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Solar Air Heater with W-shaped roughness on Absorber plate.

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Abstract: The analysis is made for Reynolds number of 18000 – 21000. The thermal performance is investigated for W – shaped roughness of thickness (t) 5mm, length of 10.5 cm, with an angle of 25°. The simulation is carried out using solar irradiance as heat input at the location of Amravati 20.93°N 77.75°E. Comparison of Reynolds no and Nusselt no is made. The thermal efficiency is found to increase as the temperature goes on increasing simultaneously the pressure at outlet is greater than inlet pressure. The mechanical power which is required is increased due to the roughness present on absorber plate. The heat transfer between smooth and roughened surface is compared. The experimental results are compared with analytical results on ANSYS 18.1. The thermal efficiency for the smooth surface is around 40 – 45% at particular temperature after roughening the absorber plate the efficiency increased upto 50 – 60% for the same temperature.

Index Terms:, Artificial roughness, Computational fluid dynamics, Laminar and turbulent flow, Solar air heater.

I. INTRODUCTION

The solar radiations that earth receives from the sun are thousand times greater than that of the requirement on the earth for energy sources [1]. Thus solar energy suits to be a better option. The easiest methods of converting solar energy into heat energy are by making use of solar air heaters. There are various types of solar devices but solar air heaters are very used because their cost is low and design is not as complicated as other solar devices and manufacturing cost is also low. Sometimes direct solar air heater is considered for use and sometimes diffuse solar air heater are considered.

The flat plate solar collectors are mostly used for many heating applications. Solar air heater is a flat plate collecting device, which stores energy in the form of circulation of hot air over absorber plate. The air becomes hot due to the hot solar radiations absorbed by absorber plate. The efficiency of solar air heater is less because convective heat transfers co-efficient is less. Hence certain methods have to be adopted in order to increase the thermal efficiency of solar air heater.

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The methods adopted are in such a way that its cost must also not increase and designing must be also not critical. One can buy easily. According to Newton's law of cooling Convective heat transfer can be increase by increasing the effective surface area of absorber plate or by increasing the convective heat transfer coefficient [2]. The surface area can increase by making use of large effective area but it requires large space and the equipment also becomes heavy and also requires large space to install. Another way to increase area is to allow the air to flow from downstream. As the air flow downstream another laminar sublayer will form at another side of plate hence this option is not so successful. So creating W- shaped roughness is the best option to break laminar sub layer over absorber of solar air heater. [3].

II. CONCEPT OF ARTIFICIAL ROUGHNESS

The thermal efficiency of solar air heater is less. The laminar sub-layer is formed over the surface of effective area of absorber plate. This act as an insulation and cause less heat to flow through absorber plate from solar irradiation. So this laminar sub-layer has to be break [2], [3], [4]. So concept of artificial came into existence and researchers are trying to find new methods of making new compact design of roughness. So that weight of plate should also not increase. In this experiment we have used W-shaped roughness and have performed calculation the effects of this W-shaped roughness geometries are listed below.

A. Effect of Rib Inclination

The rib can be of any diameter square, rectangular, triangular circular. Here the rib taken is of rectangular cross-section. [10] The height of rib is slightly inclined in order to increase vortex because the vortex is maximum in shapes of square and rectangular cross-section. The height is provided such that the flow reattachment occurs, [8], [9] if height is less and if height is more pressure drop is more and pump requires more power.

B. Effect of Rib Pitch

To avoid reattachment the rib pitch is provided so that air must move in proper zig-zag order.[8], [9] If the pitch is low or distance between two elements is low flow gets converged and there is again formation of laminar sublayer which is to be eliminated and elimination is done by proper rib space.

C. Effect of Rib Cross-section

The flow pattern which is present just above the absorber plate roughness depends on

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rib cross-sectional area. [8] If the circular cross-section is used the vortex flow formed is not so good so that laminar flow can break. To break the laminar flow over the surface the rectangular cross-section is used. [11]

D. Effect of Rib Inclination

To make the flow secondary and to transfer the vortices from leading edge to the trailing edge rib inclination is provided. [5], [6], [7] as the flow is secondary the heat transfer increases and the flow is more turbulent from leading edge to the trailing edge.

III. EXPERIMENTAL SETUP

A. Base

Base is the lower portion over which the solar air heater over which the whole body is kept. It gives support to the body and makes the body to withstand at a level higher from ground. It is made up of Mild Steel. The height of frontal legs is 450mm and height of lateral leg is 600mm.

B. Body

It is made up of mild steel (M.S) longitudinal ends are kept open to pass air as inlet and outlet. The outer surface is covered with mild steel plate to prevent damage of wooden surface. It is made to rest over base so that it should not get damage from bottom. It is kept at an angle of 45° from horizontal.

C. Insulation

Insulation is used to prevent loss of heat from absorber plate due to conduction or convection. The insulation used is wood (plywood) in the setup.

D. Absorber plate

In solar air heater over absorber without roughness there is laminar flow layer is formed on the surface of absorber plate. Due to this the laminar flow acts as an insulation and heat transfer does not occur properly between absorber plate and air flowing hence outlet air does not heat as required. Hence to remove this laminar layer over surface this artificial roughness is added and hence heat transfer is enhanced.

E. Artificial roughness

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F. Glass

Glass is used to make greenhouse effect which allows heat to come over absorber plate but doesn't allow heat to flow out and hence the temperature of absorber plate increases.

G. Hopper

Hopper is used to give a proper direction to flow of air. As the area goes on decreasing the velocity increases and as the area increases velocity decreases.

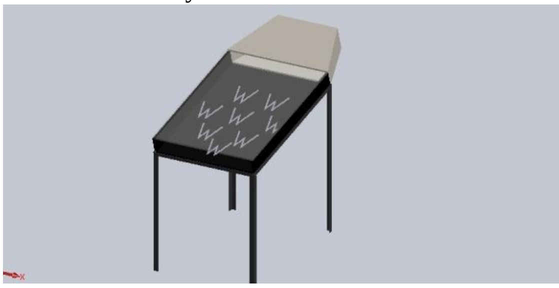


Fig: 1 Creo Parametric Model of SAH with W-shaped roughness

(a)

(b)

Fig 2: (a) , (b) Actual Setup of Solar air heater with roughness on Absorber plate

IV. EXPERIMENTAL OSEVATIONS AND CALCULATIONS

A. Sample observations table is mentioned below.

Inlet and outlet temperatures were measured by using thermocouples at inlet (T_1) and outlet (T_2). The average plate temperatures are measured by placing 8 thermocouples on plate and average temperature is calculated by formula

$T_{av}= (T_3+T_4+T_5+T_6+T_7+T_8+T_9+T_{10})/8$

The reading of temperatures in time difference of 1 hour.

Table I: Sample Temperature Reading

Sr No.	Time (in hrs)	Temperature °C		Average plate temp °C
		Inlet	Outlet	
1	8 a.m	26	31	45
2	9 a.m	32	38	53
3	10 a.m	35	43	69
4	11 a.m	37	46	78
5	12 p.m	39	53	79
6	1 p.m	40	53	79
7	2 p.m	42	56	83
8	3 p.m	38	53	76
9	4 p.m	34	40	70
10	5 p.m	32	37	64

B. Calculations

From Heat Transfer Data Book by C. P Kothandaraman and S Subramanyan

T_{mf} = (Inlet Temp + Outlet temp)/2
= (42+56)/2 = 49°C
At temp 49°C
Density = ρ = 1.093 kg/m^3
Absolute viscosity = μ = 19.61$\times 10^{-6}$ Ns/m^2
Kinematic Viscosity = υ = 17.95 $\times 10^{-6}$ m^2/s
Prandtl Number = Pr = 0.698
Specific Heat = Cp = 1005 J/kgK
Thermal Conductivity = k = 0.02826 W/mk
Hydraulic Diameter (D_h)
D_h = (4*Area)/Perimeter = 4A/P
= (4×0.41×0.085)/2(0.41+0.085)
= 0.140m

Measured Velocity by Anemometer = u = 2.5 m/s

Reynolds Number (Re)
Reynolds number = Inertial force/Viscous Force
= $(ud\rho/\mu)$
= $(uD_h\rho/\mu)$
Re = $(2.5\times0.140\times1.093)/19.61\times10^{-6}$
19507.904 >Re = 2300. Hence the flow is turbulent.
The flow is in range 5000 < Re < 10^8

ε^* = surface Roughness
$\varepsilon^* = \varepsilon/D_h$ = (0.005/0.140) = 0.035
ε = Roughness height

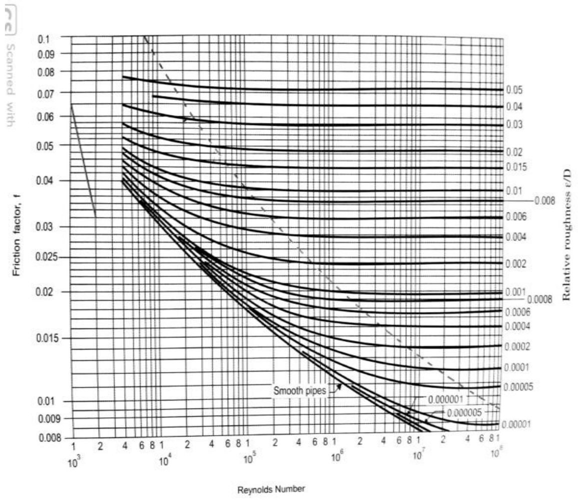


Fig 3: Graph of Friction factor vs Reynolds Number

f = friction factor
The value of friction factor is obtained from above graph
Therefore f = 0.06
Pressure drop due to friction (ΔP_f)
$f = (\Delta P_f)/ [\rho\,(L/D_h)/u^2/2)]$
$f = (\Delta P_f)/ [1.093\times (0.0615/0.140) \times (2.5^2/2)]$
$\Delta P_f = P_{out}-P_{in}$ = 0.90002 N/m^2
Mass Flow rate(m)
Re = $(4m)/(\pi\times\mu D_h)$
19507.904 = $4m/(\pi\times19.61\times10^{-6}\times0.140)$
m = 0.0420 kg/sec

Mechanical power (P_m)
$P_m = (m\Delta P_f)/\rho$
= (0.0420×0.09002)/1.093
= 0.0345 watts
To calculate heat transfer coefficient (h)
By using Dittus-Bolter Equation.
Nu = 0.023 $Re^{0.8}$ Pr^n
n= 0.4 for heating of fluids
Nu = $0.023\times19507.904^{0.8}\times0.698^{0.4}$
Therefore Nu = 53.881
We have Nu = $(hD_h)/k$
53.881 = (h×0.140)/0.02826
Therefore h = 10.876W/mk
Effective Area (A)
A = 0.4× 0.6 = 0.24 m^2
Solar Irradiance (I)
I = 5.44 $kwh/m^2/day$
I = 226.666 W/m^2
Heat transfer (Q)
Q = $hA\Delta T$
Q = $hA(T_{out} - T_{in})$
= 10.876×0.24× (56-42)
= 36.543 watts
Efficiency (η)
η = Q/IA = (36.543×100)/(226.666×0.24)
= 67.1748 %

V. RESULTS

A. *Theoretical Results*

The graph (Fig:4) shows the increase in the air flow velocity at inlet, which causes the Reynolds number to be higher. When air flow velocity increases the collisions between air particles is greater, this promotes maximum vortex generation.

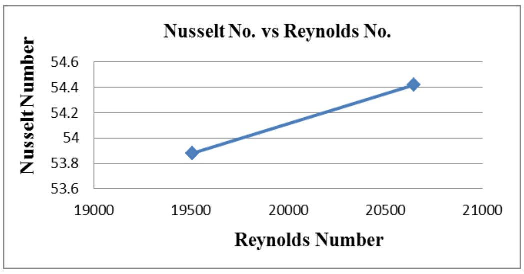


Fig 4: Reynolds number vs Nusselt number

In the following graph (Fig 5.2(b)) the temperature increases as time increases, the peak temperature is of 56 °C at 2.00pm and beyond that the temperature decreases.

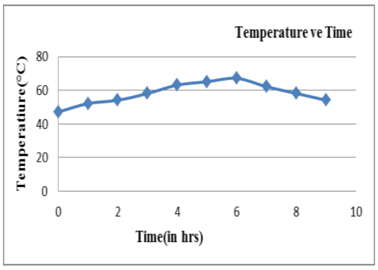


Fig 5: Temperature vs Time

The following graph (Fig: 6) shows that the thermal efficiency of solar air heater increases with increase in temperature. The maximum efficiency is at the temperature of 56 °C because the temperature is highest at that point.

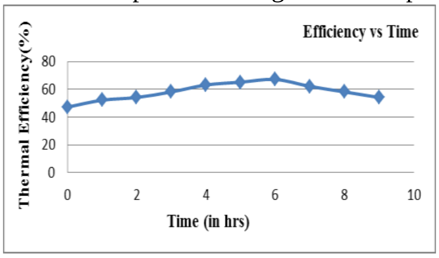
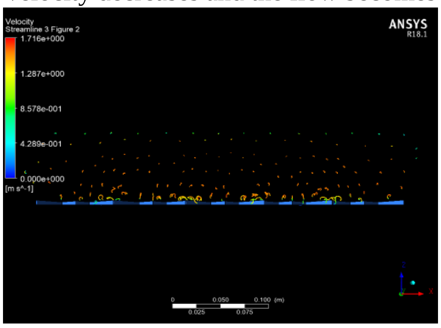


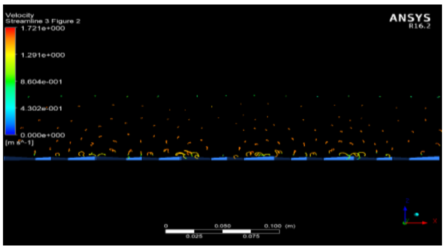
Fig 6: Thermal efficiency vs Time

B. *Analysis on ANSYS 18.1*

The result Fig 7: (a) & (b) shows that due to roughness present the laminar motion of particles is disturbed, pressure increases, velocity decreases and the flow becomes turbulent.



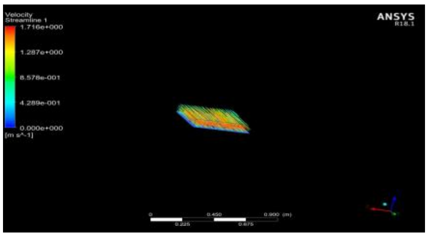
(a)



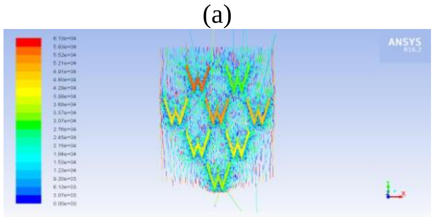
(b)

Fig 7: (a) & (b) Represents the breaking of laminar sub-layer.

The number of particles is given as an input to show streamline flow of air from inlet to outlet. The laminar flow gets disturbed due to roughness present over absorber plate and makes it turbulent as shown in figure Fig 8 (a) & (b)



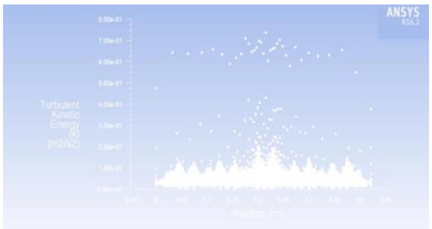
(a)



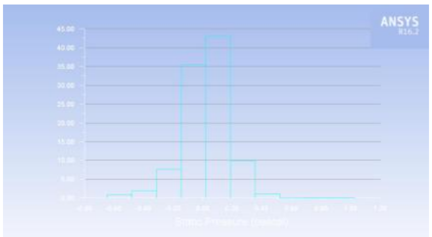
(b)

Fig: 8 (a) & (b) represents the particle ID of molecules on the flow.

The Fig: 9 (a) & (b) shows the kinetic energy and static pressure of molecules, the energy and static pressure of molecule is maximum at highest temperature.



(a)



(b)

Fig: 9 (a) & (b) represents the kinetic energy and static pressure of molecules.

VI. CONCLUSION

The aim is to find the heat transfer rate from absorber plate of solar air heater. The theoretical and experimental analysis was done of solar air heater with roughness on absorber plate. Presence of W- shaped roughness on absorber plate enhances the Nusselt number and increases the friction factor. On creating the W- shaped surface roughness on absorber plate, the laminar sub-layer breaks and the friction factor as compared to smooth surface found to be increased. In temperature vs time graph the maximum temperature we got is at 56°C and at this particular temperature the thermal efficiency, kinetic energy of molecules and static pressure is maximum.

VII. REFERENCES

1. I. Singh, S. Singh, "A review of artificial roughness geometries employed in solar air heaters" *Renewable & sustainable energy reviews* 2018, pp. 92 405-425 https://doi.org/10.1016/j.rser.2018.04.108.
2. V. S. Bisht, A. K. Patil, A. Gupta, "Review and performance evaluation of roughened solar air heaters" *Renewable & sustainable energy reviews* 2018, pp. 81, 954-977 http://dx.doi.org/10.1016/j.rser.2017.08.036.
3. M. G. Gabhane, A. B. Kanase, "Experimental analysis of double flow solar air heater with multiple C shape roughness" *Solar Energy* 2017, pp. 155 1411-1416 http://dx.doi.org/10.1016/j.solener.2017.07.038
4. A. M. Lanjewar, J. L. Bhagoria, M. K. Agrawal, " Review of development of artificial roughness in solar air heater and performance evaluation of different orientations for double arc rib roughness" *Renewable & sustainable energy reviews* 2015, pp. 43 1214-1223 http://dx.doi.org/10.1016/j.rser.2014.11.081.
5. R. Karwa, S. C. Solanki, J. S. Saini, "Thermo-hydraulic performance of solar air heaters having integral chamfered rib roughness on absorber plates" *Energy* 2001, pp. 26 161–76.
6. K. R. Aharwal, B. K. Gandhi, J. S. Saini, " Experimental investigation on heat-transfer enhancement due to a gap in an inclined continuous rib arrangement in a rectangular duct of solar air heater" *Renewable Energy* 2008, pp. 33 585–96.
7. R. P. Saini, J. S. Saini, "Heat transfer and friction factor correlations for artificially roughened ducts with expanded metal mesh as roughness element" *Heat Mass &Transfer* 1997 40 973–86.
8. V. S. Hans, R.S. Gill, S. Singh, "Heat transfer and friction factor correlations for a solar air heater duct roughened artificially with broken arc ribs" *Experimental Thermal and Fluid Science* 2017;80:77–89.
9. A. Kumar, M. H. Kim, "Heat transfer and fluid flow characteristics in air duct with various V-pattern rib roughnesses on the heated plate: a comparative study". *Energy* 2016 103 75-85.
10. S. V. Karmare, A. N. Tikekar, "Experimental investigation of optimum thermo-hydraulic performance of solar air heaters with metal rib grits roughness". *Solar Energy* 2009 83 6-13.
11. S. Singh, B. Singh, V.S. Hans, R. S. Gill, "Computational fluid dynamics investigation on Nusselt number and friction factor of solar air heater duct roughened with non-uniform cross-section transverse rib". *Energy* 2015 84 509-17.

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