ISSN: 2277-9655
Impact Factor: 4.116

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

COMPARISON OF PERFORMANCE OF DOUBLE PASS SOLAR AIR HEATER HAVING DOUBLE LAYER GLASS

Naresh Prajapati*, Ajay Kumar Singh, Ashish Verma

M.E. Scholar, Department of Mechanical Engineering, Radharaman Institute of Technology & Science, Bhopal, MP, India

Associate Professor & Head, Department of Mechanical Engineering, Radharaman Institute of Technology & Science, Bhopal, MP, India

Assistant Professor, Department of Mechanical Engineering, Radharaman Institute of Technology & Science, Bhopal, M.P.

DOI: 10.5281/zenodo.61487

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 paper comparison of the thermal performance of double pass solar air heater of different types of absorber plates has been discussed. Three different types/colours of metallic sheets have been used. The absorber plates have- metallic colour, black colour and black colour with mesh wire as auxiliary attachments. It is found that the highest heat transfer is found out to be for black coloured plate with wire mesh at all the exit wind velocity. Metallic coloured plate is able to absorb least heat.

KEYWORDS: Heat transfer, artificial roughness, passive and active techniques.

INTRODUCTION

Solar air heater is basic equipment for converting the solar energy into thermal energy. They have been simple in design, construction requires low maintenance. Solar air heater heated the air which passes through a rectangular duct bellow a metallic absorber plate of blackened upper surface which is used to facilitate the absorption of solar radiation incident on it. This heated air delivered by solar air heater utilized in many applications such as drying crops, foods, agriculture industries, drying fruits, commercial domains and buildings in heating climates such as space heating [1]. The conventional solar air heater basically consists of a penal, insulated rectangular air duct, transparent glass covers and air blower. The penal consist of a metallic absorber plate which placed inside the rectangular hot air duct. The rectangular air duct mainly made up of wooden piece or metallic material with insulation provided on the bottom and all sides of it. The transparent glass or plastic covers placed above the absorber plates for air flow [2]. The performance of solar air heaters depends on the length and width of collector, surface of absorber plate, inlet, outlet temperature of air, type of air flow etc. In the conventional solar air heater thermal efficiency is low because heat transfer coefficient between the absorber plate and the flowing air is low, and also major heat loss from the top cover [3]. For improving in the thermal efficiency of solar air heater by minimizing heat losses from top cover, double glazing was suggested by **Satccunanathan and Deonarine** [4]. One of most effective way to increases the convection heat transfer coefficient of air was to increase turbulence inside the hot air duct by using corrugated surface [5-12]. **Sebaii et al. [5]** investigated that the double pass flat and v-corrugated plate solar air heaters, they found that double pass V-corrugated plate solar air heater is 11-14% more efficient as compare to double pass flat plate solar air heater. **Nowzari et al. [6]** had performed to single and double pass solar air heaters with partially perforated cover and packed mesh. They were concluded the thermal efficiency of the double pass was always greater than the single pass air heater by 5-22.7% for the same air mass flow rate. **Gupta et al. [7]** had investigated for roughened surface on absorber plate created by inclined wire with varying relative roughness height (e/D), at angle of attack (α) 60° and 70°. In both inclined and transverse ribs inclined ribs get better performance. **Saini and Saini [8]** had reported that enhancement of heat transfer and frictional characteristics with use of wire mesh roughened absorber plate. In this investigation they considered relative long way length of mesh (L/e) in range of 25-71.87, relative short way length (S/e) range from 15.62-46.87, relative roughness height (e/D) range from 0.12-0.39 and Reynolds number (Re) range from 1900-13,000. They found that the maximum heat transfer is four times in comparison to smooth plate. **Momin et al. [9]** done an experimental investigation on V-shaped ribs surface with relative parameters, they found that the V-shaped rib increase the value of Nusselt number by 1.4 and 2.30 times and friction factor increase by 2.30 to 2.38 over inclined ribs and smooth absorber plate. **Sahu and Bhagoria [10]** had reported that thermal efficiency and heat transfer coefficient in solar air heater using 90° broken transverse ribs on absorber plate with relative parameters. They was found the result for maximum heat transfer coefficient at pitch of about 20mm, heat transfer coefficient and maximum thermal efficiency obtained as 1.25-1.44 times and 83.5 % then the smooth surface duct. **Jaurker et al. [11]** had worked on providing rib-grooved geometry on the inner surface of absorber plate with relative parameters. They observed that the compared to smooth duct, the rib roughness increase in Nusselt number up to 2.75 times, while the friction factor raised up to 3.61 times in the range of parameters investigated. **Aharwal et al. [12]** had studies on integral repeated discrete square ribs on the absorber plate. The optimum value of Nusselts number and friction factor were found 2.83 and 3.60 times respectively in comparison of the smooth ducts.`

EXPERIMENTAL SETUP

Double pass solar air heater has been designed and fabricated by a 18mm thick plywood with 8mm insulation provided around a rectangular duct at outlet to minimized the heat losses [11]. The comparison in the enhancement of heat transfer coefficient and thermal efficiency having three different type of G.I.(Galvanized Iron) absorber plate of 22 gauges to be used for experimental study, first type is metallic colour absorber plate, second is black painted absorber plate and third is black painted with fine mesh wire absorber plate for roughened surface. The flow system consists of in three sections i.e. the entry section consists of (400×200mm), test section consists of (1500×200mm) and exist section is (200×200mm) as recommended in ASHREA standard 93-77 [13]. This is suggested that the minimum entry and exit section lengths taken $5\sqrt{WH}$ and $2.5\sqrt{WH}$ respectively. Transparent glass cover sheets two sets (1950×200mm) is used as it allows shorter wavelength radiation to pass and restricts larger wavelength radiation to go back. Halogen bulbs are used to create artificial radiation for heating purpose, maximum uniform heat flux measured by solar meter up to 1050 W/m^2. Insulation provided by 25 mm thick cotton wool of thermal conductivity is 0.029 W/m^{2}K around rectangular outlet. The flow measuring orifice plate (diameter 25mm), control valve and centrifugal blower are connected by the 1000mm long G.I. pipe line (diameter 40mm) in ordered. Pressure drop across the orifice meter was measured by an inclined U-tube manometer with distilled water as manometric fluid. Six calibrated thermocouples (K-type) are attached with upper surface of the absorber plate for measurement of plate average temperature, one thermocouple is use at inlet for measure inlet temperature of air and one thermocouple is used at the outlet for measured outlet air temperature with the help of temperature indicator. A block diagram of experimental setup and cross sectional view of double pass solar air heater have been shown in fig. 4.1(a) and fig. 4.2(b) respectively.

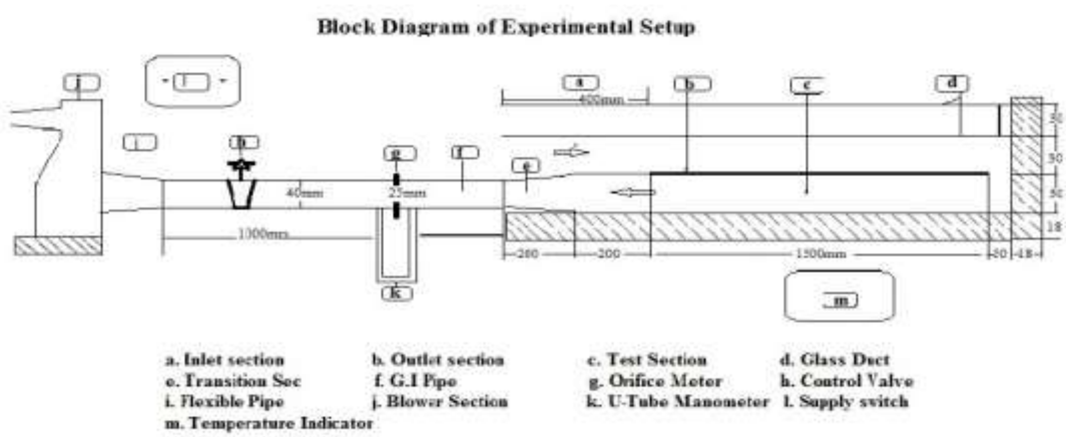


Fig. 2.1(a) Block Diagram of Experimental Setup

ISSN: 2277-9655
Impact Factor: 4.116

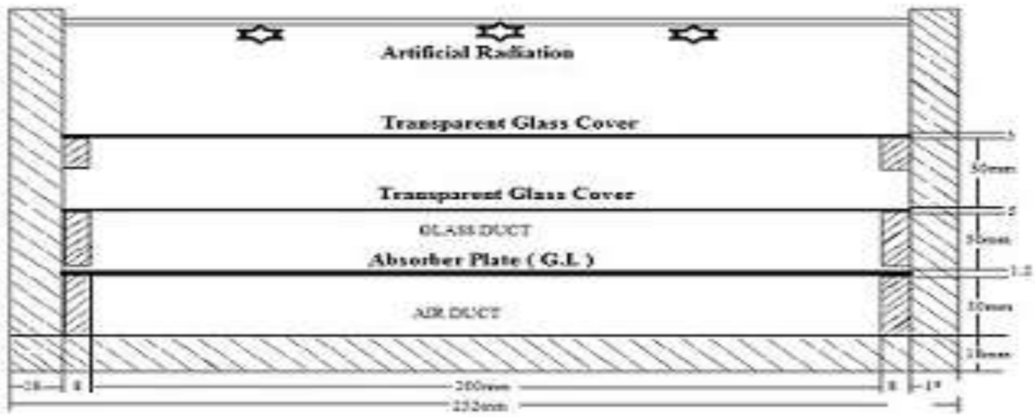


Fig. 2.1(b) Cross sectional View of Double Pass Solar Air Heat Duct

EXPERIMENTAL PROCEDURE

Before starting an experiment checked out all major components i.e. solar meter, centrifugal blower, temperature indicator, control valve and inclined U-tube manometer have been inspected for its functioning. The connection of thermocouple in our position and leak proof joint is ensured along the whole duct, after that switch on all connections. With the help of solar meter set average artificial solar radiation 930 W/m^2 was created by halogen bulbs. When the air passes through between transparent glass cover and absorber plate duct preheated by some defused solar radiation after that passed through the under the absorber plate, and heated air shucked by the centrifugal blower. Six set of readings for flow rates were considered for each absorber plate i.e. metallic colour, black colour and black colour with fine mesh wire absorber plate and this value change with the help of control valve. After fixing the mass flow rate (Reynolds number), all the value within same time interval of 30 minutes were taken when the system reached at steady state conditions. During this working air and plate temperature along with pressure drop in orifice plate were measured. An experimental set up photograph and position of thermocouples have been shown in fig. 3(a).

Fig. 3 (a) Actual Experimental Setup Photograph Inside the Room

Absorber plate:- An absorber plate made by G.I. (Galvanized Iron with 18 S.W.G) sheet of 1.2 mm thick with 1500mm×210mm in size. Three absorber plate i.e. metallic colour, one side black painted, and other is black painted with fine mesh wire for roughened surface to be used for experiment. The effective length is 1500mm, width 200mm were used for test and 5mm provided for wooden support. A set of absorber plate has been shown in fig 4.5.

Fig. 3.1 Set of Absorber Plate

Thermocouple connections:- Thermocouple have been connected on the upper sides at six position of absorber plate. Thermocouple basically (K-type) made by copper aluminium wire, it can be measured range up to 750°C. Two thermocouples one is at inlet and other one is exit connected for measuring inlet and outlet temperature of air with the help of eight channel temperature indicator. Typical photograph positions of thermocouple on absorber plate have been shown in fig. 3.1.

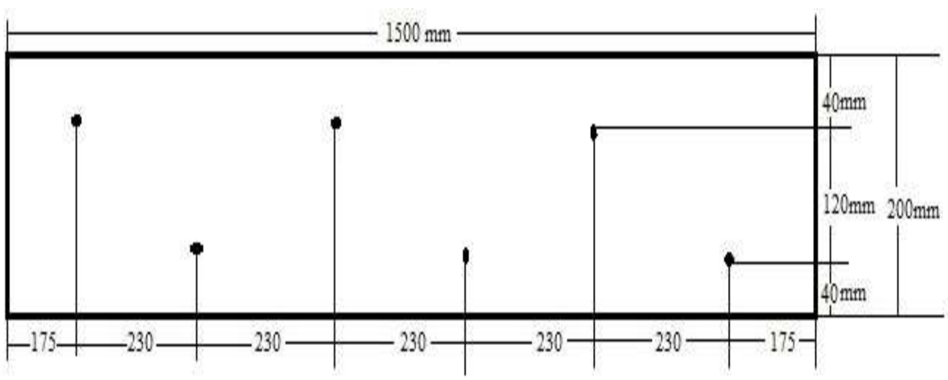


Fig. 3.2 Position of Thermocouple on Absorber Plate

EXPERIMENTAL DATA REDUCTION

The data includes thermocouple reading and air mass flow rates. This data have been deduced to obtain the average plate temperature, average air temperature, velocity of air flow in the duct, friction characteristics of the duct and the value of heat transfer coefficient. The data calculated by using following mathematical expression .

Average Temperature

The average flow temperature T_f is the measure value at the inlet and outlet of the test section by using the following equation,

$$T_f = \frac{(T_i + T_O)}{2} \tag{4.1}$$

Where,

T_i = inlet temperature (°C) T_o = outlet temperature (°C)

Mass Flow Rate

Mass flow rate, m, has been determine from the pressure drop measurement across the orifice plate,

$$\dot{m} = cd\, A_0\sqrt{\frac{2\rho(\Delta P_O)}{1-\beta^4}} \qquad (4.2)$$

Where's

Coefficient of discharge $C_d = 0.627$

Pressure difference $\Delta P_o = 9.81\rho\Delta h_o \sin\theta$.

θ = 15 degree angle for water and glass and ρ = density of water as a manometric fluid.

Heat Gain by the Air

Heat gain by the air calculated by the following equation,

$$Q_{air} = \dot{m}C_P(T_O - T_i) \qquad (4.3)$$

Heat Transfer Coefficient

The value of heat transfer coefficient between the absorber plate and fluid is given by the equation,

$$\dot{m}C_P[t_o - t_i] = hA_P[t_p - t_f] \qquad (4.4)$$

$$h = \frac{Q_{air}}{A_P(T_P - T_f)}$$

Where,

Q_{air} = heat input to air (KJ) Cp = specific heat of air (KJ/kg-K)
T_p = temperature of plate (^{0}C) T_f = temperature of fluid (°C)
T_i = temperature at entry (^{0}C) T_o = temperature at exit (°C)

Velocity Measurement

Velocity measurement by the following equation,

$$V = \frac{\dot{m}}{\rho \times W \times H} \qquad (4.5)$$

Where,

m = mass flow rate, kg/s W = width of the duct, m
H= height of the duct, m ρ = density of air, kg/m^3

Reynolds Number

The value of Reynolds number measurement by the following equation-

$$Re = \frac{\rho V D_h}{\mu} \qquad (4.6)$$

Where,

V= velocity of air (m/s) D_h = hydraulic diameter of duct (m)
P = density of air (kg/m^3) μ = viscosity of air (m^2/s)

Hydraulic Diameter

$$D_h = \frac{4WH}{2(W+H)} \qquad (4.7)$$

W = Width of duct in m
H = Height of duct in m

Nusselt's Number

$$N_u = \frac{hD_h}{k} \qquad (4.8)$$

Where,

h= heat transfer coefficient (W/m^{2}K) D_h= hydraulic diameter (m)
K= thermal conductivity of air (W/ m K) [10]

ISSN: 2277-9655
Impact Factor: 4.116

Thermal Efficiency

$$\eta = \frac{GC_{P(T_0-T_i)}}{I} \quad (4.9)$$
$$G = \frac{\dot{m}}{A_p}$$

Where,

G = mass velocity (kg/s-m^2) Ap = area of the plate (m^2)
I = heat flux (W/m^2)

RESULTS AND DISCUSSION

An experimental data has been collected, calculations for all parameters for performance of double pass solar air heater has been carried out. The readings were taken keeping same level of radiation level and exit wind velocity for all the cases. The value of heat transfer coefficient and Nusselt number for air duct has been also determined for comparison between different absorber plates.

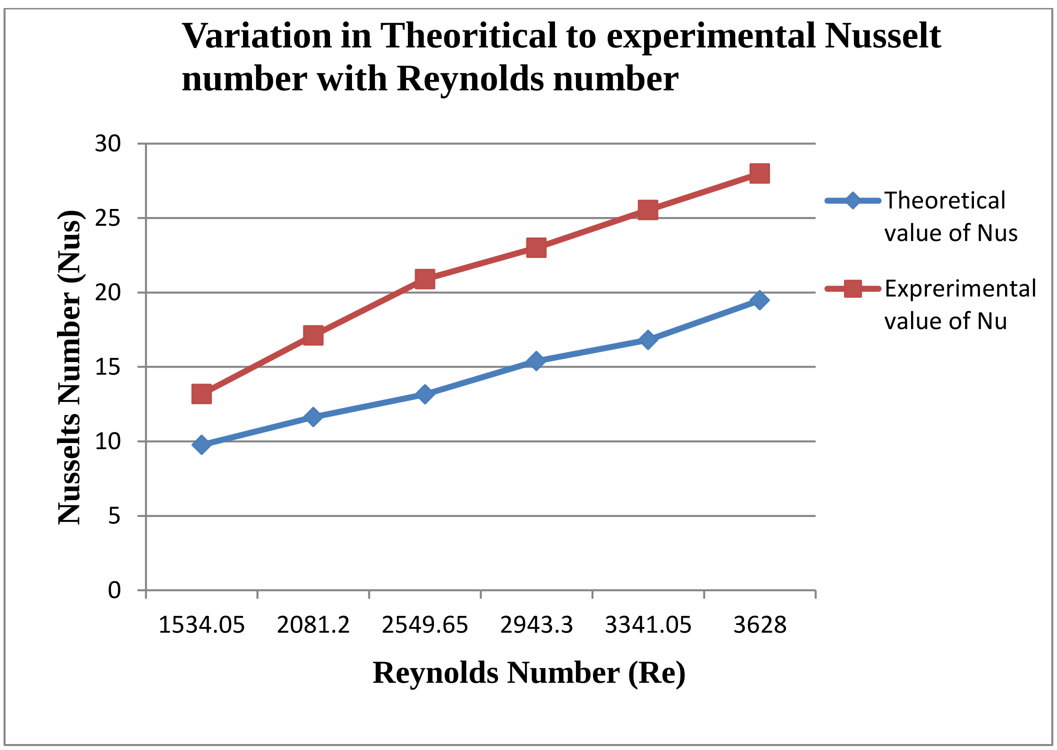
Experimental investigation also gave the variation in Reynolds number (Re) for absorber plates having different colour and auxiliary arrangement i.e. metallic colour, black colour and black colour with mesh wire roughened plated .

Variation in Non-Dimensional Numbers

An experimental data validate the results of this work for heat transfer in the form of Nusselt number and heat transfer coefficient has been determined from experimental data for comparision with the analytical values obtained from Dittus-Boelter equation. The Nusselt number for a smooth rectangular duct is given by the Dittus-Boelter equation is [12]–

$$Nu_s = 0.023Re^{0.8}Pr^{0.4} \quad (5.1)$$

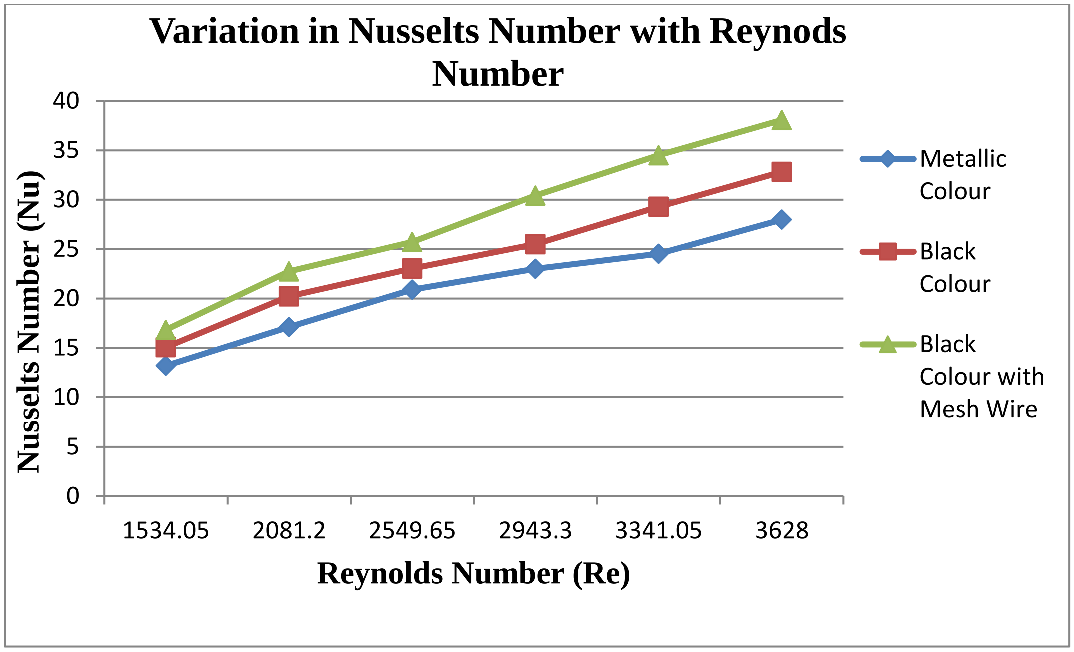
Experimental and theoretical values from equation of Nussel number has been shows in graph 5.1



Graph 5.1 Variation in Theoretical to Experimental Nusselts Number for Metallic Colour Plate

Effect of Colours and Roughness on Nusselts Number

An effect on Nusselt number by different colours i.e. metallic colour is low because of quantity of heat absorption is low and for black colour smooth plate is higher compare to metallic colour smooth plate. Nusselt number increases with increasing the roughness on the absorber plate to certain limit at fixed value of Reynolds number. This effect has been shown due to increasing turbulence of air flow. The value of experimental data for Nusselt number has been shown in graph 5.2.

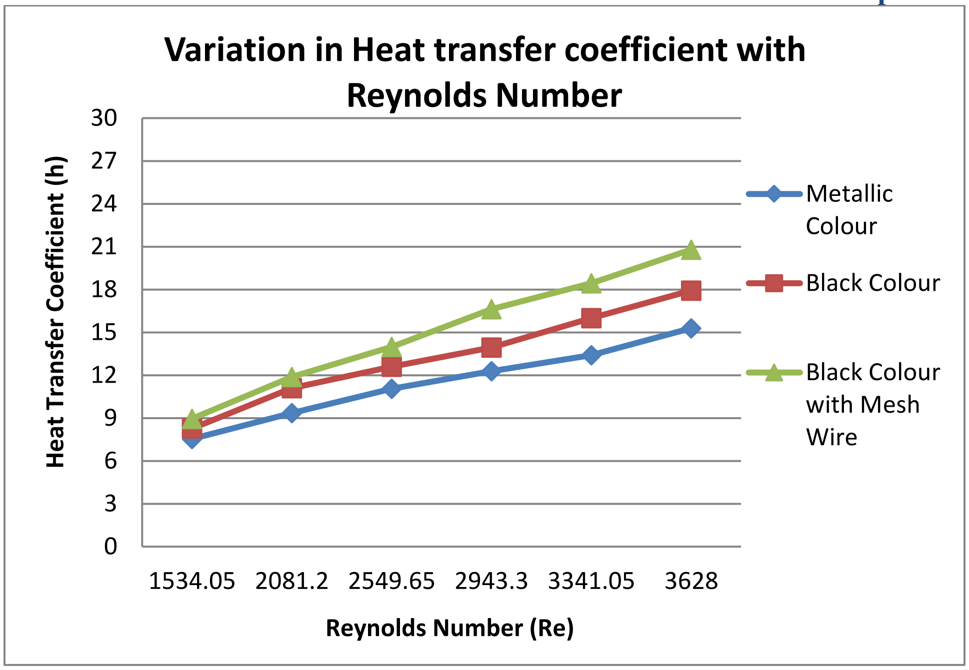


Graph 5.2 Variation in Nusselts Number with Reynolds Rumber

Effect of Colours and Roughness on Heat Transfer Coefficient

The value of heat transfer coefficient increase with increasing roughness on the absorber plate surface at certain limit for fixed relative value of Reynolds number. Minimum heat transfer coefficient has been found for metallic colour absorber plate because low heat absorption by metallic colour plate. The optimum value of heat transfer coefficient has been also found for roughened black colour with mesh wire absorber. Thus, it can be said that the value of heat transfer coefficient increases with increase in the relative value of Reynolds number due to increasing in turbulence effect. The maximum heat transfer coefficient obtained for rough mesh wire absorber plate. The experimental value of Reynolds number has been shown in graph 5.3.

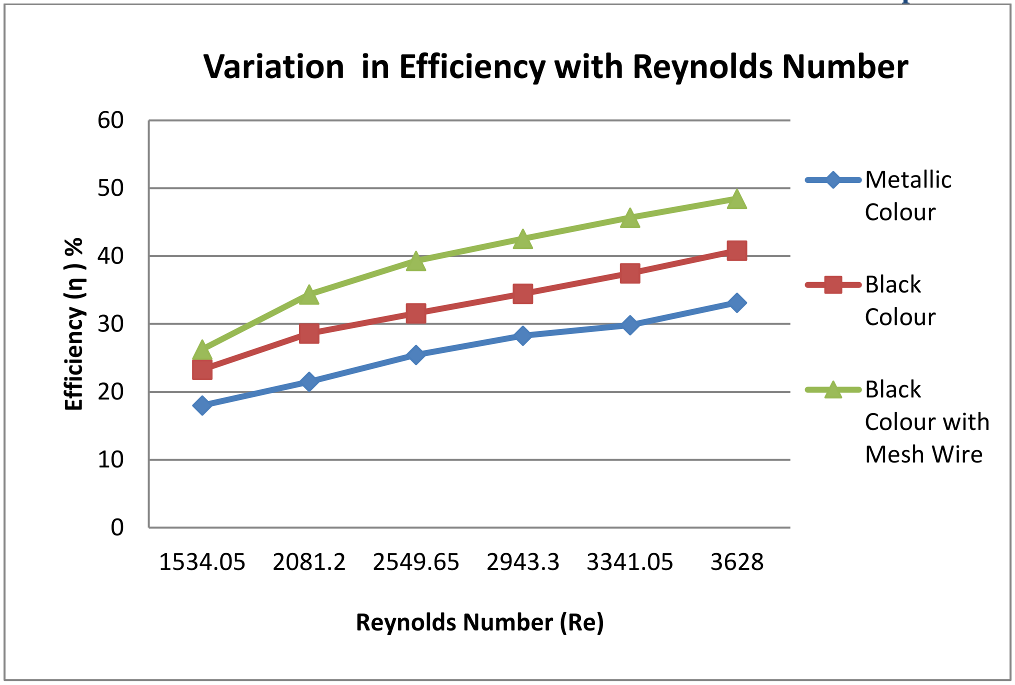
ISSN: 2277-9655
Impact Factor: 4.116



Graph 5.3 Variation in Heat Transfer Coefficient with Reynolds Number

Variation of Thermal Efficiency with Reynolds Number for Colours and Roughness

Variation of thermal efficiency with Reynolds number for colours and roughness are shows in graph 5.4. The maximum thermal efficiency has been found for roughened black colour mesh wire absorber plate due to more heat absorption and increase in turbulence effect. It has been found that the thermal efficiency increases with increase in Reynolds number. At low value of Reynolds number the laminar sub layer presence on the absorber plate surface which offer resistance to low heat transfer of air flow on the plate surface. When this is increases in a value of Reynolds number then laminar sub layer has been broken, air flow is turbulence and takes place higher value of heat transfer to air flowing on the plate surface. The thermal efficiency for a fixed relative value of Reynolds number are shows in graph 5.4.



Graph 5.4 Variation in Thermal Efficiency with Reynolds Number

CONCLUSION

The following conclusion can be drawn from above experiments.

1. The thermal efficiency of roughened mesh wire absorber plate is highest as compare to metallic colour with smooth surface absorber plate.
2. Higher values of Nusselt's number and heat transfer coefficient is observed as roughness of plate increases.
3. The maximum value of Nusselt's number has been found in the roughened black colour with mesh wire absorber plate as compare to metallic colour with smooth surface plate.
4. The maximum value of thermal efficiency and Nusselt's number of roughened absorber plate reached up to 1.46 and 1.36 times respectively higher as compare to metallic colour with smooth surface absorber plate.
5. It has been also found that the absorption of heat by the black colour absorber plate in higher as compare to metallic colour absorber plate.

REFERENCES

[1] H.P. Garg, J. Prakash, Solar Energy Fundamentals and Applications, first ed. Tata McGraw-Hill, New Delhi, 2000.
[2] S. P. Shukhatme, a text book of solar energy, Tata, McGraw-Hill publication New Delhi (2008)
[3] A.P. Omojaro, L.B.Y. Aldabbagh Experimental performance of single and double pass solar air heater with fins and steel wire mesh as absorber Applied Energy 87 (2010) 3759–3765
[4] A.A. El-Sebaii, S. Aboul-Enein, M.R.I. Ramadan, S.M. Shalaby, B.M. Moharramb Investigation of thermal performance of-double pass-flat and v-corrugated plate solar air heaters Energy 36 (2011) 1076e1086
[5] Satcunanathan S, Deonarine S. A two-pass solar air heater. Sol Energy 1973, 15: 41–9.
[6] R. Nowzari, L.B.Y. Aldabbagh, F. Egelioglu, Single and double pass solar air heaters with partially perforated cover and packed mesh. Energy 2014,73: 694-702.
[7] D Gupta, SC Solanki, JS Saini. Thermo hydraulic performance of solar air heater with roughened absorber plates. Solar energy 1997; 61:33-42.

[8] RP Saini, JS Saini. Heat transfer and friction factor correlations for artificially roughened ducts with expended metal mesh as roughness element. International Journal of Heat and Mass Transfer 1997; 40(4):973–86
[9] AME. Momin, JS Saini, SC Solanki. Heat transfer and friction in solar air heater duct with V-shaped rib roughness on absorber plate. International Journal of Heat and Mass Transfer 2002; 45:3383–96
[10] MM Sahu, JL Bhagoria. Experimental investigation of heat transfer coefficient by using 90° broken transverse ribs on absorber plate of solar air heater. Renewable Energy 2005; 30:2057–63.
[11] Jaurker AR, Saini JS, Gandhi BK. Heat transfer and friction in solar air heater duct with rib and groove shaped rib roughness on absorber plate. Solar energy 2006; 80(8):895–907.
[12] KP Aharwal, BK Gandhi, JS Saini. Investigation on heat transfer and friction characteristics of solar air heater ducts having integral inclined discrete ribs on absorber plate. Heat and Mass Transfer 2009, 52:5970–5977
[13] ASHRAE standard 93–77. Method of testing to determine the thermal performance of solar collector, 1977.