A Review on Heat Transfer and Fluid Flow within U-pipe and Bend Pipe

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Abstract—This paper focuses on extensive literature review in the field of heat transfer and fluid flow within the U pipe or bends Pipe. Several researchers have examined the fluid flow characteristics experimentally as well as computationally. Pipes are extensive been used in various application from day to day life to various engineering marvels. Within the pipe when fluid flows, due to friction various losses takes place which affects the hydrodynamics as well as thermo hydrodynamics performance.

At turbulent flow, the flow within these bend pipes have high significance in terms of secondary flow or flow separation. Researcher examined these flow characteristics and developed various empirical correlations which are particularly been used in exploring other engineering application.

Keywords—Fins, Heat Sink, CFD, Convection

I. INTRODUCTION

Usage of Curve or bend pipe are widely been used in various engineering application with the purpose of taking advantage of secondary flow and flow separation. As these secondary flows offers a mechanism for enhancing the mixing and heat or mass transfer without the need for moving parts, curved ducts are now necessary components of many industrial processes.

In bend pipes/Ducts due to local imbalance among pressure gradient and inertial forces, the flow is characterized as a secondary flow/circulation. It is mainly depend up on the curvature of the pipe which is being a characteristic length of pipe/duct cross section, for instance the radius or hydraulic radius, and c the radius of curvature. Boussinesq forecasted the presence of two symmetric secondary roll cells by acknowledging the mechanisms that drives this secondary flow. Dean developed the power series solution for the main (axial) velocity and the stream function of the secondary motion under the hypothesis of laminar stationary flow and small curvature, moreover, as per his analysis a governing parameter appeared, is now referred as Dean number, De= Reθ, which accounts for viscous, inertial and centrifugal effects. The characteristics of the secondary flow/circulation depend not only on Reynolds number and diameter, but also on the shape and size of the duct's cross section. In developing flows, e.g. in the entrance region between a straight duct and a bend, they depend also on the distance from the curve entry.

II. MATHEMATICAL MODELING

For the fluid flow through pipe, duct and channel the conventional governing equations are the Navier–Stokes equations can be written in the most useful form for the development of the finite volume method:

\[
\rho \frac{D\text{u}}{Dt} = -\frac{\partial p}{\partial x} + \text{div} (\mu \text{grad}\text{u}) + S_{\text{vis}}
\]

(1)

\[
\rho \frac{D\text{v}}{Dt} = -\frac{\partial p}{\partial y} + \text{div} (\mu \text{grad}\text{v}) + S_{\text{vis}}
\]

(2)

\[
\rho \frac{D\text{w}}{Dt} = -\frac{\partial p}{\partial z} + \text{div} (\mu \text{grad}\text{w}) + S_{\text{vis}}
\]

(3)
Governing equations of the flow of a compressible Newtonian fluid

**Continuity**
\[
\frac{\partial \rho}{\partial t} + \text{div}(\rho u) = 0
\]

**x-momentum**
\[
\frac{\partial (\rho u)}{\partial x} + \text{div}(\rho uu) = -\frac{\partial \rho}{\partial x} + \text{div}(\mu \text{grad}u) + S_{ux}
\]

**y-momentum**
\[
\frac{\partial (\rho v)}{\partial y} + \text{div}(\rho vv) = -\frac{\partial \rho}{\partial y} + \text{div}(\mu \text{grad}v) + S_{vy}
\]

**z-momentum**
\[
\frac{\partial (\rho w)}{\partial z} + \text{div}(\rho ww) = -\frac{\partial \rho}{\partial z} + \text{div}(\mu \text{grad}w) + S_{wz}
\]

**Energy**
\[
\frac{\partial (\rho \phi)}{\partial t} + \text{div}(\rho u \phi) = -p \text{div}u + \text{div}(k \text{grad}T) + \Phi + S_i
\]

Using various correlation FEV results are been compared analytically
\[
h_L = f \frac{LV^2}{D_s 2g}
\]
Where,
f is the friction factor for fully developed laminar flow
L: length of the channel, duct, pipe
V: mean velocity of the flow
d: diameter of the pipe
f is the friction factor for fully developed laminar flow:
\[
f = \frac{64}{Re} \quad \text{(For } Re < 2000) \quad Re = \frac{\rho u^2 d}{\mu}
\]
\[C_f \text{ is the skin friction coefficient or Fanning’s friction factor.}
\]
For Hagen-Poiseuille flow:
\[C_f = \frac{1}{2} \rho u^2 d = \frac{16}{Re}
\]
For turbulent flow:
\[
C_f = \frac{1}{\sqrt{f}} = 1.74 - 2.0 \log_{10} \left[ \frac{\varepsilon_p}{R} + \frac{18.7}{Re^{0.16}} \right] \quad \text{Moody’s Chart}
\]
R: radius of the channel, duct, pipe
\[\varepsilon_p: \text{degree of roughness (for smooth channel, duct, pipe, } \varepsilon_p=0)\]
Re \(\rightarrow\) \(\infty\): Completely rough channel, duct, pipe.

### III. LITERATURE REVIEW

Sumesh et al. 2017 examine the bend cross section with having ovality and thinning for 90o bend pipe with having crack. The crack has been considered due to structural distortion. The effect of ovality has been examined on cracked pipe bend with elliptic cross sections. Finite element analysis was conducted based on elastic-perfectly-plastic material considering geometric nonlinearity and twice-elastic-slope method was used to obtain collapse loads for each model.
Li et al. 2017 performed a plastic collapse load analysis for un-cracked and circumferential through-wall cracked pipe bends under torsion moment by three dimensional FE methods considering geometric nonlinearity. Results show that pipe parameters bend radius-to-radius and crack length have little impact on the weakening parameter, however radius-to-thickness have an obvious impact on the weakening parameter, which increases with decreasing weakening parameter. Results also show that radius-to-thickness has a great impact on the ovality deformation, while bend radius-to-radius hasn't. Therefore geometry effect is significant for a high yield strain value and a high radius-to-thickness value.

Bhusan et al. 2017 numerically examine the flow and heat transfer characteristics in 180 bend pipe with having flow of water-fly ash slurry. In their work they considered RNG k-ε turbulence model. The pressure drop and heat transfer has been examined for multiphase flow using finite volume
approach. The results indicate that for pipe bend the heat transfer coefficient for smaller radius ratio is 53.28% more than the larger radius ratio for the solid concentration of 10% and velocity of 1 m/s. Its value increases with increase in the particle concentration and velocity due to the presence of a secondary flow in the bends.

![Figure 3. Distribution of velocity at different angular positions, 5D, 10D distances from the bend outlet and pipe outlet of U bend [3](image)](image)

Chen et al. 2016 experimentally studied the ratcheting behavior of austenitic stainless steel Z2CND18.12N elbow pipe. An exclusive comparison has been drawn between isotropic hardening rule and without isotropic hardening rule to examine the ratcheting strain. Using FEA the Ratcheting boundary has been determined for both the cases. The result shows that the OW II model with isotropic hardening rule is slightly better than those without isotropic hardening rule.

![Figure 4. Experimental setup and comparison of Ratcheting strain [4](image)](image)

Ravi et al. 2017 evaluated the friction factor, effectiveness and heat transfer characteristics of Nano fluid flow (Fe₃O₄) in an inner tube of double pipe U-bend heat exchanger with and without longitudinal strip inserts. During analysis wide range of Reynolds number has been considered in their study i.e.15000 to 30000 along with three different volume concentrations of Nano-fluid. The results show that the Nusselt number on the nanofluid side increases with increasing Reynolds number and particle concentration, and with decreasing aspect ratio of the longitudinal strip inserts.
Janyanti et al 1993 performed CFD analysis to examine the Gas-particle motion in 90° and 180° circular cross-section pipe bends. They found that the secondary flow induced in the gas phase due to curvature affects the motion of the particles which causes the smaller particles to come out of the bend without deposition.

Dominski and Hermes 2006 experimentally determined the pressure drop correlation for Two-phase flow of R-22 and R-410A in 180 return bends. Similarly, Pietrzak and Witczak 2013 experimentally established pressure drop correlations are obtained for horizontal, upward, and downward flows in Multiphase flow in 180 U-bends using three flowing media: air, water and oil.
Figure 7. The concentration influence of phases on values of total pressure drops in U-pipe about internal diameter 0.022 m ($\rho_o = 859 \text{ kg/m}^3$, $\eta_o = 20 \text{ mPa}\cdot\text{s}$) [8]

Row 1970 experimentally examined the heat transfer effect in large wavy pipe due to secondary flow which leads to complete interchange of fluid in the wall and the central core line. Their work particularly focuses on single phase flow in various pipe bends like 180 U-bend, 45°/45° S-bend attached to the end of a long straight pipe.

Figure 8. Contours of total pressure in a 180° pipe bend and at various distances (pipe diameters) in a straight section downstream of the bend. The inside of the bend is to the right. Dashed lines show the estimated secondary flow pattern. [9]

Azzola et al.1986 used Laser-Doppler velocimetry measurement to examine the turbulent flow in turbulent flow in an 180 pipe bend. They found that the bend of angle between 90 and X/D = 5 (X and D being the axial distance from the pipe inlet and pipe diameter respectively), the
circumferential velocity profiles display secondary flow reversals which are independent of the Reynolds number

![Figure 9 The test section configuration and definition of coordinate system [10]](image)

IV. CONCLUSIONS

- Increasing in bending angle heat transfer rate increases.
- The flow separation and vortex formation at the bend section plays major role in heat and momentum transfer in bend pipe.
- The rate of turbulence intensity increases as the angle of pipe bend varies.
- On comparing the performance in terms of heat transfer between straight pipe and bend pipe, bend pipe yields better performance.
- The pressure drop at the bend section, is quite complex as compared to straight pipe.
- The wall shear stress at the bend section, i.e. at inner region and at outer region is quite different.
- The inner region experience higher rate of friction and shear stress as compared to the outer region.

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