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Exergy Analysis of Solar Air Collector Having W Shaped Artificial Roughness

Ajay Pratap Singh[1] and M.M. Sahu[2]

[1]Mtech IInd Year, Thermal Engineering LNCT, Bhopal.
Email: aju2408@gmail.com
2Asst. Professor Department Of Mechanical Engineering, LNCT, Bhopal.
Email: mmsahu.111@rediffmail.com

ABSTRACT

An experimental approach is done to determine the exergy analysis of solar air heater for enhancement of heat transfer by using artificial roughness. In this experiment we have used W shaped artificial roughness having aspect ratio (W/H) of 8:1 with one broad roughened surface. In this experiment three absorber plates are used (one smooth + two roughened plate).The roughened plate have geometry of 1W & 2W. The roughness of the plate will create the turbulence in the fluid flow.

The experiment has been performed at different mass flow rate (Reynolds No.) and at constant heat flux for forced convention in order to find exergy loss of solar air collector. Experiment has been performed on rectangular duct which covered a Reynolds Number (R_e) range of 4000 – 12000, aspect ratio W/H is 8, relative roughness height (e/D_h) = 1.3 & 1.5 mm, relative pitch of 10, hydraulic diameter 44.44 mm, angle of attack is 60°and heat flux is 816 W/m^2 has been used. Under these parameters various data's are collected from the experiments for smooth as well as roughened plate under same boundary and operating conditions.

The results of W shaped roughened plates have been compared with the result of smooth plate. It is found from the experiment that the exergy decreases with increasing in Reynolds Number. It is also observed from the experiment that artificial roughness of absorber plate will increased the exergy loss will decreases. It is found from the experiment that artificial roughness of absorber plate will increased the heat transfer rate of solar air heater.

KEYWORDS: Air Collector, Friction Factor & Exergy Loss

INTRODUCTION

Solar energy is most readily available source of energy. Solar collector is the key component of active solar heating system. Solar air collector have poor heat transfer performance due to the formation of laminar sub layer, enhancement of Heat Transfer is done by various methods. By using artificial roughness on absorber plate, use of extended surfaces and by using packed bed solar air heater. By providing artificial roughness the laminar sub layer gets broken and it increases the heat transfer coefficient.

The heat transfer between absorber plate of solar heater duct and flowing fluid can be improved by two ways. Firstly by increasing the area of absorbing plate of duct and second by increasing the turbulence of the flow fluid.

In this experiment we have made an effort to increase the heat transfer through absorber plate by using artificial roughness. On increasing the roughness of absorber plate the turbulence of fluid increase due to friction factor which result in increase in heat transfer between absorber plate and fluid flow. An effort has been carried out to get the optimum roughness geometry which increases the heat transfer at low penalty of pressure drop. In this experiment artificial roughness of 1W & 2W geometry are used. The artificial roughness breaks the laminar boundary layer of fluid flow and makes the flow turbulent adjacent to absorber plate.

NOMENCLATURE

A_p	Absorber plate area, m^2
A_{duct}	Flow cross section area = WH, m^2
A_o	Throat area of orifice plate, m^2
A_s	Area of smooth plate, m^2
e	Rib height, mm
e / Dh	Relative roughness height
f	Friction factor
W	Duct width, m
H	Duct depth, m
K	Thermal conductivity of air, W/m K
m	Mass flow rate, kg/s
C_d	Coefficient of discharge (0.62)
C_p	Specific heat of air, KJ/KgK
D_o	Diameter of orifice of the orifice plate
D_p	Inside diameter of the pipe
H	Convective heat transfer coefficient, $W/m^2 °C$
I	Heat flux, W/m^2
Nu	Nusselt number
R_e	Reynolds number
P	Rib pitch, m
P / e	Relative roughness pitch
T_i	Inlet air temperature, °C
T_o	Outlet air temperature, °C

T_{pav}	Mean plate temperature, °C
T_{oav}	Average temperature of air, °C
V	Velocity of air,
ΔH	Channel aspect ratio
ΔP	Pressure drop in duct, P_a

Symbols

ρ	Density of air, Kg/m^3
μ	Dynamic viscosity, Kg/m.sec
ν	Kinematic viscosity, m^2/sec
β	Ratio of orifice diameter to plate diameter

RANGE OF PARAMETER AND ROUGHNESS GEOMETRY

The values of operating parameters are given in Table 1. The relative roughness height (e/ D_h) is 0.02925 & 0.03375, relative roughness pitch p is 10mm and angle of attack α is 60° to achieve maximum heat transfer. The range of Reynolds no. and relative roughness height has been chooses based on the force convention (the power of blower).

Table – 1

Parameter	Values
Reynolds Number (Re)	4000 - 12000
Relative roughness height (e/Dh)	0.02925 & 0.03375
Relative roughness pitch (p/e)	10
Roughness Height (e)	1.3 & 1.5mm
Rib angle of attack (α)	60
Heat Flux (I)	816 W / m^2
Plate material	G.I Sheet
Thickness of plate	0.8 mm
Channel aspect Ratio (W / H)	8
Test Length	1500 mm
Hydraulic Diameter	44.44 mm

EXPERIMENTAL INVESTIGATION

The experimental program has two parts (a) Experimental set up (b) Experimental procedure.

Experimental Setup

The experimental schematic diagram setup including the test section is shown in Fig. 1. The flow consists of an entry section, a test section, an exit section, a flow meter and a centrifugal blower. The duct is of size 2043mm x 200mm x 25mm (dimension of inner cross section) and is constructed from wooden panel of 25mm thickness. The test section is of length 1500mm. the entry and exit length were 177mm and 353mm respectively.

In the exit section after 200mm, three equally spaced baffles are provided in a 100mm length for the purpose of mixing the hot air coming out of solar air duct to obtain a uniform temperature of air (bulk mean temperature) at the outlet.

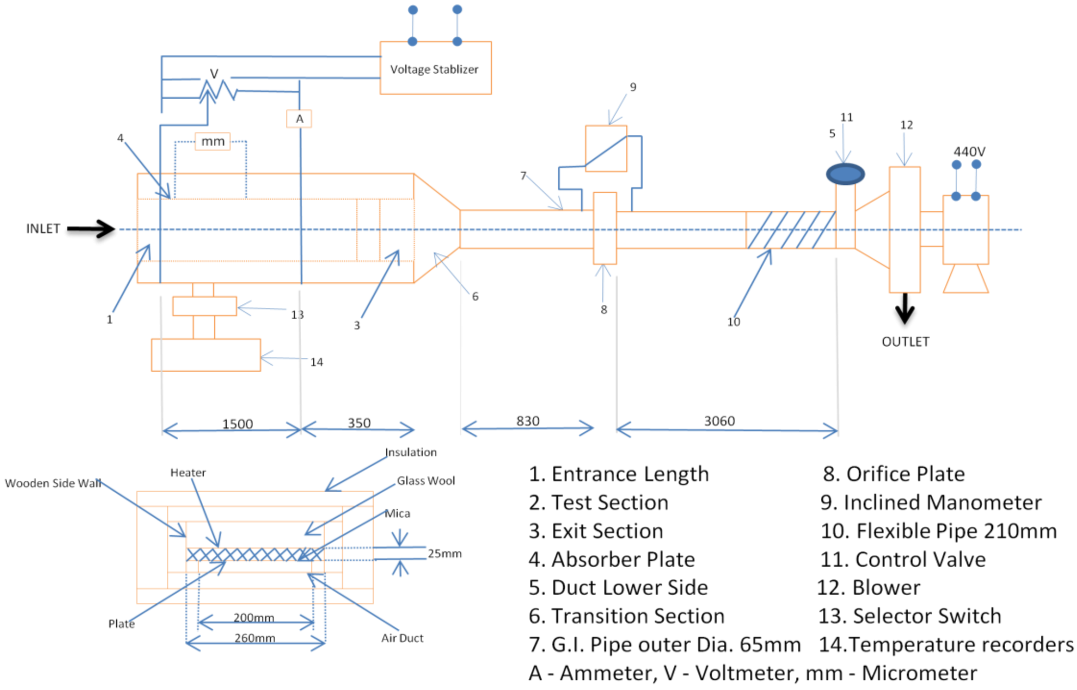

Fig – 1 Experimental Set up

In the present experiment set up we used 830 mm pipe length on the upstream and 600 mm on downstream side. The calibrated copper constantan 0.3 mm (24 SWG) Thermocouple were used to measure the air and heated plate temperature at different locations. A digital voltmeter is used to indicate the output of the thermocouple wire. The temperature measurement system is calibrated to yield temperature value ± 1°C. The pressure drop across the test section was measured by a micro manometer

An electric heater having size 1650mm x150mm was fabricated by combining series and parallel loops of heating wires on 5mm asbestos sheet. A mica sheet of 1mm is placed between the electric heater and absorber plate (aluminum plate). The mica sheet act as an insulator between the electric heater and absorber plate (G.I.Sheet). The heat flux may vary from 0 to 1000 W / m^2 by a variable resistor across it. The back of heater is covered by a 50mm glass wool layer and a 12mm thick plate of wood to insulate the top of the heater assembly.

The mass flow rate of air is measured by means of calibrated orifice meter connected with an inclined manometer and the flow is controlled by the control valves provided in lines. The orifice plate has been designed for the flow measurement in the pipe of inner diameter of 78mm. the orifice plate is fitted between the flanges so aligned that it remains concentric with the pipe.

Experimental procedure

The test is carried out to collect relevant heat transfer and the flow friction data under quasi steady state conditions. The quasi steady state condition is assumed to have been reached when the temperature at the point does not change for about 10 – 12 minutes. When the change in the operating condition is made it will takes 30 – 40 min. to reach such quasi steady state. After each change of flow rate the system was allowed to attain the steady state before the data were recorded. The following parameters were measured during the experiments:

- Pressure drop across the orifice plate.
- Inlet and outlet air temperature of the collector.
- Temperature of the plate at different location.

Analysis of Exergy

Exergy is the amount of maximum work obtained theoretically at the end of a reversible process in which equilibrium should be obtained. According to this definition, in order to calculate exergy, the environment conditions should be known.

The exergy can be written as

$$E = m\,C_p\,\Delta T - m\,C_p\,T_e \ln (T_o - T_i) - m\,R\,T_e \ln (P_o / P_i) + I\,A\,(1/T_e/T_p) \qquad 1$$

Exergy Loss

$$E_d = E / Q \qquad 2$$

The efficiency of solar air heater is depending on the efficiency of collectors. In this experiment the mass flow rate of the fluid, temperature of the collector inlet and outlet and the radiation intensity are measured simultaneously.

The thermal collector efficiency is defined as the ratio of useful energy and the incident solar radiation.

$$\eta_t = Q / I \,.\, A \qquad 3$$

The useful energy Q used in the calculation of collector efficiency can be estimated by following formula

$$Q = m\,Cp\,(T_{oav} - T_i) \qquad 4$$

Solar air collector transfer solar radiant energy into heat, which is transferred to the working fluid (air) through convention. The heat transfer obtained can be given in terms of Nusselt number.

$$Nu = hD_h / k \qquad 5$$

Where D_h is the hydraulic diameter and evaluated as

$$D_h = 4A_h / U \qquad 6$$

For coefficient of convective heat transfer

$$Q = h\,a\,\Delta T_{log} \qquad 7$$

Where, ΔT_{log} is the logarithmic mean temperature difference between temperature of absorber plate and the flow fluid.

The Reynolds number, which depends strongly on the velocity of the flowing fluid, can be written as

$R_e = \rho\ V\ D_h / \mu$ 8

The velocity of the flowing fluid is measured at the inlet of the duct

$m = \rho\ A\ V$ 9

Friction Factor is expressed as

$F = (\ 2 \times \Delta P_{micro} \times D_h \times \rho\ ) / (\ 4 \times 1.3 \times V^2\ )$ 10

RESULT AND DISCUSSION

The effect of various flow and roughness parameters on Thermal Efficiency, friction factor and exergy loss of air in rectangular ducts of different roughness (different Rib Thickness) of the present investigation are shown in Fig 2, Fig 3 & Fig 4.

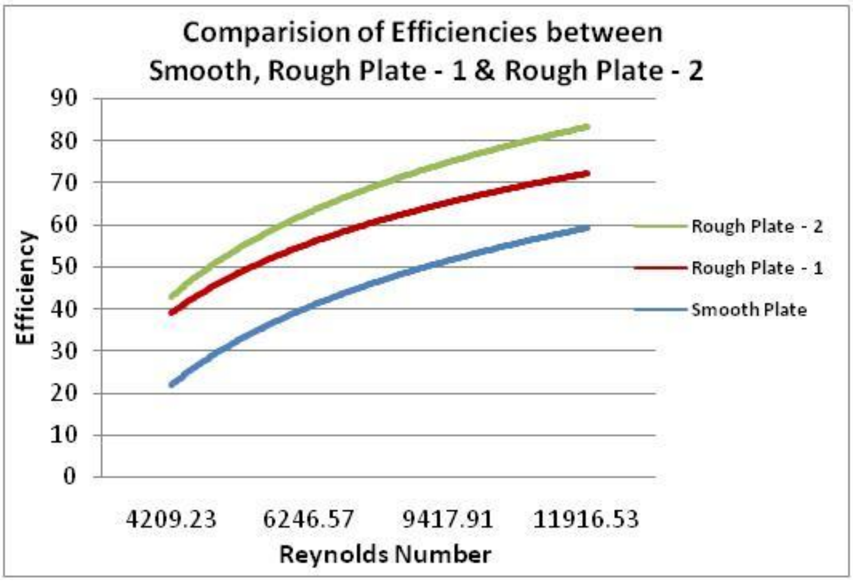

Fig. 2 Reynolds Number Vs Efficiency

It is found from the experiment and fig.2 that the efficiency of solar air heater increases with increase of mass flow rate of fluid also it is observed that with increase in the roughness of plate the efficiency of solar air collector increases. It is clear from the fig. 2 that the efficiency of Rough plate -2 is 1.3 times more than smooth plate.

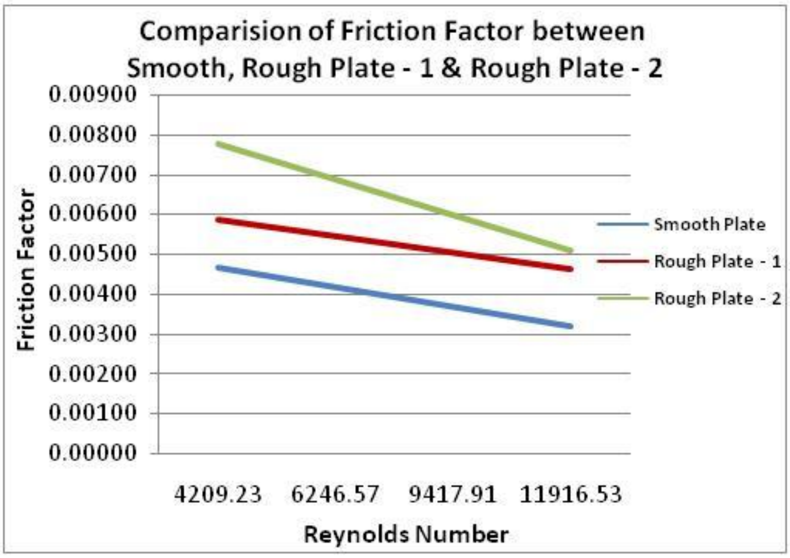

Fig. 3 Reynolds Number Vs Friction Factor

It can be seen from this fig.3 that the Friction Factor values increases with increase in roughness of plate. Here the roughness geometry 1W& 2W are used to create the turbulence and to increase the absorptivity. The heat which is absorbed by absorber plate is transferred to the fluid flow. It is clear from the fig. 3 that the Friction Factor of Rough Plate -2 is 1.8 times more than smooth plate.

It is found from the fig.4 that the exergy of solar air heater decreases with increasing of mass flow rate of the fluid, also it was observed that with increase in the roughness of plate the exergy loss of solar air heater duct decreases. It is clear from the fig. 4 that the exergy loss of Rough plate -2 is 2.2 times less than smooth plate.

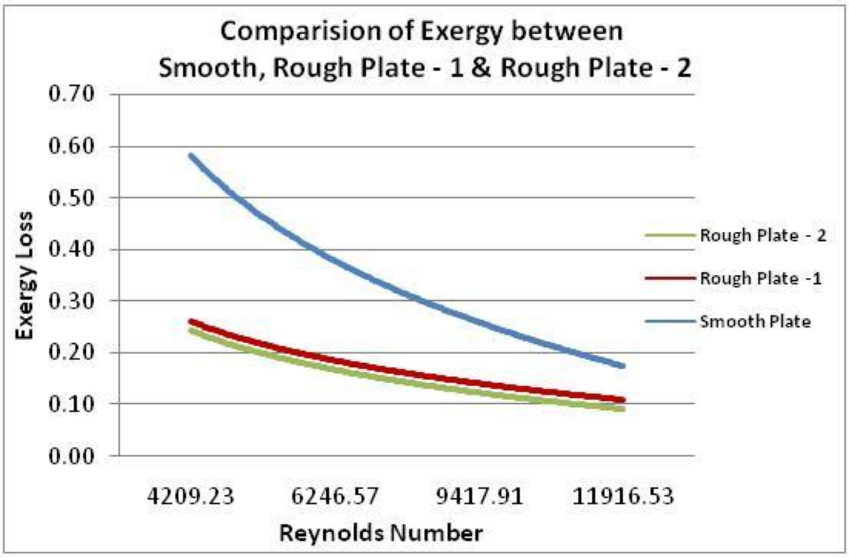

Fig. 4 Reynolds Number Vs Exergy Loss

CONCLUSION

The exergy loss of solar air collector decreases with increase in artificial roughness of absorber plate and Reynolds Number. The heat transfer and pressure drop increases with increase in absorber plate roughness. It is observed from experiment that Friction Factor will increases with increase in artificial roughness of plate. The efficiency of solar air heater collector increases with increase of surface roughness of absorber plate and increasing the Reynolds Number.

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