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Experimental Investigation on Heat Transfer and Fluid Flow Phenomena of Arc Shaped Rib with Gaps on the Plate

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ABSTRACT
Every activity in this world, whether it is associated with human being or by nature, is caused due to transformation of energy in one form to another. Every kind of work requires energy. Hence energy plays very important role in this world. Work output is function of energy input. Energy can be defined as ability to do work and it depends on the quantity of energy one can control and utilise.
A simple solar air heater has a low value of heat transfer coefficient. It is because of low interaction between absorber plate and the flowing air. In the turbulent flow near the absorber plate surface, a laminar sub layer forms, that is less efficient for the heat transfer and hence act as an insulating medium. So due to this reason we create artificial roughness on the underside of the absorber plate to break the laminar sub layer. Artificial roughness disturbs the laminar sub layer and makes it turbulent, which results in increase in the heat transfer rate.
Thermo-hydraulic performance of solar air heater duct can be improved through enhancing the heat transfer. Hence artificial roughness is an effective technique to enhance the value of heat transfer of fluid flow.
Experiments were performed to obtain maximum increase in Nusselt number and friction factor in forced convection flow of air in rectangular duct of solar air heater with Arc type rib roughness on the absorber plate. Various parameters are considered according to operating condition. The experiment encompassed with Reynolds number in the range of 2000-12000, relative roughness height (e/D_h) of 0.045,relative roughness pitch (P/e) is 10, angle of attack is 30^0, roughness height (e) is 2mm, number of gaps(N_g) are 1,2,3,4,5 with heat flux of 900 w/m^2. Result is further compared with those of smooth duct under similar flow condition to determine heat transfer coefficient and friction factor.
The maximum value of Nusselt number and friction factor obtain are 2.33 and 2.55 times for number of gap(N_g) 3 respectively,relative roughness pitch (P/e) is 10, when compared with the values of smooth plate.

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I. INTRODUCTION

1.1 ENERGY

Energy can be defined as capacity for doing work. It is important pillar to sustain life and development as well. There is various type of energy available on the earth which drives the machine. Now days as the population increasing rapidly the demand of energy also increases continuously [1].

Due to continuous rise in demand of energy causes decrease in availability of fossil fuels on the earth. As the use of fossil fuel increases the environmental problem also arises. Growing concern about cost of energy and environmental problems has forced the scientific community to focus on alternate energy source or to develop alternate energy source. Therefore it is desired to develop self-sustaining quantity of energy which is not having significant impact on climate and available in large quantity [2]. So it is required to utilise renewable energy resources which are environmental friendly and reliable as well such as hydro power energy, solar energy, water energy, geothermal energy, ocean energy etc.

Solar energy is the most favourable among all the alternate sources of energy because of two important features such as availability and eco-friendly nature [3]. Different devices are available which help in converting solar energy to usable form of energy such as solar cooker solar air heater solar water heater solar cell solar furnace etc. Solar collector system consists of solar air heater as its integral part and which is used to convert solar radiation to thermal energy, which further transferred to air flowing inside the duct. In present situation the problem connected with the use of fossil power is vital.It is become important to option sources of energy .These sources, for example sun and the wind which never can get end. Hence considered as renewable energy otherwise called as non- traditional source of energy [4].

Non-renewable resources are those energy sources whose availability is limited and which can vanish after use such as fossil fuels, while tillable energy sources in crop incorporate the wind, sun, waves,tides, geothermal, biomass etc.

1.2 Solar energy

Solar energy is considered as the light and Radiant Heat which is coming from the sun and impacts Earth's atmosphere, climate and supports life. Solar energy is the huge source of energy which is freely available in plenty and it does not cause any effect on environment. Sun based advancements are extensively delineate as passive solar or active solar filling up on the method they catch, change over and publicize solar energy. Active sunlight based system uses sun's radiation which further converts to electricity. Passive light system based on heat coming from the sun used to produce electricity.

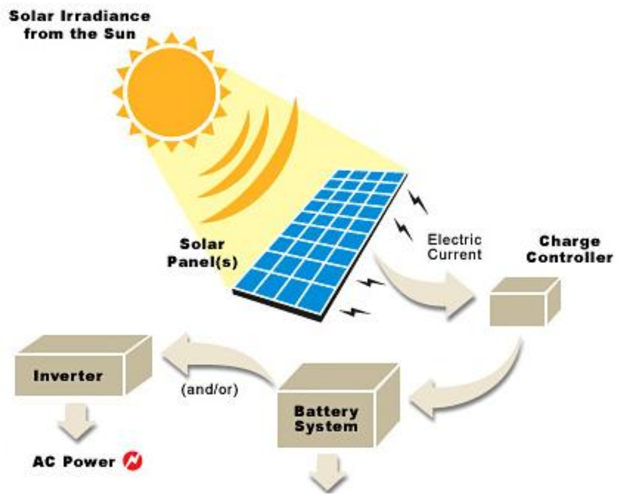


Figure-1.1 Solar energy

Solar energy now been used in many applications such as in the industrial and domestic applications. Different techniques used to utilise solar energy are solar cooking, solar lighting, solar cooling, space Technology etc. Fossil fuels are important part of solar energy which is stored in the form of organic matter. Most importantly fossil fuels affects environment badly and causes global warming acid rain smog pollution etc. as we know fossil fuels are decreasing day by day rapidly. That's why we have to select the alternate source of energy which can replace fossil fuels such as solar energy wind energy geothermal energy etc.

II. LITERATURE REVIEW

2.1 Different orientation of double arc rib roughness

A. Lanjewar et al [11] experimentally investigated double arc rib up and down type rib roughness to study the effect of orientation on double arc rib on thermo-hydraulic performance of solar air heater as shown in figure. The experiment encompassed Reynolds no. 4000 to 14000, relative roughness pitch (p/e) of 10, angle of attack (α) of 45^0, Relative angle of attack (α/90) and aspect ratio as 8. They found that the Nusselt number increased by 66.99-115.24% for double arc up and 102.57-162.45% for double arc down when compared with smooth duct

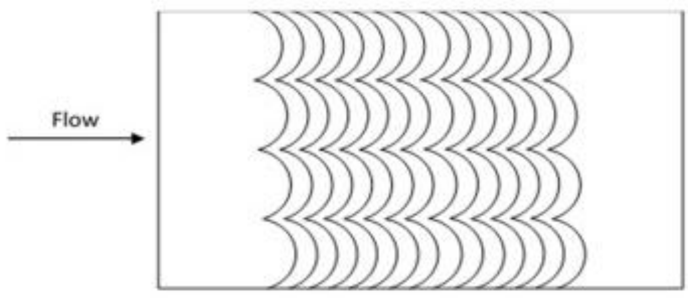


Figure-2.1 Double arc rib roughness

2.2 Different orientations of w-rib roughness

A. Lanjewar et al [12] experimentally studied the orientation of w-rib roughness on heat transfer coefficient and friction factor characteristics the experiment encompassed Reynolds no. 2300 to 14000 relative roughness pitch (p/e) of 10, angle of attack(α) of 30^0-45^0,and aspect ratio(w/H) as 8, Relative roughness height(e/Dh) is 0.03375. They found that at the angle of 60^0 with w-down arrangement the maximum hydraulic performance is achieved.

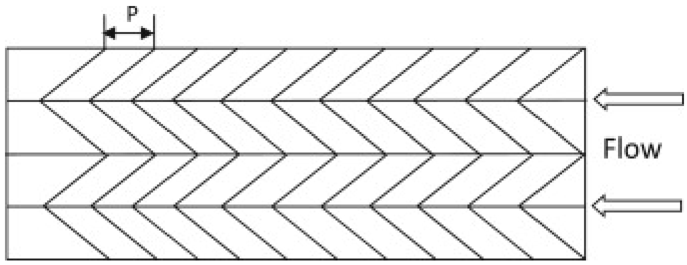


Figure-2.2 W shaped rib roughness

2.3 Circular protrusion

Yadav et al [13] experimentally investigated the effect on heat transfer coefficient and friction factor characteristics due to presence of artificially roughened Circular rotation arrangement. The experiment encompassed Reynolds number 3600 to 18,100 relative roughness pitch (p/e) of range 12 to 24, angle of attack(α) of range $45^0$to 75^0,and aspect ratio(w/H) as 8,Relative roughness height(e/Dh) of range 0.015 to .03. The maximum heat transfer coefficient and friction factor increased by 2.89 and 2.93 times respectively as compared with smooth duct.

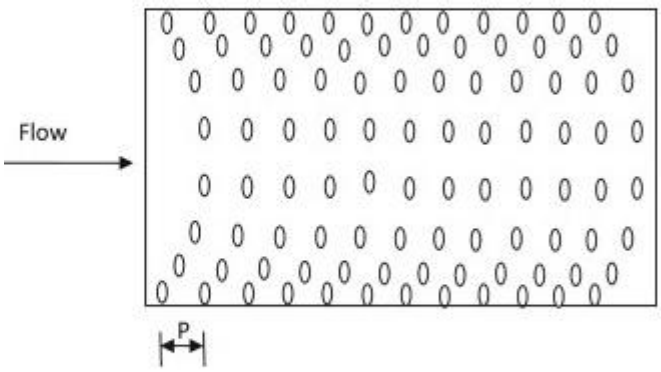


Figure- 2.3 Protrusion roughened geometry

2.4 Oblique wire roughness

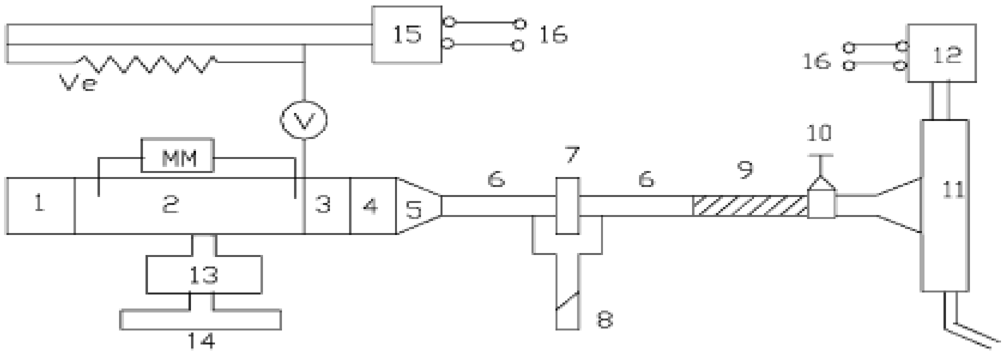
D.Gupta [14] et al investigated the performance of solar air heater using the oblique wire shaped artificial roughness. They found that the effective efficiency of solar air heater is obtained at low air flow rate. And as the height of roughness increases the optimum value of air flow rate get decreased. They also resulted that the higher effective efficiency obtain as the insolation increases for Reynolds number above 10,000 and with decrease in insolation for Reynolds number below 10,000.

III. EXPERIMENTAL INVESTIGATION

For the experiment an experimental setup is created for finding the data relating to heat transfer coefficient, friction factor and efficiency. by performing the experiment from the experimental setup the experimental readings achieved of artificial roughed Solar air heater with the arc shaped ribs on the smooth plate Solar air heater. We try to increase the heat transfer Coefficient value and thermos-hydraulic performance of solar air heater by using artificial roughness.

4.1 Dimensions of experimental setup-

The experimental setup involves a blower, control valve, a Test duct having inlet and outlet section for air flow and various temperature and pressure measuring devices. The experimental setup is shown in figure below. Blower is used to suck the atmospheric air through the rectangular duct which is having artificial roughness. Artificial roughness is created by fixing Arc-shaped ribs having attack angle of 30^0 and varying value of rib gap(g) from 1,2, 3,4,5 roughness on the bottom of the top plate. The mass flow rate of air passes through the duct controlled by control valve on the line. The rectangular duct is made up of wood having dimensions of 2042 mm in length and cross sectional area of 200 mm x 20 mm. it has a test section of length 1500 mm, entrance section of length 192 mm and an exit section of length 330 mm. Some of the other data are as follows-



1. Inlet section	11. Blower
2. Test section	12. Electric motor Selector-switch
3. Mixing section	13. Selector-switch
4. Outlet section	14. Temperature Recorder
5. Transition section	15. Power source
6. G. I. pipe	16. Voltage stabilizer
7. Orificemeter	MM Micro-manometer
8. Manometer	V Volt meter
9. Flexible pipe	A Ammeter
10. Control valve	Ai Air inlet
	Ve Variac

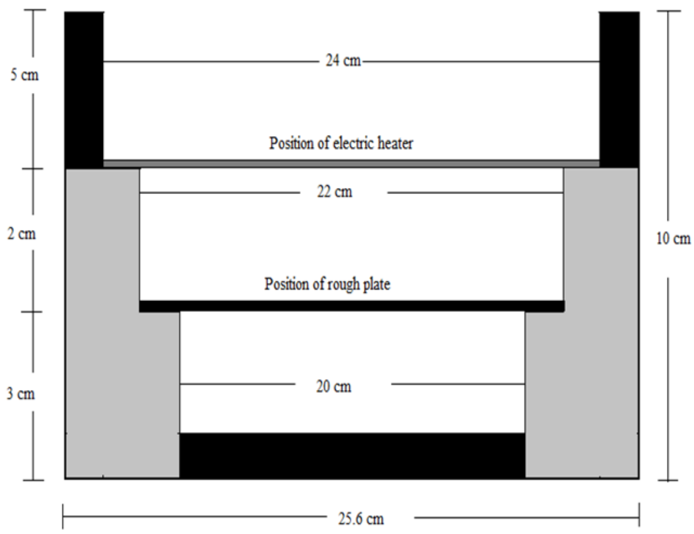


Fig-4.1 Schematic diagram of experimental setup

IV. EXPERIMENTAL DATAS

In this thesis the data is collected experimentally using various instruments for different roughness gap of absorber plate. The flow rate of air changed by control valve and the data collected for rough plate is compared with smooth plate. Different air flow characteristics such as Nusselt number, heat transfer coefficient, friction factor and thermal efficiency is determined by using experimental data

5.1 EXPERIMENTAL PARAMETERS

PARAMETERS	VALUE
Roughness height (e)	2mm
Relative roughness height (e/D_h)	0.0450
Relative gap width (g/e)	4
Number of gaps (N_g)	1,2,3,4,5
Reynolds number (Re)	2000-12000
Angle of attack of flow (α)	30^0
Equivalent diameter of air passage or hydraulic diameter (D_h)=4WH/[2(W+H)]	0.044m
Relative roughness pitch (P/e)	10
Material of the absorbing plate	HR sheet
Aspect ratio of duct (W/H)	8
Testing length	1500mm
Heat flux (I)	1000

5.2 EXPERIMENTAL DATA REDUCTION

5.2.1 Temperature of plate:-

Where,thermocouples are attached at equal length along the entire plate length. By taking average of the plate temperature at seven points, which are installed at a distance of 187 mm along the length of the plate.

$$T_{pav} = (Tp1 + Tp2 + Tp3 + Tp4 + Tp5 + Tp6 + Tp7)/ 7$$

Where,

Tp1-7 = Temperature of plate at different location of plate, ^oC

5.2.2 Pressure drop across the Orifice meter (ΔPo):-

$$\Delta Po = \Delta h \; 9.81 \; \rho_m$$

Where,

Δh = Difference of water level in U tube manometer, m

ρ_m= Density of water i.e. 1000 Kg/m^3

In the present study, the pressure drop across the test section is directly measured in Pascal using a precision micro-manometer.

5.2.3 Mass Flow Rate Measurement (m):-

Mass flow rate of air has been determined from the pressure drop measurement across the Orifice meter using the following relationship-

$$m = C_d A_o [2\rho(\Delta Po)/1-\beta^4]^{0.5}$$

Where,

$\beta = d_2/d_1$

C_d = Coefficient of discharge of orifice i.e. 0.62

A_o = Area of orifice plate, m^3

ρ = Density of air, kg/m^3

V. EXPERIMENTAL RESULT AND DISCUSSION

6.1 Experimental data validation

For experimental data validation, an experiment is conducted for smooth plate in rectangular duct of solar air heater. Collected data of friction factor and Nusselt number from the conducted experiment for smooth absorber plate was verified with following correlations of friction factor and Nusselt number are given below for rectangular smooth duct.

Dittus Boelter correlations:

Data collected from the experiment fo1r smooth plate is compared with the data calculated by Dittus Boelter correlation.

$$Nu= 0.023 \times (Re)^{0.8} \times (Pr)^{0.4} \times (2R_{av} / D_e)^{-0.2}$$

Where,

$$2R_{av} / D_e = (1.156+H/W-1)/(H/W)$$

Modified Blasius correlation:
The experimental data collected from smooth plate is compared with the data obtained by modified Blasius correlation.

$$f = 0.085 \times (Re)^{-0.25}$$

Comparison between experimental value and calculated data of friction factor and Nusselt number is shown in figure 6.1 & 6.2 respectively.

Table 6.1 Result table for validation of friction factor

S.NO.	Manometer reading (mm)	Reynolds number (Re)	Experimental (f) smooth plate	Calculated (f) smooth plate	% Deviation
1	15	2990.608	0.01253	0.011494	9.00
2	27	3976.433	0.009493	0.010704	9.50
3	54	5597.013	0.007911	0.009827	9.30
4	108	7887.046	0.005221	0.00902	8.86
5	168	9808.545	0.004577	0.008541	4.26
6	231	11493.15	0.004512	0.008209	3.5

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RESULTS

1. Friction factor of smooth plate decreases with increase in Reynolds number which is shown in figure 6.1.
2. Nusselt number of smooth plate increases with increase in Reynolds number which is shown in figure 6.2.
3. Values of Nusselt number for roughened plate having number of gap (Ng= 1,2,3,4,5) increases with increase in Reynolds number which is shown in figure- 6.3,6.6,6.9,6.12 and 6.15 respectively.
4. Values of friction factor for roughened plate having number of gap (Ng= 1,2,3,4,5) decreaseswith increase in Reynolds number which is shown in figure- 6.4,6.7,6.10,6.13 and 6.16 respectively.
5. The maximum value of friction factor, nusselt number is and THP is 2.55 times,2.33 times and 1.25 times respectively for number of gap (Ng)= 3.

VII. CONCLUSION

1. With increase in Reynolds number the Nusselt number increases and friction factor decreases. Friction factor and Nusselt number values of rough plate are higher in comparison with smooth plate for similar conditions.
2. Maximum enhancement in Nusselt number occur at result table for number of gap (Ng)= 3 which is shown in figure-6.18 among all (Ng=1,2,3,4,5 and smooth plate).
3. Maximum enhancement in THP occur at result table for number of gap (Ng)= 3 which is shown in figure-6.20 among all (Ng=1,2,3,4,5 and smooth plate).
4. Enhancement in values of heat transfer coefficient and friction factor can be done by using arc type rib roughness on the absorber plate.

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