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Experimental Investigation of Double Pass Solar Air Heater with Baffled 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 this research comparison of the thermal. Performance of double pass solar air heater with baffled and without baffled absorber plates has been conducted. Highest heat transfer was found to be on black coloured with baffled absorber plate, because the path of air has increased as compare to flat absorber plate. Increased path depends on geometry was equally spaced zig-zag path and air flowing from inlet to outlet in between baffled plate channel. It has been observed that thermal efficiency of the baffled duct solar air heater is about 16-21% higher than the smooth duct solar air heater. Furthermore thermal performance of double pass solar air heater also depends on mass flow rate of air, when mass flow rate decrease efficiency increases.
Keywords : Solar Air Heater, Solar Radiation, Blower, Baffled Plate, Thermal Efficiency.

I. INTRODUCTION

In the study, a test of solar air heater was performed based on the heating of air by baffled absorber plate and without baffled. Our study seeks an increase in the thermal efficiency of the solar air heater, by using a double pass zig-zag flow solar air heater. Conventional solar air heaters mainly consist of an absorber plate, transparent cover, insulated hot air ducts and air blowers in active systems but in baffled solar air heater over the absorber plate baffled plate attached. Different factors affect the Solar air heater efficiency such as collector dimensions, type and shape of absorber plate, glass cover, inlet temperature, wind speed, intensity of radiation and outlet temperature etc. Thermal efficiency of a solar air heater is generally considered poor because of low rate of heat transfer capability between absorber plate and air flowing in the duct. In order to make a solar air heater a more effective solar energy utilization system, thermal performance needs to be improved by enhancing the heat transfer rate from absorber plate to air flowing in the duct of solar air heater. One of the methods for the enhancement of convective heat transfer is by creating turbulence at heat transfer surface with the help of baffled absorber plate on absorber plate.

II. METHODS AND MATERIAL

1. Literature Review

B.K. Maheshwari et al.[1] An experimental study on performance of a solar air heater having perforated baffles on the air flow side of the absorber plate has been made for air mass flow rate of about 0.014-0.07 kg/s per m2 of the absorber plate area. A direct performance comparison of the performance of the solar air heater with baffled duct with the smooth duct solar air heater shows that-

1. The thermal efficiency of the baffled duct solar air heater is higher than the smooth duct solar air heater; highest thermal performance advantage is at the lowest flow rate.

2. The heat transfer enhancement due to the baffles increases the heat collection rate and reduces the mean temperature of the baffled absorber plate by 4-14oC as compared to the smooth one.
3. The pumping power requirement is found to be a small fraction of the heat collection rate in the range of the present study.

Foued Chabane et al.[2] In this paper, the heat exchanges in a Plexiglas cover solar air heater are analyzed and an explicit expression of the temperature of the air flowing in that collector is developed as a function of the space coordinate in the flow direction and the time dependent solar intensity. Then the effects of various parameters such as the inlet air temperature, the distance between the absorber and the transparent cover and the air flow on the dynamic behavior of the collector are studied. The solar air collectors were tested and their performance was compared. The efficiency depends significantly on the mass flow rate, the solar irradiation and surface geometry of the collectors. The efficiency of the collector improves with increasing solar intensity and mass flow rate both 0.012 and 0.016 kg/s, due to enhanced heat transfer to the air flow. The condition of weather affects the mass flow rate on heat transfer. The efficiency of the solar air collector is proven to be higher. The highest collector efficiency and air temperature rise were achieved by the finned collector with an angle of 45°, whereas the lowest values were obtained from the collector without fins. The efficiency of the solar air collectors depends significantly on the solar radiation and surface geometry of the collectors and the fins on the back of the absorber plate account for the mass flow rate.

Afaq Jasim Mahmood [3] In this research, the convective heat-transfer coefficient was improved and enhanced by replacing the absorber plate of the SAH with sixteen steel mesh layers. The results show that the temperature difference, thermal efficiency, and average efficiency will increase by increasing the number of baffles for a constant airflow rate (temperature difference, thermal efficiency, and average efficiency for seven baffles higher than three or five baffles). Also, when the number of baffles is fixed as constant, the thermal efficiency and average efficiency will increase by raising the airflow rate from 0.011 to 0.032 kg/s. Moreover, the temperature difference between the outlet and the inlet increased as the airflow rate was reduced for the same number of baffles. Additionally, the double-pass SAH collectors exhibited a higher thermal efficiency compared to single-pass SAH collectors for the same number of baffles and the same airflow rate. Also, at the same airflow rates with fixed number of baffles, the double-pass SAH was found to be 9% more efficient than the single-pass SAH. A small variation is found between the temperature bed difference and the temperature inlet-outlet difference of the device.

Ben Slama Romdhane[4] From the various viewpoints encountered in the study of solar air collectors, it becomes evident that the introduction of suitable baffles in solar air collectors increases the couple efficiency – increase in temperature. The measurements showed that the efficiency reached 80% for the best type of chicanes, for an air flow rate of 50 m3/h/m2, and a temperature increase of 600C.

Silvina Mariana Gonzáleza et al.[5] The experimental study of the thermal efficiency of a double-pass solar air heater that was designedand built at INENCO, Universidad Nacional de Salta, and the theoretical thermal model developed to describe its thermal behavior, were described. Air outlet temperatures reached 80ºC at solar noon by using an electrical resistor, and 75°C without it, with a daily average temperature rise of 40 °C between inlet and outlet for an air mass flow of 0.020 kg/s. An average daily efficiency of 42% was measured with maximum instantaneous values reaching 50%. These values are low when compared with the 75% efficiencies reached.
Pankaj Sharma et al.[6]

(i) It has been observed that as the value of Reynolds number increases the value of thermal efficiency also increases.
(ii) Circular inclined rib on the absorber plate enhances the rate of heat transfer as compared to smooth duct.
(iii) Comparison between smooth and roughened duct at different Reynolds number shows that average thermal efficiency increases from 5 to 11%.

Ravi Kant Ravi et al.[7] Based on the investigation, it is observed that heat transfer rate has found to be increased significantly through a double pass channel of a SAH. However, increase in pressure drop is also significant in comparison to the single pass flow. Roughness parameters investigated, are found to be the strong function of Nusselt number and friction factor. Nusselt number and friction factor for all the cases investigated under the present study are found to be maximum at r/e ¼ 2.5 and the maximum value of Nusselt number ratio and friction factor ratio for double pass and single pass channel have been found as 3.4 and 2.5.

Foued chabane et al.[8] The present studied aims to analyze a thermal efficiency of SAH. The comparison of solar collectors with smooth plate and with baffle indicates that the efficiency of the solar air collector depends significantly on the solar radiation, the volume flow rate and the position of a baffle when is fixed on the duct of solar collectors. The efficiency of the collector improves by increasing the volume flow rate from 40 m3/h to 80 m3/h due to enhanced heat transfer to the air. For Nusselt number, heat transfer coefficient and the recommended range of air mass flow rate which gives an appropriate outlet air temperature and thermal efficiency is 40 m3/h–80m3/h.

2. Experimental Detail

2.1 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 blacked colour plate, GI blacked colour baffled 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 baffled 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.

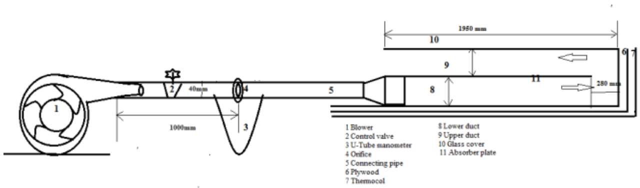


Figure 1. Block diagram of experimental setup

2.2 Data Reduction

1. Mass Flow Rate of Air (m)

$$m = \rho A_c V_d$$

where,

ρ = Density of air (kg/m^3)

A_c = Cross-section area of duct (m^2)

V_d= Velocity of air in duct (m/s)

2. Friction Factor (f)

$$f = \frac{1}{2} \Delta P \frac{D_h}{\rho_a \times {V_d}^2}$$

where,

$\Delta P = P_i - P_o$

D_h= duct hydraulic diameter (m)

ρ_a= density of air (kg/m^3)

3. Nikurande-Karman Equation to friction factor(f)

$$f=0.046Re^{-0.2}$$

4. Thermal Efficiency(η_{th})

$$\eta_{th} = \frac{mc_p\Delta T}{I \times A_s}$$

where,

m = mass flow rate of air (kg/s)

c_p= specific heat at constant pressure (J/kg°C)

ΔT = duct air temperature dif

I = Intensity of solar radiation (W/m^2)

A_s= surface area of transparent glass (m^2)

5. Performance Factor (PF)

$$PF = \frac{Nu_b/Nu_s}{(f_b/f_s)^{1/3}}$$

where,

Nu_b= Nusselt no. of baffles absorber plate

Nu_s= Nusselt no. of Smooth absorber plate

f_b= Friction factor of baffles absorber plate

f_s= Friction factor of Smooth absorber plate

6. Mean temperature of plate (T_S)

$$T_S = \frac{T_1+T_2+T_3+T_4}{4}$$

Where T_1, T_2, T_3 and T_4 are surface temperature of absorber plate at different location.

2.3 Experimental Procedure

Before start an experiment checked out all major components i.e. solar meter, 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. With the help of pyranometer meter average solar radiation measured around 1100 W/m^2. Initially start the blower around five minute for normalizes the effect of preheats 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 an comparative analysis normal GI absorber plate and baffled absorber plate so in the normal absorber plate air passes normally but in the baffled absorber plate air passes in slowly 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 all the 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 baffled absorber plate compare to normal plate. An experimental set up photograph have been shown in fig (1). The parameters measured during experimentation are:

(a) Pressure drop across orifice plate.
(b) Inlet air temperature.
(c) Outlet air temperature.
(d) Temperature of plate.
(e) Velocity measure inlet and outlet.
(f) Ambient temperature.
(g) Solar radiation intensity.

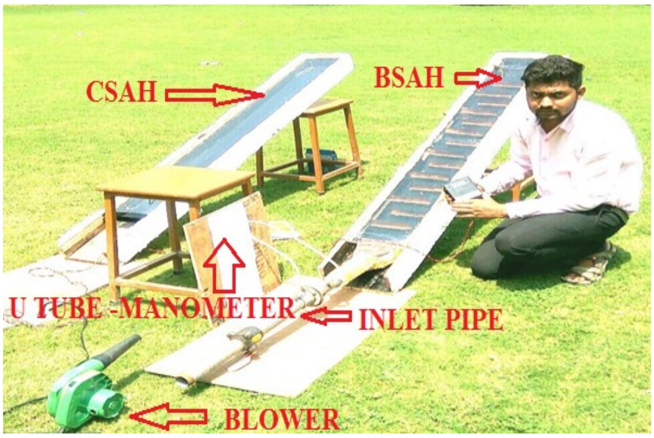


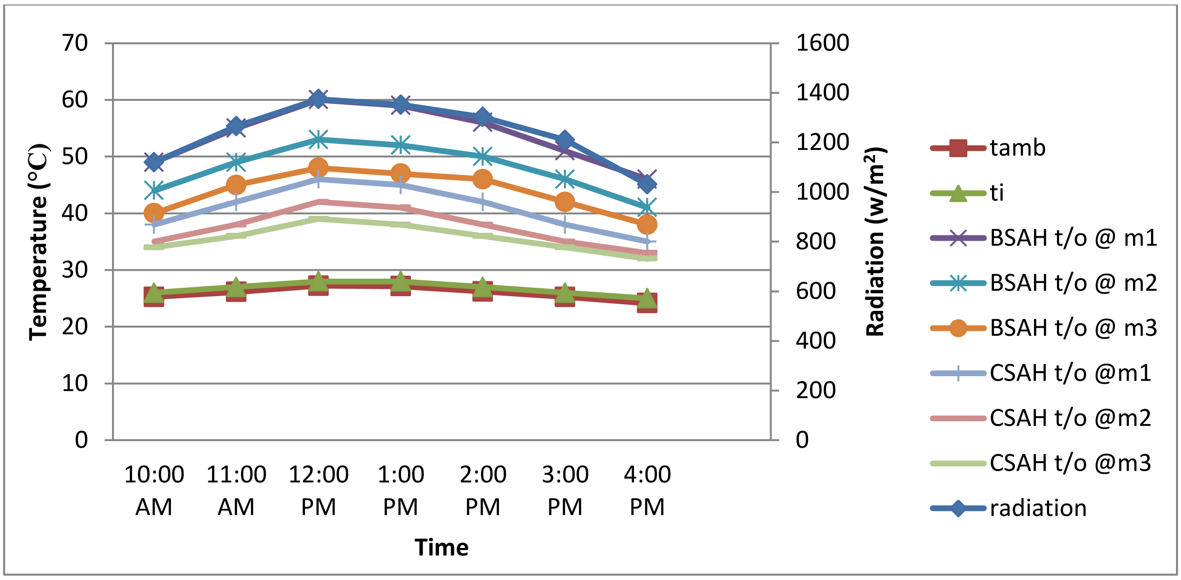
Figure 2. Pictorial view of experimental setup

III. RESULTS AND DISCUSSION

3.1 Comparative Variation of Ambient, Inlet and Outlet Temperature for CSAH and BSAH

The comparative variation of ambient inlet-outlet air temperature with time and radiation of CSAH and BSAH are shown in fig. 3.1. The outlet air temperature was always higher than inlet air temperature as shown in the figure. The minimum temperature of outlet CSAH and BSAH are mass flow rate m_1, m_2 and m_3 respectively 35, 33 and 32 and 46, 41 and 33 at 4:00 pm and maximum temperature outlet air CSAH and BSAH at mass flow rate m_1, m_2 and

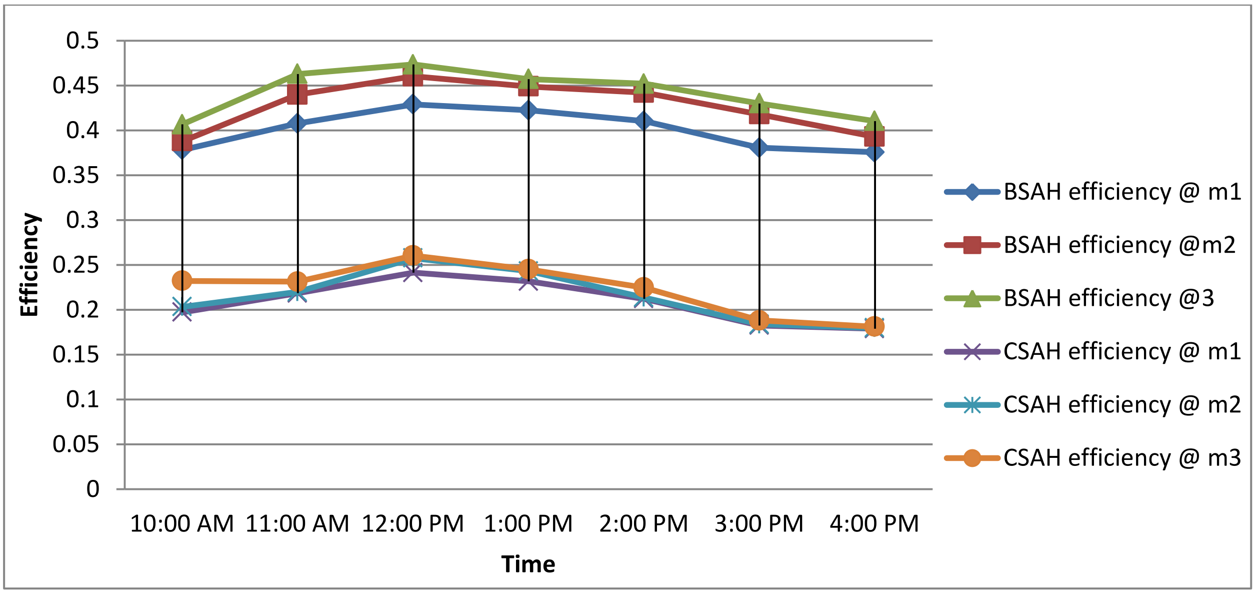
m_3 respectively 46, 42 and 39 and 60,53 and 48 at 12 p.m.. The solar radiation at 12:00 pm was measured to be the maximum i.e. 1374 W/m^2 at 23^0. Initially radiation increases with time up to 12:00 pm and then decreases till the end of experiment i.e. 4:00 pm. The maximum temperature of inlet air was 28°C at 12:00 pm and the minimum temperature was 25°C at 4:00 pm



Graph 3.1 Comparative variation of ambient, inlet and outlet temperature for CSAH and BSAH

3.2 Comparative Variation of Efficiency with Time CSAH and BSAH

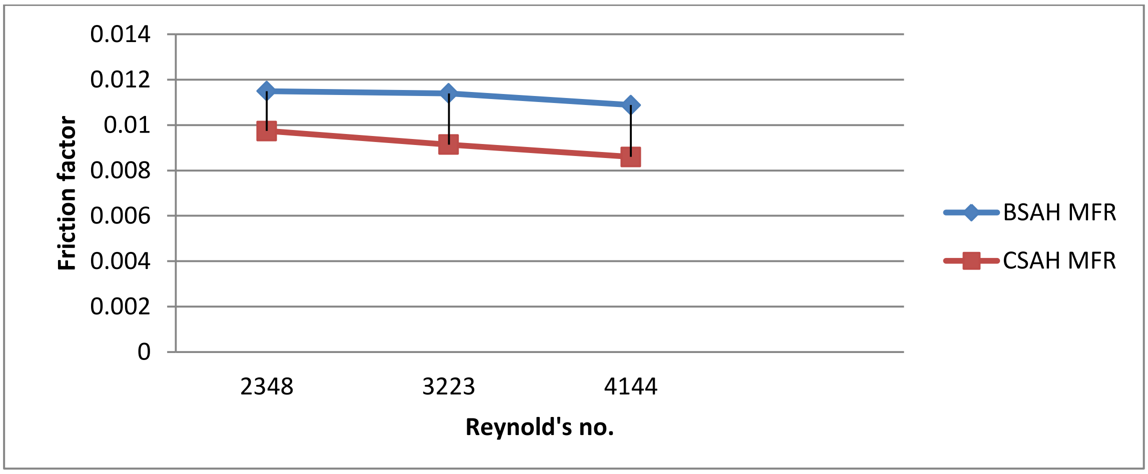
Variation of efficiency with time of CSAH and BSAH shown in fig.3.2 At the time of 12 pm maximum efficiency occur CSAH and BSAH at different mass flow rate m_1, m_2 and m_3 efficiency.2414,.2577 and .2605 and .4292, .4603 and .4736 and minimum efficiency CSAH and BSAH at same mass flow rate.1789, .1798 and .1812 and .3757, .3872 and .4067 at 4 pm. At the time 10 am it shows maximum difference of efficiency and shows minimum difference at 3 to 4 pm. At the time of 12 pm to 1pm in between maximum efficiency occur but take a reading after one hour. The efficiency maximum at 12 pm and slightly lower at 1 pm.



Graph 3.2 Comparative variation of Efficiency with time CSAH and BSAH

3.3 Comparative Variation of Friction Factor with Reynolds Number CSAH and BSAH

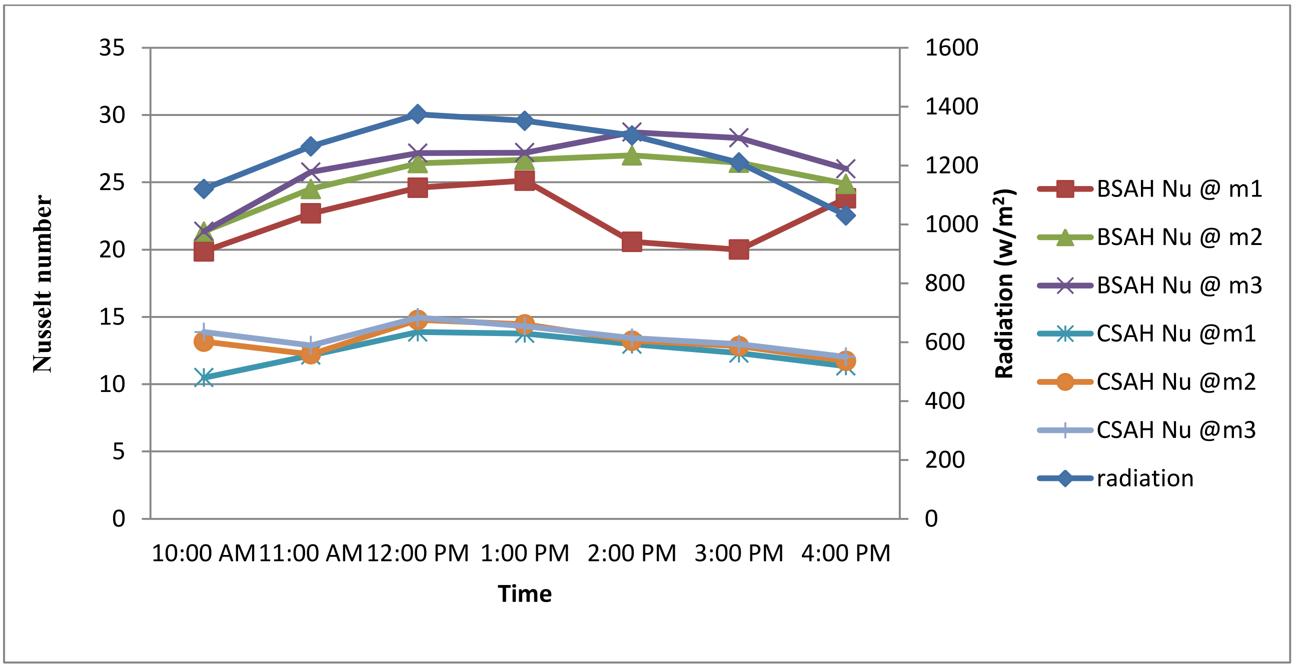
Comparative Variation of friction factor and Reynolds number CSAH and BSAH shown in fig. 3.3. The value of Friction factor in CSAH and BSAH at increases of decreases Reynolds Number. When the mass flow rate increases the value of friction factor decreases so the maximum value of friction factor in CSAH and BSAH is .00974 and 0.01154 and minimum value of friction factor is .0086 and .01080.



Graph 3.3 Comparative variation of Friction factor with Reynolds Number CSAH and BSAH

3.4 Comparative Variation of Nusselt Number with Time and Radiation CSAH and BSAH

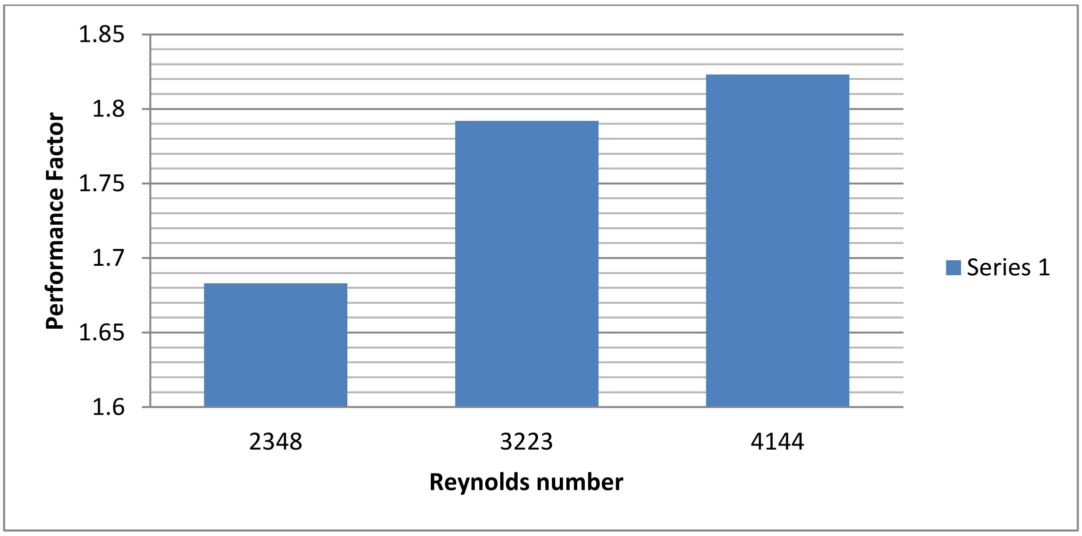
Comparative Variation of Nusselt number, Reynolds number with time CSAH and BSAH shown in fig.3.4.When the Reynolds Number increases Nusselt Number also increases. But mass flow rate second and third slightly increases Nusselt Number. The maximum Nusselt Number CSAH and BSAH At the mass flow rate m_1, m_2 and m_3 are 13.87, 14.78 and 14.96 and 25.12, 26.67 and 27.20 at12pm and 1 pm and minimum Nusselt Number at same mass flow rate is 19.87, 21.34 and 21.35 at 10am. Maximum increment of Nusselt Number is 10 am.



Graph 3.4 Comparative variation of Nusselt Number with time and Radiation CSAH and BSAH

3.5 Variation of Performance Factor with Reynolds number

Variation of performance factor with Reynolds Number shown in fig.3.5. Performance factor depends on Nusselt Number of baffled plate and smooth plate and friction factor of baffled plate and smooth plate. When the mass flow rate of of air increases Reynolds Number also increases so Performance factor also increases. The maximum value of performance factor is 1.823 and minimum value of performance factor is 1.683.



Graph 3.5 Variation of performance factor with Reynolds number

IV. CONCLUSION

An experimental study on performance of a solar air heater having perforated baffles on the air flow side of the absorber plate has been made for air mass flow rate of about 0 .00527 to 0.00946 kg/s. Performance of the solar air heater with baffled duct and smooth duct solar air heater shows that,

1. The thermal efficiency of the baffled duct solar air heater is about 16-21% higher than the smooth duct solar air heater and also highest thermal efficiency is at the maximum mass flow rate.
2. It has been observed that with the use of baffles in duct heat collection rate increases which further lead to the enhancement of heat transfer.
3. Investigation also results in the difference of 1^0C in ambient and inlet air temperature.
4. Maximum Outlet temperature obtained on baffled solar air heater was 66^0C and conventional solar air heater was 48^0C.

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