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A review for the Performance of Various Types of Line Ribs on the Absorber Plate of the Solar air Heater

Manohar Kumar Meena[1], Dr. Manoj Arya[2]

[1,2]Department of Mechanical Engineering,

Maulana Azad National Institute of Technology, Bhopal, (India)

ABSTRACT

Artificial roughness creates turbulence by disturbing laminar sub-layer. Due to this turbulence heat transfer rate increases. Artificial roughness is used to improve the Nusselt number, thermo-hydraulic performance with little enhancement in Friction factor. The shape of artificial roughness and various parameters like angle of attack, relative roughness height, relative roughness pitch etc affect the flow structure and thus these parameters affect the amount of the turbulence. There are various types of artificial roughness have been used to improve the performance of solar air heater so far. In this research paper a review is done on various shapes of artificial roughness, observe their results and compare them and find out the new geometry of artificial roughness.

Keywords - Solar air heater, artificial roughness, Thermo-hydraulic performance, Nusselt number, Friction factor, angle of attack.

I. INTRODUCTION

Energy is a primary need to live. There are various sources of energy are available in nature by which living organisms obtain energy. These energy sources can be classified into two ways – Conventional source of energy, these source of energy are non-renewable source of energy like fossil fuel (coal, petroleum, natural gas etc.) and available in limiting amount in the earth. Non – conventional source of energy, these are renewable source and clean source of energy like solar energy, wind energy, hydro energy, tidal energy, geothermal energy etc. The fossil fuels are non renewable source of energy and reserved in fixed quantities in the nature and will be depleted after few years. Use of fossil fuel are not only affects the environment, but also threats to humans life. To save the fossil fuel and to reduce the environment pollution, use of renewable energy sources is very important.

Solar air heater is an active system which is used to heat the air by absorbing solar radiation. In solar air heater generally a flat plate collector is used. Flat plat collector is also used to heat other fluids like water. Flat plate collector is very common, simple and inexpensive system to utilized solar energy. It consists of an absorber plate, cover plate and heat transport fluid (air or water). Absorber plate generally made of cupper or aluminum and painted by black color to increase heat absorbing capacity of the plate. This absorbing plate is attached to the copper tubes through which fluid flow and carries heat from the absorbing plate. Cover plate made of glass with high transmissibility and low absorptivity is used to reduce the heat losses from the upper side of heater. In case of solar air heater it also consist of back insulated cover to minimize the heat losses from the side and bottom of the duct and blower to circulate the air.

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Generally, the thermal performance of solar air heater is very poor because of plane or smooth absorbing plate and heat transfer losses through the top of the duct. Therefore thermal performance of solar air heater can be increased by decreasing the losses through the duct by using good insulating material and increasing the convective heat transfer coefficient. Heat transfer coefficient play very important role to improve the performance of solar air heater. It can be increased by increasing fluid properties, fluid velocity etc, but the most important technique is artificially rough surface on the absorbing plate.

1.1. Role of artificial roughness

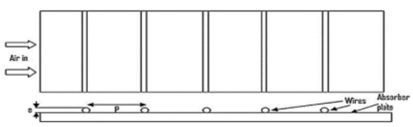
When a fluid flows over the flat plate, a boundary layer is formed over the flat plate. When the flow is turbulent this boundary layer can be divided into laminar sub layer and turbulent layer. In case of turbulent flow heat transfer rate is higher than laminar flow due to mixing of the fluid. In the region of laminar sub layer the flow is laminar because viscous forces are more dominant than eddies. Due to this layer there is no mixing, therefore it reduces heat transfer rate to increase the heat transfer rate, laminar sub layer should be disturbed by using artificially roughness and creates turbulence. Artificial roughness can be produced by machining, casting, forming, welding and other methods. Artificial roughness can be produced on a surface by

1) Fixing grooves and ridges.
2) Blasting sand over it.
3) Fixing ribs of different geometry such as round, arc, rectangular or V-shaped or inclined broken ribs, V-shaped discrete ribs etc.
4) By fixing three dimensional roughness geometries.
5) By fixing wires.

As the air flows over roughened surface, separation and reattachment are occurred in between the consecutive ribs and it increase the turbulence and thereby improving the convective heat transfer coefficient of absorber plate. Secondary recirculation of flow, further help to increase the heat transfer rate because it increases the mixing from heated surface to core flow. When turbulence increases, pressure drop is also increases due to friction that is unfavorable because high blower power is required to compensate this pressure drop. Therefore there is need to optimization between convective heat transfer coefficient and pressure drop.

II. INVESTIGATION OF DIFFERENT TYPES OF ARTIFICIAL ROUGHNESS

Table-1. Investigation of Various Types of Ribs

Investigators	Types of Artificial Roughness	Parameters	Results
Saini and Prasad [1], 1988	Transverse ribs 	p/e = 10 – 20 e/Dh = 0.02 - 0.033	(Nu/Nus)max = 2.38 (F/Fs)max = 4.25
Verma and Prasad [2], 2000	Transverse continuous ribs	p/e = 10 - 40 e/Dh =0.01 – 0.03	Max enhancement in THP =71%
Sahu and Bhagoriya [3],	Broken transverse ribs	e = 1.5mm p = 10 - 30 mm	Efficiency = 51% to 83.5%

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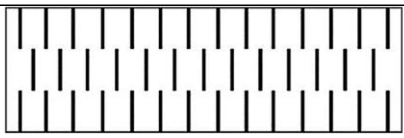
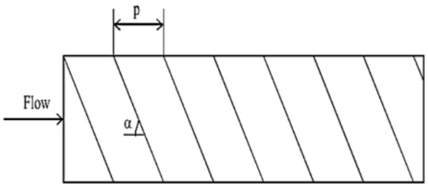
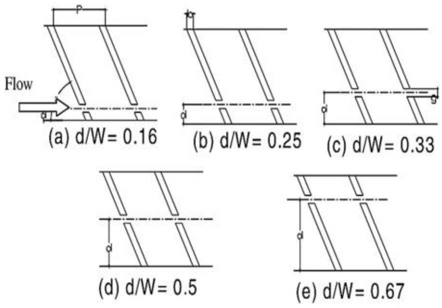
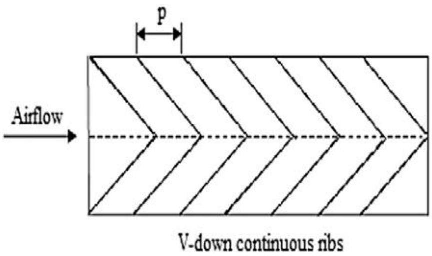
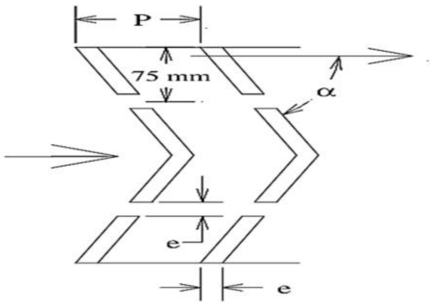
2006			
Gupta et al. [4], 1997	Continuous inclined ribs 	$\alpha = 60^0$ p/e = 10 e/Dh = 0.023 – 0.50	THP = 1.16 to 1.25 (Nu/Nus)max = 1.8 (F/Fs)max = 2.7
Aharwal et al. [5], 2009	Inclined ribs with gap 	p/e = 10 e/Dh = 0.0377 d/W = 0.16 – 0.67 g/e = 0.5 – 2	(Nu/Nus)max = 2.59 (F/Fs)max = 2.87
Aharwal et al. [6], 2009	Inclined ribs with gap	p/e = 4-10 e/Dh=0.018 - 0.0377 d/W = 0.25 $\alpha = 30^0 - 90^0$	(Nu/Nus)max = 2.83 (F/Fs)max = 3.6
Momin et al. [7], 2002	V shaped continuous ribs 	e/Dh = 0.02 – 0.034 p/e = 10 $\alpha = 30^0 -90^0$	(Nu/Nus)max = 2.30 (F/Fs)max = 2.83
Singh et al.[8], 2011	V shaped ribs with gap 	p/e = 4-16 e/Dh = 0.043 $\alpha = 30^0 - 75^0$	THP = 2.06 (Nu/Nus)max = 5.07 (F/Fs)max = 3.71
Maithani and Saini [9], 2016	V shape ribs with symmetrical gap	p/e = 6-12 $\alpha = 30^0 – 75^0$ No. of gaps = 1-5 g/e = 1 – 5	(Nu/Nus)max = 3.6 (F/Fs)max = 3.67

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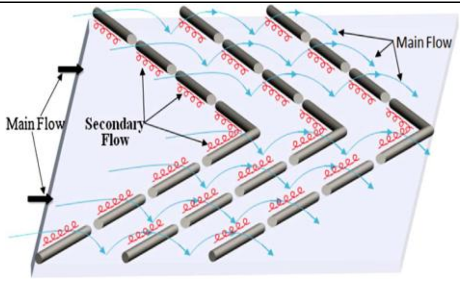
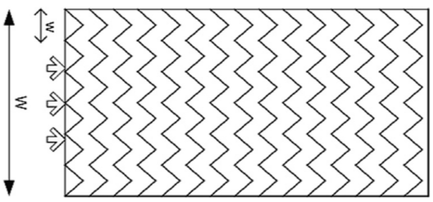
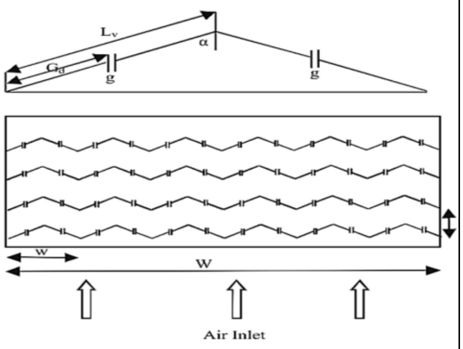
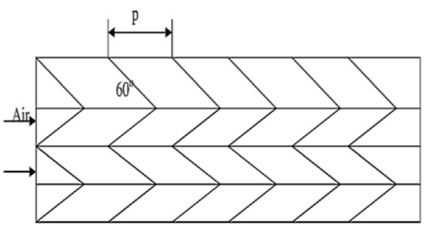
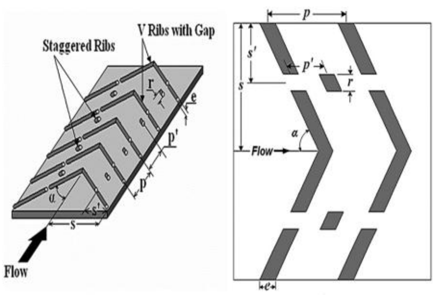
			
Hans et al. [10], 2010	Multi V shaped ribs 	e/Dh = 0.0190.034 p/e = 6–12 α = 30^0–70° W/w = 1–10	(Nu/Nus)max = 6
Kumar et al. [11-12], 2012,2011	Multi V shape ribs with gap 	p/e = 6-12 e/Dh = 0.022-0.043 α = 30^0- 75^0 Relative gap width = 0.5-1.5	(Nu/Nus)max = 6.47 (F/Fs)max = 6.37
Lanjewar et al. [13], 2011	W shape ribs 	p/e = 10 e/Dh = 0.03375 α = 45^0	THP = 1.46-1.95 in down And 1.21-1.73 I up
Lanjewar et al. [14-15], 2011	W shape ribs	e/Dh = 0.0180.0338 α = 30^0 - 75^0	(Nu/Nus)max = 2.36 (F/Fs)max = 2.01
Patil et al. [16-18], 2011, 2012	V shape ribs with gap and staggered 	p/e = 10 α = 60^0 e/Dh = 0.043 relative staggered rib size and position = 1 and 0.6 and later they varied relative staggered rib size and position = 0.2 - 0.8 and 1-2.5	THP = 1.48-2.10 And Later (Nu/Nus)max=3.18
Deo ei al. [19],	V shape ribs with gap and staggered	p/e = 4-14	(Nu/Nus)max = 3.34

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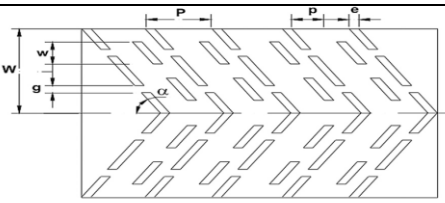
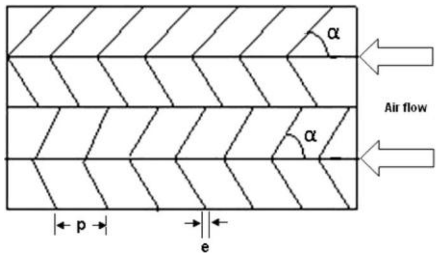
2016		e/Dh = 0.026-0.057 $\alpha = 40^0 - 80^0$ relative staggered rib size =4.5 and relative gap width=1	(F/Fs)max = 2.45
Dongxu jin et al. [20], 2016	Staggered multi V shape ribs	p/e = 10 e/Dh = 0.043 $\alpha = 45^0$-75^0	Increment in Nusselt number and THP is 26% and 18% over V shaped ribs
Arvind kumar et al. [21], 2009	Discrete W shape ribs 	p/e = 10 e/Dh=0.0168-0.0338 $\alpha = 30^0 - 75^0$	(Nu/Nus)max = 2.16 (F/Fs)max = 2.75

There are various parameters of roughness geometry like as angle of attack, relative roughness pitch, relative roughness height etc, affect the flow pattern and various investigations have been done that show the effects of these parameters on flow pattern. Investigation of various types ribs shown in table 1. Prasad and Saini [1] used transverse continuous ribs and they varies the relative pitch from 10 to 20 and also varies relative height from 0.02 to 0.033 and obtained maximum enhancement in Nusselt number and friction factor as 2.38 and 4.25 respectively at the relative pitch 10 and relative height 0.033. They also show the effect of relative roughness pitch and relative roughness height on flow pattern. If relative ribs height increases friction factor increases and if relative ribs height is less, reattachment does not possible. Therefore ribs height should we optimum. If relative pitch is large reattachment will be possible but number of reattachment decreases so it also should be optimum. Verma and Prasad [2] further studied on transverse continuous ribs experimentally by taking Re = 5000–20,000, P/e = 10–40 and e/D = 0.01–0.03 and obtain optimum thermo-hydraulic performance value as 71% at the corresponding value of relative roughness pitch (P/e) 24. Sahu and Bhagoria [3] investigated on broken transverse ribs at 90^0. Due to broken arc ribs secondary flow mixes with primary flow that increases turbulence and Nusselt number. At the pitch of 20mm they obtained maximum heat transfer coefficient. Gupta et al. [4] analyzed the effect of the parameters on thermo-hydraulic performance of the continuous inclined ribs. Due to inclined ribs more secondary flow generated which creates more turbulence by mixing with primary flow. At the angle of attack 60^0 and 70^0, they obtained maximum enhancement in Nusselt number and friction factor respectively and their corresponding values are 1.8 and 2.7 times respectively. To further improvement in heat transfer rate, Aharwal et al. [5] analyzed the inclined ribs with gap made of square cross section. Gap and square cross section of ribs due to sharp edges further creates more turbulence and hence more heat transfer rate. They fixed the relative pitch as 10 and relative height as 0.0377 and varies the relative gap position and gap width in the range of 0.16 - 0.67 and 0.5-2 respectively. Maximum increment in Nusselt number and friction factor is 2.59 and 2.87 respectively. And optimum thermo-hydraulic performance is obtained at relative gap position of 0.25 and relative gap width of 1. Further Aharwal et al. [6] varied angle of attack along with relative

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gap position and relative gap width and obtained maximum enhancement in Nusselt number and friction factor as 2.83 and 3.6 respectively at the $\alpha = 60^0$, relative gap width =1, relative gap position = 0.25 , p/e = 10, e/D = 0.0377. The advance version of inclined ribs is V shaped ribs that is more efficient than inclined ribs because it creates more turbulence. Momin et al. [7] show the effects of various parameters of V shaped ribs on Nusselt number and friction factor. They obtain the Nusselt number 1.14 times than inclined ribs for the fixed relative pitch 10. Singh et al. [8]experimentally studied on V shaped ribs with gap and varies the angle of attack from 30^0 to 75^0 by taking other fixed parameters like relative pitch, relative roughness height as 8, 0.043 respectively and obtain maximum thermo-hydraulic performance at 60^0 that is 2.06. Maithani and Saini [9] show the effect of symmetrical gaps in V-shape ribs on the friction factor and Nusselt number. They varied the Number of gaps in a single limb of V from 1 to 5, relative gap width from 1 to 5 with the range of angle of attack 30°-75° and relative rib pitch 6–12. Enhancement in friction factor and Nusselt number were found up to 3.67 and 3.6 times over smooth absorber plate, respectively. Hans et al. [10] utilized multi V shaped ribs that create more secondary flow and enhance heat transfer rate. They varied the range of relative roughness pitch from 6 to 12, relative roughness height 0.019 to 0.034, angle of attack 30^0 to 70^0 and also varied relative roughness width from 1 to 10 and obtained maximum enhancement factor at relative roughness width 10. For further improvement in heat transfer rate Kumar et al. [11, 12] used the concept of Gap in continuous V shaped ribs. Gaps in continuous ribs provide more chance to mixing which enhances heat transfer rate. Following parameters and their ranges were considered as, relative gap position from 0.24 to 0.80, angle of attack from 30° to 75°, relative gap width from 0.5 to 1.5, relative rib pitch from 6 to 12, relative, roughness width from 1 to 10 and relative rib height from 0.022 to 0.043. Relative gap width of 1 and gap position of 0.69 provided maximum enhancements in friction factor and Nusselt number as 6.37 and 6.47, respectively. Lanjewar et al. [13] utilized W-shape ribs to improve the heat transfer rate and tested down and up arrangement. W- Shaped ribs are the combination of V shaped ribs and it creates more secondary flow. They considered roughness parameters namely; roughness pitch of 10, angle of attack of 45° and relative roughness height of 0.03375.the thermo-hydraulic performance parameter was obtained in the ranges of 1.46–1.95 and 1.21–1.73 by using W shaped ribs in down and up arrangement respectively. Later, Lanjewar et al. [14, 15] also varied the angle of attack and rib roughness height in the range of 30–75° and 0.018–0.03375, respectively. Maximum thermo-hydraulic performance was obtained at the angle of attack of $60^0$and corresponding enhancement in friction factor and Nusselt number was reported as 2.01 and 2.36 times over smooth duct, respectively. Patil et al. [16–18] studied on V shaped ribs with gaps and staggered ribs to improve the heat transfer rate. For further improvements in Nusselt number, Staggered are used which further block the flow and create more secondary flow. They varied relative gap position from 0.2 to 0.8. They observed hydraulic performance parameter 1.48–2.10. Later, they also varied relative staggered rib position and relative staggered rib size in the range of 0.2–0.8 and 1–2.5, respectively and observed 3.18 times increment in Nusselt number to that of smooth duct. Deo et al. [19] also performed on V shaped ribs with gaps and staggered. They varied relative pitch, relative rib height and angle of attack in the range of 4 to 14, 0.026 to 0.057 and 40^0 to 80^0 respectively and they observed enhancement in Nusselt number and friction factor 3.34 and 2.45 respectively. Instead of inline multi V shaped ribs Dongxu Jin, Jianguo Zuoet al.[20] used staggered multiple V-shaped ribs which further creates more secondary vortex and hence more heat transfer rate. They have done numerical study by taking the fixed parameter e/Dh = 0.043, P/e = 10, Re = 10000 on the Nusselt number and thermo-hydraulic performance by taking angle of attack 75^0,

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45^0 and 60^0 and different relative staggered distance and found that maximum increment of Nusselt number is 26% at the angle of attack of 75^0 and maximum increment in thermo-hydraulic performance is 18% at 75^0 compare to inline multi V-shaped ribs. Arvind Kumar et al. [21] performed experiment by using discrete W shaped ribs. Discreteness is also one of the ways by which more secondary flow can be generated. They fixed the relative roughness pitch as 10 and varied the following parameters namely as Reynolds number, relative roughness height and angle of attack and their value were in the range of 3000 to15000, 0.0168- 0.0338 and 30^0-75^0 respectively. Maximum enhancement in Nusselt number was obtained at 60^0 that were 2.16 and maximum enhancement in friction factor was also obtained at 60^0 that were 2.75.

III. DATA REDUCTION

Steady state values of the plate and air temperatures in the duct at various locations for a given heat flux and mass flow rate of air were used to determine the values of useful parameters. Mass flow rate (m), useful heat supplied to the air (Qu), heat transfer coefficient (h), Nusselt number (Nu), friction factor (f), in the duct was calculated as:

3.1 Mean bulk air temperature (Tf)

Simple arithmetic mean of measured inlet and exit value of air under testing section

$$T_f = (T_i + T_o)/2$$

Where,

Ti = inlet Temperature of the air in ^{0}C

To = outlet Temperature of the air in ^{0}C

3.2 Pressure Drop across the Orifice Plate (ΔP_o)

$$\Delta P_o = \Delta h * 9.81 * \rho_m * 1/5$$

Where,

Δh = Difference of mercury level in U-tube manometer

ρ_m = density of manometer fluid l.e water 1000 kg/m^3

3.3 Mass flow rate measurement (m)

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

Where,

$\beta = d_2/d_1$

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

A_o= Area of orifice plate, m^2

P = Density of air in kg/m^3

3.4 Velocity of air

$$V = m / \rho W H$$

Where,

H= Height of the duct in m

W= Width of the duct, m

3.5 Reynolds Number

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$$Re = VD_h / v$$

Where,

ν = Kinematics viscosity of air at t_{fav} in m^2/s

D_h = Hydraulic diameter

=4WH/2(W+H)

3.6 Heat Transfer Rate

$$Q_a = mc_p(T_o - T_i)$$

3.7 Heat Transfer Coefficient

$$h = Q_a / A_p(T_p - T_f)$$

3.8 Nusselt Number

$$Nu = h\, D_h / k$$

Where,

k = thermal conductivity

D_h = hydraulic diameter

3.9 Thermal Efficiency

$$\eta = Q_a / A_p L$$

Where,

L= Heat Flux i.e. $1000 W/m^2$

3.10 Friction Factor

$$F = 2(\Delta P_d) D_h / 4\rho L_f V^2$$

Where,

ΔP_d = Pressure drop in N/m^2

3.11 Thermo-hydraulic performance

This parameter shows the combined effect of enhancement in Nusselt number and enhancement in friction factor over the smooth plate that is-

$$THP = \frac{Nu/Nus}{(f/fs)^{1/3}}$$

IV. CONCLUSION

The number of research paper are studied in this review paper related to inclined, V- shape and W- shape ribs. By study of these papers following conclusions can be made-

1. If relative ribs height increases friction factor increases and if relative ribs height is less, reattachment does not possible. Therefore ribs height should we optimum. If relative pitch is large reattachment will be possible but number of reattachment decreases so it also should be optimum.
2. Mostly the optimum angle of attack for the inclined ribs, V- shape ribs and W- shape ribs is 60^0 and optimum relative pitch (p/e) is 10 and relative roughness height (e/Dh) is 0.0433.
3. V shape ribs provide better performance than inclined and transverse ribs.

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4. Gaps in continuous ribs, staggered ribs and discrete ribs gives higher Nusselt number as compare to the continuous ribs due to the more generation of secondary flow and its mixing with primary flow.

According to the above study, discreteness in V shape ribs helps to increase nusselt number therefore it can be assumed that double discrete V- shape ribs gives good nusselt number.

Nomenclature

A	Absorber plate area (m^2)
Aduct	Flow cross sectional area m^2
Ao	Throat area of orifice plate (m^2)
Ap	Area of absorber plate (m^2)
As	Area of smooth plate (m^2)
Cd	Coefficient of discharge
Cp	Heat of air at constant pressure (KJ/kg K)
Dh	Equivalent diameter of air passage
Do	Diameter of orifice plate (m)
d	Dimple diameter (mm)
Dp	Inside diameter of pipe (m)
e	Roughness height (mm)
e^+	Roughness Reynolds number dimensionless
e/Dh	Relative Roughness height
F	Friction factor
Fs	Calculate friction factor for smooth plate
H	Height of air channel (m)
h	Convective heat transfer coefficient (W/m2° C)
Δh	Difference of height in Manometer fluid
L	Heat flux (W/m2)
k	Thermal conductivity of air(W/m° C)
m	Mass flow rate of air (kg/s)
Nu	Nusselt number
Nus	Calculated Nusselt number for smooth plate
P	Pitch
P/e	Relative Roughness pitch
g	Groove position or gap (mm)
g/e	Relative gap
g/p	Relative groove position
Δpo	Pressure drop across orifice meter (Pa)
Qa	Heat gained by air (w)
Re	Reynolds number
Ta	Atmospheric temperature
Tf	Average temperature of air

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Ti	Inlet temperature of air
To	Outlet temperature of air
Tp	Average plate temperature
V	Velocity of air
W	Width of air duct
Lf	Length of test section
W/H	Channel aspect ratio
d/w	Relative gap position
Greek symbols	
β	ratio of orifice diameter to pipe diameter
ρ	Density of air
μ	Dynamic viscosity
v	Kinematic viscosity
Subscripts	
S	Smooth channel
A	Ambient
I	Inlet
O	Outlet

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