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An Experimental Performance Evaluation of Parabolic Reflector Assisted Evacuated Tube Solar Air Heater

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ABSTRACT

The performance of parabolic reflector assisted solar air heater is evaluated experimentally in this present study. The evacuated tubewith parabolic reflector assisted solar air collector consists of thirty evacuated tubes and a header.In this experimental arrangement air flow rates of 170 kg/hr, 190 kg/hr and 205 kg/hr is maintained in the header. The headertube is divided into two half in centre through which air flows. The exit temperature, temperature difference and efficiency are studied for the air velocities of 6.1 m/sec, 7 m/sec and 7.8 m/sec.The parabolic reflectors are used to enhance the performance of evacuated tubesolar air heater. It is observed that in the parabolic reflector assisted evacuated tube solar air heater's outlet temperature and maximum temperature difference are found to be 87.9°C and 55.6°C at the flow rate of 205 kg/hr.The maximum efficiency of the collectorwith parabolic reflector is82.24% for the flow rate of205kg/hr. The maximum average solar air heater efficiency is 68.87%for parabolic reflector assisted evacuated tube collector for the mass flow rate of 205 kg/hr. The maximum heat collection was found to be 3185.05 J/sec and the average heat collection is 2532 J/sec during the testing time for the mass flow rate of 205 kg/hr.

Keywords: Thermal Performance, Evacuated Tube Solar Air Heater, Parabolic Reflector, Air HeaterEfficiency, Solar Collector, Solar Air Heater.

1. INTRODUCTION

Ever increasing population and standard of living leads to exhaust of the known conventional energy sources. Since the development of renewable energy application wherever is feasible is important for the future to balance energy requirements coupled with every countries commitment at the multilateral forum level to produce certain percentage of their energy consumption through renewable energy. Solar energy among the sources of renewable energy is one of the options. Solar energy is inexhaustible source of energy and it is an environmentally clean and free source of energy. Direct solar thermal applications have distinct advantage over other indirect applications. The direct solar thermal applications include solar air heating for space heating, refrigeration and air conditioning, and drying of agriculture and industrial products. Traditionally solar flat plate collectors are used for direct air heating requirements. At present for increased air outlet temperature and better performance evacuated tube assisted solar collectors are tried for air heating.Vishal Dabra *et al.*, [1] analysed the performance of air heater in radiator type arrangement of tubes using evacuated tube with the tilt angle of 30^{o} to 45^{o} and concluded that the performance of the evacuated tube with or without reflector is better at the tilt angle of 30^{o} and proved that beyond 30^{o} inclination of evacuated tubes had no positive effect on thermosyphon phenomenon inside the evacuated tubes and hence the performance. Liangdong Ma *et al.*, [2] analysed the performance of evacuated tube with 'U' tube with and without copper ring fin between inner absorber tube and 'U' tube and concluded both experimentally and analytically that the copper ring fin increases the efficiency of the evacuated tube with 'U' tube collector.Siddharth Arora *et al.*, [3]analysed the performance of evacuated tube with heat pipe assisted evacuated tube solar collector to supply heat to refrigeration through water as working medium and concluded that the air gap between the heat pipe inner tube and collector tube plays important role in the performance. Ashish Kumar*et al.*, [4] studied the performance of evacuated tube assisted solar air heater as direct heating of the air in the glass tubes with and without reflector at different mass flow rate and concluded that with reflector assisted arrangement the outlet temperature and efficiency is maximum.Pin-Yang Wang*et al.*, [5] conducted an experiment on 10 linked evacuated tube solar air heater with concentrating parabolic reflector with 'U' shaped copper tube and concluded that the system has high thermal performance, and the air gains heat gradually and proved through simulation that the outlet temperature of air can reach 200^{o}C.Selvakumar P *et al.*, [6] conducted an experiment on evacuated tube evacuated tube solar collector using therminol D-12 as heat transfer fluid coupled with parabolic trough for water heating purposes and concluded that the efficiency of therminol based evacuated tube collector coupled with parabolic trough is 40% more than that of water based evacuated tube collector coupled with parabolic trough. LamnatouChr*et al.*, [7] analysed the thermodynamic performance analysis of a solar tunnel dryer with an evacuated tube collector in which air heated directly in evacuated tubes and suggested same arrangement can be extended to industrial scale. In this experimental study a novel solar air heater is designed and developed with different air flow configuration and header matrix for drying of agriculture products/vegetable/Fruitswith an evacuated tube air collector with parabolic reflector to enhance the performance, and air heater's collector performance is evaluated at three different mass flow rates.

2. EXPERIMENTAL SETUP

The solar air heating system consists of a 125 mm diameter pipe header is concentrically placed in the 300 mm diameter pipe both of length 2250 mm with 30 number of 12.7 mm GI pipes connected to the 125 mm diameter pipe header and is inserted in Evacuated Tubes to a length of 1300 mm. The Evacuated tubes are connected to 300 mm diameter pipe. The collector header is divided into two parts, in the first fifteen numbers of tubes the air flows in downward direction in the GI pipes and upward direction in the remaining fifteen numbers of tubes. The 300 mm diameter tube is insulated with 50 mm fiberglass insulation. The twin glass evacuated tube collector is made of borosilicate of 1.6mm thickness, and the gap between the glass tubes is evacuated. The inner tube of the collector is coated with a three-layer magnetron sputter coating. Heat loss due to convection, conduction, and radiation is thus minimized, and it can withstand high temperature. The evacuated tube has inner and outer diameter of 38 mm and 48 mm respectively. The length of the evacuated tube is 1500 mm. The Collector has a dimension of 2250 mm X 1500 mm. The collector is placed at optimum tilt angle in accordance with the latitude and longitude of Chennai (13.084^{o}N, 80.27^{o}E) Tamilnadu, India along North-South direction, facing south to track maximum solar radiation throughout the day. This collector is used as a heat source for air heater. A blower motor of 0.375 KW,with three speedregulator to control the rate of flow of air is attached at the inlet of the solar collector to blow air into the collector.Temperature at inlet and outlet of the collector is measured with the help of k – type thermocouples connected to 12 point data logger and display unit, besides a hygrometer is attached to measure relative humidity. Solar insolation is measured using a solar power meter (TENMARS-TM207).The blower motor is then switched on. The air that is passed through the evacuated tube collector gets heated up.To enhance the performance of solar air heater parabolic reflectors are placed below the evacuated tubes.The arrangement of the experimental setup is as shown in the Figure-1. The experiment is conducted for air heater with parabolic reflector assisted evacuated tube for the air flow rate of 170kg/hr, 190kg/hr and 205kg/hrat the velocities of 6.1 m/sec, 7 m/sec and 7.8 m/sec. During the experiment, ambient temperature, relative humidity and wind velocity, solar insolation, inlet and outlet temperatures of the collector are recorded on hourly basis from 08.30 am to 04.30 pm.

Figure -1 Experimental setup with ParabolicReflectors

3. EXPERIMENTAL DATA ANALYSIS

The inlet temperature (T_{in}) and outlet temperature (T_{out}) of the Evacuated tube collector are recorded at one hour time interval. The mass flow rate (m_a) of the air is recorded. The solar insolation (I) is recorded at one hour time interval. With aperture area (A_p), Specific heat of air (C_{pa}) and number of Evacuated Tubes (N) are known; the Solar collector heat collection rate, Solar collection heat supplied and efficiency is given by

$$\text{Solar Collector Heat Collection Rate } Q_c = m_a C_{pa} (T_{out} - T_{in})$$

$$\text{Solar Collector Heat Supplied } Q_s = N A_p I$$

$$\text{Evacuated Tube Collector Efficiency } \eta = \frac{Q_c}{Q_s}$$

The aperture area 'A_p' of the evacuated tube collector be taken as 2(L x D),Length of the evacuated tube 'L' and Diameterof the evacuated tube 'D' is takenfor parabolic reflector assisted evacuated tube solar air collector.

4. RESULTS AND DISCUSSION

In this experimental setup the air is the heated directly in the evacuated tube collectors at three different air flow rates of 170 kg/hr, 190 kg/hr and 205 kg/hr. The experiment is performed for these three flow rates and the performance of solar air heater is evaluated with parabolic reflector is placed below the evacuated tubes to enhance the performance. The experiments were carried out during the month of March 2015 from 8.30 A.M. to 4.30 P.M on clear sky days.

4.1 Evacuated Tube Collector with Flow Rate of 170kg/hr

At the air flow rate of 170 kg/hr with parabolic reflector assisted evacuated tube air collector, it is observed that the temperature of exit air from the evacuated tube solar collector steadily increases and it attains the maximum at 12.30 P.M. and decreases afterwards.The air velocity of 6.1 m/sec measured at the header pipe outlet. The other metrological parameters of air velocity and relative humidity at the experiment site is notedwhich is shown in the Table-1.

Table –1 Hourly Variation of Wind Velocity, Relative Humidity and Temperature

Time	8.30 A.M	9.30 A.M	10.30 A.M	11.30 A.M	12.30 P.M	13.30 P.M	14.30 P.M	15.30 P.M	16.30 P.M
WindVelocity m/sec	0.8	0.8	0.4	0.6	0.3	0.6	1.8	2.0	2.3
RH in %	84.5	68.5	58.5	46.5	41	41	35	32.5	50.5
T_{in} ^oC	27.6	30.3	32.6	34.8	36.7	36.4	37.7	35.2	32.2
T_{out} ^oC	52.5	65	71.5	74.5	77.4	75.1	74.5	55.1	40.4

The relative humidity varies from 32.5% to 84.5% and wind velocity varies from 0.4 m/sec to 2.3 m/sec. Figure-2 shows the variation of inlet, exit, and temperature difference of airwith time in parabolic reflector assisted evacuated tube collector solar air heater. The exit temperature varies from 40.4^{o}C to 77.4^{o}C. The inlet temperature varies from 27.6^{o}C to 37.7^{o}C.The temperature difference varies from 8.2C to 40.7^{o}C.

The solar intensity varies from 244 W/m^2 to 1186 W/m^2. Figure-3 shows the variation of solar intensity and efficiency of the parabolic reflector assisted evacuated tube solar air heater. The maximum solar intensity is 1186W/m^2 at 12.30 P.M. The maximum solar intensity is achieved during the 12.30 P.M., after that it starts decreases till the end of the day. The exit temperature and temperature difference of air in parabolic reflector assisted evacuated tube collector depend upon solar intensity and air flow rate.

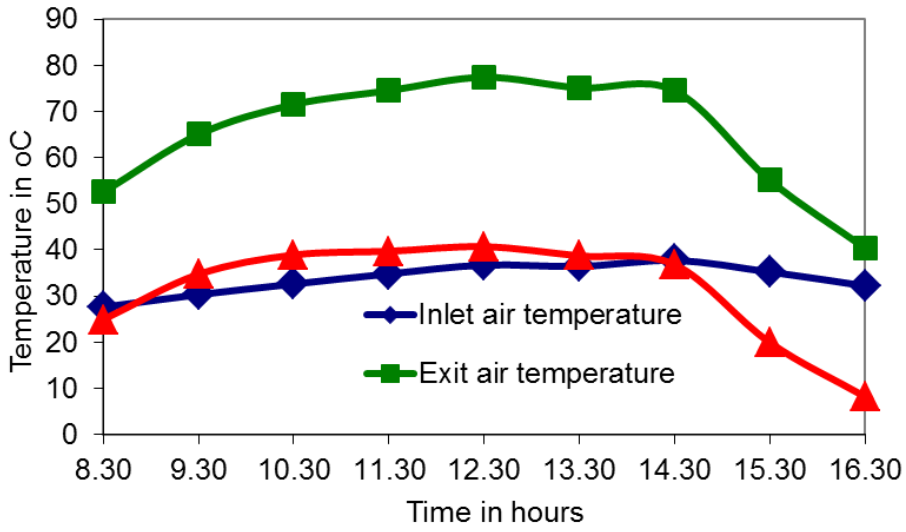

Figure -2 Variations of Air Inlet, Exit Temperatures and Temperature Difference

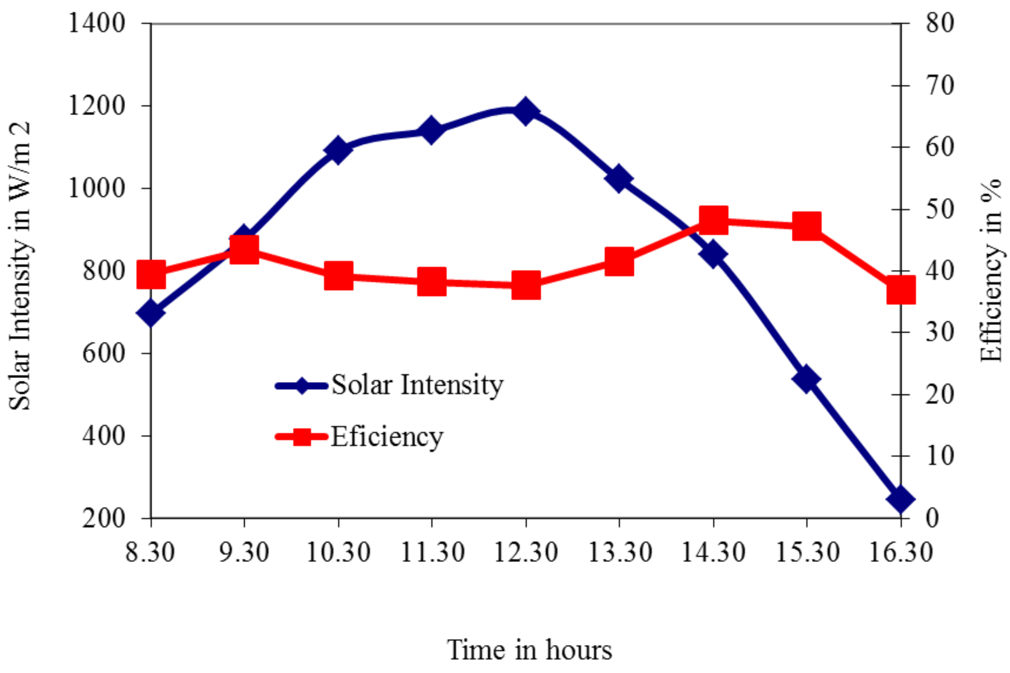

Figure -3 Variations of Solar intensity and Efficiency

Since the solar radiation absorption is high in the evacuated tubes the outlet air temperature of air increases at higher rate than the ambient temperature.After 12.30 P.M when the solar intensity decreases, the inlet, exit temperatures and temperature difference of air also decreases. The efficiency of the evacuated tube assisted solar air heater varies from 36.90% to 48.11%. It is observed from the figure that form 9.30 A.M to 12.30 P.M the solar intensity increases from 878 W/m^2 to 1091 W/m^{2}but the efficiencydecreasesfrom 43.34% to 37.68% may be due to heating of header matrix and radiation may be fluctuating. But the heat carried by the air increases from 1646.02 J/sec to 1930.64 J/sec shows increased solar collector's heat collection rate. From 1.30 P.M. to 2.30 P.M the solar radiation decreases from 1022 W/m^2 to 840 W/m^2 and the efficiency of the collector increases from 41.57% to 48.11%. This may be due to heat release by the header matrix and fluctuation in solar intensity. This can be absorbed from solar collector's heat collection rate decreases from 1835.77 J/sec to 1745.64 J/sec. For this air flow rate of 170 kg/hr the average efficiency is found to be 41.28% and average solar collector's heat collection rate is 1506.35J/sec.

4.2 Evacuated Tube Collector with Flow Rate of 190kg/hr

At the air flow rate of 190 kg/hr with parabolic reflector assisted solar collector, it is noted that the temperature of exit air steadily increasesand attains the maximum of 80.6^{o}C at 1.30 P.M. and decreases in the evening.The air velocity of 7 m/sec is noted at the header pipe outlet. The other metrological parameters of wind velocity, relative humidity at the experiment site is noted which is shown in the Table-2.

Table –2 Hourly Variations of Wind Velocity, Relative Humidity and Temperature

Time	8.30 A.M	9.30 A.M	10.30 A.M	11.30 A.M	12.30 P.M	13.30 P.M	14.30 P.M	15.30 P.M	16.30 P.M
WindVelocity m/sec	1.2	0.5	0.2	0.9	1.8	1.1	1.9	0.9	0.8
RH in %	84	65.5	43	30.5	27.5	25	26	33.5	39.5
T_{in}^{o}C	29.5	30.3	32.1	34.5	35.3	35	35.2	34.4	33.6
T_{out}^{o}C	54.9	65.4	73.1	77.1	79.9	80.6	78.7	63.9	52.8

The relative humidity varies from 25% to 84% and wind velocity varies from 0.2m/se to 1.9 m/sec. Figure-4shows the variation of inlet, exit, and temperature difference of airwith time in parabolic reflector assisted evacuated tube solar air heater. The exit temperature varies from 52.8^{o}C to 80.6^{o}C. The inlet temperature varies from 29.5^{o}C to 35.3^{o}C and the temperature difference varies from 19.2^{o}C to 45.6^{o}C.

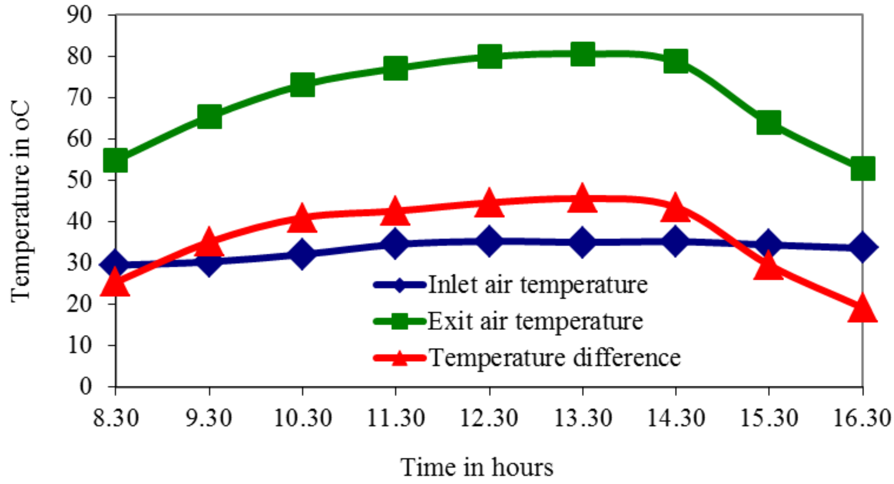

Figure -4 Variations of Air Inlet, Exit Temperatures and Temperature Difference

The solar intensity varies from 446 W/m^2 to 1275 W/m^2. Figure-5 shows the solar intensity during experiment and efficiency of the parabolic reflector assisted evacuated tube solar air heater. The maximum solar intensity is 1275W/m^2 at 11.30 A.M. The maximum solar intensity is observed at 11.30 A.M and fluctuates upto 1.30 P.M. after that it starts decreases with time.

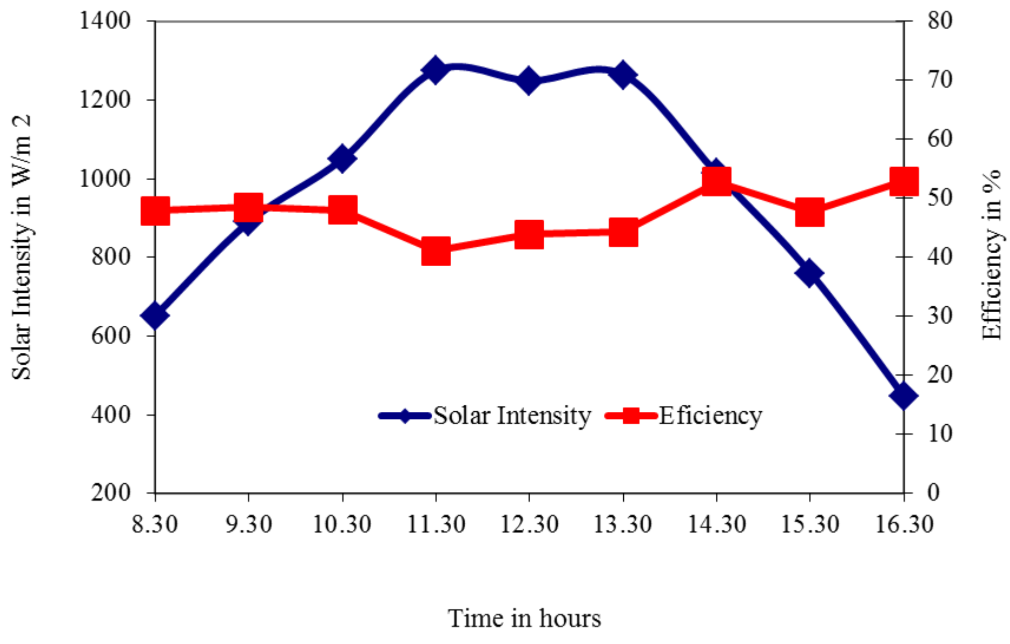

Figure -5 Variations of Solar intensity and Efficiency

The maximum exit temperature and temperature difference of air are 80.6°C and 45.6°C observed at 1.30 P.M. The efficiency of parabolic reflector assisted evacuated tube solar air heater varies from 41.04% to 52.88%. It is noted from the figure that from 9:30 A.M. to 11.30 A.M. when solar intensity increases the efficiency of the parabolic reflector assisted solar air heater decreases; this may be due to heating of header matrixand fluctuation in solar radiation intensity. During this same time period the heat collection rate in the solar collector increases from 1862.55 J/sec to 2260.53 J/sec. The reverse phenomenon is observed during 1.30 P.M to 2.30 P.M.as solar intensity decreases but the efficiency increases. This may due to heat release by the header matrix and fluctuation in solar radiation intensity. The heat collection rate in the parabolic reflector assisted solar collector decreases from 2419.72 J/sec to 2308.28 J/sec during this period.For this air flow rate of 190 kg/hr the average efficiency is found to be 47.41% and average solar heater heat collection rate is 1925.04 J/sec.

4.3Evacuated Tube Collector with Flow Rate of 205kg/hr

At the air flow rate of 205 kg/hr with parabolic reflector assisted evacuated tube solar air heater, it is found that the temperature of exit air from the evacuated tube solar air heater steadily increases and it attains the maximum at 12.30 P.M. and decreases in the afternoon thereafter.The air velocity in the solar air heater is observed at the header pipe outlet and found to be 7.8 m/sec. The other metrological parameters of relative humidity and air velocity at the experiment site is noted which is shown in the Table-3.

Table –3 Hourly Variationsof Wind Velocity, Relative Humidity and Temperature

Time	8.30 A.M	9.30 A.M	10.30 A.M	11.30 A.M	12.30 P.M	13.30 P.M	14.30 P.M	15.30 P.M	16.30 P.M
WindVelocity m/sec	3.7	1.3	1.6	0.9	1.7	1.2	2.9	4.2	3.8
RH in %	84	73.5	60.5	58.5	52	51.5	52	57	62.5
T_{in}°C	28.5	30	31.3	31.8	32.3	32.3	32.3	31.6	30.5
T_{out}°C	56.2	75.2	78.9	81.9	87.9	82.7	76.4	73.8	65.4

The relative humidity varies from 51.5% to 84% and wind velocity varies from 0.9 m/sec to 4.2 m/sec. Figure-6 shows the variation of inlet, exit, and Temperature difference of airwith time in parabolic reflector assisted evacuated tube solar heater. The exit temperature varies from 56.2°C to 87.9°C. The inlet temperature varies from 28.5°C to 32.3°C.The temperature difference varies from 27.7°C to 55.6°C.

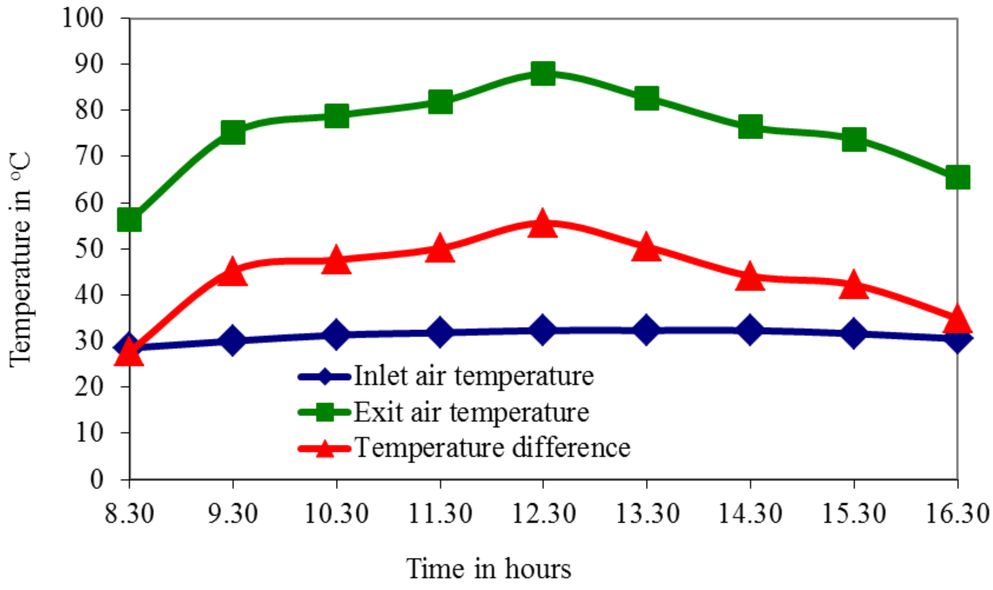

Figure -6 Variations of Air Inlet, Exit Temperatures and Temperature Difference

The solar intensity varies from 446 W/m^2 to 1196 W/m^2. Figure-7 shows the variation of solar intensity and efficiency of the parabolic reflector assisted evacuated tube solar air heater. The maximum solar intensity is 1175 W/m^2 at 12:30 P.M., after that it starts decreases with time.

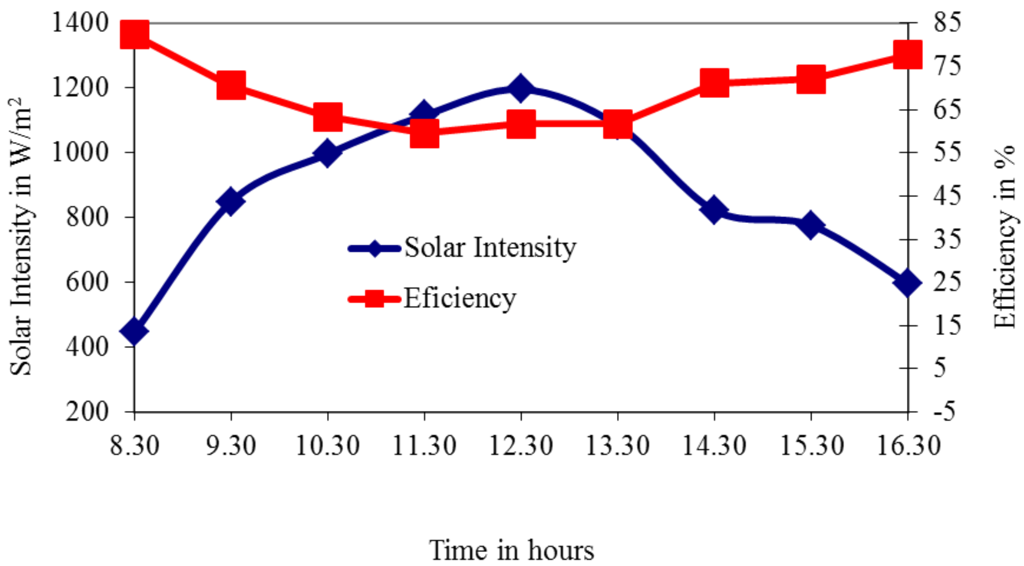

Figure -7 Variations of Solar intensity and Efficiency

The efficiency of the solar air heater varies from 59.52% to 82.24% during the testing day. It is noted that from 8.30 A.M to 11.30 A.M the solar intensity increases from 446 W/m^2 to 1116 W/m^2 and the efficiency decreases from 82.24% to 59.52%. This may be due to heating of header matrix and fluctuation in solar intensity during this time. But the heat collection rate of this parabolic reflector assisted solar air heater steadily increases from 1586.79 J/sec to 2869.98 J/sec during this time. From 11.30 A.M.to 12.30 P.M the solar intensity increases from 1116 W/m^2 to 1196 W/m^2 and the efficiency also increases from 59.52% to 61.65%. The solar heat collection rate increases from 2869.98 W/m^2 to 3185.05 W/m^2. From 12.30 P.M to 4.30 P.M the solar intensity continuously decreases from 1196 W/m^2 to 596 W/m^2 and efficiency continuously increases from 61.65% to 77.65%. This may be because of release of heat from header matrix to air and fluctuation of solar intensity. This may rightly be observed from the heat collection rate of the parabolic reflector assisted solar air heater, which continuously decreases from 3185.05 W/m^2 to 1999.25 W/m^2 during this time period. For this air flow rate of 205 kg/hr the average efficiency is found to be 68.87% and average solar heater heat collection rate is 2532 J/sec.

5. CONCLUSION

The maximum efficiency of 82.24% for the mass flow rate of 205 kg/hr is observed for parabolic reflector assisted evacuated tube solar air heater collector. The parabolic reflector assisted evacuated tube solar collector/air heater performance is evaluated for mass flow rates of 170 kg/hr, 190 kg/hr and 205 kg/hr. It is noted from this experimental study that the increase in mass flow rate leads to increase in efficiency of the collector. In this solar air heater the wind velocity has no effect and relative humidity do not have considerable influence on evacuated tube collector performance for all modes of mass flow rate, since it makes use of evacuated tube collector. The temperature of outlet air of parabolic reflector assisted air heater steadily increases at higher rate than the ambient temperature due to high absorption rate of solar radiation in evacuated tubes.

The average solar intensity for parabolic reflector assisted evacuated tube solar air heater for mass flow rates of 170 kg/hr, 190 kg/hr and 205 kg/hr are 844.44 W/m^2, 955.44 W/m^2 and 875.78 W/m^2 respectively. The average efficiency efficiencies are 41.28%, 47.41% and 68.87% for these three different mass flow rates. The maximum average efficiency of 68.87% is observed forparabolic reflector assisted evacuated tube solar air collector for the mass flow rate of 205 kg/hr.

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