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Performance Evaluation on Double Pass Solar Air Heater with Broken Multiple V-Type Baffles

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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 the present work an experimental comparison of the thermal performance of double pass solar air heater on different types of absorber plates has been conducted. Two different types of absorber plate have been used. The absorber plate's have - black colour and black colour with broken V-shaped baffles. It is found that the highest heat transfer coefficient and thermal efficiency is found out to be for black colour with broken V-shaped baffles at all the exit wind velocity. The thermal efficiency of the broken V-shaped baffle absorber plate solar air heater is about 7-10% higher than the conventional solar air heater.
Keywords: Solar Air Heater,V-Type Baffles,Thermal efficiency,Mass flow rate.

1. INTRODUCTION

Developed and developing countries have been craving to produce the energy without affecting the environment specifically by CO_2 emission, after accepting Kyoto agreement. It can be achieved by using 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 [1]. 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 [2]. 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 [3].

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 W shape baffles on absorber plate.

2. LITERATURE REVIEW

A variety of roughness geometries like ribs, protrusions, wire mesh and baffles have been investigated to examine that's 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 [3- 4].

Kumar et al. [5] had investigated about artificial roughness has been found to enhance the rate of heat transfer from the collector plate to the fluid (air). Investigators reported various roughness geometries in literature for studying heat transfer and friction characteristics of an artificially roughened duct of solar air heaters. In the present paper an attempt has been made to categorize and review the reported roughness geometries used for creating artificial roughness. Heat transfer coefficient and friction factor correlations developed by various investigators for roughened ducts of solar air heaters have also been reported in the present paper.

Saravanakumar et al. [6] studied the thermo hydraulic performance enhancement of solar air heater (SAH) with various design configurations. Analytical modeling is carried out to study the effect of absorber plate integrated with arc shaped rib roughened barrier with fins and baffles on thermal and effective efficiency of SAH. Variations of flow factors such as Reynolds number and temperature rise parameter with reference to baffle design parameters are presented. The proposed SAH improves the energy and effective efficiency by 28.3% and 27.1% compared with arc shape rib roughened solar air heater. From the results, it is also concluded that lower baffle width and length values provide maximum effective efficiency at higher mass flow rates. Further, the correlations as a function of Reynolds number, baffle width, length and number of fins is developed for predicting the values of effective efficiency. Thereafter, a plot is developed for comparing analytical effective efficiency with predicted effective efficiency and it is found that the averaged deviation of 13%. This present mathematical model for proposed SAH is validated with models available in the literature.

Matheswaran et al. [7] investigated the thermal performance of single-pass double-duct jet plate solar air heater with various designs of artificial roughness is analyzed by developing a mathematical model. The influence of artificial roughness designs on the performance of the solar air heater is analyzed based on energy and exergy basis, and the results are compared with single-pass single-duct jet plate solar air heater. Further, year-around enviro-economic analysis is carried out for artificial roughness design providing the better performance. The results show that single-pass double-duct jet plate solar air heater with arc shaped rib roughness produces highest energetic and exergetic efficiency. The results are compared with single-pass single duct jet plate solar air heater in the form of energetic and exergetic efficiency enhancement ratios, annual overall energy and exergy gain and amount of carbon credit earned. The mathematical model has been validated with analytical and experimental results available in the literature with acceptable deviation. On the basis of numerical calculations, it has been concluded that single-pass double-duct jet plate solar air heater improves annual usual energy and exergy gain by 111.7% and 185.6%, respectively. Further, it reduces 2.11 times of production of CO_2 mitigation per year and enhances the revenue of annual carbon credit by 2.85 times.

Deo et al. [8] experiment reported that the thermohydraulic performance has been lifted up to 2.45 by creation of multiple gaps in V-down rib roughness with staggered ribs while keeping the roughness pitch (p/e) of 12, roughness height (e/Dh) of 0.044 and angle of attack of 60° at Reynolds number of 12,000.

Kumar et al. [9] observed that both Nusselt number and friction factor attained maximum value at an angle of attack (α) of 55°. It was found that the V-pattern dimpled obstacles performed better than other dimple shaped obstacles and the optimum value of thermal hydraulic performance parameter was obtained as 3.26.

Thakur et al. [10] performed 3D CFD simulation analysis on novel hyperbolic rib as roughness geometry with parabolic tip in the experiment showed the best performance with V-shaped configuration for rib height of 1 mm, rib pitch of 10 mm and angle of attack of 60° at the Reynolds number of 6000.

Jin et al. [11] investigated the effect of staggered multiple V-shaped ribs and concluded that the subsidiary vortex strength in the inter-rib region and redevelopment length in the leading end region are dependent on the stagger distance which greatly affects the heat transfer enhancement.

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 broken V-shaped 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 coefficient and thermal efficiency having two different type of

G.I. absorber plate of 22 gauges to be used one normal black painted and other one is broken V-shaped baffle absorber plate for experimental study. The flow system consists of in 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 12 thermocouples were used out of which 8 thermocouples were provided over the test section for measuring the surface temperatures and 4 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 sectional view of the duct is shown in above Fig 3.1. 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.

Fig. 3.1 GI black painted broken V-shaped baffle absorber plate

Fig. 3.2 Pictorial view of experimental setup

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. When the air passes through between transparent glass cover and absorber plate duct. It is a comparative analysis of GI black colour absorber plate and broken V-shaped baffle absorber plate, so in the black colour absorber plate air passes normally but in the broken V-shaped baffle absorber plate air passes slowly as compare to normal absorber plate. 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 measured. And the entire temperature and pressure drop calculated on the basis of mass flow rate of air, in the setup three mass flow rate are used to calculate the value of temperature and pressure. Observed that the difference of pressure head is more in brokrn V-shaped baffle absorber plate compare to normal plate. An experimental set up photograph have been shown in Fig. 3.1 and 3.2.

4. RESULTS AND DISCUSSION

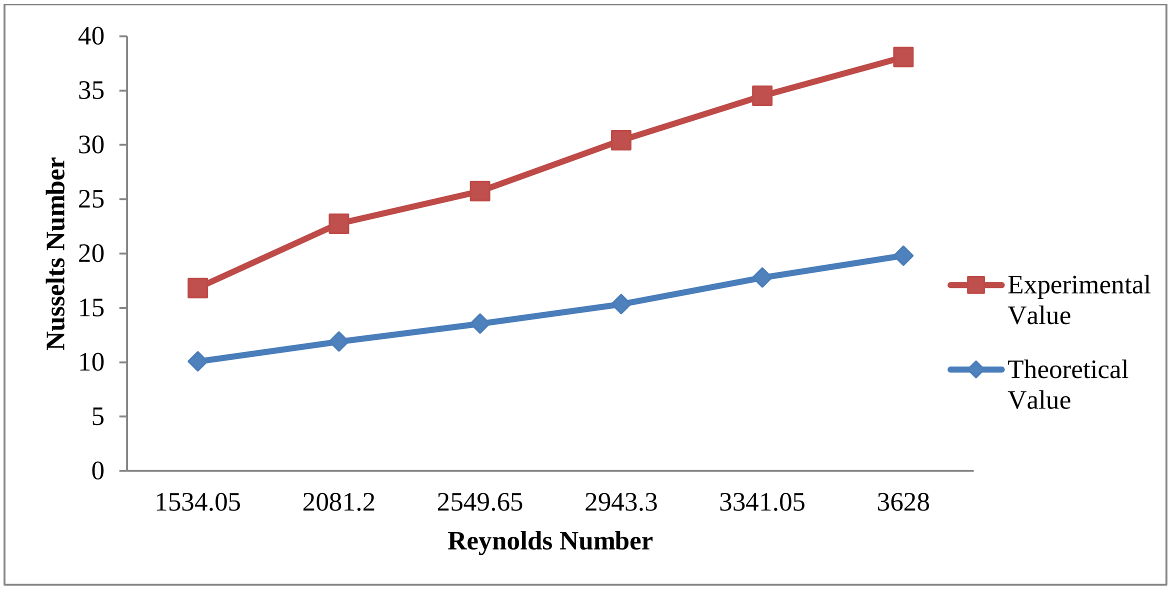
Data has been collected using experimentation. Calculations of all the parameters for the performance prediction of the solar air heater have been carried out. The readings were taken keeping same radiation level and exit wind velocity for all the cases. The value of heat transfer coefficient and Nusselt number for air duct has been determined.

The experimental readings have been taken at same time interval (30 minutes) and same mass flow rate of air at constant average radiation for the two absorber plate's i.e. Black absorber plate and broken V-shaped baffle absorber plate. On the basis of above observations following results were drawn and represented graphically in below articles.

4.1 Variation in Non-Dimensional Numbers

The variation in Nusselt Number and Reynolds Number for obtained experimental value and theoretical value is shown in Graph 4.1. An experimental data validate the results of present work for heat transfer in the form of Nusselt number and heat transfer coefficient which has been determined from experimental data to compare with the analytical values obtained from Dittus-Boelter equation. The Nusselt number for a smooth rectangular duct is given by the Dittus-Boelter equation [12].

$$Nu_s = 0.023 Re^{0.8} Pr^{0.4} \tag{4.1}$$

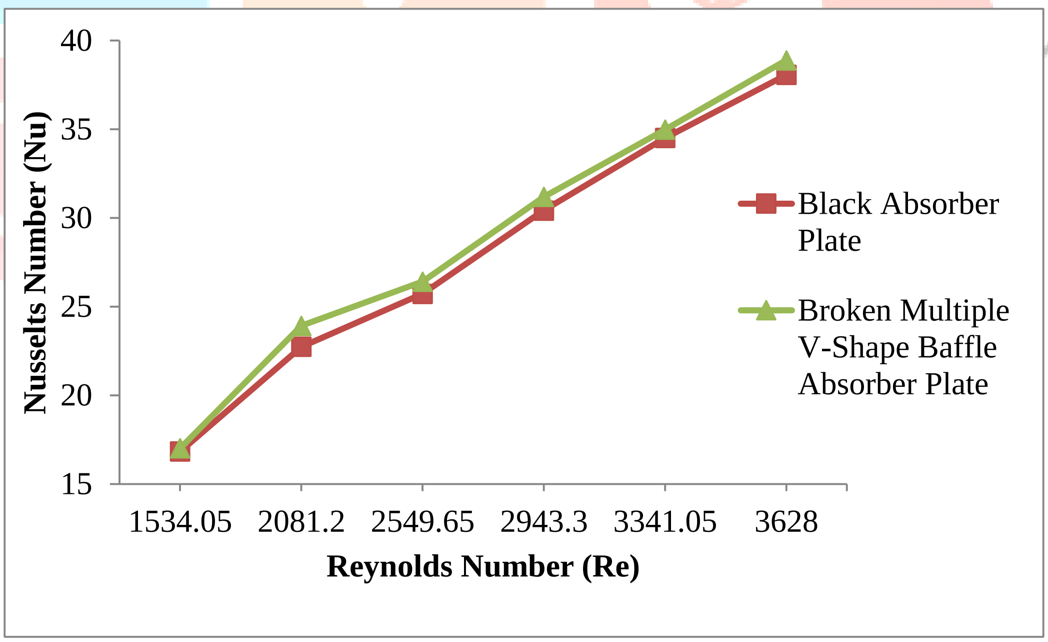


Graph 4.1 Variation in theoretical to experimental Nusselt Number for different absorber plate

Graph 4.1 shows that Nusselt number agrees reasonably well with the values predicted. As the experimental values for Nusselt number is in reasonably good agreement with predicted values, the validity of the experimental results is ensured. The results shows similar trend as the results obtained by researcher [12].

4.2 Variation in Nusselts Number and Reynolds Number for Different Absorber Plates

The variation in Nusselts number and Reynolds number for different absorber plates is shown in Graph 4.2.



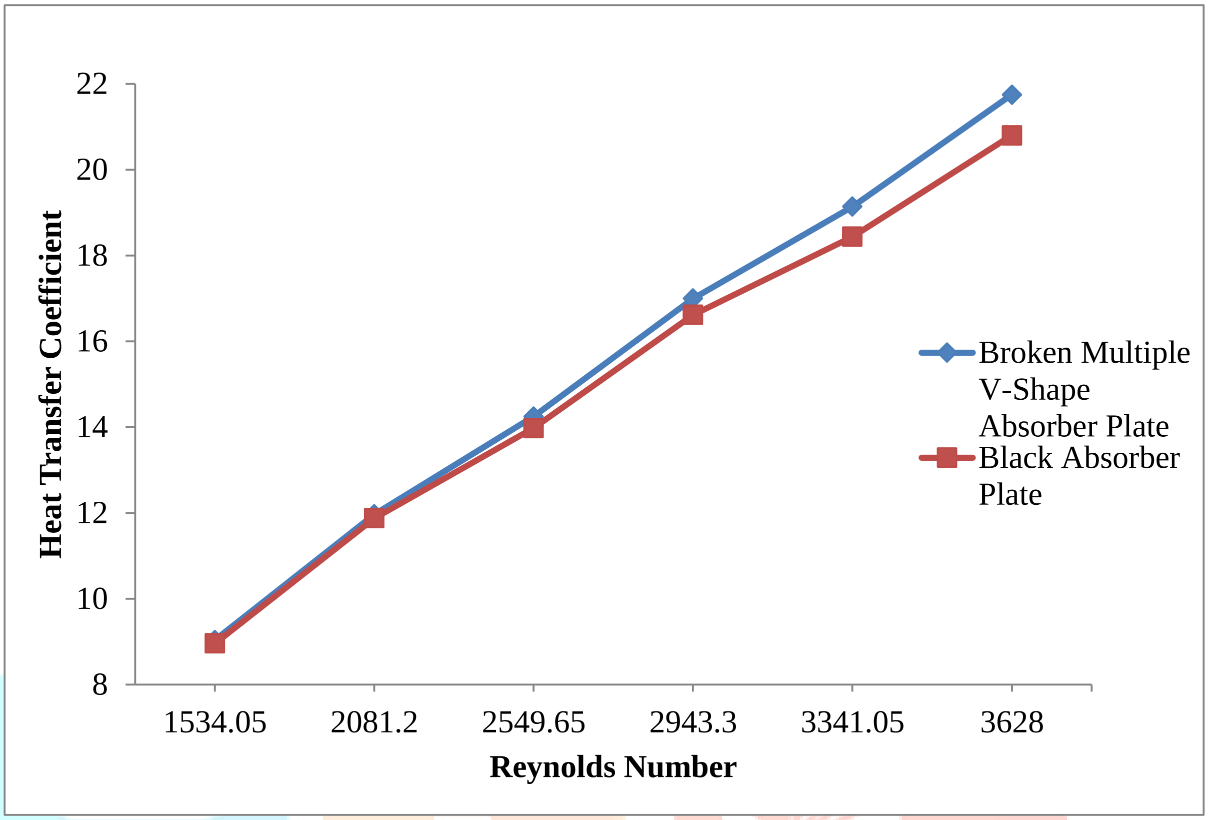
Graph 4.2 Comparative variation in Nusselts Number with Reynolds Number for different absorber plate

Graph 4.2 shows that as Nusselts Number increases with increase in Reynolds Number for both absorber plates. The reason for increase in Nusselts Number for both absorber plates is increase in heat content and high temperature of working fluid [11].

Furthermore, higher values were obtained for broken V-shaped baffle absorber plate as the high temperature of working fluid is observed for the same. This effect is due to increase in roughness on absorber plate from broken V-shaped baffle which create turbulence in working fluid [12].

4.3 Variation in Heat Transfer Coefficient and Reynolds Number for different absorber plate

The variation in Heat Transfer Coefficient and Reynolds number for different absorber plates is shown in Graph 4.3.

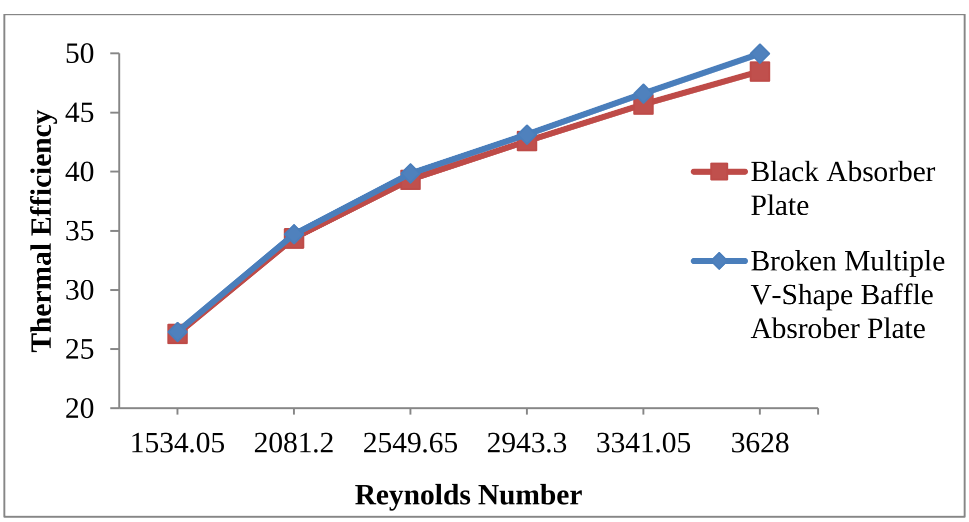


Graph 4.3 Variations in Heat Transfer Coefficient with Reynolds Number for different absorber plate

Graph 4.3 shows that heat transfer coefficient increases with increase in Reynolds Number for different absorber plates. The value of heat transfer coefficient increase with increasing roughness on the absorber plate surface for hike in Reynolds number [11]. Lower value of heat transfer coefficient has been found for black absorber plate as compared to that of broken V-shaped baffle absorber plate. The whole sole difference in heat transfer coefficient can be achieved with increase in turbulence due to roughness of the plate.

4.4 Variation in Thermal Efficiency and Reynolds Number for different absorber plate

The variation in Thermal Efficiency and Reynolds number for different absorber plates is shown in Graph 4.4.



Graph 4.4 Variation in Thermal Efficiency with Reynolds Number

Graph 4.4 shows that for variation in Reynolds number and Thermal efficiency of both the plate's increases with increase in Reynolds number. The reason for this is increase in turbulence on increasing the mass flow [12]. The higher values of thermal efficiency are found out for broken V-shaped baffle absorber plate. The reason for this can be high exit temperature of working fluid (air) which may be due to increased turbulence for plate with broken V-shaped baffle [12].

5. CONCLUSION

An experimental analysis on performance of conventional and broken V-shaped baffle absorber plate solar air heater having the air flow on absorber plate has been made for air mass flow rate of about 0.00527kg/s. The following are the major conclusions that are drawn.

1. It has been found that the thermal efficiency of broken V-shaped baffle absorber plate is higher as compare to black colour absorber plate solar air heater.

2. It has been observed that an enhanced Nusselt's number and heat transfer coefficient is obtained on an artificial roughness provided on under sides of absorber plate as compare to smooth plate.

3. The maximum value of Nusselt's number has been found on the broken V-shaped baffle absorber plate as compare to black colour absorber plate solar air heater.

4. The maximum value of thermal efficiency and Nusselt's number of broken V-shaped baffle absorber plate is found to be 1.46 and 1.36 times respectively higher as compare to black colour absorber plate solar air heater.

5. The value of heat transfer coefficient can be increased by creating artificial roughened surface for braking viscous sub layer to reduced thermal resistance to close on heat transferring surface.

6. It has been also found that the absorption of heat by the broken V-shaped baffle absorber plate is higher as compare to black colour absorber plate solar air heater.

7. The thermal efficiency of the broken V-shaped baffle absorber plate solar air heater is about 7-10% higher than the conventional solar air heater.

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