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Determining coefficient of skin friction on a cylindrical pipe in the presence of a conical turbulator enhancing heat transfer

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***Abstract*— In this study analysis is done on the effect of a fluids skin friction on heat transfer enhancement. The variation in fluid internal friction during flow is due to a diverging conical ring insert placed in a cylindrical pipe to generate multi longitudinal vortex. Using computational fluid dynamics software 'solid works' the values of pressure and horizontal velocity along the pipes centre line are determined. It is noted that the fluids skin friction increases with reduction of Reynolds number, which is affected by the ratio of fluid pressure to the velocity during flow.**

***Index Terms*— Skin friction, Heat transfer enhancement.**

I. INTRODUCTION

Heat transfer enhancement is an active and essential field of research since it increases the effectiveness of heat exchangers. Suitable heat transfer techniques achieve considerable technical advantage in fluid transmission. Heat transfer enhancement methods are categorized into active, passive and compound techniques. A diverging conical ring insert with slits placed in a cylindrical pipe is a passive technique. Passive enhancement of convective heat transfer can be achieved in three ways:

i) Decreasing thermal boundary layer thickness – the enhancing surfaces such as offset fin in compact heat exchanger are adopted.

ii) Increasing interruption in the fluid – inserted devices belong to this type of enhancement where plates are obliquely positioned to an oncoming flow.

iii) Increasing velocity gradient near a heat transfer wall - by inserting a co-axial tube in a pipe it appreciably enhances heat transfer in the fluid flow.

In fixed flow rate the insertion makes velocity gradient near heat transfer wall larger than that without an insert, leading to enhancement of heat transfer. Many researchers focus on whether heat transfer is enhanced and to which degree it is enhanced, while ignoring the increase in flow resistance which sometimes may exceed the degree of heat transfer enhancement. With growing concern about energy saving in heat exchangers which are widely used in the industry, researchers are now devoted to develop heat transfer enhancement units which can work efficiently with low power consumption. Since the overall performance of convective heat transfer is heavily dependent on heat transfer process, great emphasis should be on the process of optimization. The power needed in transmission of an incompressible fluid flow is partly obtained from fluid viscosity reflecting frictional resistance and profile resistance as well as from momentum change.

II. LITERATURE REVIEW

Promvonge and Eiamsa-ard [8] performed an experimental investigation of heat transfer and friction factor characteristics for flow of air through horizontal pipe with and without conical turbulators, using conical rings with three different ratios of the ring to tube diameter (d/D = 0.5, 0.6, 0.7) and for each ratio the rings are placed with three different arrangements such as converging conical ring, diverging conical ring and converging–diverging conical ring. The boundary layer disruption causes a better chaotic mixing between the core and wall region fluid, thus enhancing the convective process. However diverging conical ring provides higher heat transfer and yields higher pressure loss at small Reynolds number than other arrangements. Kongkaitpaiboon [6] investigated experimentally the influences of perforated conical rings on the turbulent convective heat transfer, friction factor and thermal performance factor characteristics. The perforated conical-rings used were of three different pitch ratios (d/D= 4, 6 and 12) and three different numbers of perforated holes (N=4, 6 and 8 holes) and found that the thermal performance factor of all perforated conical-rings arrangements is higher than those of the conical ring over the range studied. The heat transfer rate and friction factor of perforated conical-rings increase with

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decreasing pitch ratio and decreasing number of perforated holes. Shivalingaswamy and Narahari [9] analysed heat transfer enhancement in a tube fitted with circular-ring turbulator (CRT) as reported in a thesis simulated using ANSYS Fluent computational fluid dynamics (CFD) software. Insertion of turbulators in the flow passage is one of the favorable passive heat transfer augmentation techniques due to their advantages of easy fabrication and operation as well as low maintenance. Influence of the diameter ratio and pitch ratio on the heat transfer rate, friction factor and thermal performance factor behaviors was investigated under uniform wall heat flux condition. The CRTs with different diameter ratios (d/D=0.5, 0.6 and 0.7) and pitch ratios (4 and 8) were employed for the Reynolds number ranging between 4000 and 20,000. Over the entire range investigated CRTs propose heat transfer enhancement around 57% to 195% compared to that in the plain tube. Jia et al. [4] proposed the way to enhance convective heat transfer based on minimum power consumption principle and found that it could provide strong theoretical guidance for designing high-efficiency and low resistance heat transfer enhancement units. Karakaya and Durmus [5] devised the conical spring turbulators for three different conical arrangements (converging, diverging and converging diverging) and three different cone angles 30°, 45° and 60° in Reynolds number range of 10000 to 34000. It was found that the best results in terms of heat transfer are respectively diverging, converging diverging and converging arrangements, while the turbulator best results were obtained, for cone angles 30°, 45° and 60°; respectively. Mugambi et al. [7] investigated heat transfer enhancement in a cylindrical pipe with a diverging conical ring insert (DCR), using CFD flow simulation where the DCR insert had slits symmetrical positioned on the slant edges generates multi longitudinal vortices, to obtain the heat transfer enhancement, two slits have the highest rate of heat transfer when compared with a case of zero, one or three slits. Bhuiya et al [3] determined that inserting turbulators with different spacing ratio of 11, 6.4 and 4.2 gives enhancement efficiency with rate more than unity. This indicates that enhancing heat transfer is more than the effect of increasing friction loss with the maximum heat transfer enhancement achieved at 4.2 with rate a 9.8 %. Avinash et. al [1] gives an analysis of heat transfer in pipe with twisted tape inserts to understand the effect of change in pitch of twisted tape on the flow pattern, results at Re 800 and twist ratio 2, 3, 4 and 5 considered and conclude that variation of twist ratio and Re on heat transfer and flow characteristics using twisted tape inserts and also the heat transfer increases with decrease in twist ratio and increase in Re. Hossain, et. al. [3] analyzed heat transfer enhancement in circular tube with and without inserts for laminar flow in the range of Re= 1600~2400 by using COMSOL Multi physics to perform CFD simulation. Here a non-isothermal flow model was considered in which water was taken in the model and copper was considered as material of circular pipe under constant heat flux of 32.087 KW/h. Using governing equation of non-isothermal flow together with continuity equation, the dynamic behavior of the flow was described which transport heat. In the simulation four, six, eight inserts were used for experimental length 800mm and they got highest output temperature 319.28 K for four insert while the output temperature was 307.85 when there was no insert in the tube, also noting that not just increasing the number of inserts will increase the heat transfer but determining specific distance between the inserts also need to be considered.

III. CONICAL RING INSERT WITH SLITS

A conical ring insert with slits to generate multi-longitudinal vortex flow is placed in a cylindrical pipe at a point of detachment. The ratio of an inserts inlet to outlet diameter provides the pitch ratio i.e. d/D. If an angle at the vertex of a conical insert has a divergence half angle of 7.5^0 then an inlet diameter of 0.036 m and outlet diameter of 0.05 m provides a pitch ratio of 0.72 with a horizontal distance of 0.07 m between the inlet and outlet. Figure 1 below show the position of a conical ring insert in the cylindrical tube with two slits on opposite sides.

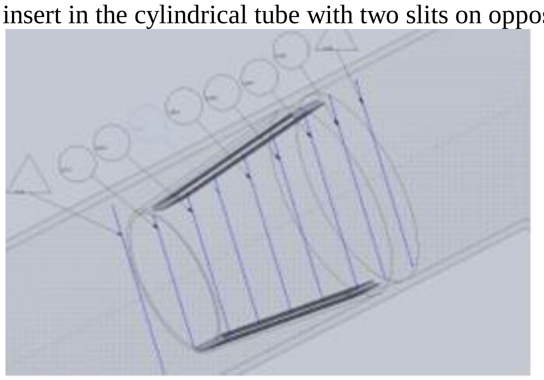

Fig 1. Schematic diagram of a diverging conical ring (DCR) insert with two slits.

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The lines perpendicular to the pipe indicate points along which velocity and pressure of the fluid flow in the pipe are determined. 'Solid works' was used in simulation, which is a design analysis application fully integrated to provide a one screen solution. It is a three dimensional solid modeling package which allows users to develop full models of simulated environment.

IV. COEFFICIENT OF SKIN FRICTION

The fluid friction is a dimensionless quantity that depends on flow velocity, density, viscosity and diameter of the pipe. which similarly determined coefficient of skin friction $C_f = \frac{\tau}{\frac{1}{2}\rho u^2}$. (1)

Where $C_f = \frac{\mu \frac{\partial u_z}{\partial r}}{\frac{1}{2}\rho u^2} = \frac{2\mu\, a}{\rho u^2}$ given that an incompressible fluid of density ρ moving at a horizontal velocity component u_z in a pipe of radius r. The fluid accelerates when passing through the diverging conical ring insert at

$$a = \frac{F}{m} = \frac{F}{\rho\pi r^2 L} = \frac{F}{\rho AL}$$ (2)

Substituting and grouping the terms $C_f = \frac{2\mu}{\rho u^2}\frac{F}{\rho AL} = \frac{\mu}{\rho uL}\frac{2F}{\rho uA} = \frac{1}{\mathrm{Re}}\frac{F}{A}\frac{2}{\rho u} = \frac{2}{\mathrm{Re}\,\rho}\frac{P}{u_z}$

In discrete form the coefficient of skin friction is proportional to the ratio in blankets, that is $C_{f\,i,k} = \frac{2}{\mathrm{Re}\,\rho}\left[\frac{P_{i,k}}{u_{z_{i,k}}}\right]$ (3)

Which compares with fluid flow in a cylindrical pipe whose friction factor is $f = \frac{\Delta P}{\left(\frac{L}{D}\right)\left(\rho\frac{u^2}{2}\right)}$.

(4)

V. SIMULATION OF FLOW

When using hot water the flow parameters are set up as follows, at the pipe inlet axial velocity $u_z = 4m/s$ while at the diverging conical ring insert inlet $u_z = 6m/s$, inlet pressure is P_0 =110,000 Pa and temperature is T_0=370 K. While Reynolds number (Re) satisfies the inequality 1000 < Re < 3000, pressure coefficient (P_C) = 6.5 and Prandtl number (Pr) = 1.75. The thermo physical properties of water at the above temperature and pressure as used in the simulation are; density is 957.9kg/m^3, specific heat (C_p) is 4217kJ/Kg.K, thermal conductivity (k) is 0.679W/m.k, dynamic viscosity is 2.82X10^{-4}Kg/m.s and a volume expansion coefficient is 7.5X10^{-4}k^{-1}. Simulating the fluid flow using a soft ware solid works which reveals that velocity profile before and after a DCR insert is as indicated in figure 2 below showing a rise of velocity within the insert and a flow separation thereafter. Fluid velocity in the DCR insert is illustrated by a colour code with values along the pipe centre line provided in a tabulated form which is given in table 1.

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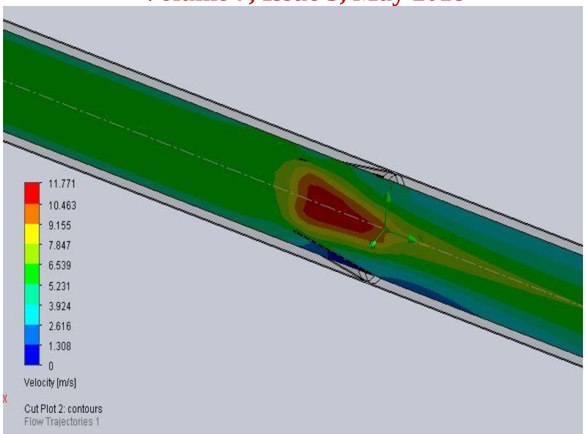

Fig 2: Fluid velocity contours in a pipe with diverging conical ring insert.

In the next part figure 3 presents contour of fluid pressure distribution through the smooth cylindrical pipe with a conical insert. The fluid pressure at the pipe centre line is provided in table 1. The figure below represents fluid pressure distribution through the smooth cylindrical pipe with a DCR insert, with variations shown by colour coding and a key provided indicating the values.

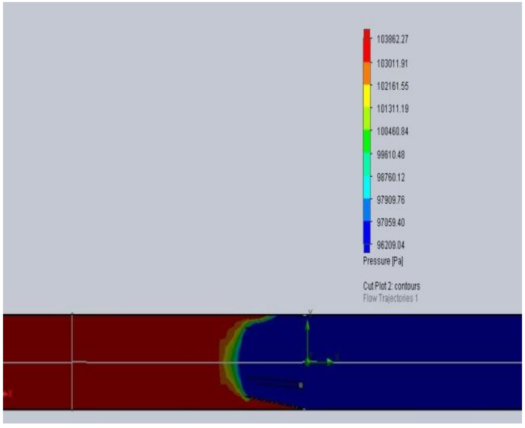

Fig 3: Fluid flow pressure distribution in a pipe with diverging conical ring insert.

The simulation provides horizontal velocity components u_z and pressure P at specific radial distance $r_{i,k}$ along the pipe's centre line. The horizontal components of axial velocities are obtained along the lines marked in figure 1 with plains chosen before fluid enters the DCR insert, when within the insert and after it passes through.

TABLE 1: VARIATION OF HORIZONTAL DISTANCE WITH PRESSURE, HORIZONTAL VELOCITY COMPONENT AND TEMPERATURE ALONG THE PIPE.

Horizontal distance from pipe inlet	Velocity $u_{z_{i,k}}$	Pressure $P_{i,k}$	$\frac{P_{i,k}}{u_{z_{i,k}}}$	Temperature $T_{i,k}$
6.50	6.394	107914.51	16877.4	370.00630
6.55	6.394	107826.91	16863.76	370.00633
6.60	6.394	107739.31	16850.06	370.00637
6.65	6.394	107651.70	16836.36	370.00641
6.70	6.394	107564.11	16822.66	370.00645

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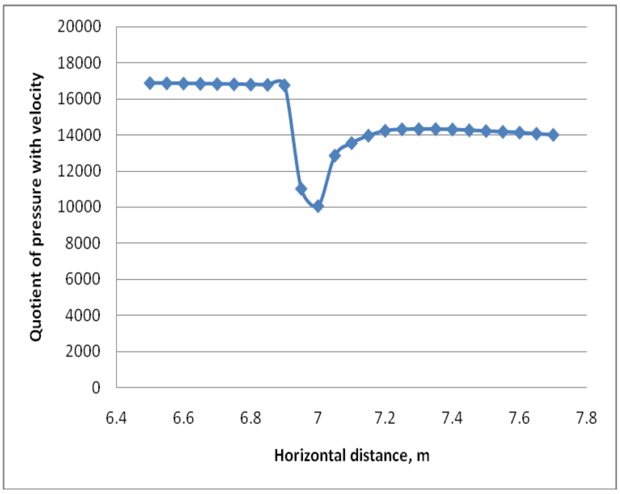
6.75	6.394	107476.49	16808.95	370.00648
6.80	6.395	107388.89	16792.63	370.00652
6.85	6.395	107301.29	16778.93	370.00656
6.90	6.373	107213.69	16759.99	370.00664
6.95	8.501	93609.95	11011.64	370.00643
7.00	8.338	83779.35	10047.89	370.00534
7.05	6.738	86570.29	12848.07	370.00972
7.10	6.418	86936.02	13545.65	370.01005
7.15	6.233	87011.55	13959.82	370.01030
7.20	6.104	86867.07	14231.17	370.01060
7.25	6.059	86722.6	14313.02	370.01065
7.30	6.046	86578.13	14319.9	370.01070
7.35	6.033	86433.65	14326.81	370.01075
7.40	6.030	86244.64	14302.59	370.01080
7.45	6.035	86055.63	14259.42	370.01085
7.50	6.040	85866.61	14216.32	370.01090
7.55	6.045	85677.60	14173.3	370.01095
7.60	6.051	85488.59	14128.01	370.01100
7.65	6.064	85299.58	14066.55	370.01101
7.70	6.078	85110.57	14003.05	370.01101

VI. RESULTS

Plotting the horizontal distance in the cylindrical pipe against a quotient of pressure divided by horizontal velocity a graph is obtained as shown below in graph 1. The analysis is done from a distance of 6.5m to avoid the hydrodynamic entrance region effect, where viscous shearing forces are felt. The part beyond an entrance region has velocity profile fully developed and remains unchanged with the temperature remaining constant.



GRAPH 1: A QUOTIENT OF PRESSURE WITH HORIZONTAL VELOCITY COMPONENT AGAINST HORIZONTAL DISTANCE

This observation describes the variation of skin friction along the pipe in presence of a turbulator. An abrupt change of velocity and a drop in pressure are noted at the point where a DCR insert is placed on the pipe, which also generates the heat transfer enhancement. With the quotient considered to have stabilized at 14,000 then the coefficient of skin friction is determined on a range of Reynolds number as tabulated in table 2 below.

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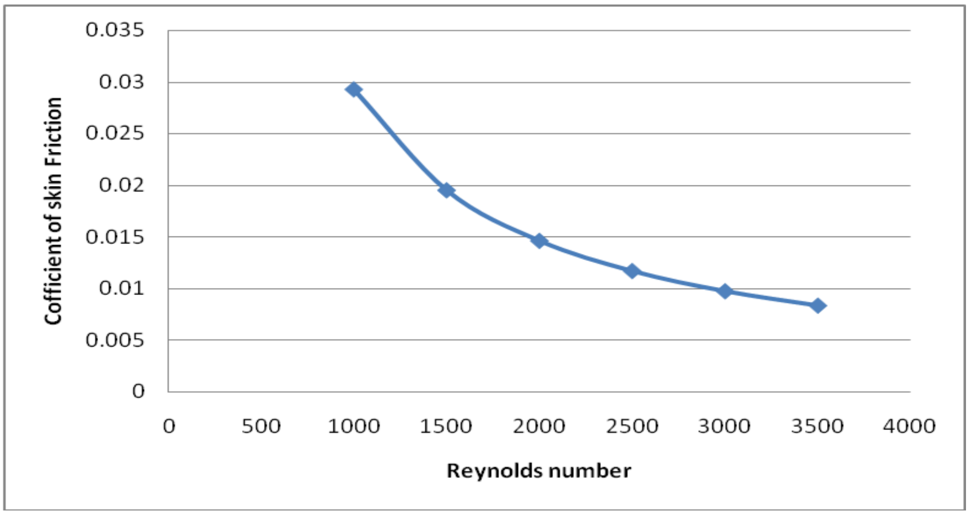
TABLE 2: VARIATION OF REYNOLDS NUMBER WITH COEFFICIENT OF SKIN FRICTION.

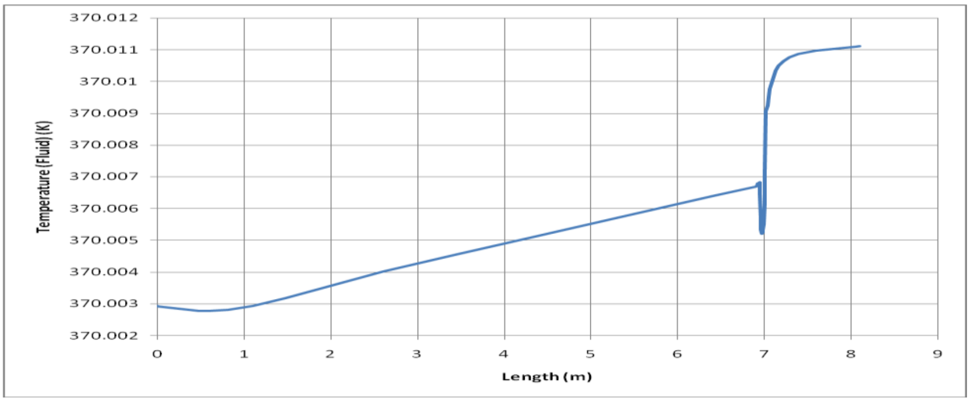
Reynolds number (Re)	Re ρ	Coefficient of Skin friction (C_f)
1000	957,900	0.02923
1500	1,436,850	0.01948
2000	1,915,800	0.01461
2500	2,394,750	0.01169
3000	2,873,700	0.00974
3500	3,352,650	0.00835

From equation 3 the coefficient of skin friction is determined and using values in table 1, which provide comparison of Reynolds number to skin friction to give the relationship shown in graph 2 below.



GRAPH 2: COEFFICIENT OF SKIN FRICTION AGAINST REYNOLDS NUMBER

The fluids coefficient of skin friction reduces with increase in Reynolds number or decreasing value of the quotient between fluid pressure to horizontal velocity component.



GRAPH 3: TEMPERATURE VARIATION ALONG THE CYLINDRICAL PIPE

Swirl flow created by placement of the DCR insert with slits in symmetrical positions helps in decreasing the boundary layer thickness of fluid flow and increases the residence time in the pipe. This increases the fluids internal friction leading to enhancement of heat transfer.

VII. RECOMMENDATION

Determining the coefficient of skin friction will enable establishment of which insert design in a cylindrical pipe will have the highest heat transfer enhancement with minimum energy required to have the fluid flow through the turbulator.

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NOMECLATURE

ROMAN SYMBOL	QUANTITY
A	Tube inner cross sectional area, m^2
a	acceleration, m/s^2
C_f	Skin friction
D	inner diameter of tube, m
d	inlet diameter of diverging conical insert, m
f	friction factor
F	Force, $kgms^{-2}$
$...k-1, k, k+1...$	Counters of discrete points
L	Axial pitch length, m
m	mass, kg
P	pressure, Pa (Nm^{-2})
Re	Reynolds number
r	radial distance in the tube , m.
T	temperature, K
u_z	axial fluid velocity, m/s

GREEK SYMBOLS	QUANTITY
Δ	Small change
ρ	Fluid density, kg/m^3
π	Pi $\cong$ 3.1415926
τ	Shear stress
μ	Coefficient of dynamic fluid viscosity kg/ms

LIST OF ABBREVIATIONS

CRT	Circular ring turbulator
CFD	Computational fluid dynamics
DCR	Diverging conical ring

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