COMPARISON OF RESULTS OF SOLAR COLLECTOR WITH INLINE AND PERFORATED W SHAPE RIB ROUGHENED ABSORBER PLATE

ABSTRACT:

Solar air heater is one of the commonly used thermal collection equipment because it is easy to use and maintain. In general, for using smooth surface or plane plate of solar air heater, the energy saving in the form of thermal performance is quite low due to low convective heat transfer coefficient. It can be enhanced by employing passive methods in the form of artificial irregularity on the absorber plate of solar air heaters. This paper presents results of a study of the performance of solar air heaters with W-shaped inline and staggered perforated fin as roughness on the air flow side of the absorber plate. Investigations have been carried out by testing the collector under clear sky with available solar radiations intensity with variation in mass flow rate of air passing through collector ranging from 0.01484 kg/sec to 0.01726 kg/sec for three different absorber plates. Collector efficiency has been evaluated for plane absorber plate and compared with the absorber plate having inline and staggered W shape perforated rib roughened absorber plate. It is found that instantaneous collector efficiency for staggered W shape perforated fin roughened absorber plate solar collector is 18 % higher as compared with plain absorber plate solar collector for mass flow rate of 0.01726 kg/sec and 12 % higher than the absorber plate with inline W shape rib roughened absorber plate collector. Enhancement in the collector efficiency is due to the increase in the turbulence of the air for staggered W shape absorber plate solar collector. The instantaneous collector efficiency increases with increase in intensity of solar radiation and mass flow rate of air passing through the collector. The results of the study are presented in the form of plots to show the effect of ambient, design and operating conditions collector efficiency.

Keywords: Solar air heater. Flat plate collector (FPC), rib roughened surfaces, perforated fins

INTRODUCTION:

Energy is a decisive driving factor in today's world and plays foremost role in economic growth and industrial development. Population progression and its material needs increase the mandate of energy every year. On the other side, depletion of fossil fuel reduces the available resource and cause to environmental deprivation and it creates the consciousness towards renewable energy sources. Considering other alternatives, solar energy positions an encouraging future of renewable energy. Solar energy is free and offers an unlimited and eco-friendly reservoir of energy. The easiest way to exploit solar energy is by transforming it into thermal energy using solar collectors.

Solar energy is the energy source that is existing freely and applicable never-ending used. The maximum useful work of solar energy is needed to increase efficiency of the thermal collection apparatus. Solar air heater is one of the commonly used thermal collection equipment because it is easy to use and maintain. In general, for using smooth surface or plane plate of solar air heater, the energy saving in the form of thermal concert is quite low due to lower convective heat transfer.

The importance of heat transfer enhancement has gained greater significance in such areas as microelectronic cooling, especially in central processing units, macro and micro scale heat exchangers, gas turbine internal airfoil cooling, fuel elements of nuclear power plants, and bio medical devices. A tremendous amount of effort has been devoted to developing new methods to increase heat transfer from fined surface to the surrounding flowing fluid. Rib turbulators, an array of pin fins, and dimples have been employed for this purpose.

In case of the electronics industry, due to the demand for smaller and more powerful products, power densities of electronic components have increased. The maximum temperature of the component is one of the main factors that control the reliability of electronic products. Thermal management has always been one of the main issues in the electronics industry, and its importance will grow in coming decades.

Heat sink performance can be evaluated by several factors: material, surface area, flatness of contact surfaces, configuration, and fan requirement.

Aluminum is the most common material because of its high conductivity (205W/mK), low cost, low weight, and easiness with respect to manufacturability. Copper is also used for heat sinks because of very high conductivity (400W/mK), but its disadvantages include high weight, high price, and fewer choices as far as production methods. To combine the advantages of aluminum and copper, heat sinks can be made of aluminum and copper bonded together.

Solar thermal energy is the cheapest and widely available renewable energy that often replaces fossil-fuelled or electrical water heating, reducing utility bills and greenhouse gas emissions. All the developed nations are in the process of promoting the use of solar energy for various applications. India is endowed with a high solar energy potential. India is actively pursuing the development of renewable energy technologies, especially solar based technologies, as high solar radiation is present in major regions, with a majority of days of clear sun.

To obtain higher performance from a heat sink, more space, less weight, and lower cost are necessary. Thus, efforts to obtain more optimized designs for heat sinks are needed to achieve high thermal performance. One method to increase the convective heat transfer is to manage the growth of the thermal boundary layer. The thermal boundary layer can be made thinner or partially broken by flow disturbance. As it is reduced, by using interrupted and/or patterned extended surfaces, convective heat transfer can be increased. Pin fins, protruding ribs (tabulators), louvered fins, offset-strip fins, slit fins and vortex generators are typical methods.

The pattern and placements are suitably chosen based on the required cooling.

Heat transfer inside flow passages can be enhanced by using passive surface modifications such as rib tabulators, protrusions, pin fins, and dimples. These heat transfer enhancement techniques have practical application of internal cooling of turbine airfoils, combustion chamber liners and electronics cooling devices, biomedical devices and heat exchangers.

Ribs are used to increase the heat transfer rate from surface to the surrounding fluid when 'h' value is generally smaller on the surface. Familiar examples are the ribs around the blades of gas turbine. The use of ribs, in addition to enhancing heat transfer coefficient considerably, results in higher frictional penalty. These ribs, which are also known as tabulators, increases the level of mixing by turbulence and disturb the laminar sub-layer, also increases the surface area for convective heat transfer, thereby enhances the cooling capacity of the passage. The use of ribs, in addition to enhancing heat transfer coefficient considerably, results in higher frictional penalty. Hence, it is essential to optimize the geometrical parameters of the artificial roughness (ribs) in order to achieve the maximum possible enhancement in heat transfer with minimum frictional penalty.

Solar air heater have low effectiveness because of low heat transfer coefficient between the air and absorber plate which leads to greater temperature of absorber surface due to which more thermal losses occurs. It was found that the major resistance to the convective heat transfer coefficient is due to the creation of the boundary layer on the heat conveying surface. Attempt has to be made to interrupt this layer by using artificially roughened planes. Artificial irregularity has been used to create the turbulence in the laminar sub layer. Thus the artificial roughness can be used for the augmentation of heat transfer coefficient between the absorber plate and air, improving the thermal performance of solar air heater. Opposing to this by providing more disturbances across the layer will cause more pumping power essential which increase the friction which results in reduction of effective efficiency. Solar collector efficiency can be enhanced by employing passive methods in the form of artificial irregularity on the absorber plate of solar air heaters. Numerous techniques have been developed for enhancing the heat transfer rate between the airflow and the absorber plate. In the solar air heater design, fin, baffle, rib, groove, wing and winglet are regularly introduced in order to increase the convective heat transfer rate leading to the compact heat exchanger and the increase in thermal performance. Another way of increasing the heat transfer rate is to employ ribs with perforations or disconnected ribs. The perforated ribs or blocks allow a part of the flow to pass through the punctures and hence the hot zone and form drag are decreased. Thus the perforated elements improve the heat transfer rate with lower pressure loss consequence.

The main components of a solar air heater are an absorber plate, one or more channels for the flow of air, insulation for the bottom and lateral sides of the solar collector and one or more transparent covers. The use of a blower is optional for the air supply. Detailed information is as follows.

This work aims to investigate the thermal performance of the solar flat plate collector with inline and staggered W shape perforated rib roughened absorber plat. The performance of the collector has been predicted with variation in mass flow rate for three different absorber plates.

Objectives:

Following are the research objectives for proposed work:

- To study effect of artificially roughened absorber plate on the rate of heat transfer.
- To find the instantaneous collector efficiency of flat plate solar collector at different mass flow rate of air.
- To find the effect on instantaneous collector efficiency with Inline and staggered W-shaped perforated absorber plate solar collector.
- To find the effect on temperature rise across the FPC with Inline and staggered W-shaped perforated absorber plate solar collector.

DESIGN AND DEVELOPMENT OF EXPERIMENTAL SYSTEM:

Experimental system has been developed with Flat plate solar collector, blower and flow regulating arrangement with orifice meter to measure the mass flow rate of air and the temperature sensors along with digital temperature indicator to measure the inlet and outlet temperature off the air. A flat-plate collector consists cover (the glazing) and a black coloured absorber plate . Solar radiation is absorbed by the absorber plate and transferred basically through an insulated metal box with a glass or plastic to air that circulates through the collector. The air taken from the atmosphere pressurises when it passes through the blower, the pressurised air then flows through the flow control valve where flow is regulated. Air then passes through the orifice meter, which is used to calculate the discharge. The air is fed to the solar collector where is absorbs the heat from the absorber plate which receives the heat from incident solar radiations. The heated air then taken out from the outlet of the collector. The temperature sensors (RTD) are mounted at inlet and outlet of the collector to measure the air inlet and outlet temperature.

1. The Flat Plate collector is used for air heating purpose which further is supplied to the chamber using blower. Specifications of the Flat Plate collector are:

   Reflecting material used = Aluminum
   Dimensions of collector:
   Effective aperture area = 0.8m
   Aperture width =0.8m

Fig: Flat Plate Collector

2. **Blower**

   Blower is implemented for carrying out forced convection.

   The specifications of the blower are:

   Volume flow rate: 500CFM

   Pressure head: 200 mm of water

   Motor power: 2HP

3. **Orifice meter with U- tube manometer**
   - Orifice diameter = 16 mm
   - U tube manometer having range 200 - 0 -200 mm

LAYOUT OF EXPERIMENTAL SET UP

The Flat Plate collector is used for air heating purpose. The air is supplied to the collector using blower. Physical parameters of the solar air heating systems are

Overall Size of the collector = Length * Width* Height=1000m*800mm*150mm

- Specifications of the Flat Plate collector are:
- Reflecting material used = Aluminum
- Dimensions of collector
  - Effective aperture area = 0.8 m^2
  - Aperture width =0.8 m
  - Length of collector: 1 m
- Reflecting material used = Aluminum
- Glass area 0.8 m2
- Collector glazing Window glass with 3 mm thickness
- Bottom insulation 50 mm thickness of glass wool

Three absorber plates are used for the experimental investigation. The details of the absorber plate are given below.

Absorber plate Width: 800 mm, length: 1000 mm

- Plane plate
- Absorber plate with Inline W shaped perforated ribs (Fig. 2)
- Absorber plate with Staggered W shaped Perforated ribs (Fig.3)

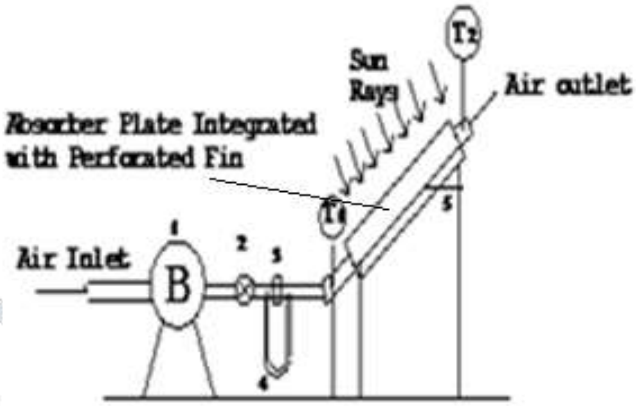

Fig.1: Schematic layout of experimental set up

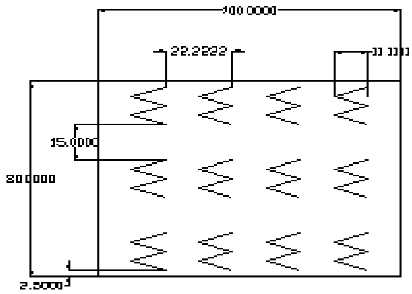

Fig.2: Inline W shape perforated rib roughened absorber plate

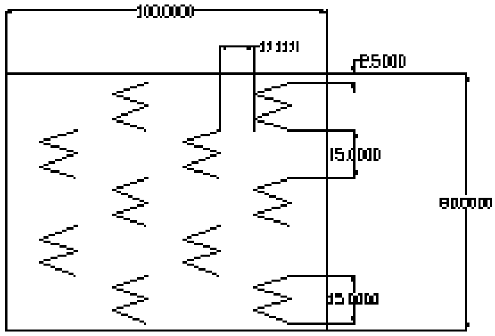

Fig.3: Staggered W shape rib roughened absorber plate

Proposed experimental system for Performance investigation of temperature variation from flat plate different absorber surface consists of the components like Blower, G. I. Pipe for connection, Flow control valve, Orifice meter with U tube manometer, Acrylic sheet duct, Voltmeter, Ammeter, Dimmerstat, plate type heater, Temperature sensors, Temperature indicator, Insulating materials, air vane anemometer etc.

TEST METHODOLOGY

The experiments were carried out using different test conditions. The mass flow rate of air was varied and the subsequent effects on the temperature rise were calculated. Also studied the effect of using FPC with three different configuration of absorber plate. Initially the experiment was carried out with plane absorber plate and then with inline W shaped perforated fin absorber plate and staggered W shaped perforated fin absorber plate

The mass flow rate of air was varied from 0.01726 kg/sec to 0.01484 kg/sec. The experiments were conducted throughout the day for given absorber plate and mass flow rate of air. The mass flow rate was measured with the help of orifice meter and temperatures were recorded from Temperature indicator. The Solar radiations are measured with the help of radiation pyranometer. The instantaneous collector efficiency is calculated at a particular instant of time.

RESULTS:

The inlet and outlet temperature readings are taken for the flat plate collector at the time interval of half hour and results are obtained for the different mass flow rate varying from **0.01484 kg/sec to 0.01726 kg/sec.** the experiment was carried out with plane absorber plate and then with inline W shaped perforated fin absorber plate and staggered W shaped perforated fin absorber plate.

From the obtained observations the Solar Radiation intensity is calculated for different mass flow rates, these are given as follows:

Table 5.1.Variation of intensity of solar radiation for mass flow rate = 0.01484kg/s

Time am/pm	Solar Radiation Intensity(w/m^2)		
	Plane Absorber Plate	Perforated Inline W shaped Fin Absorber Plate	Perforated Staggered W shaped Fin Absorber Plate
10.00	638	640	653
10.30	715	705	727
11.00	799	780	813
11.30	854	860	873
12.00	927	920	950
12.30	940	935	967
1.00	974	955	990
1.30	940	950	970
2.00	915	920	920
2.30	845	850	852
3.00	755	765	772
3.30	674	650	688
4.00	554	555	568
4.30	476	475	502
5.00	459	440	465

Table 5.2.Variation of intensity of solar radiation for mass flow rate = 0.01569 kg/s

Time am/pm	Solar Radiation Intensity(w/m^2)		
	Plane Absorber Plate	Perforated Inline W shaped Fin Absorber Plate	Perforated Staggered W shaped Fin Absorber Plate
10.00	653	643	640
10.30	727	711	705
11.00	813	793	780
11.30	873	850	860
12.00	950	931	920
12.30	967	945	935
1.00	990	970	955
1.30	970	945	950
2.00	920	910	920
2.30	852	840	850
3.00	772	760	765
3.30	688	670	650
4.00	568	550	555
4.30	502	480	475
5.00	465	455	440

Table 5.3.Variation of intensity of solar radiation for mass flow rate = 0.01649 kg/s

Time am/pm	Solar Radiation Intensity(w/m^2)		
	Plane Absorber Plate	Perforated Inline W shaped Fin Absorber Plate	Perforated Staggered W shaped Fin Absorber Plate
10.00	643	638	638
10.30	711	715	715
11.00	793	799	799
11.30	850	854	854
12.00	931	927	927
12.30	945	940	940
1.00	970	974	974
1.30	945	940	940
2.00	910	915	915
2.30	840	845	845
3.00	760	755	755
3.30	670	674	674
4.00	550	554	554
4.30	480	476	476
5.00	455	459	459

Table 5.4.Variation of intensity of solar radiation for mass flow rate = 0.01726kg/s

Time am/pm	Solar Radiation Intensity(w/m^2)		
	Plane Absorber Plate	Perforated Inline W shaped Fin Absorber Plate	Perforated Staggered W shaped Fin Absorber Plate
10.00	640	653	643
10.30	705	727	711
11.00	780	813	793
11.30	860	873	850
12.00	920	950	931
12.30	935	967	945
1.00	955	990	970
1.30	950	970	945
2.00	920	920	910
2.30	850	852	840
3.00	765	772	760

3.30	650	688	670
4.00	555	568	550
4.30	475	502	480
5.00	440	465	455

From the above results, it is clear that the intensity of the solar radiation remained approximately same for the everyday of the experiment performance. The temperature varies in relation with the solar radiation intensity. The average solar radiation intensity considered for the energy calculations is 800W/m^2.

Also the variation in Flat plate collector efficiency is obtained.

Table 5.9.Variation of FPC efficiency with plane absorber plate with different mass flow rate

Time am/pm	Flat Plate Collector Efficiency (%)			
	Mass flow rate 0.01484 kg/sec	Mass flow rate 0.01569 kg/sec	Mass flow rate 0.01649 kg/sec	Mass flow rate 0.01726 kg/sec
10.00	15.27	17.89	20.40	23.50
10.30	15.99	19.35	21.09	25.66
11.00	17.12	19.48	21.53	27.66
11.30	18.65	21.32	22.54	29.14
12.00	18.80	21.69	24.16	29.14
12.30	20.13	22.95	25.56	30.77
1.00	20.39	23.21	25.76	30.12
1.30	22.72	25.53	25.12	30.51
2.00	22.53	26.27	28.83	30.56
2.30	23.73	27.21	29.01	32.31
3.00	21.59	23.10	27.95	30.48
3.30	21.13	22.73	27.97	30.51
4.00	20.29	20.91	26.13	28.27
4.30	19.29	21.31	24.30	27.07
5.00	18.78	21.30	24.72	26.25

the variation in the thermal efficiency of the FPC with plane absorber plate for the four different mass flow rates of the air throughout the day from 10 am to 5 pm. The maximum thermal efficiency obtained during experimentation is about 30-31% at around 2.00pm to 2.30pm for the maximum mass flow rate of 0.01726kg/sec.

Table 5.10.Variation of FPC efficiency with perforated Inline W Shaped absorber plate with different mass flow rate

Time am/pm	Flat Plate Collector Efficiency (%)			
	Mass flow rate 0.01484 kg/sec	Mass flow rate 0.01569 kg/sec	Mass flow rate 0.01649 kg/sec	Mass flow rate 0.01726 kg/sec
10.00	17.86	22.18	24.15	25.69
10.30	19.67	21.45	25.34	26.98
11.00	20.66	22.23	26.32	28.14
11.30	20.48	24.24	27.80	29.45
12.00	21.59	23.40	28.76	29.59
12.30	22.64	26.41	29.47	31.56
1.00	21.97	26.75	28.86	30.82
1.30	22.88	27.67	29.24	32.13
2.00	24.24	29.39	31.64	34.35
2.30	24.69	29.01	31.05	32.50
3.00	21.80	26.32	27.31	30.50
3.30	23.35	25.13	29.97	31.66
4.00	22.28	23.41	27.82	31.45
4.30	22.48	24.76	28.88	27.79
5.00	21.29	23.07	27.68	28.12

Table shows the variation in the thermal efficiency of the FPC with inline W shaped perforated absorber plate for the four different mass flow rates of the air throughout the day from 10am to 5 pm. The maximum thermal efficiency obtained during experimentation is about 34-35% at around 2.00pm to 2.30pm for the maximum mass flow rate of 0.01726kg/sec.

Table 5.11.Variation of FPC efficiency with perforated Staggered W Shaped absorber plate with different mass flow rate

Time am/pm	Flat Plate Collector Efficiency (%)			
	Mass flow rate 0.01484 kg/sec	Mass flow rate 0.01569 kg/sec	Mass flow rate 0.01649 kg/sec	Mass flow rate 0.01726 kg/sec
10.00	20.36	25.38	28.40	29.15
10.30	22.16	26.41	28.25	31.88
11.00	22.81	27.94	28.67	31.61
11.30	22.96	27.64	29.26	31.79
12.00	22.48	28.42	29.65	33.71
12.30	23.65	29.02	30.35	35.06
1.00	23.28	30.28	31.22	35.95
1.30	25.69	29.19	32.35	37.36
2.00	26.07	30.14	32.77	38.32
2.30	26.62	32.39	35.00	36.32
3.00	24.28	30.30	32.82	35.27
3.30	23.68	30.78	32.13	34.81
4.00	22.75	27.13	30.07	33.68
4.30	22.02	26.69	29.75	31.33
5.00	22.16	28.36	29.49	31.61

the variation in the thermal efficiency of the FPC with staggered W shaped perforated fin absorber plate for the four different mass flow rates of the air throughout the day from 10am to 5 pm. The maximum thermal efficiency obtained during experimentation is about 37-38 % at around 2.00pm to 2.30pm for the maximum mass flow rate of 0.01726kg/sec.

CONCLUSION

In this study experimental performance evaluation has been carried to investigate the variation in instantaneous collector efficiency for inline and staggered W shape perforated rib roughened absorber plate solar collector and results are compared with that of plane plate absorber plate collector. The effect of variation in mass flow rate of the air on instantaneous collector efficiency has also been evaluated.

The following conclusions were drawn from this study.

- Solar collector with artificially roughened absorber plate enhances the rate of heat transfer from absorber plate to air and thus increases the instantaneous collector efficiency of the solar collector. Thus results obtained from this study are in line with the findings of previous researcher.
- The instantaneous collector efficiency of flat plate solar collector increases with increase in mass flow rate of air.
- Enhancement obtained in instantaneous collector efficiency with staggered W-shaped perforated absorber plate solar

collector ranges from 8-12 % as compared with inline W-shaped perforated absorber rib roughened absorber plate solar collector.

- Enhancement obtained in instantaneous collector efficiency with staggered W-shaped perforated absorber plate solar collector ranges from 13-18 % as compared with plain absorber plate solar collector.
- Temperature rise across the FPC is more 2-3 ^{0}C%& 4-5 ^{0}C% in case of staggered W-shaped perforated absorber plate solar collector as compared to two others that is plane absorber plate and inline W-shaped perforated absorber plate respectively.
- The maximum temperature rise across the FPC in case of staggered W shaped perforated fin absorber plate is 16-17^{0}C % for the maximum mass flow rate of 0.01726 kg/sec.