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Effect of Slits in A Diverging Conical Ring Insert on Heat Transfer Enhancement in A Cylindrical Tube

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Abstract: Diverging conical ring insert in a cylindrical tube is a passive augmentation technique aiming to improve the heat transfer enhancement. An insert disrupts the flow creating a mixture between core and near wall fluid leading to enhancement of heat. In this research work hot water is used as the test fluid in a simulation to establish the pressure and temperature variation along a tube 4m long with an insert placed at 3.5m from the entrance. At this position uniform velocity is attained to avoid the boundary layer and pipe entry effect. Analysis of the results shows a positive heat transfer enhancement rate compared with a plain tube, the highest rate achieved when two slits are placed on opposite sides of the conical ring.
Key words: heat transfer enhancement, multi longitudinal vortex, Slit, Diverging ring insert and Thermal performance factor.

I. INTRODUCTION

Heat transfer is a study on exchange of thermal energy through a body or between bodies which occurs when there is a temperature difference. Thermal energy transfers occur from a body with a higher temperature to another with lower temperature. Heat transfer enhancement is an improvement in the performance of a thermal system by change of surface geometry to obtain higher energy efficiency also referred to as heat transfer augmentation. The heat transfer rate can be improved by introducing a disturbance in the fluid flow using different enhancement technologies breaking the viscous and thermal boundary layer. Augmentation techniques are broadly classified into three different categories: Passive, Active and Compound. Passive techniques are those that do not require any direct input of external power, rather they use it from the system itself which ultimately leads to an increase in fluid pressure drop. They are divided into displacement enhancement devices like conical rings and swirl flow devices that produce superimposed swirl flow or secondary recirculation on the axial flow in a tube e.g. helical strip or coiled screw type tube inserts and twisted tapes. Active techniques are those that have external power used to facilitate the desired flow modification and improvement in the rate of heat transfer like in the case of rotating tubes and surface vibration. Compound techniques occur when any two or more of these techniques are employed simultaneously to obtain enhancement in heat transfer that is greater than that produced by either of them when used individually.

II. LITERATURE REVIEW

Ayhan et al. [1] provided the effect of truncated hollow cone inserts on heat transfer and friction in a tube. Durmus [3] investigated the effect of cutting out conical turbulators on heat transfer with different types of turbulators and different conical-angles of 5^0, 10^0, 15^0 and 20^0 establishing that heat transfer rate as well as friction coefficients increased with the angles. Promvonge [11] conducted experiments by inserting several conical rings as turbulators over a test tube with conical rings of three different diameter ratios of the ring to the diameter (d/D = 0.5, 0.6, 0.7) were introduced in the tests and for each ratio the rings were placed with three different arrangements; Converging conical ring-CCR, Diverging conical ring-DCR, Converging diverging conical ring-CDCR in which cold air at ambient air temperature was passed through the tube with the DCR being the most efficient. Fan et al. [4] numerically investigated turbulent flow and heat transfer in a circular tube fitted with conical strip inserts using k-ε turbulence. Kongkaitpaiboon et al. [7] studied the perforated conical–ring with different pitch ratios and different numbers of perforated holes. They found that it leads to a heat transfer rate up to 137% over that in the plain tube. The perforated conical-rings enhanced heat transfer more than typical conical-rings on the basis of thermal performance factor of around 0.92 at the same pumping power which was found at the smallest pitch ratio and maximum number of holes. Karakaya and Durmus [6] devised the conical spring turbulators for three

different cone angles 30º, 45º and 60º in Reynolds number ranging from 10000 to 34000. They found that the best results in terms of direction of flow are diverging, converging –diverging and converging respectively, while the turbulator best results for the cone angle are 30º, 45º and 60º respectively. Guo et al. [5] carried out a theoretical study about the effect of a secondary flow on the laminar convection heat transfer, while Saqr and Wahid [12] proposed an empirical correlation for predicting the entropy augmentation as a function of the swirl number. Nuntadusit et al. [10] studied the effect on Nusselt number of different set ups of multiple swirling jets. As for the design of swirl generators Zohir et al. [13] evaluated the increase of heat transfer rate when modifying the location and pitch angle of the swirl generator upwind the test chamber. Liu et al [8] explained the physical quantity synergy principle from field synergy by reflecting the physical mechanism of convective heat transfer in the laminar and turbulence flows and explained physical essentials on reducing flow resistance by revealing how heat transfer performance is influenced by physical quantity synergy relation on temperature, velocity and pressure. Chen et al. [2] proposed the entransy dissipation based thermal resistance method for heat exchanger performance design and optimization. By setting entransy dissipation as optimization objective and viscous dissipation as a constraint condition, the optimization flow field equation for convective heat transfer is expressed by Meng et al [9]. Therefore the optimum velocity field indicates the basic characteristics of the flow pattern that benefits the heat transfer most for the laminar flow heat transfer in a tube as between 2 to 4 multi-longitudinal vortex pairs.

III.   ASSUMPTIONS IN THE STUDY.
In this research using a viscous Newtonian fluid, the following assumptions are made:

A.   The fluid flow is steady and in the axial direction.
B.   The fluid is Newtonian i.e. stress is proportional to the rate of shear force.
C.   The no-slip condition is satisfied i.e. on the surface of the solid wall the velocity of the fluid layer adjacent to it is stationary.
D.   The fluid is incompressible i.e. density of the fluid is assumed to be a constant.

IV.   BOUNDARY CONDITIONS
Using hot water the flow parameters at the inlet of the tube are $u_z = 3m/s$ while pressure P_0 =110,000 Pa and temperature T_0=370K. The Reynolds number (Re) satisfies the inequality 1000<Re<5000, pressure coefficient: P_C =6.5 and Prandtl number: Pr = 1.75, Figure 1 shows the position of a conical ring insert in the cylindrical tube, with the axis indicated. The DCR insert inlet radius is 18mm and the outlet radius is 25mm, with the length along the z axis as 70mm.
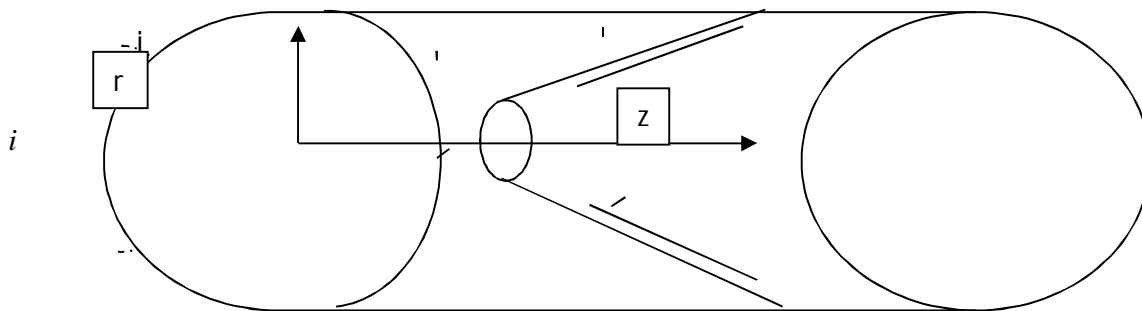

Fig 1: Schematic diagram of a diverging conical ring insert with two slits in a pipe.

Momentum flux on the fluid force through the ring at the DCR is $\overset{\circ}{m} = 2\pi\rho\int\limits_0^\infty u^2 rdr$ a constant and on the wall surfaces

temperature T hot water =T wall.

The conical insert has a half angle of $\alpha = 7.5^0$ in a pipe of radius R= 2.5cm, and a pressure difference of 10k Pa.

V.   PHYSICAL SIMULATION OF THE FLOW PROBLEM.
To determine the flow parameters we simulate a physical situation by modeling the cylindrical tube with a diverging conical ring insert having slits on the slant edge. A software 'Solid works' is used to simulate the flow after construction of the pipe geometry to

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demonstrate a case of hot water flowing in a horizontal pipe. Fluid velocity along the tube is illustrated by a colour code as shown in figure 2. The slits generate fluid circulation in the tube with axial velocity u_z along the axial planes. A cross section diagram at the DCR insert outlet displays the streamlines indicating two multi-longitudinal vortex pairs generated by two slits.
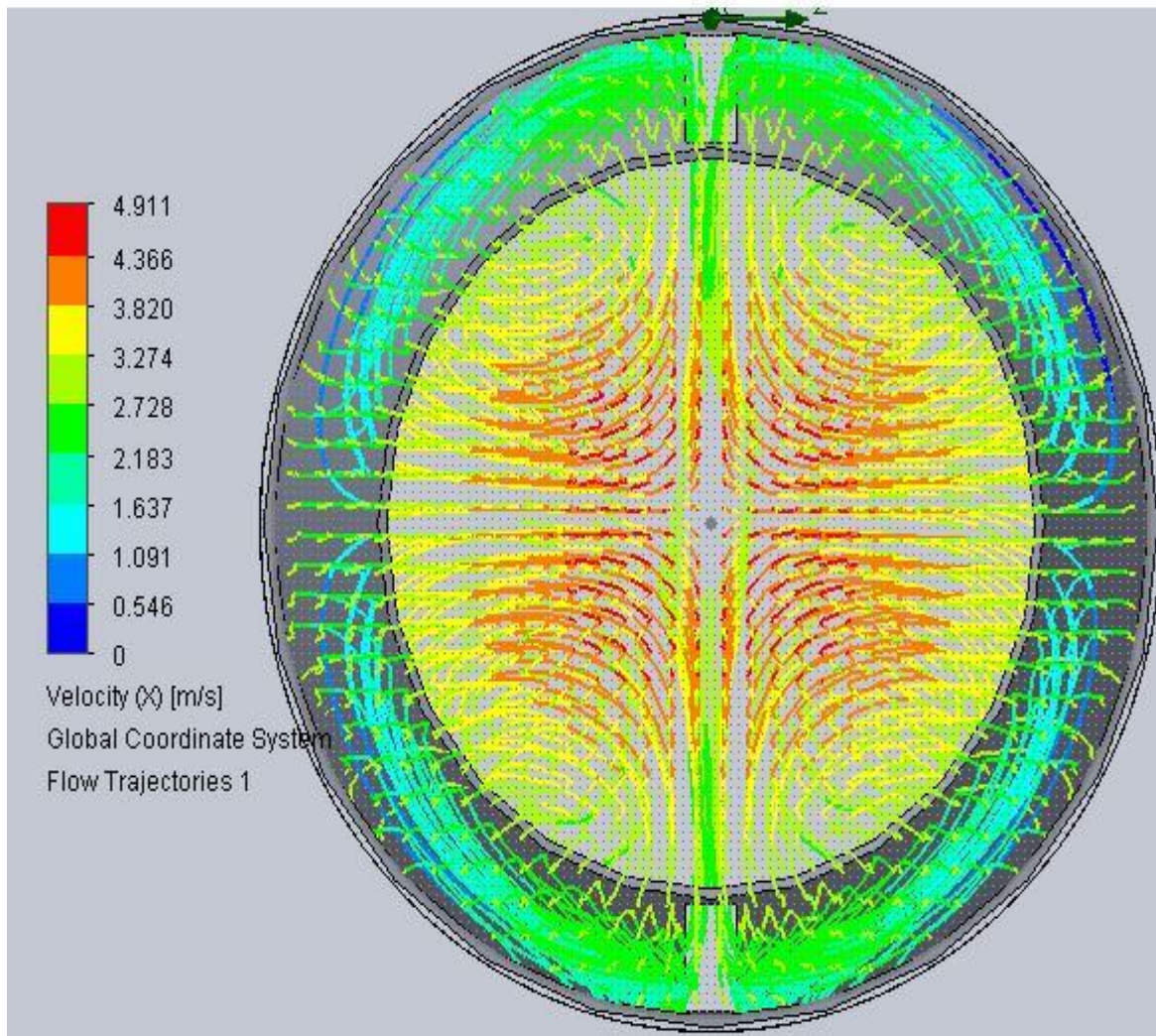

Fig. 2 Streamlines generated by 2 slits form two multi-longitudinal vortex pairs.

The number of vortex pairs is equal to the number of slits on the cone, these causes a mixture of inner core and near wall fluid which enhances heat transfer.

VI.   GRAPHICAL REPRESENTATION OF THE RESULTS

A.   Variation of Pressure

Results are obtained using a 4m long tube of internal radius 0.05m, to compare what happens when there is no conical ring insert and if one is placed in the tube a distance 3.5m from the entrance. Thereafter different DCR inserts are used by having four different cases i.e. with no slit, one, two and three slits. Pressure variation is observed at $i = 0$ which is the centre line of our pipe.

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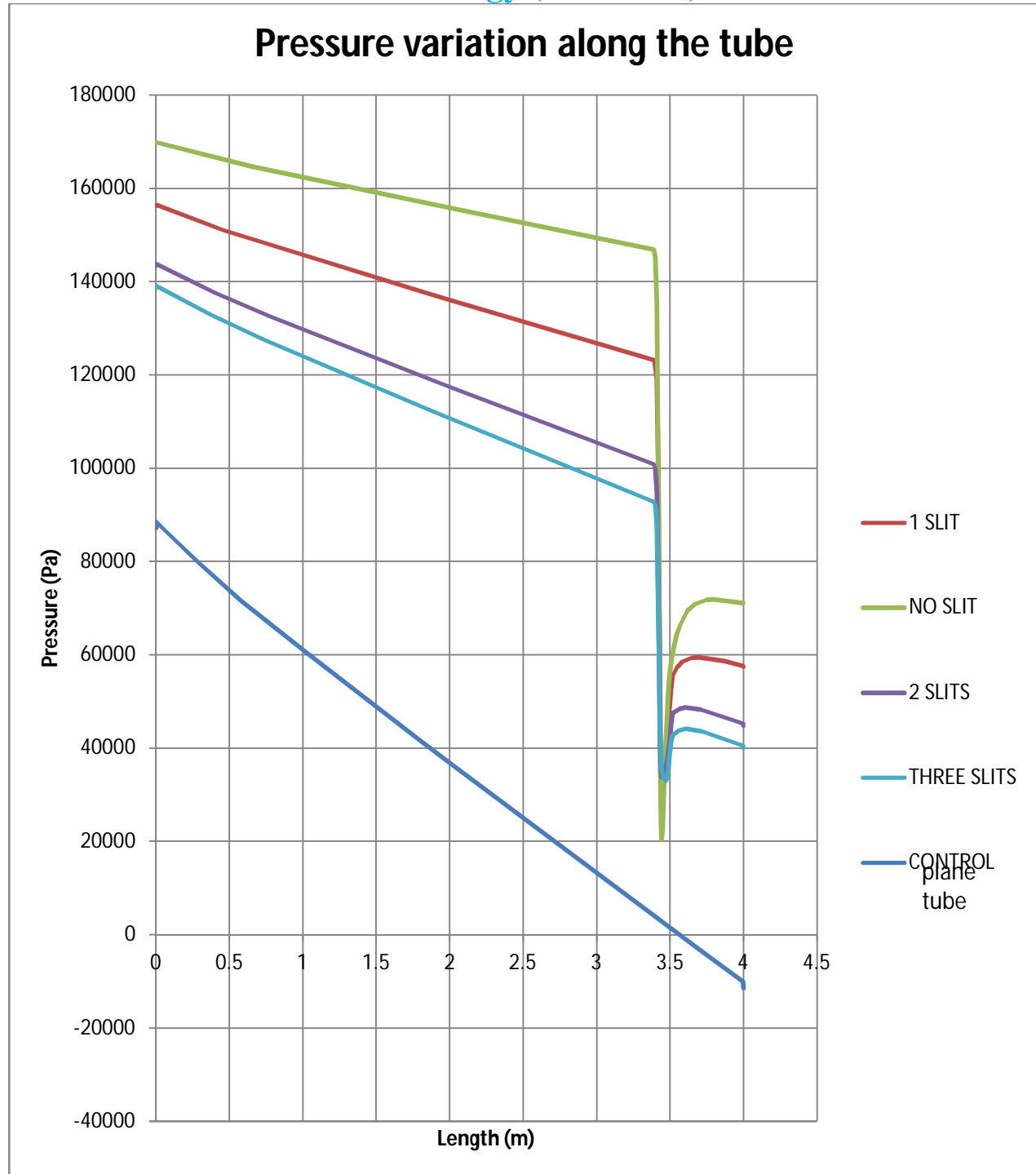

Figure 3: Pressure drop due to an insert placed in a plane tube.

A consistent pressure drop is observed in the four different cases with a DCR insert although a higher-pressure gradient is noted as the number of slits increases.

B.   Variation of Temperature along the Tube.
Temperature of the fluid along a tube is determined for the different set ups to compare the effect due to number of slits on heat enhancement.

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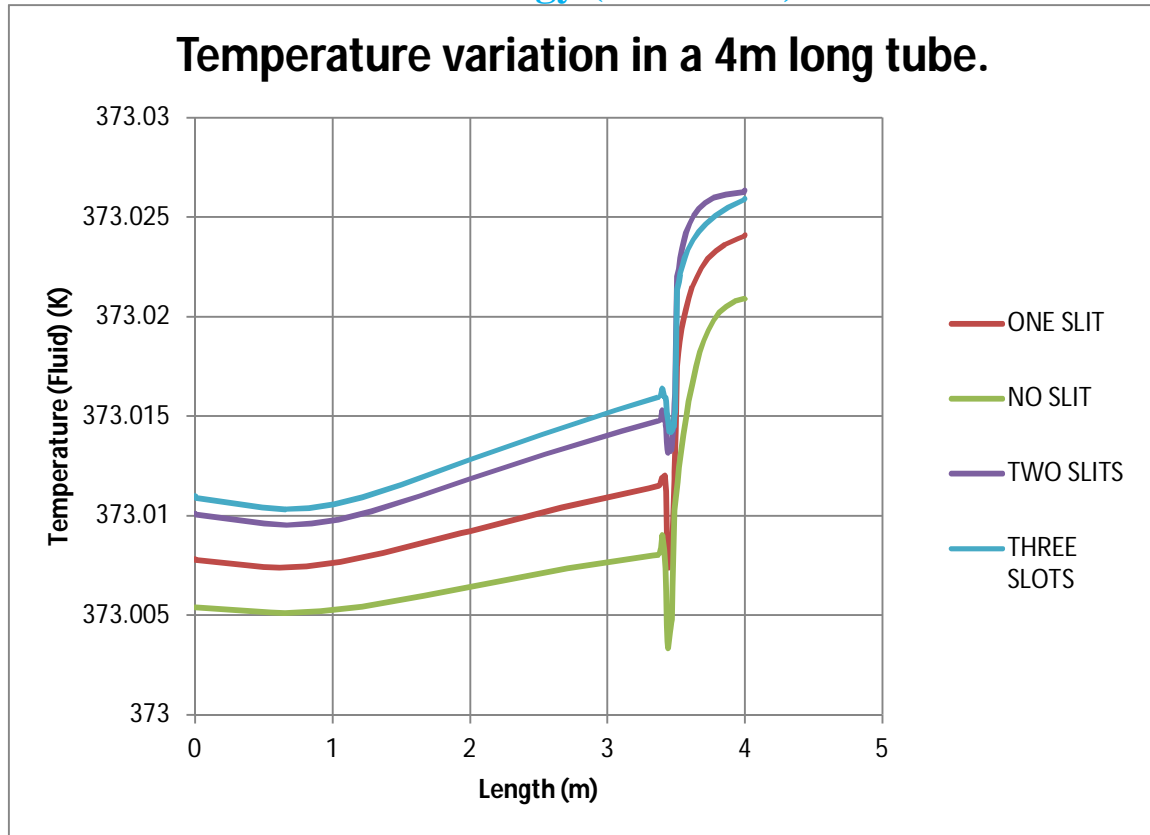

Figure 4: Effect of number of slits on heat transfer enhancement.

It is observed that after the pressure drop temperature in the case where DCR insert has two slits attains the highest temperature at the tube's outlet.

Number of slits on a DCR	0	1	2	3
$\Delta T = T_{outlet} - T_{inlet}$	0.015356	0.016099	0.016128	0.014882

Obtaining the temperature difference between the inlet and outlet we realize that heat gain for the 2 slit on a DCR is greatest among the different set ups.

VII.   DETERMINATION OF THERMAL PERFORMANCE FACTOR

The overall heat enhancement factor for a plane tube fitted with a DCR insert is obtained analytically by obtaining several non dimensional factors. If hot water is used as the test fluid then the physical properties can be taken as follows: Inlet temperature T_0=370K, Tube inlet pressure P_0 = 110 000 Pa, while the tube outlet pressure is $P_{out\ let}$ =101 330Pa =1 atm, maximum velocity v= 4 m/s at the insert inlet, Density of water at 100^0c ρ = 957.9kg/m^3. Specific heat at constant pressure C_p= 4217kJ/Kg.K, Thermal conductivity k=0.679W/m.k , coefficient of Dynamic viscosity μ =2.82X10^{-4}Kg/m.s.

Using the tube's inner diameter =0.05m and fluid flow velocity = 3.5m/s. Mass flow rate (Kg/s) is the product of density (Kg/m^3),

tube's cross sectional area (m^2) and fluid flow velocity then $\overset{\circ}{m} = \rho A v = 957.9 \times \pi \left(\dfrac{0.05}{2}\right)^2 \times 3.5 = 6.5829$ Kg/s at the tubes

inlet. When the fluid encounters the DCR with a smaller radius, a higher pressure drop is experienced and a rise in fluid velocity. Heat transfer rate in a tube bearing a DCR with no slits is

Q= $\overset{\circ}{m}$ C$_p$(T$_{out\ let}$−T$_{in\ let}$)=6.5829X 4217(373.0207-373.0054)= 424.7294 J/s.

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Heat transfer coefficient in a tube bearing DCR insert with no slits is

$$h_{DCR0s} = \frac{Q}{\pi D L \Delta T} = \frac{424.7294}{\pi \times 0.0360 \times 4(0.0153)} = 61{,}363.2748$$

In a tube bearing a DCR with two slits an approximate increase in inlet area at 2.5×10^{-5} m^2 per slit, i.e length x width at 0.005m x 0.005m. Then a DCR with two slits as an equivalent inlet diameter of 0.0364m therefore heat transfer rate is

$Q = \overset{\circ}{m} C_p(T_{out\ let} - T_{in\ let}) = 6.5829 \times 4217 \times (373.0262 - 373.0101) = 444.1614$ J/s.

Heat transfer coefficient $h = \frac{Q}{\pi D L \Delta T}$.

For the DCR with 2 slits $h_{DCR2s} = \frac{Q}{\pi D L \Delta T} = \frac{444.1614}{\pi \times 0.0364 \times 4(0.0161)} = 60{,}311.9943$

Thermal performance factor $\eta = \frac{h_{DCR2s}}{h_{DCR0s}} = \frac{60{,}311.9943}{61{,}363.2748} = 0.9828$

In this analysis the wall is non conducting hence flow is adiabatic.

VIII.   CONCLUSION

The investigation has been performed to determine heat transfer enhancement rate for varying number of slits on a common DCR insert with a constant pitch ratio.
The simulation of convection heat transfer in a straight circular tube shows that the two multi-longitudinal vortex pair in the tube is a flow pattern that enhances the heat transfer enormously.

IX.   ACKNOWLEDGEMENTS

A.   *Nomenclature*
1)   Roman Symbol   Quantity

C_P	Specific heat capacity at constant pressure
D	inner diameter of tube, m
d	inlet diameter of the diverging conical insert, m
h	heat transfer coefficient W/m^{2}k
k	thermal conductivity W/mk
L	Axial pitch tube length , m
$\overset{\circ}{m}$	mass flow rate , Kg/s
Nu	Nusselt number
P	pressure, Pa (Nm^{-2})
P_o	pressure at the inlet, Pa (Nm^{-2})
Pr	Prandtl number
Q	convential heat transfer
r	tube radius
T	temperature, K

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U	mean velocity of flow
u_z	axial velocity, m/s

2) Greek Symbols   Quantity

Δ	Small change
α	Half angle at the vertex, rad
μ	Coefficient of dynamic viscosity kg/ms
ρ	Fluid density, kg/m^3
η	Thermal performance factor

3) List of Abbreviations

DCR   Diverging conical ring

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