Heat Transfer and Frictional Characteristics in a Circular Tube Fitted With and Without Perforated V-Nozzle Turbulators: A Proposed Work

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Abstract—The conventional sources of energy have been depleting at an alarming rate and it makes future sustainable development of energy use very difficult. Heat transfer enhancement technology has been developed and widely applied to heat exchanger applications like refrigeration, aerospace, automotive, process industry, solar water heater, etc. The heat transfer in the circular tube could be promoted by fitting with V-nozzles while it brings about the energy loss of the fluid flow. The increase in friction factor is much higher than the increase in Nusselt number at the same Reynolds number. Perforated conical-ring (PCR) is one of the turbulence-promoter/turbulator devices for enhancing the heat transfer rate in a heat exchanger system. The PCRs can enhance heat transfer more efficient than the typical CR on the basis of thermal performance factor. The Nusselt number increases with the rise of Reynolds number and the maximum heat transfer is obtained for the smallest pitch arrangement. In the proposed work, v-nozzle turbularors are used with and without perforated shape, circular holes and diamond holes for the forced convection of Reynolds number range 18000 to 25000. The proposed work uses the circular pipe fitted with the plain v-nozzle turbulators having PR=3, l=138mm and D=46 mm and the circular tube fitted with the perforated v nozzle turbulators having four number of holes (circular and diamond shapes) with D=46 mm, d=23 mm respectively. The objective of to the proposed work is to enhance the heat transfer coefficient, Increases Thermal performance factor and reduced the friction factor.

Index Terms— Perforated V-Nozzle Turbulators, Frictional Characteristics, perforated conical-rings (PCRs), Nusselt number

I. INTRODUCTION

Heat transfer enhancement technology has been developed and widely applied to heat exchanger applications while the reduction in overall resistance can lead to a smaller heat exchanger. To date, there have been a large number of attempts to reduce the size and costs of heat exchangers. In general, enhancing the heat transfer can be divided into two groups. One is the passive method, without stimulation by the external power such as a surface coating, rough surfaces, extended surfaces, swirl flow devices, the convoluted (twisted) tube, additives for liquids and gases. The other is the active method, which requires extra external power sources, viz. mechanical aids, swirl flow-turbulator devices, flow-induced vibration, surface-fluid vibration, injection and suction of the fluid, jet impingement, and use of electrostatic fields.

Heat transfer enhancement is the process of improving the performance of a heat transfer system. It generally means increasing the heat transfer coefficient. The performance of heat exchanger depends how effectively heat is utilized. Reduction of the size of the heat exchanger may be possible due to improvement in the performance of heat exchanger. On the other hand, a high performance heat exchanger of a fixed size can give a increased heat transfer rate and also there is decrease in temperature difference between the process fluids enabling efficient utilization of thermodynamic availability. The performance can be improved by using various augmentation techniques such as finned surfaces, integral roughness and insert devices. A variety of different techniques are employed for the heat transfer process. The reverse flow device or the turbulator is widely employed in heat transfer engineering applications. The reverse flow is sometimes called "re-circulation flow". The effect of reverse flow and boundary layer eruption (dissipation) is to enhance the heat transfer coefficient and momentum transfers. The reverse flow with high turbulent flow can improve convection of the tube wall by increasing the effective axial Reynolds number, decreasing the cross-section flow area, and increasing the mean velocity and temperature gradient. It can help to produce the higher heat fluxes and momentum transfer due to the large effective driving potential force but also higher pressure drop. S. Eiamsa-ard and P. Promvonge highlighted the heat transfer in the circular tube could be promoted by fitting with V-nozzles while it brings about the energy loss of the fluid flow. The increase in friction factor is much higher than the increase in Nusselt number at the same Reynolds number. The enhancement efficiency decreases with increasing Reynolds number [3]. The heat transfer in the circular tube could be enhanced considerably by fitting it with conical-nozzle inserts and snail entrance. The increase in pressure drop is much higher than the increase in Nusselt number at the same Reynolds number [4].

The application of the C-nozzles and free-spacing snail entry results in a considerable increase in heat transfer rate and friction loss at smaller pitch ratio. Instead of the snail with no entry length, the free-spacing snail entry gives lower friction loss associated but still favorable the heat transfer rate [5].Converging conical ring, referred to as CR array, diverging conical-ring, DR array and converging– diverging conical-ring, CDR array on the heat transfer rate and friction factor. The results revealed that the conical-ring with the DR array provided superior thermal performance compared to those with the CR and CDR arrays [6]. A. Durmus used conical turbulators with four conical angles (5°, 10°, 15°and 20°) for heat transfer enhancement. The heat transfer rates as well as friction coefficients increased with increasing turbulator angles [7].

The combined effects of the reverse flow (conical-ring) together with swirl flow (twisted-tape) to improve the heat transfer in a circular tube [8].

Sivashanmugam and Nagarjan, proved that the heat transfer coefficient enhancement through a circular tube fitted with right and left helical screw inserts is higher than that for straight helical twist inserts of equal and unequal length for a given twist ratio[9].

Yakut and Sahin reported the flow induced vibration characteristics of conical-ring turbulators used for heat transfer enhancement in heat exchangers. The result shows that the Nusselt number increases with the rise of Reynolds number and the maximum heat transfer is obtained for the smallest pitch arrangement. [10].

V. Kongkaitpaiboon, K. Nanan, S. Eiamsa-ard experimentally investigated heat transfer and turbulent flow friction in a tube fitted with perforated conical – rings (PCR). , the thermal performance factor of all PCRs arrangements is higher than those of the Conical Rings. The heat transfer rate and friction factor of PCRs increase with decreasing pitch ratio (PR) and decreasing number of perforated hole (N) [2].

Dr. Akeel Abdullah Mohammed et.al. highlighted the augmentation process done by using divergent Nozzle-Turbulator arrangement with and without perforation models (triangle holes, square holes, and circle holes). The triangle hole shape perforation provided a higher heat transfer rates than those of the circular and square hole shapes perforation, The friction factors in the tube fitted with perforated nozzle-turbulator are smaller than those provided by the traditional nozzle-turbulator at the corresponding Reynolds number, Triangular perforation gives higher thermal performance factor than non-perforated nozzle-turbulators, the perforated Nozzle-Turbulators with triangle holes gave the highest thermal performance factor among all other perforated and non-perforated nozzle turbulators [1].

In the proposed work, v-nozzle turbularors are used with and without perforation shape (circular holes and diamond holes) for the forced convection of Reynolds number range 18000 to 25000 The present work is the circular pipe fitted with the plain v-nozzle turbulators having PR = 3, L = 138mm and D = 46 mm. and the circular tube fitted with the perforated v nozzle turbulators having four number of holes (circular and diamond shapes) with D = 46 mm, d = 23 mm respectively.

The significant objective of to the proposed work is to enhance the heat transfer coefficient, Increases Thermal performance factor and reduced the friction factor.

II. LITERATURE SURVEY

Dr. Akeel Abdullah Mohammed et.al.[1] experimentally investigated the enhancement of forced convection heat transfer by means of passive techniques for a turbulent air flow through an Aluminum test tube. Reynolds number range is from 6000 to 13500 with boundary conditions of constant heat flux. The augmentation process is done by using divergent Nozzle-Turbulator arrangement with and without perforation models (triangle holes, square holes, and circle holes). The insertion of the nozzle turbulators were made thoroughly inside the heating section by pressure with pith ratio of (PR = L/D = 5). The nozzle-turbulators were constructed from Aluminum with the length of a=45 mm and with ends diameters of (D=45 mm and d=22.5 mm). For all types of perforated Nozzle-turbulators, each Nozzle -tabulator was perforated with four holes.

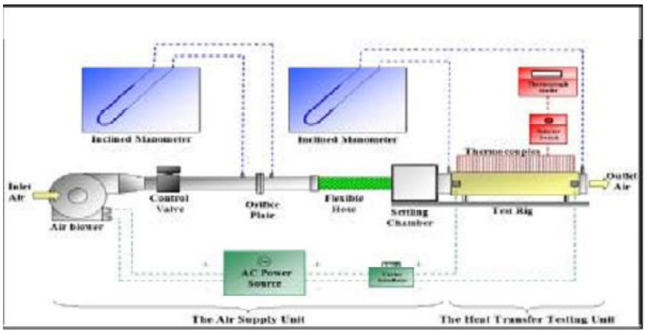


Fig. 1. Schematic diagram of the experimental setup.

The experimental results at the same Reynolds number show that the divergent nozzle-turbulators without perforation provides the highest heat transfer rate 317% and highest friction factor 17 times over that of plain tube with a performance factor of (1.58) the perforated Nozzle-Turbulators with triangle holes gave a thermal performance factor of (1.7) which is the highest thermal performance factor among all other perforated and non-perforated nozzle turbulators.

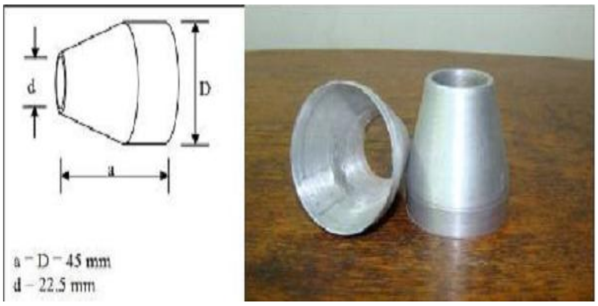


Fig. 2(a). Dimensions of the nozzle-turbulators

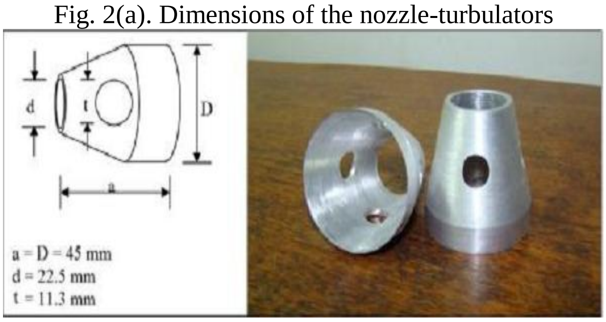


Fig. 2(b) Circle shape perforation Nozzle-turbulators.

Fig. 2(c). Triangle shape perforation Nozzle-turbulators

All the holes (regardless of its shape) were fabricated to have the same area of 100 mm2.Nozzle-turbulators with or without perforation could be inserted inside the flow tube to enhance the heat transfer rate, this is because of its influence in disrupting the boundary layer and the reverse flow that enhance the convection heat transfer process by increasing the average Nusselt number. Inserting Nozzle-turbulators with or without perforation increase pressure drop because of the secondary flow obtained from the interaction of the pressure forces with the internal forces of the boundary layer. The triangle hole shape perforation provided a higher heat transfer rates than those of the circular and square hole shapes perforation. The friction factors in the tube fitted with perforated nozzle-turbulator are smaller than those provided by the traditional nozzle-turbulator at the corresponding Reynolds number, the perforation with any shape reduces the obstructing of the nozzle-turbulator to the air flow which leads certainly to reduce the friction factor across the plain tube. Triangular perforation gives higher thermal performance factor than non-perforated nozzle-turbulators, this is because it increases the average Nusselt number more than the increasing in the friction factor.

V. Kongkaitpaiboon, K. Nanan, S. Eiamsa-ard [2] experimentally investigated heat transfer and turbulent flow friction in a tube fitted with perforated conical – rings (PCR). The perforated conical-rings (PCRs) used are of three different pitch ratios (PR =p/D=4, 6 and 12) and three different numbers of perforated holes (N=4, 6 and 8 holes). The experiment conducted in the range of Reynolds number between 4000 and 20,000, under uniform wall heat flux condition and using air as the testing fluid. The experimental results obtained by using the plain tube and the tube equipped with the typical conical-ring (CR) are also reported for comparison.

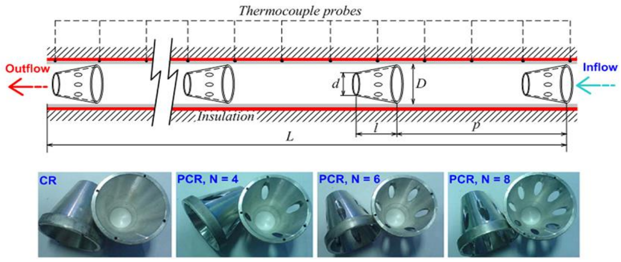


Fig. 3. The arrangement of CR/PCR in a round tube.

At the similar test conditions, the PCRs offers lower heat transfer enhancement than the Conical Rings (CRs). However, they generate friction factor only around 25% of that produced by the PCRs. Consequently, the thermal performance factor of all PCRs arrangements is higher than those of the Conical Rings. The heat transfer rate and friction factor of PCRs increase with decreasing pitch ratio (PR) and decreasing number of perforated hole (N). However, the thermal performance factor increases with increasing number of perforated hole and decreasing pitch ratio.

The mean heat transfer rates obtained from using the PCR with PR=4, 6, and 12 are found to be respectively, 185%, 140%, and 86%, over the plain tube. Over the range investigated, the maximum thermal performance factor of around 0.92 is found at PR=4 andN=8 holes with the Reynolds number of 4000.

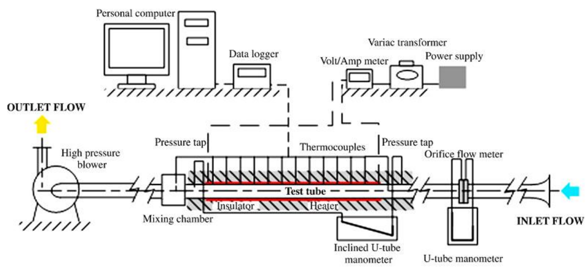


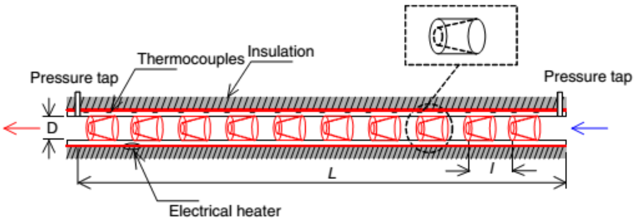
Fig. 4. Experimental heat transfer apparatus

S. Eiamsa-ard and P. Promvonge [3] experimentally investigated the effects of the V-nozzle turbulators on heat transfer, friction and enhancement efficiency, in a circular tube. The heat transfer in the circular tube could be promoted by fitting with V-nozzles while it brings about the energy loss of the fluid flow. The mean heat transfer rates obtained from using the V-nozzles with PR= 2.0, 4.0, and 7.0 are found to be 270%, 236%, and 216%, respectively, over the plain tube. However, the increase in friction factor is much higher than the increase in Nusselt number at the same Reynolds number.

The enhancement efficiency decreases with increasing Reynolds number. The maximum value of enhancement efficiency obtained from using the PR= 2.0, 4.0, and 7.0, are found to be 1.19, 1.14, and 1.09, respectively. In addition, the enhancement efficiency increases as the pitch decreases and, generally, it lowers at high Reynolds number for all pitches.

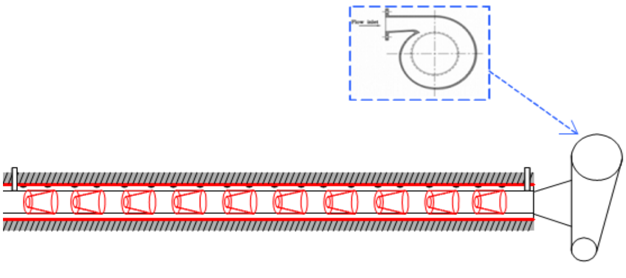
P. Promvonge and S. Eiamsa-ard [4] highlighted the experimental investigation for using conical-nozzle inserts and snail entrance of a tube that have been conducted.

The heat transfer in the circular tube could be enhanced considerably by fitting it with conical-nozzle inserts and snail entrance. Although they provide higher energy loss of the fluid flow; the loss is low especially at low Reynolds number. The value of the Nusselt number increases in a range of 236–278% over that of the plain tube for the conical-nozzle inserts and up to 316% for using the conical nozzle and the snail entrance. However, the increase in pressure drop is much higher than the increase in Nusselt number at the same Reynolds number.



(a)

Fig. 5(a). Test tube fitted with conical-nozzle arrangement



(b)

Fig. 5(b). Test tube fitted with conical nozzles combined with a snail

The Nusselt number increases with reduction of the pitch ratio and increasing Reynolds number. The maximum heat transfer rates obtained from using the conical nozzles with PR = 2.0, the snail and the conical nozzles with snail are found to be 278%, 206% and 316%, respectively. The enhancement efficiency generally increases at lower Reynolds number and pitch ratio (PR). The efficiency for PR = 0.2 is 2–3% and 3–6% higher than those for PR = 0.4 and 0.7, respectively. The turbulators are applicable effectively at low Reynolds number because they provide low enhancement efficiency at high Reynolds number for all pitch ratios.

P. Promvonge and S. Eiamsa-ard [5], Experimental investigations examine the effect of a combination of C-nozzle turbulators and a snail with free-spacing entry on heat transfer rate and flow friction characteristics in a uniform heat flux tube using air as the test fluid. The application of the C-nozzles and free-spacing snail entry results in a considerable increase in heat transfer rate and friction loss at smaller pitch ratio. Instead of the snail with no entry length, the free-spacing snail entry should be introduced to lower friction loss associated but still favorable the heat transfer rate.

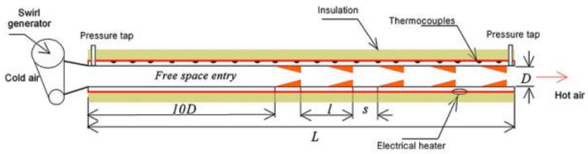


Fig. 6. Test tube fitted with C-nozzle turbulators and snail with free-spacing entry.

Depending on the flow conditions and pitch ratio, the maximum improvements of heat transfer rate over the corresponding plain tube are found to be about 315%, 300% and 285%, for PR = 2.0, 4.0, and 7.0, respectively. The variations of the enhancement efficiency for Reynolds number ranging from 5000 to 18000 are between 0.76 and 0.93; 0.7 and 0.85; and 0.67 and 0.8 for PR= 2.0, 4.0 and 7.0, respectively. This means that the C-nozzle turbulators and snail with free-space entry are not feasible in terms of energy saving. Though, the devices of C-nozzle turbulators and a snail with free-spacing entry can be employed effectively at low Reynolds number or in places where pumping power is not important but compact sizes and ease of manufacture are needed.

Promvonge[6] investigated the effect of the conical ring turbulator arrangements (converging conical ring, referred to as CR array, diverging conical-ring, DR array and converging– diverging conical-ring, CDR array) on the heat transfer rate and friction factor. The results revealed that the conical-ring with the DR array provided superior thermal performance compared to those with the CR and CDR arrays.

Durmus used conical turbulators with four conical angles (5°,10°, 15°and 20°) for heat transfer enhancement. Author's finding showed that the heat transfer rates as well as friction coefficients increased with increasing turbulator angles. Durmus focused the effect of cutting out conical turbulators, placed in a heat exchange tube, on the heat transfer rate with four different types of turbulators and different conical- angles and reported that the heat transfer improvement depends on the type and the angle of the turbulators[7].

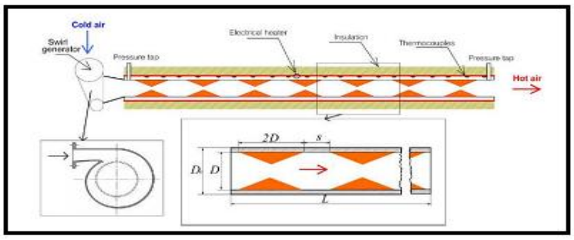


Fig. 7. A detailed view of topologies of V Nozzle Inserts.

Promvonge and Eiamsa-ard highlighted that combined effects of the reverse flow (conical-ring) together with swirl flow (twisted-tape) to improve the heat transfer in a circular tube. The result showed that that average heat transfer rate in the tube with the combined devices was approximately 10% over that in the tube with the conical-ring alone [8].

Sivashanmugam and Nagarjan, proved that the heat transfer coefficient enhancement through a circular tube fitted with right and left helical screw inserts is higher than that for straight helical twist inserts of equal and unequal length for a given twist ratio[9].

K. Yakut, B. Sahin [10] experimentally investigated the effect of conical ring turbulators on the turbulent heat transfer, pressure drop and flow-induced vibrations. The experiments were analyzed and presented in terms of the thermal performances of the heat-transfer promoters with respect to their heat-transfer enhancement efficiencies for a constant pumping power. The authors highlighted the flow induced vibration characteristics of conical-ring turbulators used for heat transfer enhancement in heat exchangers. The Nusselt number increases with the rise of Reynolds number and the maximum heat transfer is obtained for the smallest pitch arrangement.

III. METHODOLOGY

The experiments were carried out in an open-loop experimental facility as shown in Fig. 1. The loop consisted of a 2.2 kW blower, orifice meter to measure the flow rate, and the heat transfer test section. The copper test tube has a length of L= 1250 mm, with 47 mm inner diameter (D), 51 mm outer diameter (Do), and 2 mm thickness (t)as depicted in Fig. 2. The tube was heated by continually winding flexible electrical wire to provide a uniform heat flux boundary condition. The electrical output power was controlled by a variance transformer to obtain a constant heat flux along the entire length of the test section and by keeping the current less than 3 A. The outer surface of the test tube was well insulated to minimize convective heat loss to surroundings, and necessary precautions were taken to prevent leakages from the system. The inner and outer temperatures of the bulk air were measured at certain points with a multichannel temperature measurement unit in conjunction with the Chromel–constantan thermocouples as can be seen in Fig. 8. Fifteen thermocouples were tapped on the local wall of the tube and the thermocouples were placed round the tube to measure the circumferential temperature variation, which was found to be negligible. The mean local wall temperature was determined by means of calculations based on the reading of Chromel–constantan thermocouples.

The copper pipe is used in the experimental test rig the copper is one of the materials having the highest thermal conductivity. The tube was heated by continually winding flexible electrical wire to provide a uniform heat flux boundary condition. The electrical output power was controlled by a variance transformer to obtain a constant heat flux along the entire length of the test section and by keeping the current less than 3 A. The outer surface of the test tube was well insulated to minimize convective heat loss to surroundings, and necessary precautions were taken to prevent leakages from the system.

Specifications

- Pipe ID = 47 mm
- Pipe OD=51 mm
- Material of Construction= Cu (Copper)
- Heat Transfer Length= 1.25 M

V- nozzle turbulators are a turbulators device they varies the velocity of the flow and made it turbulent due to this the contact time of the fluid increases and more heat transfer is possible. The v-nozzle turbulators increases the Reynolds No. and hence increases the heat transfer. The figure shows the v-nozzle turbulators.

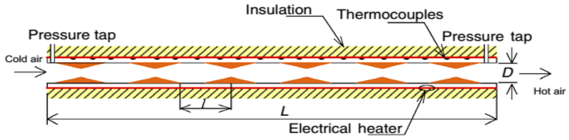


Fig. 8. Test tube fitted with V-nozzle turbulators.

Fig. 9 (a) represents the V-nozzle without perforated arrangement used in the present work. The V-nozzle are made of Aluminum with 138 mm (3.0D) in length and its end and throat diameters were 46 mm and 24 mm, respectively. The V-nozzles were placed with pitch length of arrangements, having l = 138 mm (PR = 3.0), for the experiment.

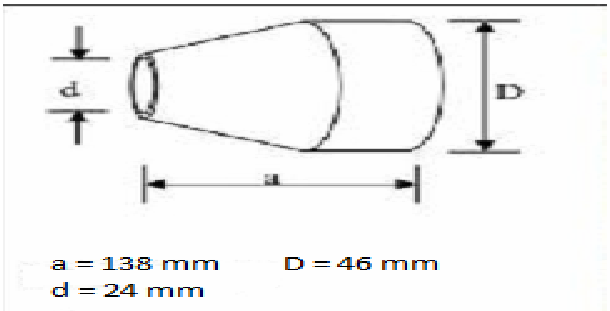


Fig. 9 (a). Dimensions of the nozzle-turbulators

Fig. 9 (b) Represent the V-nozzle with perforated (circular shape) arrangement used in this work. The V-nozzle are made up of Aluminum with four number of holes, with a = 46 mm (1.0D) in length and its end and throat diameters were 46 mm and 23 mm, respectively. The perforated holes are of t = 11.3 mm of each in convergent and divergent nozzle. Fig. 10 (c) Represent the V-nozzle with perforated (Diamond shape) arrangement used in this work. The V-nozzle are made up of Aluminum with four number of holes, with a = 46 mm (1.0D) in length and its end and throat diameters were 46 mm and 23 mm, respectively. The perforated holes are of p = 20 mm and q = 20 mm of each in convergent and divergent nozzle.

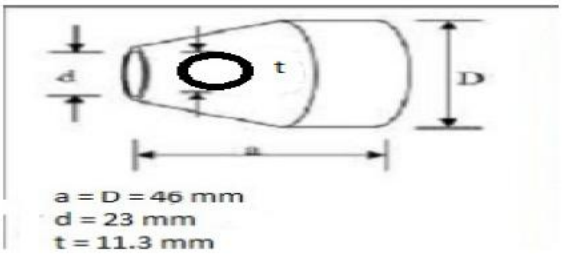


Fig.9 (b) Circle shape perforation Nozzle-turbulators.

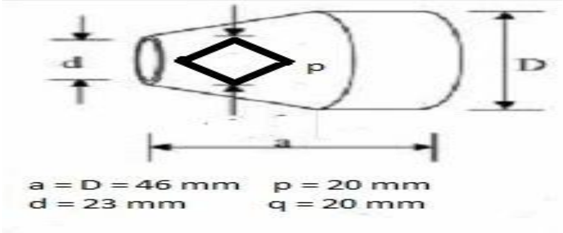


Fig. 9 (c) Diamond shape perforation Nozzle-turbulators.

IV. EXPERIMENTAL PROCEDURE

In the apparatus setting, the inlet bulk air at 25 °C from a 2.2 kW blower was directed through the orifice meter and passed to the heat transfer test section. Manometric fluid was used in U-tube manometers with specific gravity (SG) of 0.826 to ensure reasonably accurate measurement of the low pressure drop encountered at low Reynolds numbers. Also, the pressure drop of the heat transfer test tube was measured with inclined U-tube manometers. The volumetric air flow rates from the blower were adjusted by varying motor speed through the inverter, situated before the inlet of test tube. During the experiments, the bulk air was heated by an adjustable electrical heater wrapping along the test section. Both the inlet and outlet temperatures of the bulk air from the tube were measured by multi-channel Chromel–constantan thermocouples, calibrated within ±0.2 °C deviation by thermostat before being used. It was necessary to measure the temperature at 15 stations altogether on the outer surface of the heat transfer test pipe for finding out the average Nusselt number.

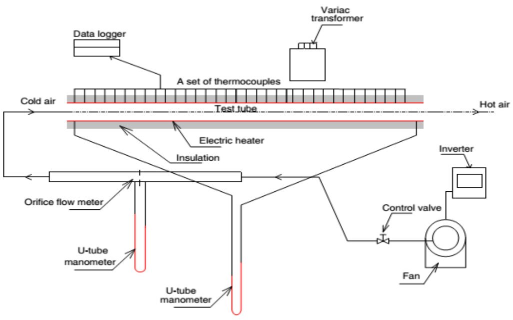


Fig. 10. Schematic diagram of experimental heat transfer set-up.

For each test run, it was necessary to record the data of temperature, volumetric flow rate and pressure drop of the bulk air at steady state conditions in which the inlet air temperature was maintained at 25 °C. The Reynolds number of the bulk air was varied from 18000 to 25 000. The various characteristics of the flow, the Nusselt number, and the Reynolds number were based on the average of tube wall temperatures and outlet air temperature.

V. OBSERVATIONS AND DISCUSSION

In the present work, the air is used as working fluid and flowed through a uniform heat flux and insulation tube. The steady state of the heat transfer rate is assumed to be equal to the heat loss from the test section which can be expressed as:

$$Q_{air} = Q_{conv} \qquad (1)$$

in which

$$Q_{air} = mCpa(To-Ti) \qquad (2)$$

The convection heat transfer from the test section can be written as:

$$Q_{conv} = hA(Tw-Tb) \qquad (3)$$

whereas,

Tb = (To-Ti)/2 (4)

And

Tw = ∑ Tw/6 (5)

Where Tw is the local wall temperature and evaluated at the outer wall surface of the inner tube. The averaged wall temperatures are calculated from 6 points, lined between the inlet and the exit of the test pipe. The average heat transfer coefficient, h and the mean Nusselt number, Nu are estimated as follows:

h = mCpa (To-Ti)/A(Tw-Tb) (6)

Nu = hD/k (7)

The Reynolds number is given by

Re = UD/v (8)

Friction factor, f can be written as:

$$f = \frac{\Delta P}{\left(\frac{L}{D}\right)\left(\rho \frac{U^2}{2}\right)} \quad (9)$$

In the proposed work, v-nozzle turbularors are used with and without perforated shape, circular holes and diamond holes for the forced convection of Reynolds number range 18000 to 25000. The proposed work uses the circular pipe fitted with the plain v-nozzle turbulators having PR=3, l=138mm and D=46 mm and the circular tube fitted with the perforated v nozzle turbulators having four number of holes (circular and diamond shapes) with D=46 mm, d=23 mm respectively.

The behavior of different kinds of v nozzle are studied to improve the thermal performance. The result of the proposed work will enhance the heat transfer coefficient, Increases Thermal performance factor and reduced the friction factor.

VI. CONCLUSION

The result of the proposed work will enhance the heat transfer coefficient, Increases Thermal performance factor and reduced the friction factor.

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