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Experimental Analysis & Heat Transfer Enhancement of Solar Air Heater having Different Types of Roughness Element on Absorber Plate

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ABSTRACT

Solar air heaters are used to capture heat from solar radiation, give it to the working fluid and that hot fluid can be used in various applications. In present work an experimental comparison on thermal performance of double pass solar air heater has been conducted by using three different absorber plates and at different mass flow rate. Three different types of absorber plate have been used. The absorber plate's have - black colour smooth plate, black colour with V-Shaped baffles and black colour with Arc-Shaped baffles plate. Research also includes the effect of mass flow rate. In research it has been investigated that baffle solar air heater (BSAH) both with V-Shaped and Arc-Shaped baffles on black colour absorber plate has reasonably high performance to heat air as compared to conventional solar air heater (CSAH) with black colour absorber plate. The experiment evaluate that the presence of V-Shaped baffles on absorber plate in the solar air heater rises the outlet temperature, which further increases the thermal efficiency and also shows substantial potentiality to heat air in both type solar air heater. The maximum difference in temperature was found 39°C, 28°C and 18°C at m1 (0.005383 kg/s) mass flow rate in case of V-Shaped baffle, Arc-Shaped baffle and smooth black colour absorber plate solar air heater respectively. Also, the results reveal that the V-Shaped baffles are thermo-hydraulically superior as compared to the Arc-Shaped baffle and conventional solar area heater.

Keywords: Solar Air Heater, V-Shape Baffle, Arc-Shape Baffle, Thermal Efficiency, Mass Flow Rate

1. INTRODUCTION

Renewable energy is the energy obtained from the earth's natural resources that are not limited or depleted. Renewable energy is an alternative to traditional energy that relies on fossil fuels and appears to do very little harm to the environment. The most popular renewable energy sources currently are solar energy, wind energy, hydro energy and geothermal energy [1-3]. Solar thermal equipment, which absorbs the energy of the Sun and uses it to heat air, is known as a solar air heater (SAH) [2]. This renewable energy based technology is currently used for its efficiency for heating buildings or in process heat applications including food products, chemical products, manufacturing of non-metallic mineral products and etc [4]. A solar thermal equipment, which absorbs the energy of the sun and uses it to heat air, is known as a solar air heater (SAH) [5]. Solar air heaters (SAH), which are direct thermal energy converting devices capable of producing the required amount of energy to meet the energy demand in process industries and space heating. The major pitfall of conventional SAH is poor in thermal performance. Therefore, the thermal performance of the solar air heater is improved by enhancing the convective heat transfer coefficient between air and absorber plate by avoiding the laminar sublayer formation and increasing the turbulence intensity [6]. To reduce this negative effect, perforated baffles are suggested [2]. Further, the researchers also attempted to enhance the efficiency by passing the air on both the sides of SAH and using recycling techniques. In this investigation, as the air flows on both the sides, the convective heat transfer increases due to more surface area. In recycling techniques, convective heat transfer coefficient has been significantly increased by increasing fluid velocity [6].

Generally, conventional solar air heater has very low thermal performance because smooth absorber plate offers low convective heat transfer to flowing air, leading to high heat losses to environment. The performance of solar air heater can be improved by mainly two techniques: 1. reducing the top heat losses to environment, 2. enhancing the convective heat transfer coefficients at absorber plate. Second technique is the most popular due to its wide applicability. Various techniques are available to enhance the heat transfer rate which depends on the applications. The most auspicious technique is to increase the heat transfer rate using roughened surfaces instead of smooth surface. Artificial roughness creates turbulence on the heated surface and helps to break the thermal boundary layer. Enhanced heat transfer is also accompanied with higher pressure drop, which is undesirable. The researcher always tries to optimize the roughness which provides high heat transfer at low pressure drop penalty. In this article, an attempt has been made to enhance thermal performance of solar air heater by creating baffles on absorber plate and to compare V-Shape and Arc-shape baffle solar air heater.

2. LITERATURE REVIEW

A variety of roughness geometries like ribs, protrusions, wire mesh and baffles have been investigated to examine the effect with respect to plane on the thermo-hydraulic performance of solar air heater. There are some detailed review of the roughness geometries used by researchers in the solar air heater have been presented in the recent past.

Ajeet pratap singh et al. [7] investigated the performance enhancement of a curved solar air heater using CFD. In this paper, he report the investigation of various curved solar air heater designs that shows significant enhancement of heat transfer. It was observed that secondary vortex formation near the absorber wall increases the Nusselt number significantly. New correlations for friction factor and Nusselt number has been developed as a function of Reynolds number and various geometric parameters such as relative groove height and pitch ratios for different design of air heaters. It is hoped that data of parameters i.e. Nusselt number ($\boldsymbol{Nu}$), outlet air temperature ($\boldsymbol{T_o}$), thermal efficiency (η_{th}) and friction factor ($\boldsymbol{f}$) presented in this paper would help researchers and industry in developing efficient designs of solar collectors.

Kumar et al. [8] investigated the effect of arc shape wire ribs arranged in 'S' shape on heat transfer and friction factor of air flowing in solar air heater. These 'S' ribs induced the secondary flow which affects the main flow. Experiments were performed for different geometrical parameters include Reynolds number from 2400 to 20000, relative roughness height from 0.022 to 0.054, angle of attack from 300 -750 and relative roughness pitch in the range of 4-10 and relative roughness width from 1-4 at fixed aspect ratio of 12. From experimental investigation, it was observed that maximum enhancement of Nusselt number and friction factor 4.64 & 2.71 times respectively at arc angle of 600 , relative roughness width of 3, relative roughness pitch of 8 and relative roughness height of 0.043. The statistical correlation of Nusselt number and friction factor was developed with maximum deviation of 10.8% and 10% respectively

Raj kumar et al. [9] had investigated the heat transfer enhancement in solar air channel with broken multiple V-type baffle. Investigation deals with experimental analysis of the heat transfer behavior and optimum relative width parameter of the solar air channel of aspect ratio of 10.0 with 60° angled broken multiple V-type baffles. The current experiment enclosed a wide range of parameter such as Reynolds number varied from 3000 to 8000, relative width varied from 1.0 to 6.0, relative baffle height of 0.5, relative baffle pitch of 10.0, relative discrete distance of 0.67 and relative gap width of 1.0. The obtained experimental results showed that higher overall thermal performance occurred at a relative baffle width of 5.0. Also, the results reveal that the broken multiple V-type baffles are thermo-hydraulically superior as compared to the other baffles shaped solar air channel.

Arun K. Behura et al. [10] had investigated the Heat transfer, friction factor and thermal performance of three sides artificially roughened solar air heaters. The experimental results on heat transfer, friction factor and thermal performance of a novel type of three sides artificially roughened and glass covered solar air heater under fully developed turbulent flow conditions. The results on heat transfer and friction factor compare well with analytical values, for the range of the values of operating parameters. Such solar air heaters have higher value of heat transfer coefficient than those of one side artificially roughened solar air heaters in the range of 21–78% for the same values of operating parameters. The values of performance parameters, F_RU_L and $F_R(\tau\alpha)$ and consequently those of F_R and F', have been found to be superior to those of one side roughened solar air heaters. Thermal performance equations in terms of the performance parameters have been derived. Enhancement of about 40–48% in thermal performance over those of one side artificially roughened solar air heaters has been achieved.

Anil kumar et al. [11] had studied the Convective heat transfer enhancement in solar air channels. Heat transfer enhancement in solar air ducts at low and moderate Reynolds numbers has been a major subject of intensive research over the years. Various techniques, based on both active and passive methods, have been proposed to enhance convective heat transfer in these applications. Among these methods are systems involving vortex generators such as ribs and baffles. Disturbance promoters increase fluid mixing and interrupt the development of the thermal boundary layer, leading to enhanced heat transfer. The objective of this article is to review various studies in which different turbulence promoter elements (ribs, baffles) were used to enhance heat transfer with a minimum pressure drop. Convective heat transfer coefficient and pressure drop correlations reported in literature are also presented. These correlations may be used to predict the overall thermal performance of turbulence promoters in solar air channels. In this work a comparative study are also carried out to select best rib and baffle roughness shapes for maximum heat transfer rate and minimum pressure drop losses. Critical reviews of the existing experimental and numerical studies in the literature are given, and various future possibilities in this area, such as the use of turbulence promoters in a solar air channels, are also addressed.

3. EXPERIMENTAL SET-UP

The experimental set-up is a rectangular channel with forced convection flow having entrance, test and exit sections. The components of experimental set up consists blower, wooden rectangular duct, GI pipe, GI black colour absorber plate, GI blacked colour with V-Shape baffle absorber plate, GI blacked colour with Arc-shape baffle absorber plate, control valves, orifice plate, U-tube manometer and thermocouples. Double pass solar air heater has been designed and fabricated by 18mm thick plywood with 10mm insulation provided around a rectangular duct at outlet to minimize the heat losses. The comparison in the enhancement of heat transfer and thermal efficiency having three different type of G.I. absorber plate of 22 gauges to be used one normal black colour, blacked colour with V-Shape baffle absorber plate and blacked colour with Arc-Shape baffle absorber plate for experimental study. The flow system consists of three sections i.e. the entry section consists of (300×200mm), test section consists of (1670×200mm) and exit section is

(300×200mm). Transparent glass cover sheets are (1950×200mm) is used as it allows shorter wavelength radiation to pass and restricts larger wavelength radiation to go back. In total 18 thermocouples were used out of which 12 thermocouples were provided over the test section for measuring the surface temperatures and 6 thermocouples were used to measure the inlet and outlet temperature.. The mass flow rate of air was measured by means of calibrated orifice meter connected with a U-tube manometer and we have to use another method to find the mass flow rate of air i.e. anemometer. In anemometer find the velocity of air and calculated the mass flow rate on the basis of velocity and other standard parameter of air. Control valves were provided to control the flow. An orifice plate was designed for flow measurement in the pipe having diameter 40 mm. Upper side of transparent glass used insulator to minimize the heat loss.

The duct is the main part of the experimental setup. The duct is fabricated from wooden planks of different cross-sections. The inner dimension of the duct is 1950mm× 180mm×60mm.

3.1 Experimental Procedure

Before start an experiment checked out all major components i.e. pyranometer, centrifugal blower, temperature indicator, control valve, inclined U-tube manometer and anemometer have been inspected for its functioning. The connection of thermocouple and leak proof joint is ensured along the whole duct, after that switch on all connections. Initially starts the blower around five minute for normalizes the effect of preheat of solar air heater. In this experiment used three speed of blower that is three velocities of air passes on the duct. After that air passing from blower by the help of GI pipe. In the GI pipe consist of flow control valve and orifice. Orifice normally used to calculate the difference of pressure and the difference of pressure head shown in the U tube manometer. The air passes through between transparent glass cover and absorber plate duct. In the absorber plate thermocouple wire are used to measure the surface temperature, inlet air temperature and exit air temperature by the help of temperature indicator display. During this process plate temperature along with pressure drop in orifice plate were also measured. And the entire temperature and pressure drop calculated on the basis of mass flow rate of air, in the setup three mass flow rates are used to calculate the value of temperature and pressure. An pictorial view of experimental set is shown in Fig. 3.1.

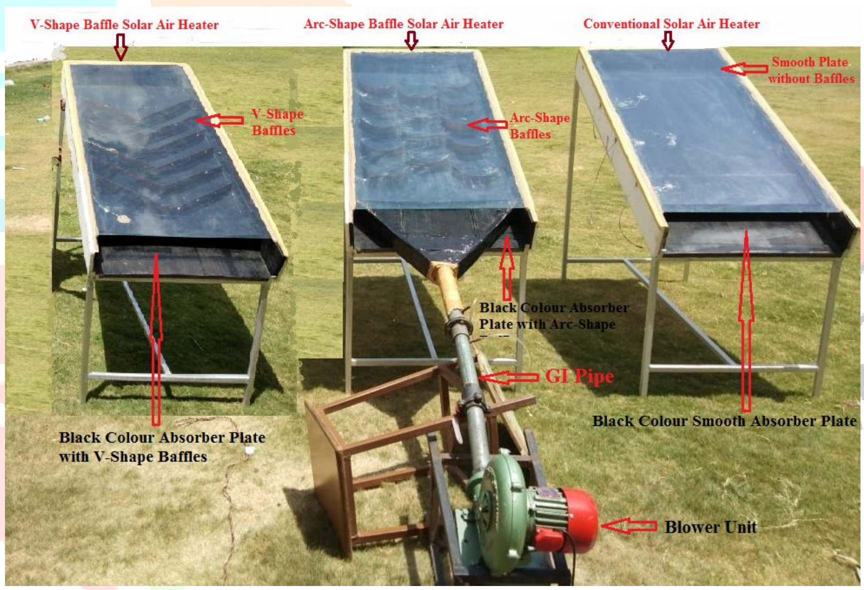

Fig. 3.1 Pictorial view of experimental setup

4. RESULTS AND DISCUSSION

Data has been collected using experimentation. Calculations of all the parameters for the performance prediction of the solar air heater have been carried out. The setup was arranged as per the latitude of Bhopal that is 23.26°N 77.41°E. The experiment was performed from 10:00 am to 04:00 pm every day at the campus of Radharaman Institute of Technology and Science, Bhopal, MP, India.

The experimental readings have been taken at same time interval (30 minutes) and at three different mass flow rate of air i.e. m1 (0.005383 kg/s), m2 (0.007388 kg/s) and m3 (0.0095 kg/s) for the CSAH (Conventional Solar Air Heater), V-Shape and Arc-Shape Baffle Solar Air Heater. On the basis of above observations following results were drawn and represented graphically in below articles.

4.1 Variation in Ambient, Inlet and Outlet temperature with Time at Different Mass Flow Rate for CSAH, V-Shape and Arc-Shape Baffle Solar Air Heater

The variation in ambient, inlet and outlet temperature with time at different mass flow rate for CSAH, V-Shape and Arc-Shape Baffle Solar Air Heater are shown in Fig.4.1.

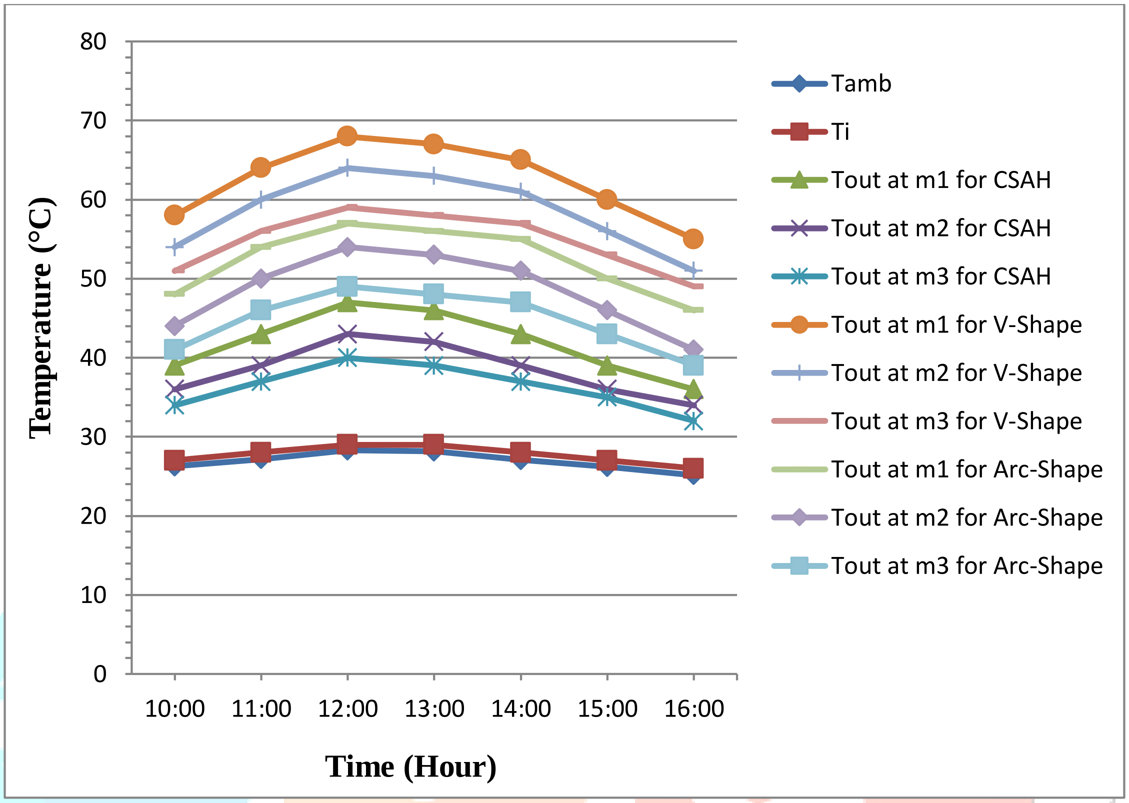

Fig 4.1 Variation in Ambient, Inlet and Outlet Temperature with Time at Different Mass Flow Rate for CSAH, V-Shape and Arc-Shape Baffle Solar Air Heater

It is observed that the outlet air temperature is always higher than the inlet temperature for all solar air heaters at different mass flow rates. The outlet air temperature increases with decrease in mass flow rate for all solar air heaters. Also it is reported that higher outlet air temperature is obtained for V-Shape and Arc-Shape baffle solar air heater as compared to black colour smooth plate conventional solar air heater. Further maximum outlet air temperature is obtained for V-Shape baffle solar air heater at m1 mass flow rate.

The high heat transfer coefficient in case of V-Shaped baffles is due to the turbulence effect on the flow and larger surface area exposed to the flowing air. A better heat transfer performance is given by V-Shaped baffles because the baffles top induces secondary streams jets. These secondary jets have the form of two counter rotating vortices which carries cold fluid from the central core area towards the baffled walls [12]. These secondary flow jets interacts with the main stream affect the flow reattachment and recirculation among baffles and interrupt boundary layer growth downstream of the reattachment regions. These jets are responsible for rise in heat transfer [13–15].

4.2 Variation of Efficiency with Time at Different Mass Flow Rate for CSAH, V-Shape and Arc-Shape Baffle Solar Air Heater

The variation in efficiency with time at different mass flow rate for CSAH, V-Shape and Arc-Shape Baffle Solar Air Heater is shown in Fig 4.2.

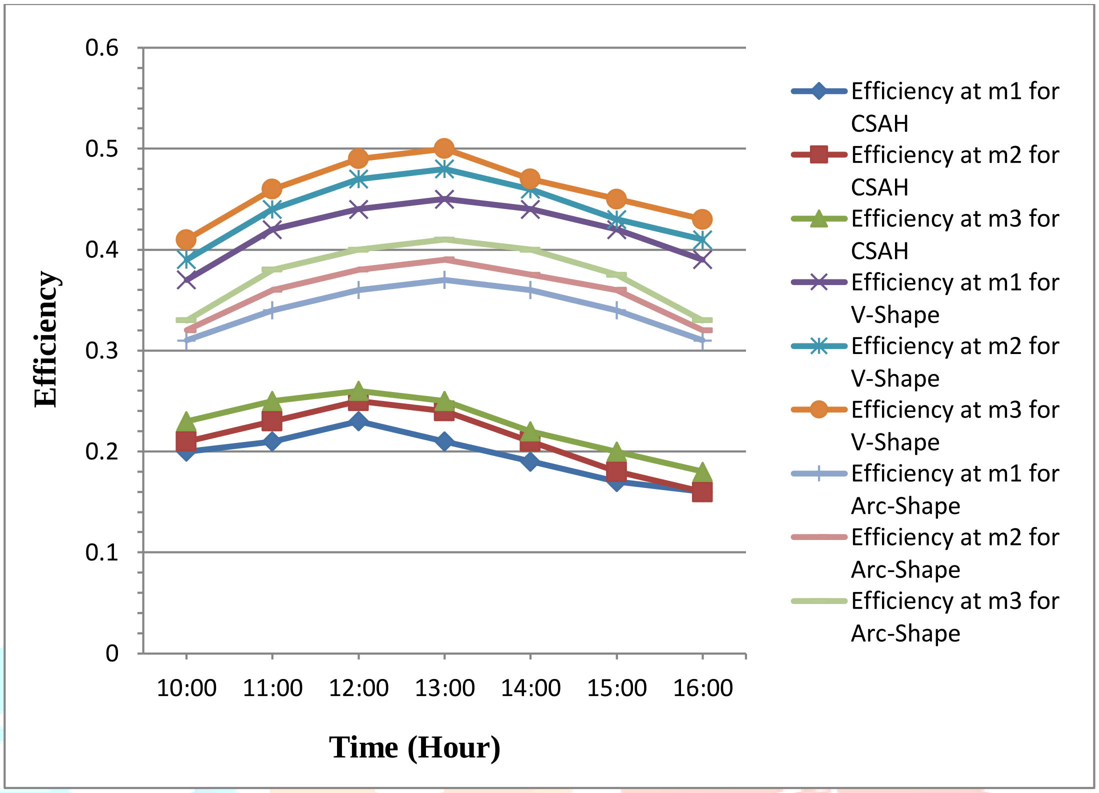

Fig 4.2 Variation in Efficiency with Time Different Mass Flow Rate for for CSAH, V-Shape and Arc-Shape Baffle Solar Air Heater

The thermal efficiency increases with increase in mass flow rate for all solar air heaters. Also it is reported that higher thermal efficiency is obtained for V-Shape and Arc-Shape baffle solar air heater as compared to black colour smooth plate conventional solar air heater. Further highest thermal efficiency is obtained for V-Shape baffle solar air heater at m3 mass flow rate.

The thermal efficiency is drastically increased by attaching the baffles on absorber plate. As baffles disintegrate and mix the flow of fluid, heat transfer between V-Shape baffle absorber plate and flowing fluid is maximized [15]. The increasing mass flow rate leads to increase in Reynolds number which further enhances thermal efficiency monotonically. It is due to the fact that increasing Reynolds number induces turbulence flow and increases heat capacity of the fluid thereby results in increased heat transfer rate [16].

4.3 Variation of Friction Factor with Reynolds Number at Different Mass Flow Rate for CSAH, V-Shape and Arc-Shape Baffle Solar Air Heater

The variation in friction factor and Reynolds number at different mass flow rate for CSAH, V-Shape and Arc-Shape Baffle Solar Air Heater are shown in Fig. 4.3.

The Friction factor decreases with increase in Reynolds number for all solar air heaters. Also it is reported that higher Friction factor is obtained for V-Shape and Arc-Shape baffle solar air heater as compared to black colour smooth plate conventional solar air heater. Further highest Friction factor is obtained for V-Shape baffle solar air heater.

Further the plots of experimental values of the friction factor as the function of Reynolds number for smooth plate and rough surface. It is clear that Value of friction factor drop proportionally as the Reynolds number increases due to the suppression of viscous sub-layer with increase in Reynolds number [16].

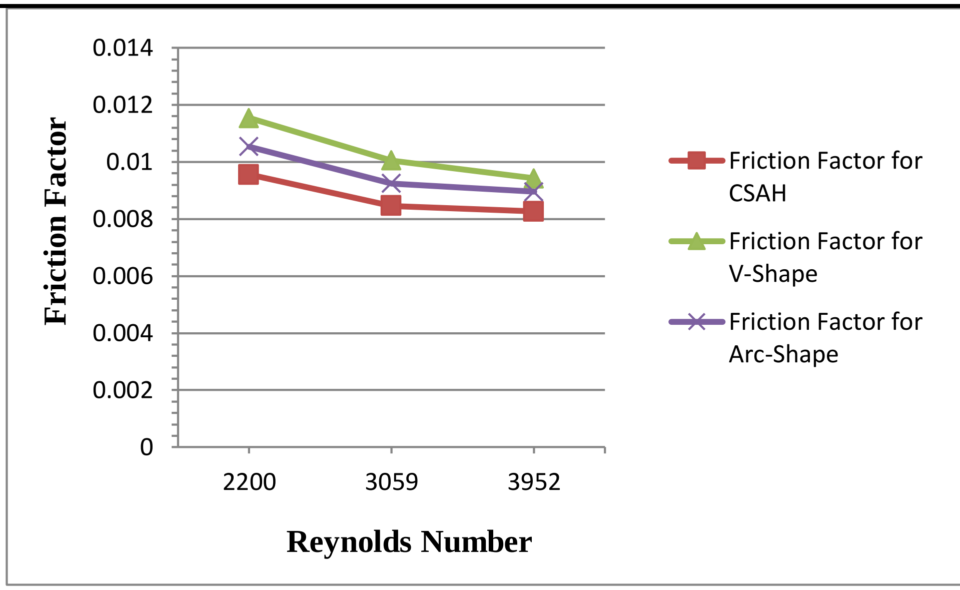

Fig. 4.3 Variation in Friction factor with Reynolds Number at Different Mass Flow Rate for CSAH, V-Shape and Arc-Shape Baffle Solar Air Heater

4.4 Variation of Nusselt Number with Time at Different Mass Flow Rate for CSAH, V-Shape and Arc-Shape Baffle Solar Air Heater

The variation of Nusselt number with time at different mass flow rate for for CSAH, V-Shape and Arc-Shape Baffle Solar Air Heater are shown in Fig. 4.4

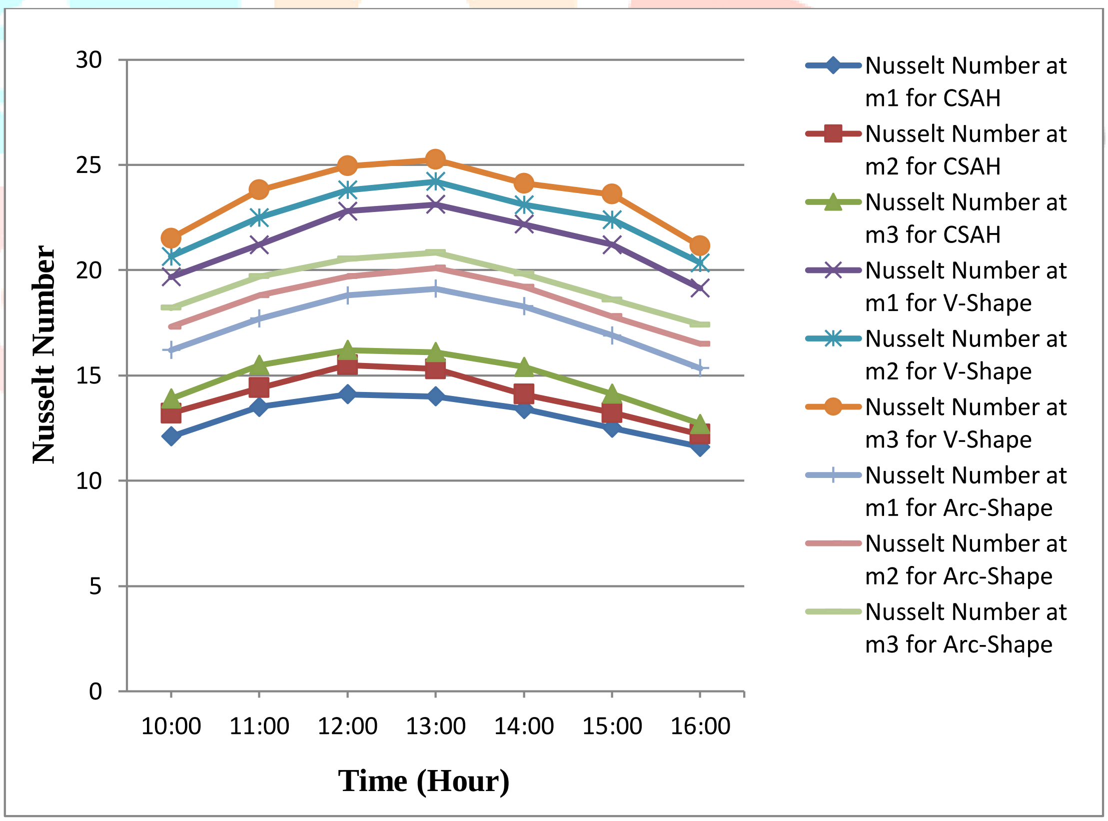

Fig. 4.4 Variation in Nusselt number with Time at Different Mass Flow Rate for CSAH, V-Shape and Arc-Shape Baffle Solar Air Heater

The Nusselt number increases with increase in mass flow rate for all solar air heaters. Also it is reported that higher Nusselt number is obtained for V-Shape and Arc-Shape baffle solar air heater as compared to black colour smooth plate conventional solar air heater. Further highest Nusselt number is obtained for V-Shape baffle solar air heater at m3 mass flow rate. The values of Nusselt number increases with increases in Reynolds Numbers because it is nothing but the ratio of conductive resistance to convective resistance of heat flow and as Reynolds Number increases thickness of boundary layer decreases and hence convective resistance decreases which in turn increase the Nusselt Number [16].

5. CONCLUSION

An experimental analysis on performance of conventional, V-Shape and Arc-Shape baffle solar air heater at different mass flow rate. Intensity of solar radiation was changed time to time and maximum value was found at 12:30 PM in cleaned day. A direct performance comparison of conventional, V-Shape and Arc-Shape baffle solar air heater shows that:

1. The thermal efficiency of the V-Shaped baffle solar air heater is higher than the Arc-Shape baffle and conventional solar air heater, highest thermal efficiency is at the high mass flow rate.
2. Thermal efficiency is increases with increasing the mass flow rate in all solar air heaters.
3. Outlet air temperature is decreases with increasing the mass flow rate in all solar air heaters.
4. It was observed that with the use of V-Shaped baffle absorber plate the heat collection rate was increases which further enhanced the heat transfer.
5. Investigation also results in the difference of 10°C in ambient and inlet air temperature.
6. Maximum outlet temperature obtain for V-Shaped baffle absorber plate solar air heater was 68°C. Further maximum outlet temperature for Arc-Shaped baffle & conventional solar air heater was 58°C and 47°C respectively.

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