Heat Transfer and Friction Factor Analysis of Turbulent Flow through a Circular Tube Having Vortex Generator Inserts: A Review

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Abstract

Air is used as the working fluid and local heat transfer measurements for both smooth and rough surface sides of the tube are reported for fully developed turbulent flow with Reynolds number (Re) varying between 10,000 and 45,000. Empirical correlations are developed for Nusselt Number and friction factor in terms of Reynolds number (Re), pitch to projected length ratio (p/pl), height to tube inner diameter ratio (e/d) and angle of attack (a).

Keywords
Heat transfer enhancement, Vortex generators, Local Nusselt number, Turbulent flow,Circular pipe.

1 INTRODUCTION

The heat transfer performance of conventional heat exchanger devices can be substantially improved by a number of heat transfer enhancement techniques. Passive techniques for increasing heat transfer coefficients use different types of obstructions which disturb the flow. In the current work the heat transfer performance of a different type of insert based on curved delta wing vortex generators is reported but a brief review of the existing inserts is presented for the sake of completeness.

2 CLASSIFICATION OF TECHNIQUES USED IN HEAT TRANSFER ENHANCEMENT

These techniques are basically divided in to three categories: active method, passive methods and compound method.

2.1 Active Method

This method involves some external power input for the enhancement of heat transfer. Some examples of active methods include induced pulsation by cams and reciprocating plungers, the use of a magnetic field to disturb the seeded light particles in a flowing stream, mechanicals aids, surface vibration, fluid vibration, electro- static fields, suction or injection and jet impingement requires an external activator/power supply to bring about the enhancement [1].

2.2 Passive Method

This method generally uses surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. For example, inserts extra component, swirl flow devices, treated surface, rough surfaces, extended surfaces, displaced enhancement devices, coiled tubes, surface tension devices and additives for fluids [2].

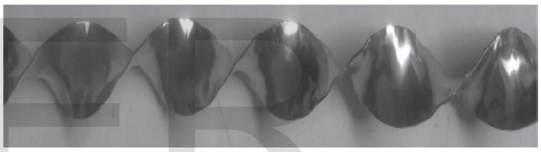


Fig. 1 the typical twisted tape[10]

2.3 Compound Method

Combination of the above two methods, such as rough surface with twisted tape swirl flow device,or rough surface with fluid vibration, rough surface with twisted tapes [3].

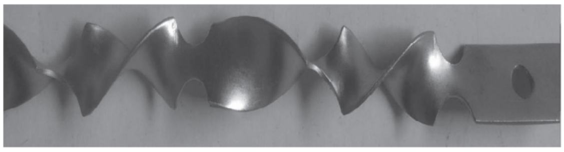
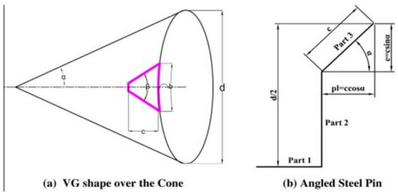


Fig. 2 the ACCT tape[9]

3 GEOMETRIC DETAILS OF VORTEX GENERATOR INSERT

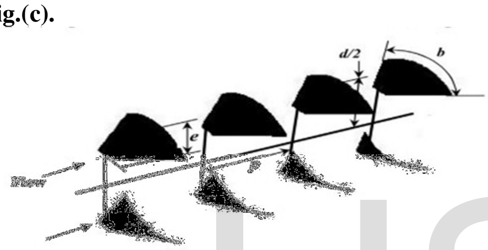
In **Fig.(a)** 0.5 mm thick aluminum sheet was bent in the form of a hollow cone having included angle equal to twice the desired angle of attack of vortex generator. The curved triangular shaped vortex generator with base ‘b’, included angle ‘b’ and length ‘c’ was cut from this cone.



(a) VG shape over the Cone (b) Angled Steel Pin [8]

A 1 mm diameter steel pin as shown in **Fig.(b),** was bent such that it has three parts, lying in a single plane. The first part is horizontal, the second part is perpendicular to first and third part is at an angle 'a' equal to desired angle of attack, to the first part.

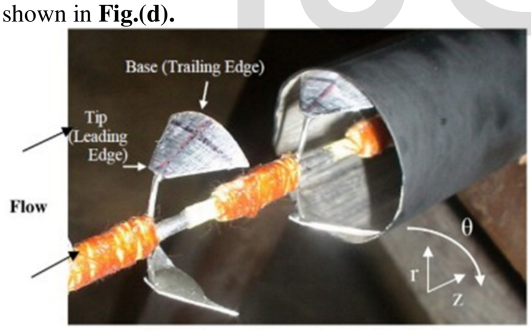
The delta wing shaped curved vortex generator was then glued to the third part in a manner such that the projected area of the curved vortex generator on a plane normal to that containing the steel pin is maximum. These steel pins were periodically glued on a 2 mm diameter rod to make the required insert as shown in **Fig.(c).**



(c) Vortex Generator Insert

[8]

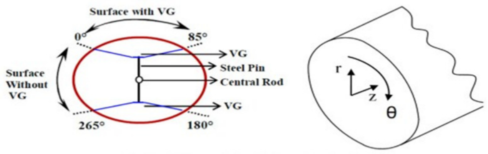
A photograph of the insert being inserted into the tube is shown in **Fig.(d).**



(d) Picture of Insert with the Tube

[8]

The end view of the tube with the insert along with the circumferential and flow directions, h, z respectively are shown in the **Fig.(e).**



(e) End View of the Tube with the Insert [8]

NOMENCLATURE

Symbol & Meaning

A inside surface area of test section (pdL) (m2)
b base of vortex generator (refer Fig.a) (m)
c vortex generator length (refer Fig.a) (m)
DP pressure drop of fluid (N/m2)
d inside diameter of test section (m)
e height of vortex generator (e = c sina) (m)
k thermal conductivity of the material (W/m K)
L heated length of test section (m)
l length of the tube between the pressure taps (m)
m mass flow rate of fluid (kg/s)
p pitch of vortex generator (refer Fig.c) (m)
pl projected length of vortex generator (pl = c cosa) (m)
T temperature (K)

Greek symbols

a angle of attack, degrees for vortex generators,
a = a sin (e/c) and helix angle for helical wire coil
K vortex generator aspect ratio, K = 2 b/c (refer Fig.a)

Dimensionless parameters

Re Reynolds number,
R3 Nusselt number ratio at equal pumping power
Pr Prandtl number,
f average friction factor
Nu local/average Nusselt number
p/pl ratio of pitch to projected length of vortex generator
e/d ratio of vortex generator height to inside diameter of tube

4 BRIEF DESCRIPTION OF REVIEW OF WORK:

Garcia et al. [4] studied the thermo-hydraulic behavior of different configurations of helical wire coil inserts in the laminar, transition and turbulent flow regimes.

Shivashanmugam et al. [5], Eiamsa-ard et al. [6] reported the use of a different type of insert called the helical screw tape insert.These inserts have a twisted tape wound on a central rod which gives the flow a screw like churning motion. The performance ratio, at constant pumping power was reported to reduce from 2.0 to 1.5 when the Reynolds number increased from 5000 to 13,000.

Liu et al. [7] observed the various passive heat transfer enhancement choices available in the literature. They indicated that the twisted tape inserts perform better in laminar flow conditions whereas wire coil inserts perform better in turbulent flow. Discrete vortex generators have been reported for square and rectangular geometries for heat transfer enhancement.

Feibig et al. [8] reported heat transfer and drag measurements using delta wing type of longitudinal vortex generators for rectangular channel flow. They concluded that Nusselt number enhancement Nua/ Nus is a function of the vortex generator aspect ratio, K, angle of attack, a, and Reynolds number, Re. A higher angle of attack a and aspect ratio, K results in enhancement in both heat transfer and pressure drop.

5 CORRELATIONS USED AND GRAPHICAL REPRESENTATION:

Empirical correlations for Nusselt number Nu, friction factor f, have been developed for tubes with vortex generator inserts for Reynolds number range between 10,000 and 45,000, angle of attack a between 15_ and 45_ i.e. e/d ratio 0.09–0.25, p/pl ratio of 1.4–7.9 for aspect ratio, K of 3.8

Nu=0.46Re^(0.77)*(p/pl)^(-0.17)*(e/d)^(0.79)*(0.125-(e/d)^2)^(0.125) (1)

f=0.77Re^(-0.14)*(p/pl)^-(0.59)*(e/d)^(1.22)*(0.125-(e/d)^2)^0.7 (2)

Below Figs. A and B show comparison between the predicted experimentaldata and the present predictions by the Eqs. (1) and (2) above. In the figures, calculations using the present correlations agree reasonably (within}20%) with experimental data for the friction factor and Nusselt number.

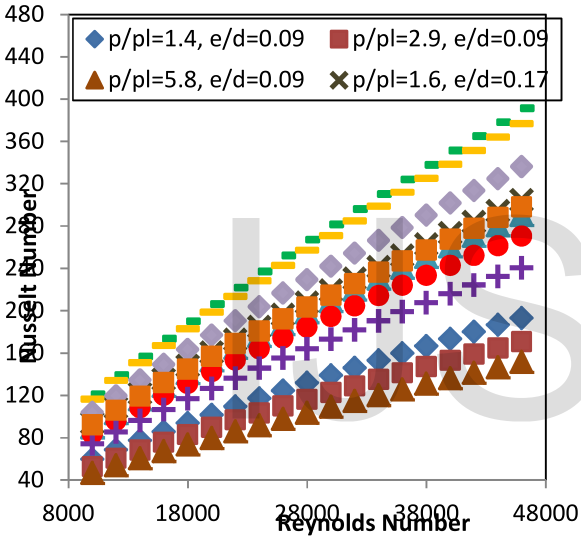


Figure A

6 CONCLUSION

Vortex generator inserts of almost all the configurations show Nusselt number values about 150–500% higher than the corresponding smooth tube values. The inserts with e/d = 0.25, p/pl = 1.6, a = 45 degree and e/d = 0.17, p/pl = 2.1, a = 30degree, were observed to produce the best enhancement at constant pumping power. The average heat transfer enhancement for the surface with vortex generators is found to be much higher than that for the surface without vortex generators. In general, the average heat transfer characteristics of the vortex generator insert are found to be superior to the conventional helical wire coil insert.

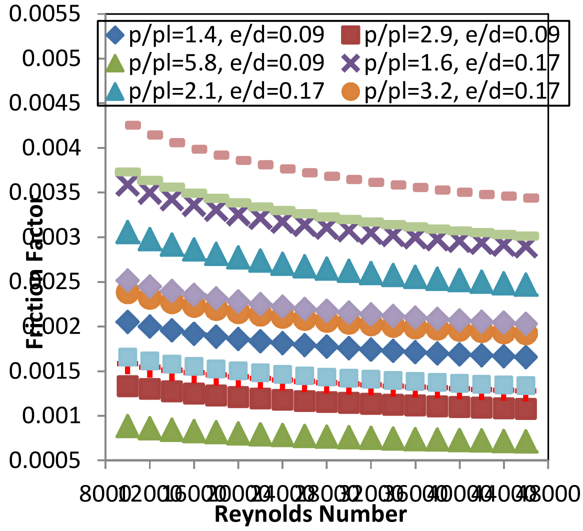


Figure B

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