Engineering Universe for scientific Research and management
ISSN (Online): 2319-3069
Vol. 11 Issue 3
March 2019

EXPERIMENTAL INVESTIGATION ON HEAT TRANSFER AND FLUID FLOW PHENOMENA OF ARC SHAPED RIB WITH GAPS ON THE PLATE

Rohit Sampat Jadhav[1], Sanjay Kalraiya[2], Sachin Baraskar[3]
[1,2,3] Department of Mechanical Engineering, SSSUTMS, Sehore, India
Rohitjadhhav2230@gmail.com

ABSTRACT

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 arc shaped artificial roughness is an effective technique to enhance the value of heat transfer of fluid flow

Keyword - *Solar Air Heater, Thermal Conductivity, Heat Transfer, Artificial Roughness, Thermo-hydraulic performance*

1. INTRODUCTION

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.

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.

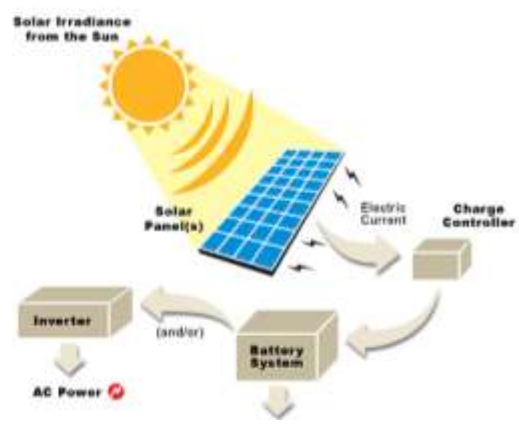

Fig.1: Solar energy

As the development in the field of solar energy technology is rapid and limited fossil fuels, solar energy become the most affordable and cheapest source of energy. In solar energy the initial cost of installation is very high but running and maintenance cost is very low.

2. LITERATURE SURVEY

Yadav et al 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.

D. Guptaet 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.

Aharwal et al performed an experiment to investigate the heat transfer and friction characteristics of rectangular duct. The experiment encompassed relative roughness pitch (p/e) of 10,, angle of attack(α) of 60^0,Relative roughness height(e/D_h) of range 0.0377.They found that the Nusselt number and friction factor increase by 2.59 times and 2.87 times respectively as compared with smooth duct.

Sachin Baraskar et.al Artificial roughness in the form of repeated ribs is generally used for enhancement of heat transfer from heated surface to the working fluid. This paper presents the experimental investigation of heat transfer and friction factor characteristics of a rectangular duct roughened with repeated v-shape ribs with and without gap on one broad wall arranged at an inclination of 60° with respect to the flow direction. A rectangular duct of aspect ratio of (W/H) of 8, relative roughness pitch (p/e) of 10, relative roughness height (e/Dh) of 0.030, and angle of attack 600. The heat transfer and friction characteristics of this roughened duct have been compared with those of the smooth duct under similar flow condition. The effect of gap in v-shaped rib has been investigation for the range of flow Reynolds numbers from 5000 to 14000. The maximum enhancement in Nusselt number and friction factor is observed to be 2.57 and 2.85 time of that of the smooth duct.

Singh s. Chander et al investigated on discrete v-down rib roughened absorber plate to examine the thermos-hydraulic performance and efficiency of solar air heater. They found that the effectively increased in efficiency by 91% as compared to smooth plate solar air heater.

R.P. Saini et al performed an experiment to study the effect of Dimple shape rib roughness on the performance of solar air heater. The experiment encompassed Reynolds number ranges from 2000 to 12000 relative roughness pitch (p/e) of range 8 to 12,Relative roughness height (e/Dh) vary from 0.018 to .037.They found that the maximum muscle number achieved at relative roughness height (e/D_h) of 0.037 and relative pitch of 10. While the minimum value of friction factor is achieved at relative roughness height of 0.0289 and relative pitch of 10.

Anil Kumar et al [19] experimental investigated the effect of geometrical parameters of multi v-shaped ribs with gap on heat transfer and fluid flow characteristics. the experiment encompassed Reynolds number from 2000 to 20,000 relative roughness pitch (p/e) of 10, angle of attack(α) of 60^0 ,and aspect ratio(w/H) as 6, relative gap distance of 0.24 to 0.80 Relative roughness height(e/Dh) is 0.043,aspect ratio(w/H) vary from 0 to 10. They resulted that the Nusselt number and friction factor is increased by 6.32 times and 6.12 times respectively as compared with smooth duct.

Patil et al [20,21,22] studied the effect of discrete v-rib with combined staggered rib pieces on heat transfer and friction factor characteristics on the rectangular duct. the experiment encompassed Reynolds number from 3000 to 17,000 relative roughness pitch (p/e) of 10,staggered rib position of 0.2 to 0.8, angle of attack(α) of 60^0,and aspect ratio(w/H) as 6, relative gap distance of 0.2 to 0.8, relative staggered rib size of 1 to 2.5 . They resulted that the maximum value of Nusselt number and friction factor corresponds to relative gap position of 0.6, relative staggered rib size of 2.5 and staggered rib position of 0.6.

3. 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. Air Inlet Section, 2. Test Section, 3. Air Outlet, 4. Varice, 5. Selector Switch, 6. Mixing Section, 7. G.I Pipe, 8. Orifice Plate, 9.Inclined U-Tube, 10. Micro Manometer, 11. Flow Control Valve, 12. Flexible Pipe, 13.Blower

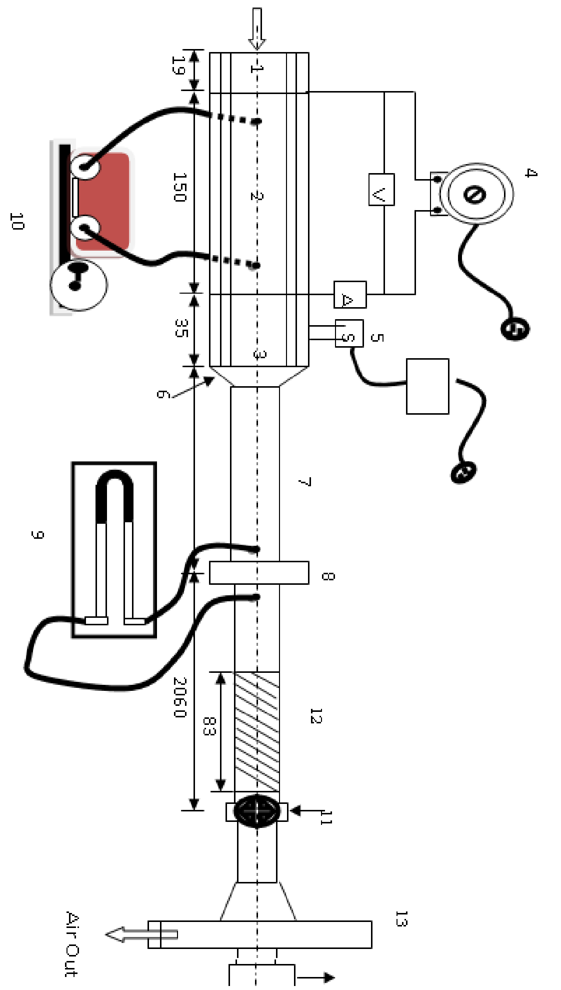

Fig.2: Schematic Diagram Showing Top View of Experimental Setup

According to ASHRE standard 93-77(1950) the entry length is $5(H)^{3/2}$, and exit length is 2.5(W.H)½ [5]. The experimental setup is designed according to this data. At the exit section three baffle plates are placed with an equal distance of 75mm Length. For proper mixing of air baffles are employed. At the exit of rectangular duct a plenum is installed to connect the circular pipe with rectangular duct. A HR plate having dimension 1500 mm x 200 mm x 1.6 mm is used as absorber plate which is having artificial roughness of arc shape at the test section of duct. The copper wires are stick on the underside of the absorber plate work as artificial roughness. The wire diameter and the angle of attack are remains fixed while the number of rib gaps varies to obtain very shape of roughness. To heat the plate uniform heat flux is supplied by electric heater assembly. The electric heater size is 1500 mm x 200 mm was assembled by combining loops of parallel and series of heat resistance wire installed on asbestos sheet of 5 mm. thermal insulating material such as polystyrene is used on the backside of electric heater to reduce the thermal energy losses.

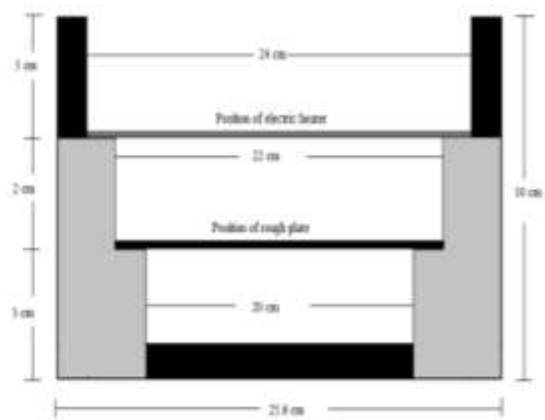

Fig.3: Schematic diagram of experimental setup

The gap between absorber plate and electric heater is taken as 20 cm. The energy input to the heater is controlled by the variac such that we can obtain desired amount of heat flux. The centrifugal blower, which is driven by three phase 5HP, 2880 rpm blower used to suck the atmospheric air through the rectangular duct. The ambient air sucked by the blower using pipeline through the rectangular duct delivered to the atmospheric air. Air flow rate is control by control valve at the desired level. The mass flow rate of air is controlled by orifice metre through the rectangular duct.

HEATER- Since we have indoor type explain experimental set up. It is become important to remain on our goal to provide the similar atmosphere to sun primary based radiation on the absorbing plate by an electric heater dimension of 1650 mm x 216 mm which was created by applying heating wire in series and parallel loop type arrangement on 5 mm asbestos sheet acting as an insulating sheet to prevent heat transfer losses 1 mm thick sheet of mica is placed in between the absorbing plate and heater which act as a casing. Where is used to vary heat flux from 0 to 1000 W/m^2. The top portion of the channel is completely secured with 1.2 mm thick ply board which insulate the whole get along.

EXPERIMENTAL DATA

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.

Table 1: Experimental Parameters

Parameters	Value
Roughness height (e)	2 mm
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)]	0.044 m
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

4. SAMPLE CALCULATIONS

Sample calculation for D_h= 44.44mm.
Reynolds number- 2000-14000 and
Relative roughness $e/D_{h=}$ 0.045

Mean bulk air temperature (T_{tav}):-
Simple arithmetic mean of measured inlet ant exit value of air under testing section

$$(T_{tav})= (T_i + T_o)/2 \quad (1)$$

Where
Ti= Inlet temperature of air in ^{0}c
To= Outlet temperature of air in ^{0}c

Heat transfer rate (Q_a):-

$$Q_a = mC_p (T_o - T_i) \quad (2)$$

Where,
m= Mass flow rate, kg/s
Cp= Specific heat of air at constant pressure (kJ/kg K)
Ti= Inlet temperature of air in o C
To= Outlet temperature of air in ^{o} C

Thermal Efficiency (η_{th}):-

$$\eta_{th} = Q_a/A_p I \quad (3)$$

Where,
Q_a= Heat transfer rate
A_p= Area of absorber plate (m^2)
I= Heat flux i.e. 950 W/m^2

Thermal Hydraulic Performance (THP):-

$$Nu_s= 0.023 \text{ x } (Re)^{0.8} \text{ x } (Pr)^{0.4} \text{ x } (2R_{av} / D_e)^{-0.2} \quad (4)$$

Where,
$2R_{av} / D_{e\,=}$ (1.156+H/W-1)/(H/W)
f_s= 0.085 x $(Re)^{-0.25}$
THP= $(Nu_r/Nu_s)/(f_r/f_s)^{0.33}$

5. CONCLUSION

With increase in Reynolds number the Nusselt number increases and friction factor decreases. This paper used arc shaped rib with gaps on the roughness plate. Friction factor and Nusselt number values of rough plate are higher in comparison with smooth plate for similar conditions.

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