

Bends, Flow and Pressure Drop in

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Single-Phase Flow

The main feature of flow through a bend is the presence of a radial pressure gradient created by the centrifugal force acting on the fluid. Because of this, the fluid at the center of the pipe moves towards the outer side and comes back along the wall towards the inner side. This creates a double spiral flow field shown schematically in Figure 1. If the bend curvature is strong enough, the adverse

pressure gradient near the outer wall in the bend and near the inner wall just after the bend may lead to flow separation at these points, giving rise to a large increase in pressure losses. Even for fairly large-radius bends, the flow field in the bend will be severely distorted as illustrated by the data of Rowe (1970) shown in Figure 2.

The pressure losses suffered in a bend are caused by both friction and momentum exchanges resulting from a change in the direction of flow. Both these factors depend on the bend angle, the curvature ratio and the Reynolds Number. The overall *pressure drop* can be expressed as the sum of two components: 1) that resulting from friction in a straight pipe of equivalent length which depends mainly on the Reynolds number (and the pipe roughness); and 2) that resulting from losses due to change of direction, normally expressed in terms of a bend-loss coefficient, which depends mainly on the curvature ratio and the bend angle. The pressure loss in a bend can thus be calculated as:

(1)

$$\Delta P = \frac{1}{2} f_s \rho u^2 \frac{\pi R_b}{D} \frac{\theta}{180^\circ} + \frac{1}{2} k_b \rho u^2$$

where f_s is the Moody friction factor in a straight pipe; ρ , the density; u , the mean flow velocity; R_b the bend radius; D , the tube diameter; θ , the bend angle; and k_b , the bend *loss coefficient* obtained from Figure 3. Extensive data on loss coefficient for bends are given by Idelchik (1986).

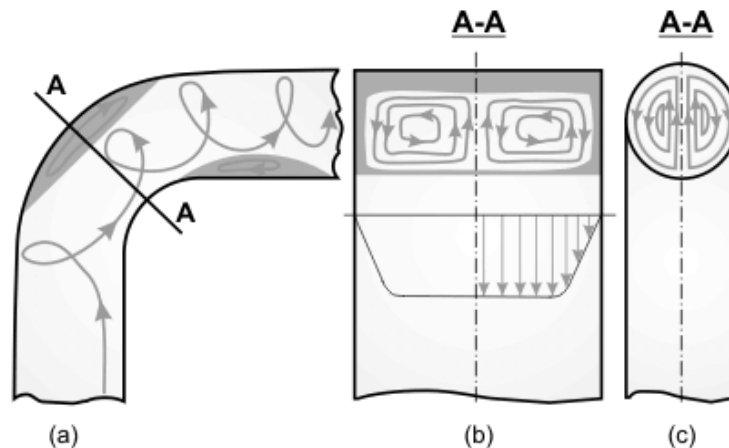


Figure 1. Schematic diagram of a double spiral flow in a bend: a) longitudinal section; b) cross-section (rectangular section); c) cross-section (circular cross-section) (Idelchik, 1986).

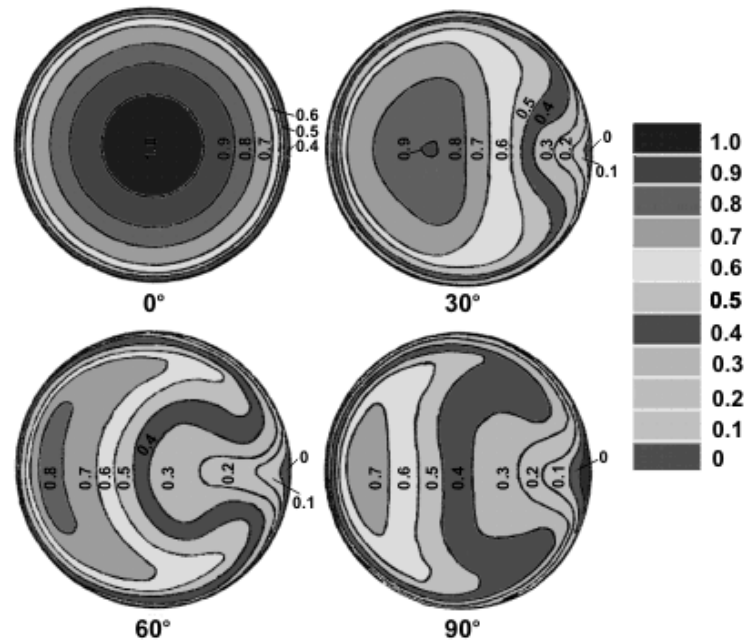


Figure 2. Total pressure contours in a U-bend of a bend-to-pipe diameter ratio of 24; Reynolds number = 236000 (Rowe, 1970).

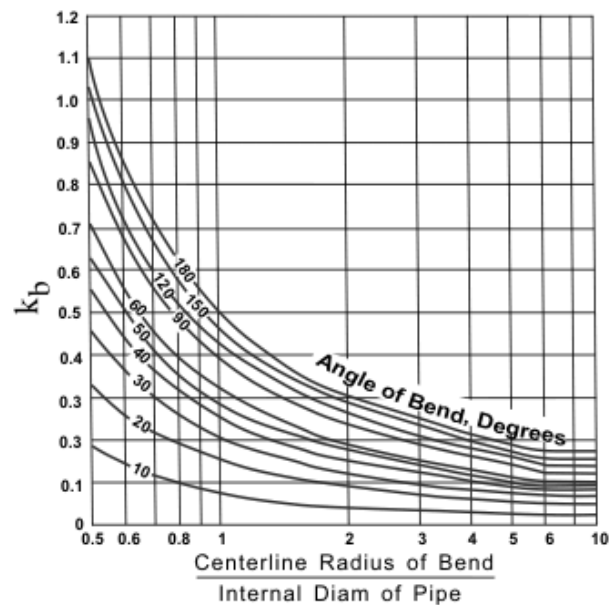


Figure 3. Bend loss coefficients for a pipe (Babcock & Wilcox Co., 1978).

Two-Phase Flow

Two-phase flow in bends is rendered more complex by the centrifugal-force-induced stratification of the two phases. This manifests itself in the migration of

bubbles in bubbly flow towards the inner side of the bend, and more paradoxically, in the migration of the heavier phase towards the inner side in separated flows (a process known as *film inversion*) under certain conditions.

The pressure losses suffered in two-phase flow through bends are influenced by a number of parameters, and no generalized method is available to calculate them accurately. The usual practice is to multiply the single phase pressure losses by a factor known as the *two-phase multiplier*, which is empirically correlated. Chisholm (1980) has examined a number of data sets and proposed the following method:

$$\frac{\Delta p_{TP}}{\Delta p_{LO}} = 1 + \left(\frac{\rho_L}{\rho_G} - 1 \right) \times \left[\left(1 + \frac{2.2}{k_{LO} \left(2 + \frac{R_b}{D} \right)} \right) x(1-x) + x^2 \right], \quad (2)$$

where Δp_{TP} is the pressure drop in two-phase flow, Δp_{LO} is that in a single phase flow of the total mass flux and liquid properties, k_{LO} is the bend loss coefficient for single phase flow, and x is the quality.

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