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Prediction of Pressure Drop for Turbulent Fluid Flow in 90° Bends

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Abstract

The pressure drop for turbulent single-phase fluid flow around sharp 90° pipe bends has proven to be difficult to predict due to the complexity of the flow arising from frictional and separation effects. Existing models accurately predict the frictional effects, but no precise models are available to predict the flow due to separation. It is the purpose of this work to propose a model capable of such prediction. The proposed model is presented and added to an existing model to predict pressure losses over the turbulent Reynolds number range up to 3×10^5 . The predicted data is within a spread of +3% to -2% of existing experimental data. Future work will validate this model experimentally and computationally.

Notation

μ	dynamic viscosity (kg/ms)
ρ	density (kg/m ³)
τ	shear stress at pipe wall (kg/ms ²)
d	pipe diameter (m)
D	pipe bend centreline diameter (m)
De	Dean number
f	friction factor
l_e	equivalent straight pipe length (m)
r	pipe radius (m)
R	pipe bend centreline radius (m)

Re Reynolds number

v velocity (m/s)

Subscripts

A curved pipe

B elbow bend

Flow in pipe bends is characterised by the Dean number De [1], which governs the relative importance of viscous, inertia and curvature terms. The Dean number represents the ratio of the product of the inertia and centrifugal forces to the viscous forces and can be defined in terms of either the centre-line bend radius R or diameter D .

$$De = \left(\frac{dv\rho}{\mu} \right) \left(\frac{r}{R} \right)^{\frac{1}{2}} \quad (1)$$

The pressure drop for the bend can be expressed as either the bend friction factor ϕ_A or the equivalent length of straight pipe l_e .

Essentially, the bend pressure drop can be viewed as the sum of two separate effects. The first is due to the adverse pressure gradient at the outer wall, as the fluid flows around the bend it encounters the pressure gradient, which results in excess friction on the surface of the bend outer wall (Point A, Figure 1). The second effects arises by the flow separating from the pipe wall at the inside surface of the bend (Point B, Figure 1). Due to the geometry of the bend and flow conditions at entry to the bend, secondary flow is set up, which adds significantly to the pressure loss causing a rapid rise in friction as R/d falls and the bend tightens. These two effects are obviously interlinked but normally with the former at A, the flow is fully developed and inlet and outlet tangent effects are absent. The latter effect at B only becomes of practical significance when $R/d < 15$, the actual value falling with the fluid Reynolds number. Above this value of R/d the bend is referred to as a

curved pipe, while below this value of R/d as an elbow bend. Wilson *et al.* [2] has shown that the bend pressure drop, when properly constructed is only marginally dependent on the fluid Re .

In Fig. 2 data are presented for turbulent flow in a 90° bend as a full line [3, 4]. The data are composed of the addition of the pressure loss for the two effects at A and B mentioned above. The curved pipe data at higher R/d values represents effect A and has been shown to follow the models of Ito [3].

$$\phi_A \left[\frac{D}{d} \right]^{0.5} = 0.003625 + 0.038 \left[\text{Re} \left(\frac{d}{D} \right)^2 \right]^{-0.25} \quad (2)$$

and Mori and Nakayama [5].

$$\phi_A \left[\frac{D}{d} \right]^{0.5} = 0.0375 \left[\text{Re} \left(\frac{d}{D} \right)^2 \right]^{-0.2} \left[1 + 0.112 \left[\text{Re} \left(\frac{d}{D} \right)^2 \right]^{-0.2} \right] \quad (3)$$

where

$$\left(\frac{l_e}{d} \right) = 19.8333 \phi_A \text{Re}^{0.25} \left(\frac{D}{d} \right) \quad (4)$$

within $\pm 1\%$. Other models for prediction of pressure loss in curved pipes are available [6 – 15], but not all are as precise in the prediction of accurate data.

In this work it has been found that the effect B of separation at the inner part of the bend can be predicted by the relation

$$\left(\frac{l_e}{d} \right)_B = 22.2126 \left[\text{Re} \left(\frac{d}{D} \right)^2 \right]^{0.7888} \text{Re}^{-0.71438} \quad (5)$$

Equation (5) summed together with equation (2) gave prediction of the bend pressure drop data over the turbulent Re range up to $Re = 3 \times 10^5$ within a spread of $+3\%$ to -2% .

A preliminary CFD (Computational Fluid Dynamics) validation has shown a good correlation with Ito's work on R/d values greater than 10. Future publications will include experimental and CFD validation of the above model.

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Figure Captions

Figure 1 Pipe bend

Figure 2 Variation of pressure loss with the ratio of diameters for a 90° bend at $Re = 10^4$

Figure 1 - Pipe bend

Figure 2 – Variation of pressure loss with the ratio of diameters for a 90° bend at $Re = 10^4$