Also by adding some absorbing materials such as silica

sand, glass pieces, different results can be obtained.

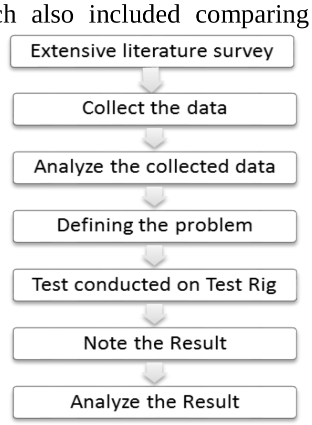
- To that place a lots of effect of inclined angle of duct, so by changing it also we can get more desired effect.

B) OBJECTIVES

- Experimental study and comparison of heat transfer of even plate and plate with fins by using forced convection in rectangular duct.
- Experimental study and comparison of temperature variation of even plate and plate having fins with respect to a point of time of the day.
- Experimental study and comparison of outlet intensity of heat on even plate and plate having fins with respect to time of day.
- The experimental study and comparison of convective heat transfer coefficient of smooth plate and plate with fins.
- Study and comparison of Nusselt number of even plate and plate with fins.

C) Methodology

Usually experimentation is done over solar-air heater for its performance improvement. For this experiment, a potential survey was conducted over use of solar energy and solar-air heater which uses this energy. Qualitative data was obtained from this survey. After analysis of this data, actual problem was found on which research is to be done. Further the problem regarding solar-air heater & solar energy was defined which also included comparing the experiment of solar-air heater with fins & without fins.



An actual model of solar heaters, one having fins & other in the absence of fins was made for this research. Testing of model includes numerical experimental analysis & Computational fluid dynamics simulation.

The result obtained after experimentation and simulation is further discussed, analyzed and judgment reached by reasoning is recorded.

IV. EXPERIMENTAL SETUP

A solar-air heater consists of wooden duct, absorber plate, transparent cover, flexible pipe, blower, frame, anemometer, and thermometer.

Pictures of experimental setup, of different solar air heaters are shown in fig. (6). One solar-air heater has absorber plate with fins welded over its surface & reflector is also attached to both side for reflection of solar radiations, whereas other air heater has smooth plate absorber with no reflector

A wooden duct is placed over stand with 22˚ inclination angle to ground. Black color is painted to inner sides of duct. Absorber is put in duct, & duct is covered with acrylic glass. Blower is used to supply air flow through air heaters. Equal mass flow compute flows through both air heater at a same time. Both air heaters undergoes same working, experimentation & climatic conditions

In experiment fins are placed in the opposite direction of airflow and the distance between two successive fins is 10cm.Total 84 fins are placed on setup aluminium sheet.

Due to reflector more solar radiations are reflected over absorber as compared to flat pate air heater, so we will have higher temperature for air heater with reflector & also fins will slower down the velocity of air which will leads to more heating of air as compare to flat plate air heater. Thus we are expected to obtain higher Outlet temperature of air leaving from air heater having fins & reflector as compared to flat plate reflector.

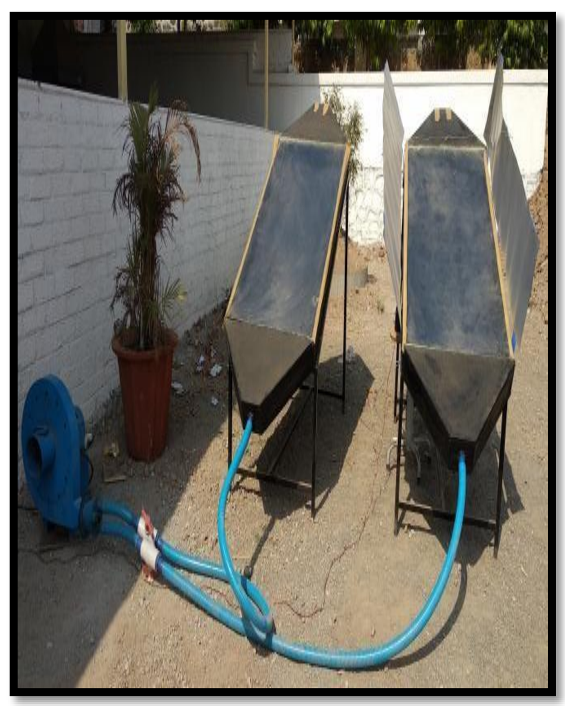


Fig. 07 Experimental Setup

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V. EXPERIMANTAL ANALYSIS

A).Reading Tables

Table 1: Readings taken for flat plate at mass flow rate of 0.013113 kg/s

TOD	T1	T2	T3	T4	T5	T6	T7	T8	ΔT
9:30 A.M.	32	64	64	65	66	70	68	35	3
10:30 A.M.	52	68	72	74	73	81	79	58	6
11:30 A.M.	54	70	74	77	76	82	81	60	6
12:30 P.M.	56	71	73	76	76	82	80	63	7
1:30 P.M.	55	67	69	70	70	76	74	60	5
2:30 P.M.	50	59	60	62	61	64	63	53	3
3:30 P.M.	50	54	55	56	56	59	57	52	2

Table 2: Readings taken for plate with fins at mass flow rate of 0.013113 kg/s

TOD	T1	T2	T3	T4	T5	T6	T7	T8	ΔT
9:30 A.M.	32	65	53	55	62	66	64	38	6
10:30 A.M.	52	69	63	66	74	75	74	59	7
11:30 A.M.	55	72	67	69	76	79	78	62	7
12:30 P.M.	56	73	78	70	75	79	78	64	8
1:30 P.M.	55	68	64	65	72	72	71	61	6
2:30 P.M.	50	58	57	58	63	61	61	54	4
3:30 P.M.	48	54	53	52	53	56	56	50	2

Table 3: Readings taken for flat plate at mass flow rate of 0.015069 kg/s

TOD	T1	T2	T3	T4	T5	T6	T7	T8	ΔT
9:30 A.M.	41	55	57	62	60	66	64	45	4
10:30 A.M.	50	65	68	70	69	76	74	56	6
11:30 A.M.	55	68	71	75	71	80	77	59	4
12:30 P.M.	59	73	76	78	77	83	71	63	4
1:30 P.M.	51	64	65	65	63	66	65	55	4
2:30 P.M.	47	51	50	50	51	52	52	50	3
3:30 P.M.	46	47	47	49	50	52	50	48	2

Table 4: Readings taken for plate with fins at mass flow rate of 0.015069 kg/s

Table 5: Readings taken for flat plate at mass flow rate of 0.009892 kg/s

TOD	T1	T2	T3	T4	T5	T6	T7	T8	ΔT
9:30 A.M.	46	64	66	69	68	75	73	52	6
10:30 A.M.	53	72	76	77	76	84	82	60	7
11:30 A.M.	58	76	79	81	80	88	86	63	5
12:30 P.M.	58	75	78	78	78	85	83	63	5
1:30 P.M.	57	71	74	75	75	81	78	62	5
2:30 P.M.	54	64	67	67	66	71	70	57	3
3:30 P.M.	47	54	57	56	56	59	58	51	4

Table 6: Readings taken for flat plate at mass flow rate of 0.009892 kg/s

TOD	T1	T2	T3	T4	T5	T6	T7	T8	ΔT
9:30 A.M.	47	64	59	60	67	70	70	53	6
10:30 A.M.	53	72	68	69	77	80	78	61	8
11:30 A.M.	57	77	72	73	81	85	81	65	8
12:30 P.M.	56	74	71	73	78	82	79	63	7
1:30 P.M.	51	71	69	68	74	77	75	63	12
2:30 P.M.	52	63	62	61	65	66	66	57	5
3:30 P.M.	47	54	51	53	56	56	56	53	6

TOD	T1	T2	T3	T4	T5	T6	T7	T8	ΔT
9:30 A.M.	41	57	52	54	60	66	63	47	6
10:30 A.M.	50	66	61	64	71	75	71	58	8
11:30 A.M.	54	70	67	67	74	78	78	59	5
12:30 P.M.	58	73	76	78	77	83	71	63	5
1:30 P.M.	51	59	59	64	70	70	67	57	6
2:30 P.M.	46	48	48	52	51	53	52	50	4
3:30 P.M.	46	46	47	50	50	52	52	49	3

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1. Fins are provided on aluminium sheet. The distance between two successive fins is 10cm and total 84 fins are used. There is a relationship between pitch and height of the fin as follows

$$\frac{P}{e} = 5 \text{ to } 10.$$

Where, P= Pitch (distance between two fins)

e= Height of fin

The dimension of the fins is 5cm X 1.5cm X 0.2cm

1. Temperature of Plate (T_P):

$$T_P = \frac{T2+T3+T4+T5+T6+T7}{6}$$

I. Flat plate @9:30 A.M.

$$T_P = \frac{64+64+65+66+70+68}{6}$$

T_P = 66.16667 °C

II. Plate with fin @ 9:30 A.M.

$$T_P = \frac{65+53+55+62+66+64}{6}$$

T_P = 60.83333 °C

3. Fluid temperature (T_F): $T_F = \frac{T1+T8}{2}$

I. Flat plate @9:30 A.M.

$$T_F = \frac{32+35}{2}$$

T_F = 33.5 °C

II. Plate with fin @ 9:30 A.M.

$$T_F = \frac{32+38}{2}$$

T_F = 35 °C

4. Temperature difference between plate and ambient (ΔT_{pf}): $(\Delta T_{PF}) = (T_P - T_F)$

I. Flat plate @9:30 A.M.

(ΔT_{PF}) = (66.16667 - 33.5)

ΔT_{PF} = 32.66667 °C

II. Plate with fin @ 9:30 A.M.

(ΔT_{PF}) = (60.83333- 35)

ΔT_{PF} = 25.83333 °C

5. Inlet and outlet temperature difference (ΔT):

$\Delta T = (T8 - T1)$

I. Flat plate @9:30 A.M.

6. Mass flow rate ($\dot{m}$):

$\dot{m} = \rho AV$

ρ = 1.1575 kg/m³ at 32 °C

$A = \frac{\pi d^2}{4} = \frac{\pi 0.038^2}{4}$ = 0.0011343 m²

V = 10m/s

$\dot{m}$ = 1.1575×0.0011343×10

$\dot{m}$ = 0.013133 kg/s

7. Heat transfer rate (Q):

$Q = \dot{m}\, C_p\, \Delta T$

I. Flat plate @9:30 A.M.

Q_{flat} = 0.013133×1006.55×3

Q_{flat} = 39.65706 J/s or W

II. Plate with fin @ 9:30 A.M.

Q_{fin} = 0.013133×1006.55×6

Q_{fin} = 79.3141 J/s or W

8. Convective heat transfer coefficient (h):

$Q = \dot{m}\, C_p\, \Delta T = hA\,(T_P - T_F)$

A = Area of Aluminium plate = 0.75×1.5 = 1.125 m²

I. Flat plate @9:30 A.M.

Q = 0.013133 × 1006.55 × 3 = h×1.125 (66.16667 - 33.5)

h = 1.079103357 W/m²k

II. Plate with fin @ 9:30 A.M.

Q = 0.013133 × 1006.55 × 6 = h×1.125 (60.83333 - 35)

h = 2.729089 W/m²k

9. % change in heat gain

$$\% \text{ Change} = \frac{Q_{fin} - Q_{flat}}{Q_{fin}} \times 100$$

$$\% \text{ Change} = \frac{79.3141 - 39.65706}{79.3141} \times 100$$

% Change = 50.00 %

10. Nusselt number (Nu):

$$Nu = \frac{\text{Total heat transfer}}{\text{convective heat transfer}} = \frac{hd_h}{k}$$

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$$d_h = \frac{4 \times A_{rectangular\,opening}}{P_{rectangular\,opening}}$$

$$= \frac{4 \times 1.5 \times 0.75}{2(1.5+0.75)}$$

$d_h = 0.2068$ m

I. Flat plate @9:30 A.M.

$h = 1.079103357$ W/m^{2}k

$k = 0.027374$ W/mk

$$Nu = \frac{1.079103357 \times 0.2068}{0.027374}$$

$Nu = 8.155757$

II. Plate with fin @ 9:30 A.M.

$h = 2.729089$ W/m^{2}k

$k = 0.027374$ W/mk

$$Nu = \frac{2.729089 \times 0.2068}{0.027374}$$

$Nu = 20.61719999$

11. Efficiency of solar-air heater (η):

$$\eta = \frac{Q}{I \times A}$$

Where: Q = Heat gain in watt

I = Intensity of solar radiation

A = Area of collector duct

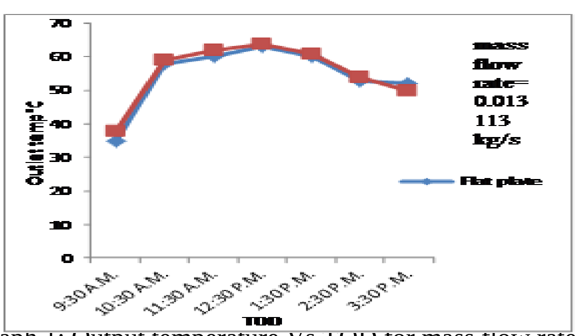
I) $\eta_{flat} = (39.65)/ (901 * 1.5 * 0.750)$

$\eta_{flat} = 3.91$ %

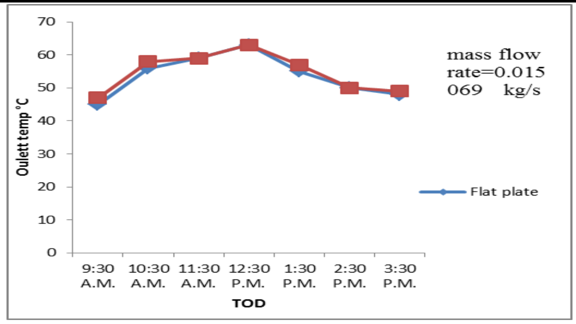
II) $\eta_{fin} = (79.31)/ (901 * 1.5 * 0.750)$

$\eta_{fin} = 7.81$ %

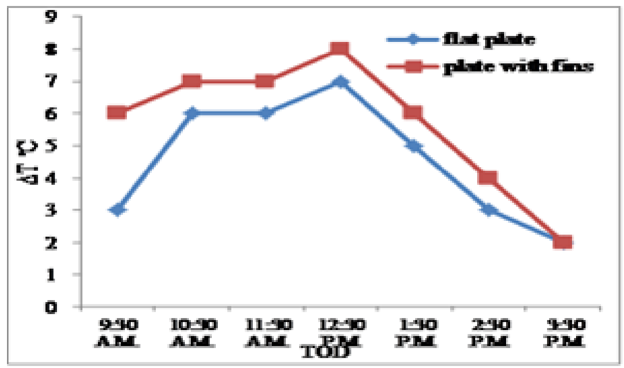
VII. GRAPHICAL ANALYSIS



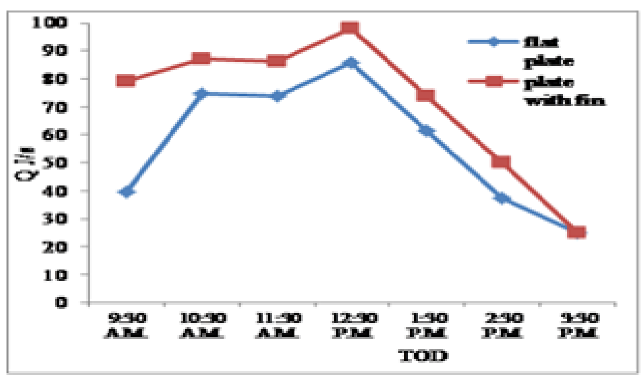
Graph 1: Output temperature Vs TOD for mass flow rate of 0.013113 kg/s



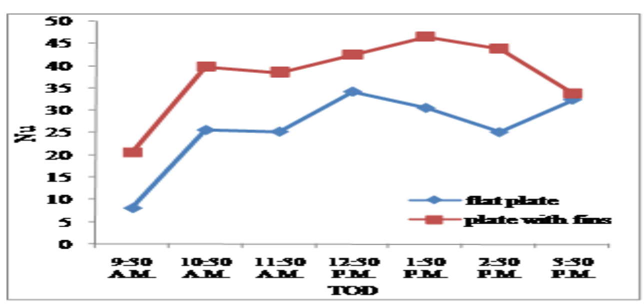
Graph 2: Output temperature Vs TOD for mass flow rate of 0.015069 kg/s



Graph 3: Temperature difference ΔT Vs TOD for mass flow rate of 0.013113 kg/s



Graph 4: Heat Gain Q Vs TOD for mass flow rate of 0.013113 kg/s



Graph 5: Nusselt Number (Nu) Vs TOD for mass flow rate of 0.013113 kg/s

VIII. RESULT

- ✓ The maximum outlet temperature of plate with fins is 65°C and at the same time the temperature for flat plate is 63°C.
- ✓ Maximum temperature difference which we are getting from this experiment is 12°C for plate with fins and that for flat plate is 7°C.
- ✓ The maximum value of heat gain obtained is 119.6004
- ✓ J/s for plate with fins at mass flow rate of 0.009892 kg/s at 1:30 P.M. At same flow rate and same time maximum efficiency of air heater with fin and
- ✓ reflector found 9.16 % at same time flat plate air heater has efficiency 3.77 %
- ✓ The maximum value of Nusselt number is 154.5313 for plate with fins and that for flat plate is 123.223
- ✓ There is maximum % change in the value of heat gain is 59.08721% for mass flow rate of 0.009892 kg/s

VII. CONCLUSION

The study of forced discharge of heat transfer from horizontal rectangular plate solar-air heater has been studied experimentally by this research. We are studied five different types of parameter with respect to time of day. These are like outlet temperature, temperature difference between inlet and outlet temperature, heat gain by aluminium plate, Nusselt number and % change in heat gain of solar air heater. This investigation is conducted for 3 days in the month of April 2019.

- ✓ It is noticed that all the parameters which we have studied are dependent on solar intensity.
- ✓ From analysis of data we concluded that the outlet temperature of plate with fin is always more than that of flat plate.
- ✓ It is observed that heat gain is dependent on time of day, Generally the maximum value of heat gain is obtained in the time span of 12:30 P.M. to 1:30 P.M. for all values of mass flow rate.
- ✓ For mass flow rate of 0.009892 kg/s at 1:30 P.M. maximum efficiency of air heater with fin and reflector found
- ✓ From the calculated data the value of Nusselt number is found to be maximum between the timing of 12:30 P.M. to 1:30 P.M.
- ✓ From graph we concluded that the value of % change in heat gain is varying with respect to time of day as well as solar intensity.
- ✓ From all analysis it is seen that the value of heat gain for both plate is maximum for lower value of mass flow rate.

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