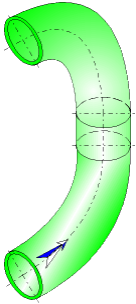




**U-shaped Bends
(with flow in one plane)
Circular Cross-Section
(IDELCHIK)**



Model description:

This model of component calculates the head loss (pressure drop) of U-shaped bends (with flow in one plane) whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized at the entrance bend.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Cross-section area (m²):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Total length measured along the axis (m):

$$l = 2 \cdot \left(2 \cdot \pi \cdot R_0 \cdot \frac{\delta}{360} \right) + l_{el}$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m³):

$$V = F_0 \cdot l$$

Fluid mass (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

$$\bar{\Delta} = \frac{\Delta}{D_h}$$

■ Case of a single bend of relative radius of curvature lower than 3 ($R_0/D_0 < 3$) ([1] diagram 6-1)

Coefficient of effect of the roughness:

$$k_{\Delta} = f\left(\frac{R_0}{D_0}, Re, \bar{\Delta}\right) \quad ([1] \text{ diagram 6-1})$$

- $0.50 \leq R_0/D_0 \leq 0.55$

| $\bar{\Delta}$ | Re | |
|----------------|-------------------------------|---|
| | $3 \cdot 10^3 - 4 \cdot 10^4$ | $> 4 \cdot 10^4$ |
| 0 | 1.0 | 1.0 |
| 0 - 0.001 | 1.0 | $1 + 0.5 \cdot 10^3 \cdot \bar{\Delta}$ |
| > 0.001 | 1.0 | 1.5 |

- $R_0/D_0 > 0.55$

| $\bar{\Delta}$ | Re | | |
|----------------|-------------------------------|-----------------------------------|-------------------------------|
| | $3 \cdot 10^3 - 4 \cdot 10^4$ | $> 4 \cdot 10^4 - 2 \cdot 10^5$ | $> 2 \cdot 10^5$ |
| 0 | 1.0 | 1.0 | 1.0 |
| 0 - 0.001 | 1.0 | $\lambda_{\Delta} / \lambda_{sm}$ | $1 + 10^3 \cdot \bar{\Delta}$ |
| > 0.001 | 1.0 | 2.0 | 2.0 |

with:

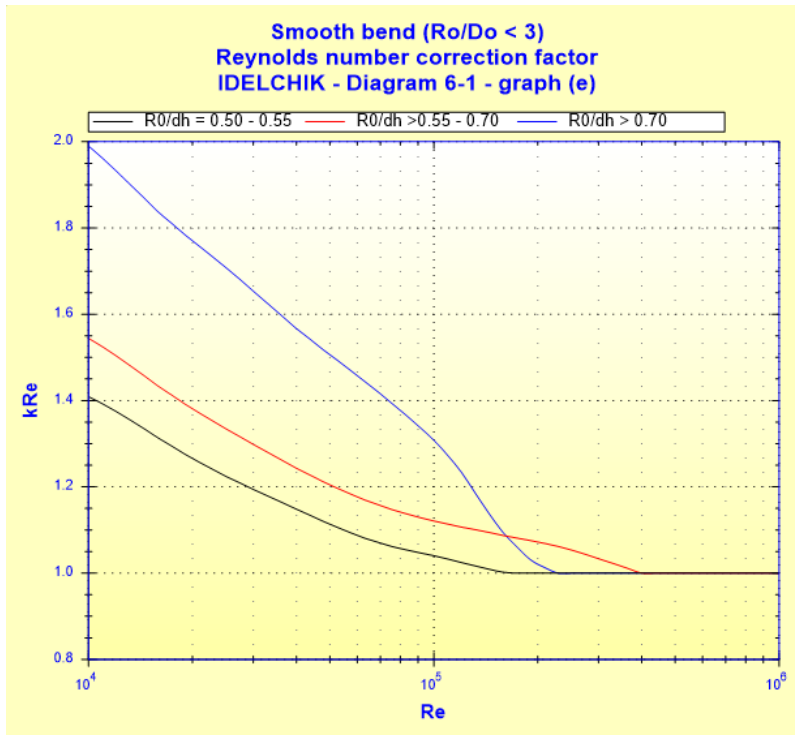
λ_{sm} : Darcy friction factor for hydraulically smooth pipe ($\bar{\Delta} = 0$) at Re

λ_{Δ} : Darcy friction factor for rough pipe ($\bar{\Delta} = \Delta/D_h$) at Re

Coefficient of effect of the Reynolds number ($Re \geq 10^4$):

$$k_{Re} = f\left(\text{Re}, \frac{R_0}{D_h}\right)$$

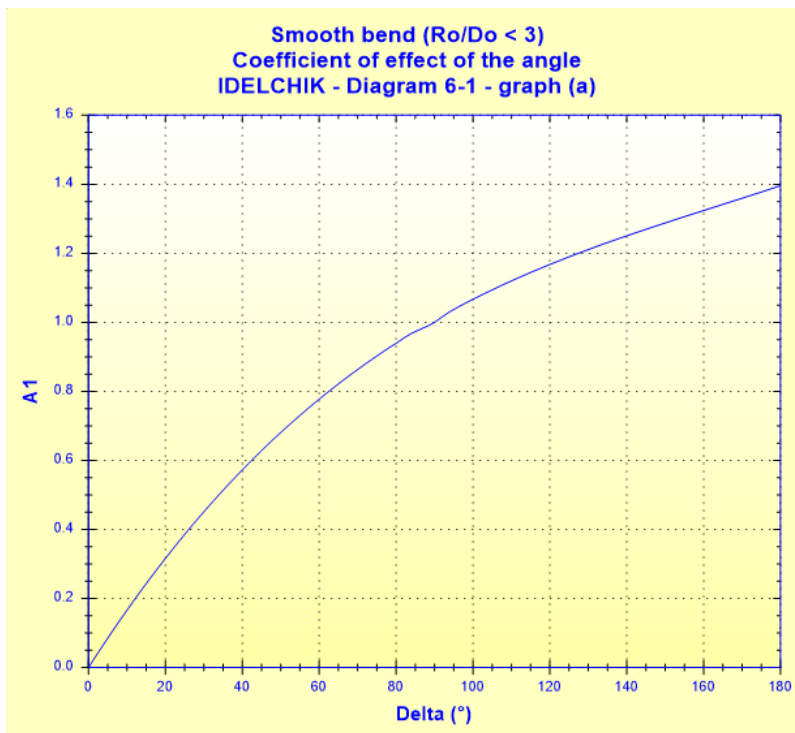
([1] diagram 6-1)



Coefficient of effect of the angle:

$$A1 = f(\delta)$$

([1] diagram 6-1)

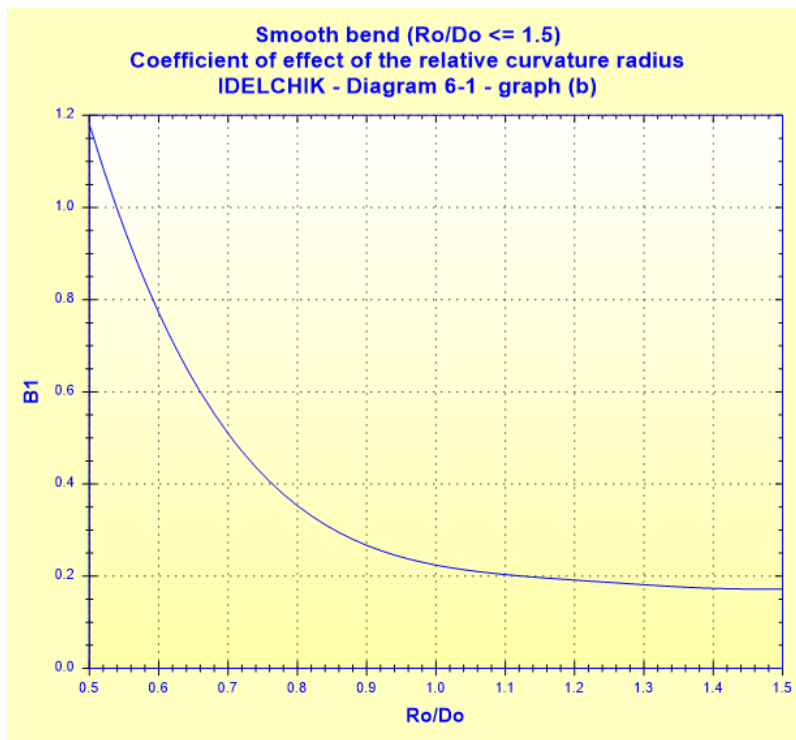


Coefficient of effect of the relative curvature radius:

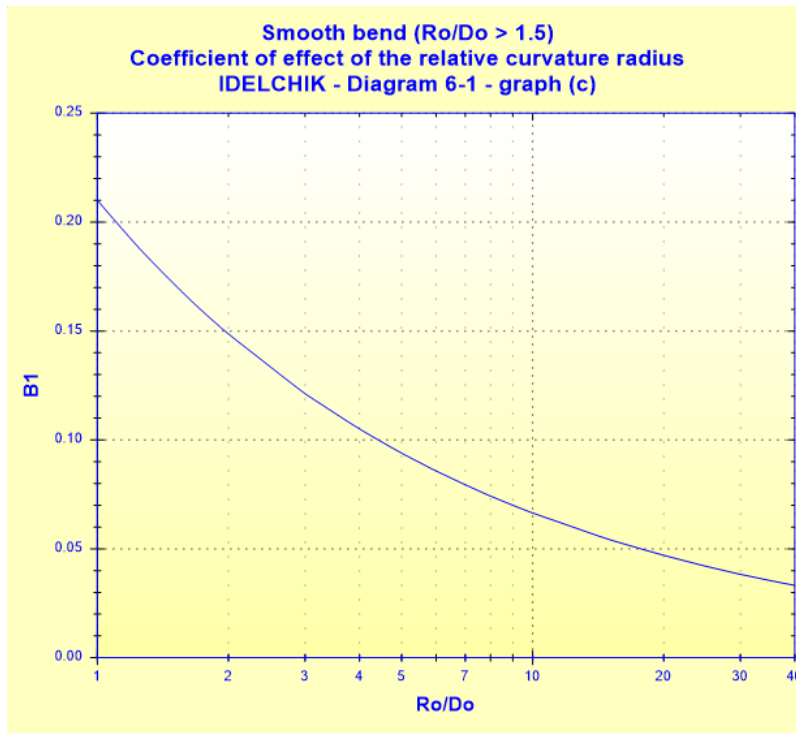
$$B1 = f\left(\frac{R_0}{D_h}\right)$$

([1] diagram 6-1)

- $0.5 \leq R_0/D_0 \leq 1.5$



● $R_0/D_0 > 1.5$



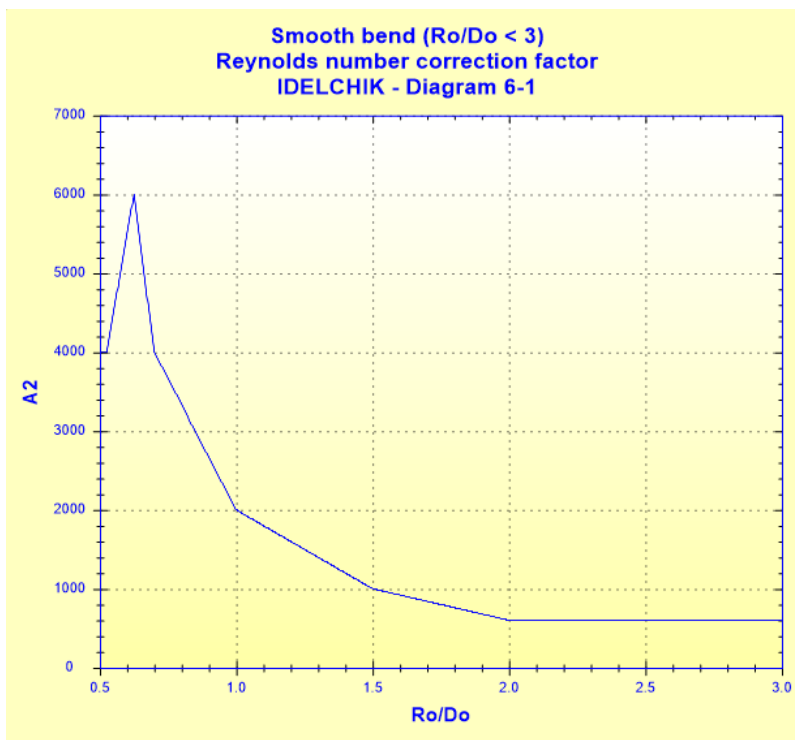
Coefficient of effect of the relative elongation of the cross section:

$$\boxed{C_1 = 1} \quad ([1] \text{ diagram 6-1})$$

Reynolds number correction factor that depends on the relative curvature radius:

$$\boxed{A_2 = f\left(\frac{R_0}{D_0}\right)} \quad ([1] \text{ diagram 6-1})$$

| R_0/D_0 | 0.50 - 0.55 | >0.55 - 0.70 | >0.70 - 1.0 | >1.0 - 2.0 | >2.0 |
|----------------------|-------------|--------------|-------------|------------|------|
| $A_2 \times 10^{-3}$ | 4.0 | 6.0 | 4.0 - 2.0 | 1.0 | 0.6 |



Pressure loss coefficient (without friction):

- $Re \geq 10^4$

$$\zeta'_{loc} = k_{\Delta} \cdot k_{Re} \cdot A1 \cdot B1 \cdot C1 \quad ([1] \text{ diagram 6-1})$$

- $3 \cdot 10^3 < Re < 10^4$

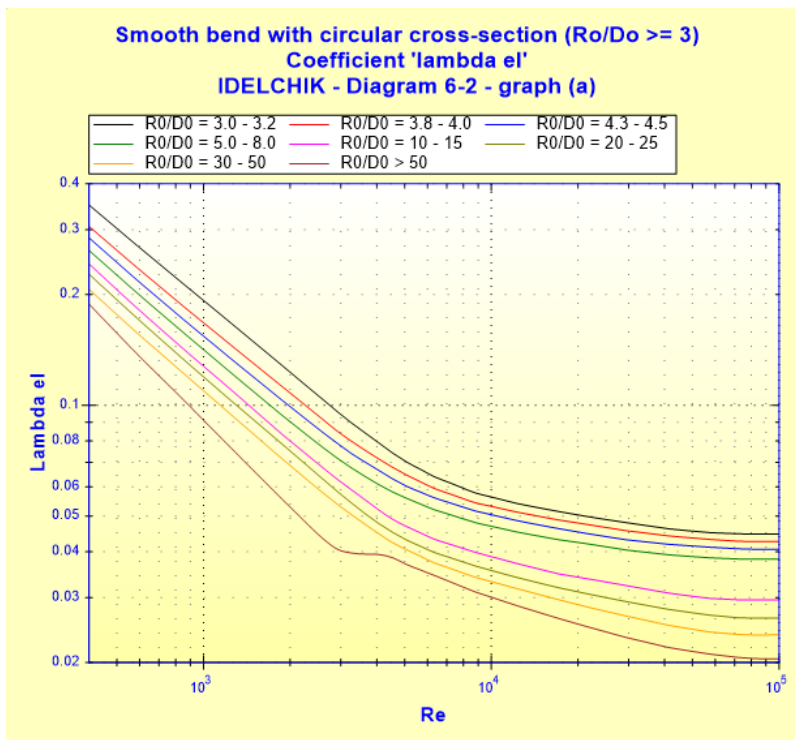
$$\zeta'_{loc} = \frac{A2}{Re} + A1 \cdot B1 \cdot C1 \quad ([1] \text{ diagram 6-1})$$

■ Case of a single bend of relative radius of curvature greater than or equal to 3 ($R_0/D_0 \geq 3$) ([1] diagram 6-2)

Total friction factor with smooth wall:

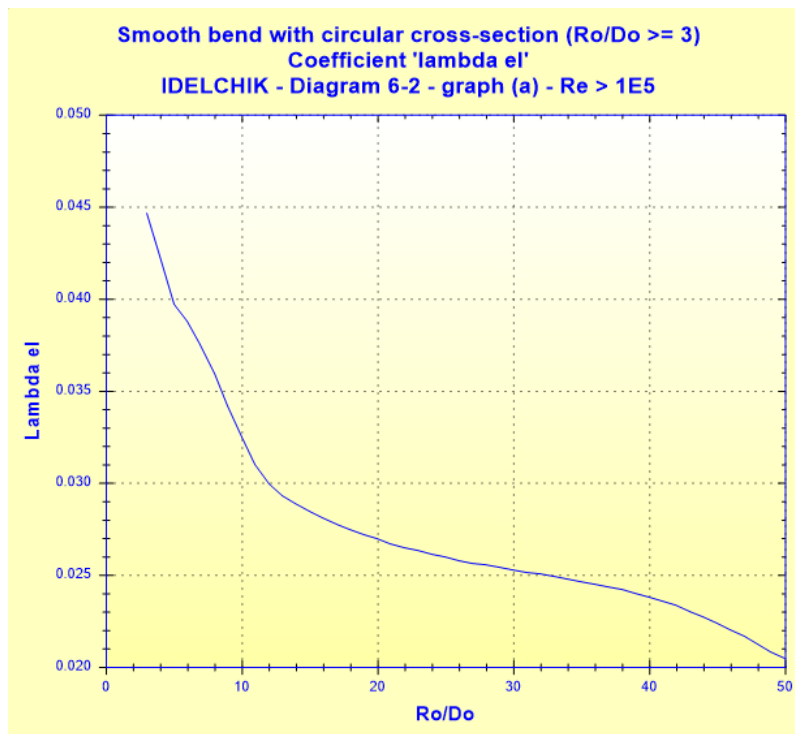
- $4 \cdot 10^2 \leq Re < 10^5$

$$\lambda_{el} = f\left(Re, \frac{R_0}{D_0}\right) \quad ([1] \text{ diagram 6-2})$$



● $Re \geq 10^5$

$$\lambda_{el} = f\left(\frac{R_0}{D_0}\right) \quad ([1] \text{ diagram 6-2})$$



Estimation of the coefficient of local resistance

$$\zeta'_{loc} = (\lambda_{el} - \lambda_s) \cdot \frac{2 \cdot \pi \cdot R_0 \cdot \delta / 360}{D_h}$$

with:

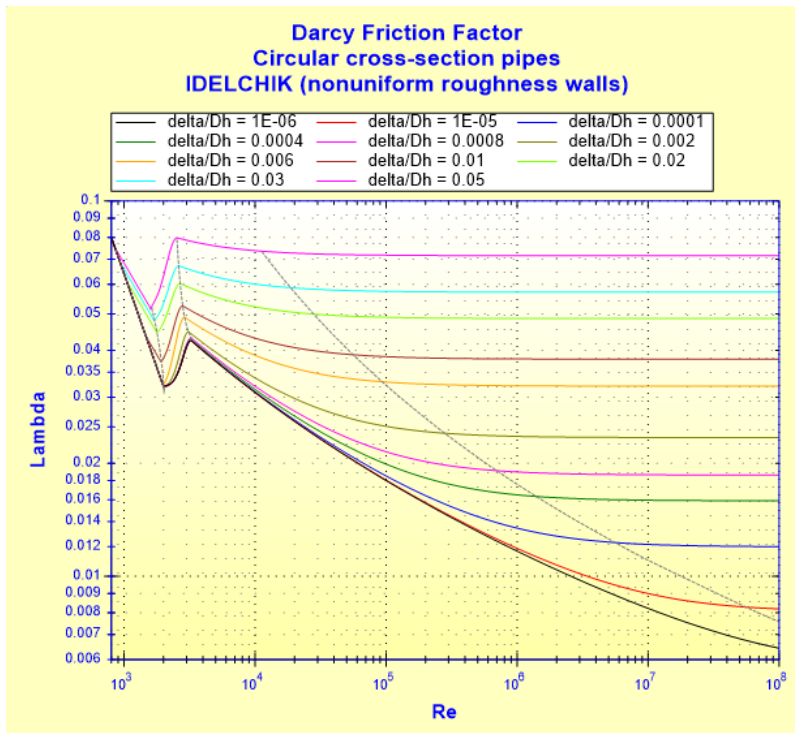
λ_s : Darcy friction factor for hydraulically smooth pipe ($\bar{\Delta} = 0$) at Re

■ Case of the U-shaped Bends ([1] diagram 6-20)

Darcy friction factor:

$$\lambda = f\left(\text{Re}, \frac{\Delta}{D_h}\right)$$

See [Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls \(IDELCHIK\)](#)

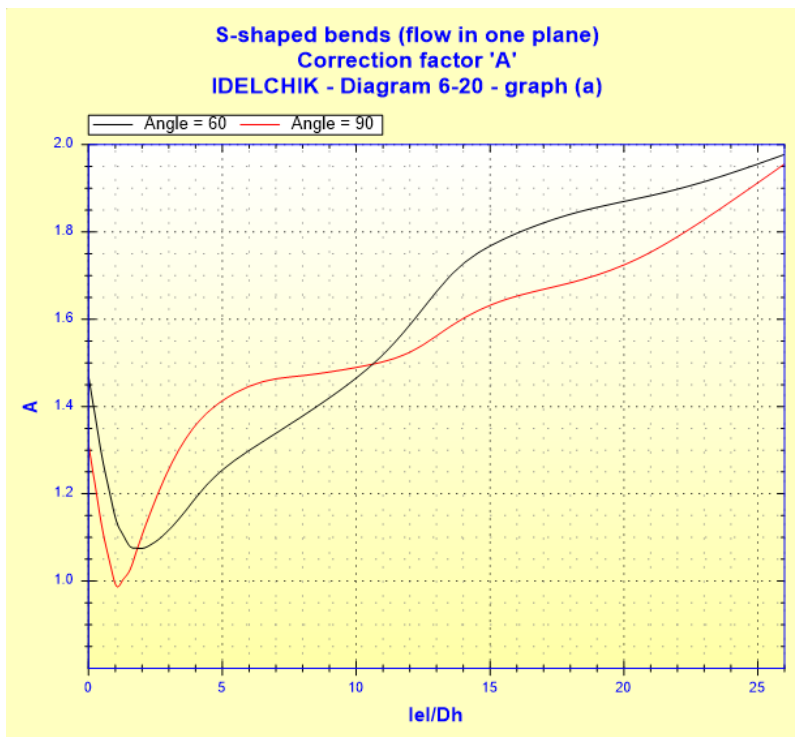


Pressure loss friction factor:

$$\zeta_{fr} = \lambda \cdot \left[2 \cdot \left(0.0175 \cdot \delta \cdot \frac{R_0}{D_h} \right) + \frac{l_{el}}{D_h} \right] \quad ([1] \text{ diagram 6-20})$$

Coefficient of correction:

$$A = f\left(\frac{l_{el}}{D_h}, \delta\right) \quad ([1] \text{ diagram 6-20 graph a})$$



Total pressure loss coefficient (based on the mean velocity in the bends):

$$\zeta = A \cdot \zeta'_{loc} + \zeta_{fr} \quad ([1] \text{ diagram 6-20})$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = \zeta \cdot \frac{D_0}{\lambda}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2} \quad ([1] \text{ diagram 6-20})$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

| | |
|-----------------|--|
| D _h | Bend hydraulic diameter (m) |
| D ₀ | Bend internal diameter (m) |
| F ₀ | Cross-sectional area (m ²) |
| l | Total length measured along the axis (m) |
| l _{el} | Straight length between bends (m) |
| R ₀ | Radius of curvature (m) |
| δ | Curvature angle of each bend (°) |
| Q | Volume flow rate (m ³ /s) |

| | |
|----------------|--|
| w_0 | Mean velocity (m/s) |
| G | Mass flow rate (kg/s) |
| V | Fluid volume (m ³) |
| M | Fluid mass (kg) |
| Re | Reynolds number () |
| Δ | Absolute roughness of walls (m) |
| $\bar{\Delta}$ | Relative roughness of walls () |
| k_{Δ} | Coefficient that allows for the effect of the roughness () |
| k_{Re} | Coefficient that allows for the effect of the Reynolds number () |
| A_1 | Coefficient that allows for the effect of the angle () |
| B_1 | Coefficient that allows for the effect of the relative curvature radius () |
| C_1 | Coefficient that allows for the effect of the relative elongation of the cross section () |
| A_2 | Reynolds number correction factor that depends on the relative curvature radius () |
| ζ'_{loc} | Coefficient of local resistance () |
| λ_{el} | Total friction factor with smooth wall () |
| λ | Darcy friction coefficient () |
| ζ_{fr} | Pressure loss friction factor () |
| A | Coefficient of correction () |
| ζ | Total pressure loss coefficient (based on the mean velocity in the bend) () |
| L_{eq} | Straight length of equivalent pressure loss (m) |
| ΔP | Total pressure loss (Pa) |
| ΔH | Total head loss of fluid (m) |
| Wh | Hydraulic power loss (W) |
| ρ | Fluid density (kg/m ³) |
| ν | Fluid kinematic viscosity (m ² /s) |
| g | Gravitational acceleration (m/s ²) |

Validity range:

- stabilized flow upstream bend
- length of the straight section downstream: $\geq 10 D_0$
- relative radius of curvature: greater than or equal to 1 ($R_0/D_0 \geq 1$)
- curvature angle of one bend: 0 to 180°

for ' δ ' angles less than 60° the pressure loss coefficient ' ζ ' is estimated by taking into account an interaction correction factor ' A ' corresponding to that of an angle of 60°.

for ' δ ' angles greater than 90° the pressure loss coefficient ' ζ ' is estimated by taking into account an interaction correction factor ' A ' corresponding to that of an angle of 90°.

- case of relative radius of curvature lower than 3 ($R_0/D_0 < 3$)
 - flow regime: $Re \geq 3 \cdot 10^3$

- case of relative radius of curvature greater than or equal to 3 ($R_0/D_0 \geq 3$)
 - flow regime: $Re \geq 400$
- for Reynolds number 'Re' lower than 400 the coefficient ' λ_{el} ' is linearly extrapolated.

Example of application:

The screenshot displays the HydraulCalc 2023a software interface for a U-shaped bend. The window title is "HydraulCalc 2023a - [U-shaped bends with circular cross-section (flow in one plane) - IDELCHIK (3rd Ed.)]".

Fluid characteristics:

- Fluid: Water @ 1 atm [HC]
- Ref.: IAPWS IF97
- Temperature: $T = 20$ °C
- Pressure: $P = 1.013$ bar
- Density: $\rho = 998.2061$ kg/m³
- Dynamic Viscosity: $\mu = 0.00100159$ N.s/m²
- Kinematic Viscosity: $\nu = 1.00340E-06$ m²/s

Geometrical characteristics:

- Pressure loss: $\Delta P = 0.002979399$ bar
- $\Delta H = 0.0304$ m of fluid
- Angle: $\delta = 90^\circ$
- Relative radius of curvature: $R_0 = 0.175$ m
- Hydraulic diameter: $D_0 = 0.0703$ m
- Length between elbows: $l_{el} = 0.1$ m
- Relative roughness: $\Delta = 1.0E-05$ m
- Mass flow rate: $G = 4.9910$ kg/s
- Volume flow rate: $Q = 0.005$ m³/s
- Mean velocity: $w_0 = 1.288$ m/s (Turbulent)

Complementary results:

| Designation | Symbol | Value | Unit |
|---|---------------|--------------|----------------|
| Hydraulic diameter | D_h | 0.0703 | m |
| Passage cross-section area | F_0 | 0.003881508 | m ² |
| Relative radius of curvature | R_0/D_0 | 2.489331 | |
| Length between elbows / hydraulic diameter ratio | l_{el}/D_h | 1.422475 | |
| Developed straight length from the axis | l | 0.6497787 | m |
| Relative roughness | Δ | 0.0001422475 | |
| Reynolds number | Re | 90251 | |
| Darcy Friction Factor | λ | 0.01907611 | |
| Coefficient of local resistance | ζ_{loc} | 0.181306 | |
| Coefficient of friction resistance | ζ_{fr} | 0.1763193 | |
| Interaction correction factor (Diagram 6-20) | A | 1.011713 | |
| Pressure loss coefficient (based on the mean bend velocity) | ζ | 0.3597489 | |
| Hydraulic power loss | W_h | 1.489699 | W |
| Straight length of equivalent pressure loss | Leq | 1.325761 | m |

References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik