Experimental Investigations of Triangular Duct with Artificial Roughness

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Abstract— Surface roughness is one of the first active techniques to be considered for the augmentation of forced convection heat transfer. It is necessary that the flow near the heat transfer surface should be turbulent so as to attain higher coefficient of heat transfer. However, energy for creating such turbulence has to come from the fan or blower and the excessive turbulence leads to excessive power requirement to make the air flow through the duct. In this experiment the air was blown by blower through a 45^0 and 60^0 angle of rib artificially manufactured on heated horizontal surface present in duct. This created more turbulence for improving heat transfer compared to plane surface.

Key words: Triangular Duct, Artificial Roughness

I. Introduction

The subject of fluid flow and heat transfer in noncircular ducts from a fundamental view point has been virtually neglected in the literature. This probably resulted from the industrial practice of generally using round pipes in heat transfer equipment. Unconventional heat transfer design problem and the increasing industrial use of noncircular ducts in heat exchangers, the problem becomes more than just academic question. Mixed convection heat transfer in channels characterized by non- circular cross sections is a fundamental issue in many fields such as research and industry fields. Because of its uses in many thermal applications such as compact heat exchangers, solar collectors and cooling of electrical and electronic devices. Different shapes of the cross section area have been analyzed, like square, rhombic, rectangular, triangular, sinusoidal, elliptical ones, even with truncated corners.

Artificial roughness provides the turbulence to the flow which leads to increase the heat transfer between the air and the heated wall. Roughness is created in such a way that it breaks the laminar sub layer region i.e. near the wall. There are several methods to provide artificial roughness on the absorber plate such as casting, forming, machining, blasting, welding ribs and/or fixing thin circular wires, etc. The easiest and cheapest way of providing artificial roughness on the underside of the absorber plate is sticking of ribs.

II. Theoretical Work

The roughness was produced by fixing the ribs of different diameter at 45° and 60^0 inclinations and relative roughness pitch (p/e) of 12.61, 8, 6.29 on the top side of the absorber plate. The schematic view of the absorber plate is shown in Fig. No. 3.1 at the end of the duct, a plenum was provided to connect the triangular duct to a circular ribs.

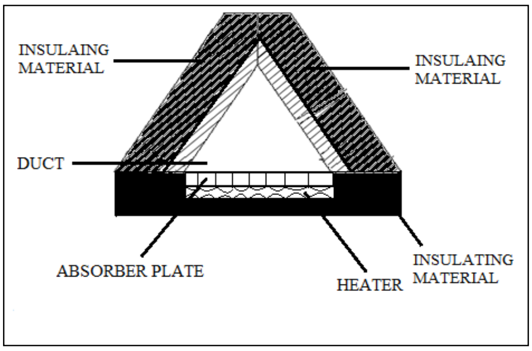


Fig. 2.1: Sectional View of the Duct

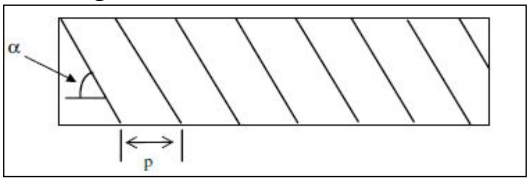


Fig. 2.2: Schematic Diagram of the Absorber Plate

III. Experimental Setup

Schematic diagram of experimental set-up for investigation of forced convection heat transfer in a triangular duct provided with different configurations of circular shaped rib having different angles as shown in fig below.

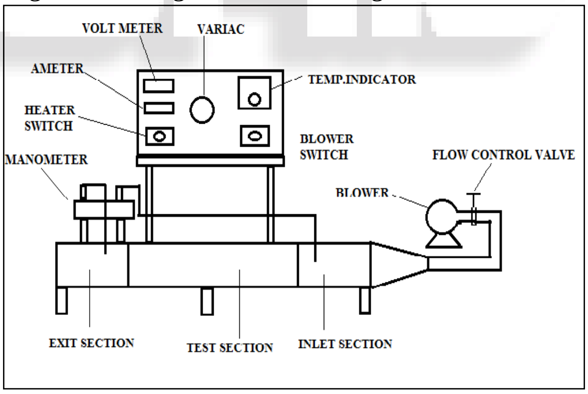


Fig. 3.1: Schematic Diagram of Experimental Set-Up

The test apparatus is an open loop air flow system which comprises of centrifugal blower, flow control valve, manometers, Anemometer, test section, control panel, etc. The vertical walls of the triangular duct are insulated properly for avoiding loss of heat from environment. The lower surface of triangular duct is surrounded by band heater for heating purpose. Ten thermocouples are embedded on the test section and two thermocouples are placed in the air stream at the entrance and exit of the test section to measure air inlet and outlet temperature. The temperatures at different locations can be read directly from the temperature indicator by using selector switch. The outer surface of the test section was well insulated to minimize heat loss to surrounding. Air velocity is controlled by a flow control valve and is measured with the help of anemometer. Heat input can be set with the help of variance provided on control panel and same can be read out digitally with the help of voltmeter and ammeter. The manometer is connected across the test section to measure the pressure drop occurred during the flow through test section.

A. *Methodology*

1) The test section is prepared for given configurations of round shaped rib turbulators.
2) The blower was switched on after keeping the valve open at desired rate to allow the airflow through the duct.
3) Initially the experiment was carried out for plain duct.
4) Then the experiment was carried out for different configurations of round shaped rib turbulators having inclination angle of 45° and 60° with the direction of flow of air.
5) A constant heat flux is applied to the test section by adjusting the voltage to desired value.
6) Note down the temperature, voltmeter and ammeter readings when steady state condition attained.
7) Four values of flow rates were used for each set at fixed uniform heat flux.
8) The pressure drop across the test section and flow rate was also measured when steady state was reached.
9) Repeat the procedure for different heat inputs and flow rates.

During experimentation the following parameters were measured

Parameter	Dimension in mm
W	160
H	138.56
P	40
e	3.17, 5, 6.35

Table 3.1: Selected Dimensions for Triangular Duct

Related Calculations:

1) Area of triangle
 $A = 0.5 \times W \times H = 11084.8 mm^2$
2) 2. Perimeter of triangle
 $P = 3 \times W = 480 mm$
3) Hydraulic diameter
 $D_h = (4 \times P) \div A = 92.37$ mm

For artificial rough surface:
The selected angles of attacks are 45^0 and 60^0.
From above data we have calculated, value for relative Roughness height (e/D_h) are as follows,

Case 1: (e= 3.17) $e/D_h = 0.034$
Case 2: (e= 5) $e/D_h = 0.05$
Case 3: (e= 6.3) $e/D_h = 0.068$

IV. CALCULATION PROCEDURE

1) Note down all the parameters displayed on control panel which includes all the temperatures, voltage and current values.
2) Note down manometer readings giving pressure drop across test section.
3) Calculate average temperature of duct wall and bulk temperature of air.
4) Obtain properties of air like thermal conductivity, kinematic viscosity, Prandtl number from the air table corresponding to above bulk temperature of air.
5) Calculate mass flow rate with help of velocity of air flowing through the test section.
6) Calculate convective heat transferred to air.
7) Calculate convective heat transfer coefficient.
8) Calculate experimental Nusselt number and friction factor.
9) Calculate the Reynolds number.
10) Calculate theoretical Nusselt number and friction factor values.

Standard Equations Used:

– Average temperature of Duct Wall:

$$T_{pm} = \frac{T1+T2+T3+T4+T5+T6+T7+T8+T9+T10}{10}$$

− Bulk Temperature of Air:

$$T_{fm} = \frac{T11+T12}{2}$$

Properties of air were taken from the air table corresponding to above bulk temperature of air.

− Mean Temperature:

$$T_m = \frac{Tfm+Tpm}{2}$$

− Area:

i. Cross sectional area:
$Ac = 0.5 \times W \times H$
ii. Test section duct area:
$A_p = W \times L$

− Mass flow rate of air:
Is measured by anemometer.

− Convective heat transferred to air:
$Q_u = m \times C_p \times (T_{12} - T_{11})$

− Convective heat transfer coefficient:

$$h = \frac{Qu}{Ap(Tp-Tfm)}$$

− Experimental Nusselt number:

$$N_u = \frac{hDh}{k}$$

− Experimental Friction Factor:

$$(\Delta P)_d = (\rho_{water} - \rho_a) \times g \times h$$

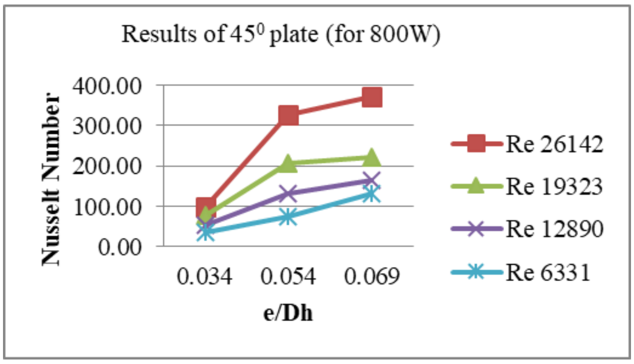
$$f = \frac{2(\Delta P)_d D_h}{4\rho L V^2}$$

− Experimental Reynolds number:

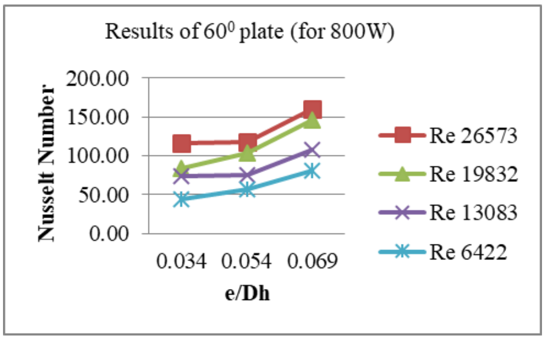
$$Re = \frac{V \times Dh}{\nu}$$

V. EXPERIMENTAL GRAPHS AND RESULTS

Experimental graphs were prepared to know the graphical representation. The graphs were plotted between Nusselt No. and relative roughness height for different Reynolds No. at different Watts.



Graph 1: Experimental Nusselt Number Vs Relative Roughness Height



Graph 2: Experimental Nusselt Number Vs Relative Roughness Height

Graphs 5.1 and 5.2 shows the variation of experimental Nu Vs e/D_h with Reynolds number for triangular duct with 45^0 and 60^0 angle of attack for ribs at 800 W input respectively. It is evident from graphs that when triangular duct is provided with different types of rib angled plate there is significant improvement in Nusselt number because of turbulence induced due to rib and secondary flow. This causes mixing of fluid which leads to increase in temperature gradient, which ultimately leads to enhancement in the heat transfer coefficient.

Q plane plate	Q rough plate e = 3.17	Q rough plate e = 5	Q rough plate e = 6.35	Increase in heat transfer for e = 3.17 (%)	Increase in heat transfer for e = 5 (%)	Increase in heat transfer for e = 6.35 (%)
61.6	167.1	139.4	165.644	171.4	126.4	169.107
92.0	157.6	172.1	220.666	71.3	87.0	139.79
61.3	129.6	126.8	180.507	111.3	106.7	194.227
30.6	98.5	100.5	118.9	221.9	228.5	288.634
122.7	122.7	259.7	311.517	0.0	111.6	153.886
137.9	151.7	275.5	219.894	10.0	99.8	59.4406
122.4	140.7	228.0	231.093	15.0	86.3	88.8354
76.2	121.6	258.3	237.463	59.7	239.2	211.831
183.2	208.4	321.7	343.258	13.7	75.6	87.3216
182.9	238.2	380.4	379.233	30.2	108.0	107.318
152.3	186.0	324.1	459.487	22.1	112.8	201.694
91.2	172.3	293.1	371.224	88.8	221.3	306.952
243.9	293.2	655.3	757.478	20.2	168.7	210.571
228.5	292.4	562.6	603.102	28.0	146.3	163.993
182.4	251.9	483.0	503.054	38.1	164.8	175.734
106.2	200.2	341.8	647.675	88.5	221.7	509.653

Table 1: Percentage Increase in Heat Transfer between Plane and 45^0 Rough Plate.

Q plane plate	Q rough plate e=3.17	Q rough plate e = 5	Q rough plate e = 6.35	Increase in heat transfer for e = 3.17 (%)	Increase in heat transfer for e = 5 (%)	Increase in heat transfer for e = 6.35 (%)
61.55	123.1	121.9	122.4	100.0	98.1	98.8
92.02	138.5	137.1	182.9	50.5	49.0	98.8
61.35	122.7	121.6	152.3	100.0	98.3	148.3
30.59	76.4	90.6	106.2	149.6	196.1	247.2
122.70	183.9	182.8	183.2	49.9	49.0	49.3
137.92	229.1	227.2	228.5	66.1	64.8	65.6
122.38	213.2	181.2	242.4	74.2	48.0	98.1
76.15	181.2	237.7	239.4	137.9	212.1	214.4
183.25	244.8	243.3	243.3	33.6	32.7	32.7
182.92	274.4	317.6	317.6	50.0	73.6	73.6
152.30	303.0	271.5	271.5	98.9	78.3	78.3
91.22	240.0	253.4	253.4	163.1	177.8	177.8
243.90	304.6	305.4	427.6	24.9	25.2	75.3
228.45	318.7	364.9	457.3	39.5	59.7	100.2
182.44	331.8	331.8	453.7	81.9	81.9	148.7
106.24	253.8	283.3	422.3	138.9	166.6	297.5

Table 2: Percentage Increase in Heat Transfer between Plane and 60^0 Degree Rough Plate

Comparing both results of the angle of attacks of ribs i.e. 45^0 and 60^0, the better heat transfer enhancement is in 45^0 plates at 200,400,600, 800 watt and highest Nusslet no is 373.33 for e/d_h.069 at 800 watt and for e=6.35.

The results were obtained and tabulated as given below. In that for different rough plates the heat transfer form 45^0 and 60^0 angle of attack were measured. From this, it was concluded that heat transfer from 45^0 plate was more due to more turbulence.

VI. Conclusion

The experimental investigation of forced convection heat transfer in a triangular duct provided with different configurations of Round-shaped rib turbulators has been carried out.

Following conclusions have been drawn from the experimentation:

1) The Nusselt number increases with increase in Reynolds number at different heat inputs for triangular duct provided with different types of rib angle.
2) The experimental results are in line with the analytical results.
3) In most of cases of triangular duct provided with different types of rib angles, the overall enhancement ratio is found to be in the range of 0.035, 0.054 and 0.069 relative roughness height for 45^0 and 60^0 rib angles.
4) The triangular duct provided with 45° rib angled plates obtain highest value of Nusselt number is 373.33 at relative roughness height e/D_h 0.069 for 800 watt heat input.
5) In plain triangular duct the percentage change in theoretical friction factor with compared to experimental friction factor is in the range of 12 % to about 38.11% for Nusslet no. and 6.7% to about 67%.
6) Velocity levels are same across all the cases for 200 W and 800 W simulations.
7) Temperature of the plain plate considerably reducing as the velocity is increasing. For low velocity (1.2 m/s), not much heat is carried away from the plate surface.
8) 45^0 rib plates' shows great improvement in surface temperature levels as compared to plain plate. Temperature is considerably dropped in case of 45^0 plates as compared to plain plate.

VII. Future scope

Future scopes:

- Find HTC parameters by changing material of rough surface.
- Find HTC parameters by changing c/s of roughness.
- Distance between two consecutive ribs can be varied to see their effect on heat transfer & friction factor.

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