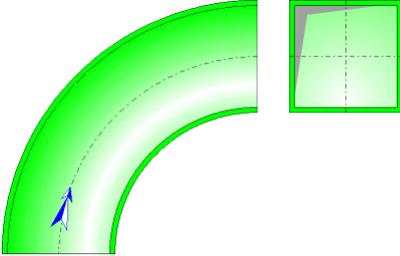




Smooth Bend Rectangular Cross-Section (IDELCHIK)



Model description:

This model of component calculates the head loss (pressure drop) of a bend smoothly curved whose cross-section is rectangular and constant. In addition, the flow is assumed fully developed and stabilized at the entrance bend.

Model formulation:

Hydraulic diameter (m):

$$D_h = \frac{2 \cdot a_0 \cdot b_0}{a_0 + b_0} \quad ([1] \text{ diagram 6-1})$$

Cross-section area (m²):

$$F_0 = a_0 \cdot b_0$$

Length measured along the axis (m):

$$l = 2 \cdot \pi \cdot R_0 \cdot \frac{\delta}{360}$$

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 relative radius of curvature lower than 3 ($R_0/b_0 < 3$) ([1] diagram 6-1)

Coefficient of effect of the roughness:

$$k_{\Delta} = f\left(\frac{R_0}{b_0}, Re, \bar{\Delta}\right) \quad ([1] \text{ diagram 6-1})$$

● $0.50 \leq R_0/b_0 \leq 0.55$

$\bar{\Delta}$	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

● $R_0/b_0 > 0.55$

$\bar{\Delta}$	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

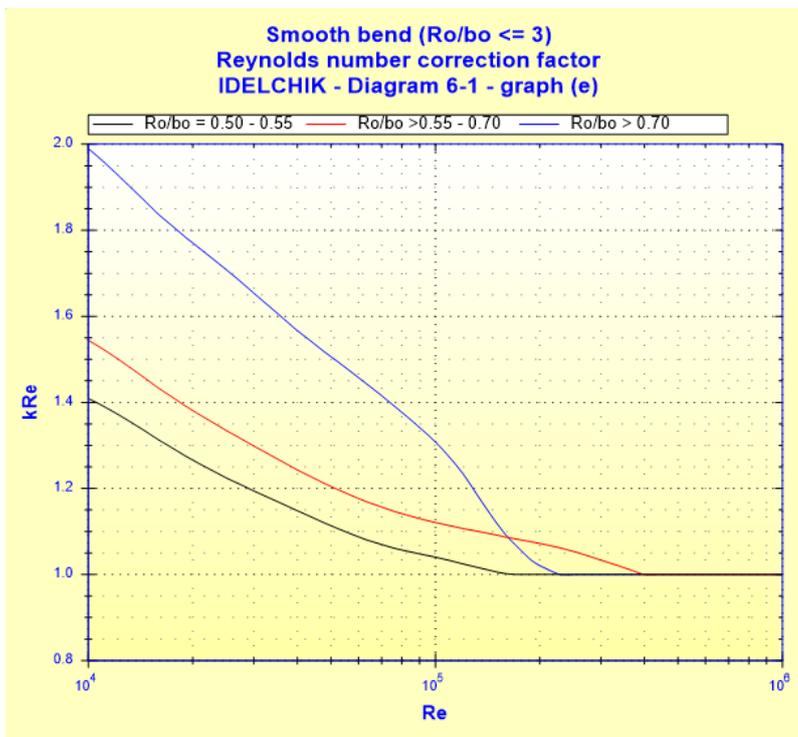
with:

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 ($Re \geq 10^4$):

$$k_{Re} = f\left(Re, \frac{R_0}{b_0}\right) \quad ([1] \text{ diagram 6-1})$$



Coefficient of effect of the angle:

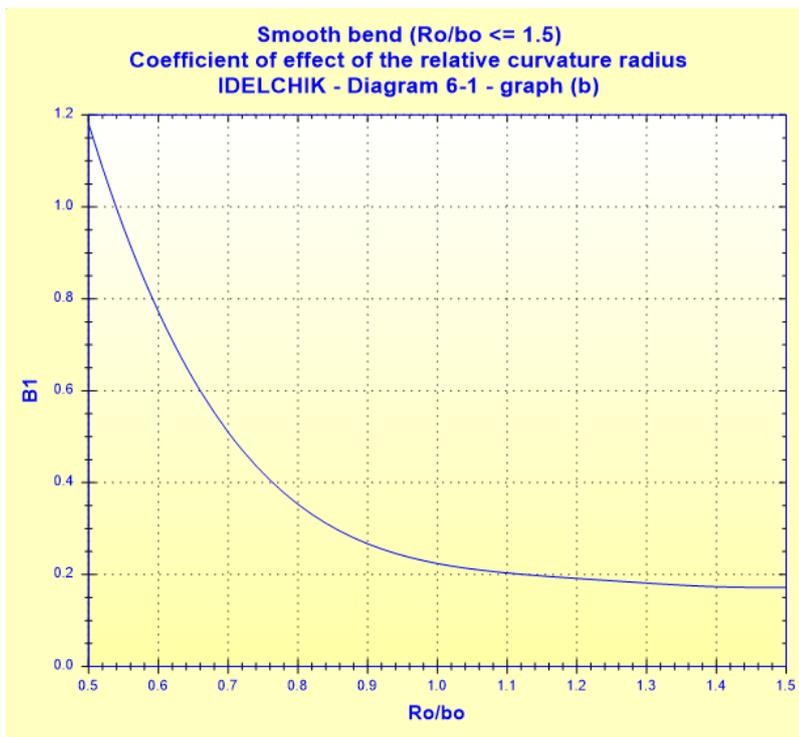
$$A1 = f(\delta) \quad ([1] \text{ diagram 6-1})$$



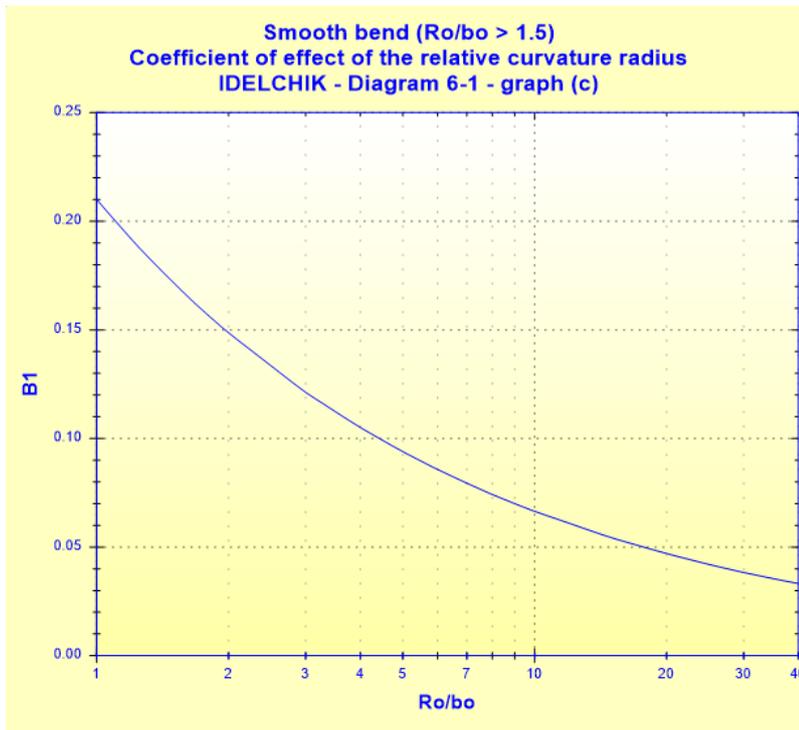
Coefficient of effect of the relative curvature radius:

$$B1 = f\left(\frac{R_0}{b_0}\right) \quad ([1] \text{ diagram 6-1})$$

- $0.5 \leq R_0/b_0 \leq 1.5$

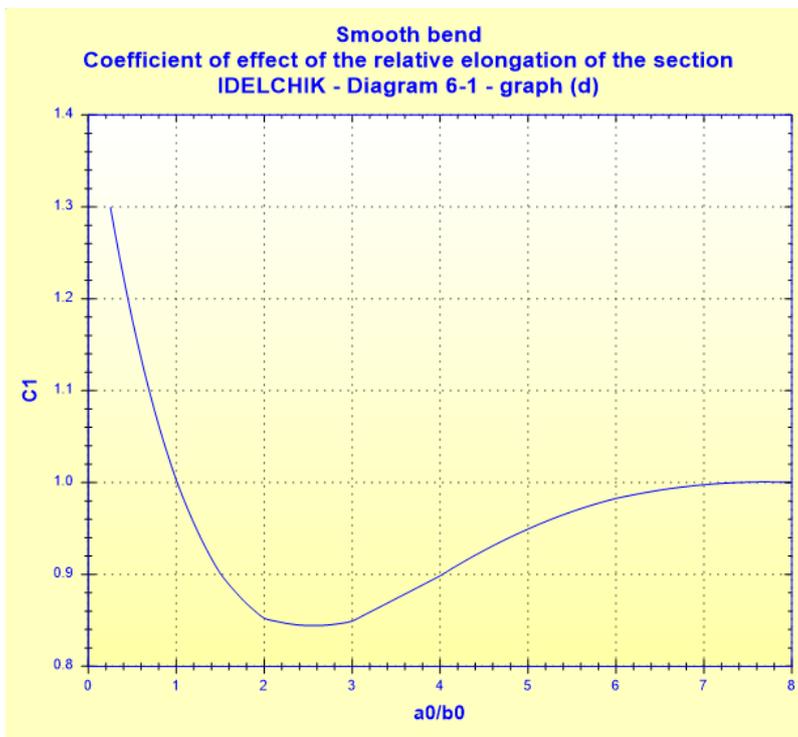


- $R_0/b_0 > 1.5$



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

$$C_1 = f\left(\frac{a_0}{b_0}\right) \quad ([1] \text{ diagram 6-1})$$



Coefficient of local resistance:

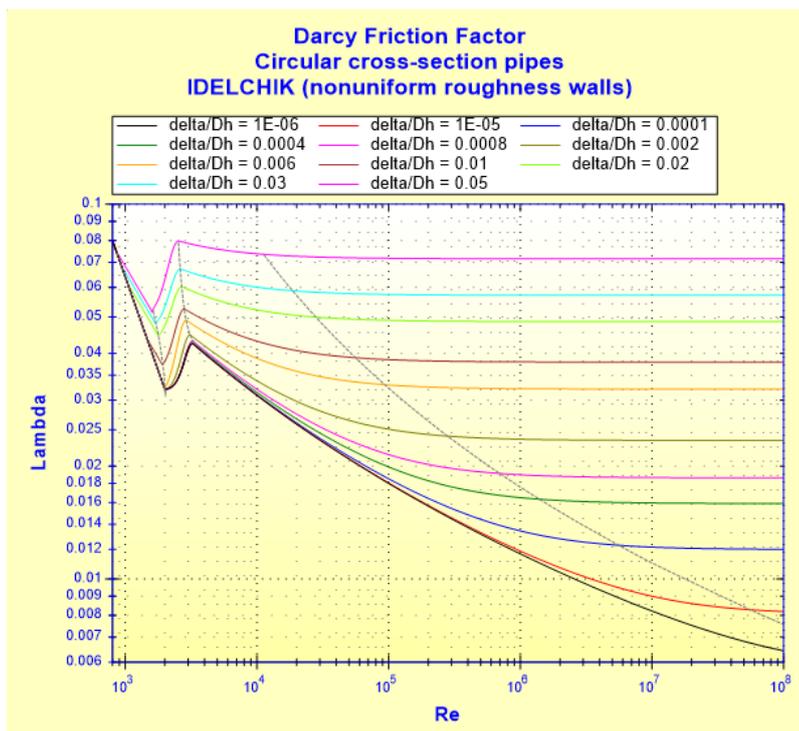
$$\zeta_{loc} = A1 \cdot B1 \cdot C1 \quad ([1] \text{ diagram 6-1})$$

Darcy friction factor:

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

■ Darcy friction factor for circular cross-section

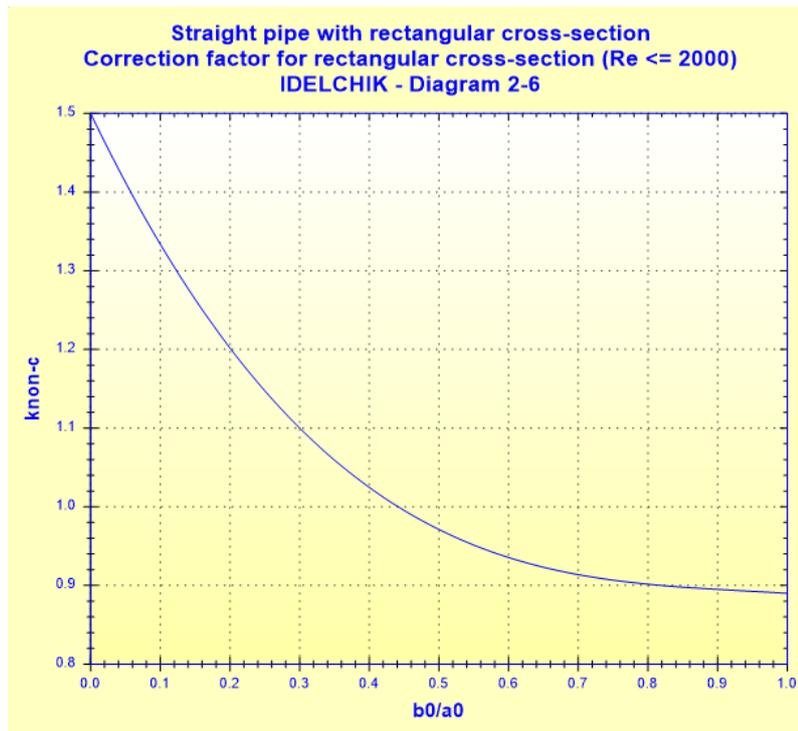
$$\lambda_{circ} = f \left(Re, \frac{\Delta}{D_h} \right)$$



■ Correction for Darcy friction factor for noncircular cross-section

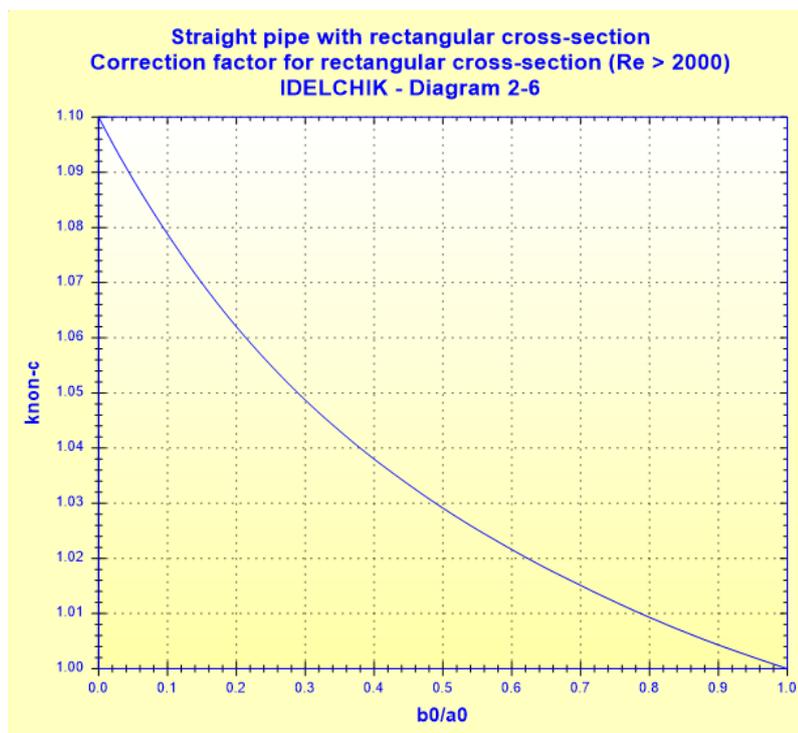
- laminar flow ($Re \leq 2000$):

$$k_{non-c} = f(b_0/a_0) \quad ([1] \text{ diagram 2.6})$$



- turbulent flow ($Re > 2000$):

$$k_{non-c} = f(b_0/a_0) \quad ([1] \text{ diagram 2.6})$$



- Darcy friction factor for rectangular cross-section

$$\lambda_{rect} = \lambda_{circ} \cdot k_{non-c} \quad ([1] \text{ diagram 2.6})$$

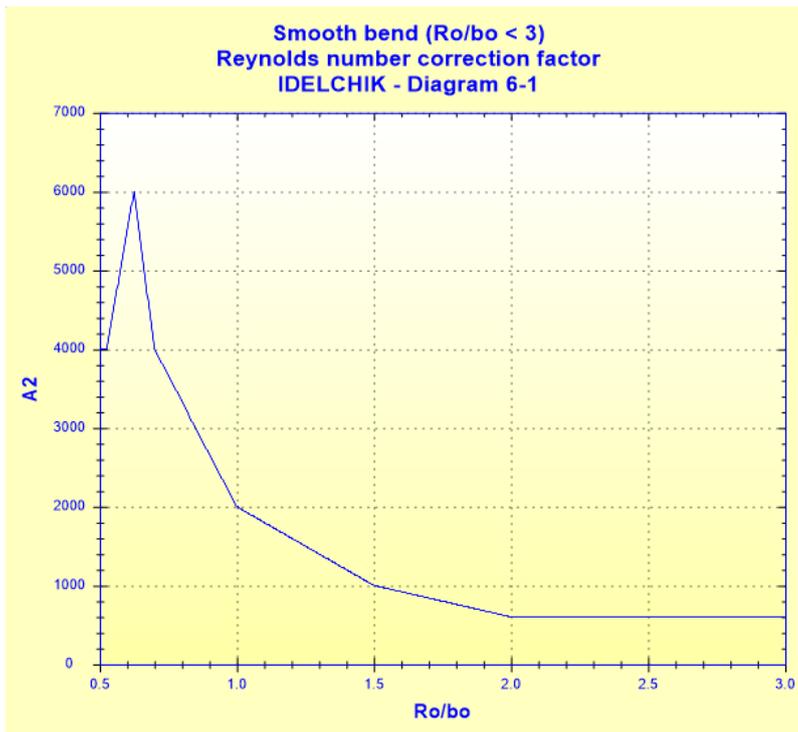
Pressure loss friction factor:

$$\zeta_{fr} = 0.0175 \cdot \delta \cdot \lambda_{rect} \cdot \frac{R_0}{D_h} \quad ([1] \text{ diagram 6-1})$$

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

$$A2 = f\left(\frac{R_0}{b_0}\right) \quad ([1] \text{ diagram 6.1})$$

R_0/b_0	0.50 - 0.55	>0.55 - 0.70	>0.70 - 1.0	>1.0 - 2.0	>2.0
$A2 \times 10^{-3}$	4.0	6.0	4.0 - 2.0	1.0	0.6



Total pressure loss coefficient:

- $Re \geq 10^4$

$$\zeta = k_{\Delta} \cdot k_{Re} \cdot \zeta_{loc} + \zeta_{fr} \quad ([1] \text{ diagram 6-1})$$

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

$$\zeta = \frac{A2}{Re} + \zeta_{loc} + \zeta_{fr} \quad ([1] \text{ diagram 6-1})$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = \zeta \cdot \frac{D_h}{\lambda_{rect}}$$

■ Case of relative radius of curvature greater than or equal to 3 ($R_0/b_0 \geq 3$) ([1] diagram 6-2)

Friction factor smooth wall:

- $0.5 \cdot 10^3 < Re < 6 \cdot 10^3$ (laminar regime)

$$A_{lam} = 1.97 + 49.1 \cdot \left(\frac{D_h}{2 \cdot R_0} \right)^{1.32} \cdot \left(\frac{b_0}{a_0} \right)^{0.37}$$

([1] diagram 6-2)

$$\lambda_{el} = A_{lam} \cdot Re^{-0.46}$$

([1] diagram 6-2)

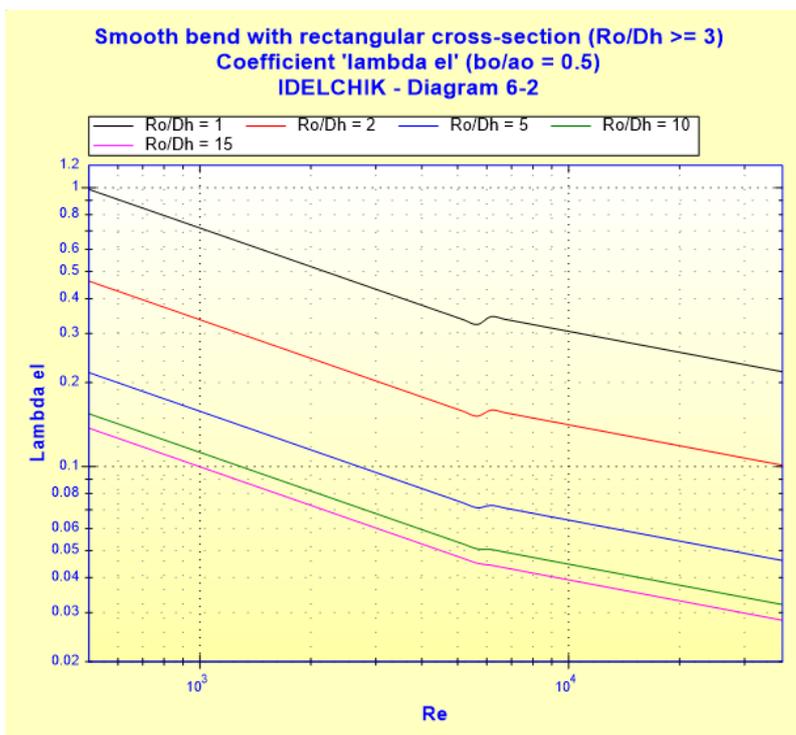
- $7 \cdot 10^3 < Re < 38 \cdot 10^3$ (turbulent regime)

$$A_{turb} = 0.316 + 8.65 \cdot \left(\frac{D_h}{2 \cdot R_0} \right)^{1.32} \cdot \left(\frac{b_0}{a_0} \right)^{0.34}$$

([1] diagram 6-2)

$$\lambda_{el} = A_{turb} \cdot Re^{-0.25}$$

([1] diagram 6.2)



([1] diagram 6-2 with

$b_0/a_0 = 0.5$)

Roughness correction factor:

$$C_f = \frac{\lambda_r}{\lambda_s}$$

([2] equation 9-3)

with:

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

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

Pressure loss coefficient (based on the mean velocity in the bend):

$$\zeta = 0.0175 \cdot \delta \cdot \lambda_{el} \cdot C_f \cdot \frac{R_0}{D_h}$$

([1] diagram 6-2 & [2] equation 9.3)

Straight length of equivalent pressure loss (m):

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

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot w_0^2}{2}$$
 ([1] diagram 6-1 - 6-2)

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:

a_0	Rectangular cross-section width (m)
b_0	Rectangular cross-section height (m)
D_h	Bend hydraulic diameter (m)
F_0	Cross-sectional area (m ²)
l	Length measured along the axis (m)
R_0	Radius of curvature (m)
δ	Curvature angle (°)
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
ζ_{loc}	Coefficient of local resistance ()
λ_{circ}	Darcy friction coefficient for circular cross-section ()
λ_{rect}	Darcy friction coefficient for rectangular cross-section ()
k_{non-c}	Correction for Darcy friction factor for noncircular cross-section ()
ζ_{fr}	Pressure loss friction factor ()
ζ	Total pressure loss coefficient (based on the mean velocity in the bend) ()

L_{eq}	Straight length of equivalent pressure loss (m)
λ_{el}	Friction coefficient ()
A_{lam}	Laminar coefficient ()
A_{tur}	Turbulent coefficient ()
C_f	Roughness correction factor ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
W_h	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: $\geq 10 D_h$
- curvature angle: 0 to 180°
- case of relative radius of curvature lower than 3 ($R_0/b_0 < 3$)
 - flow regime: $Re \geq 3 \cdot 10^3$
- case of relative radius of curvature greater than or equal to 3 ($R_0/b_0 \geq 3$)
 - flow regime: $500 \leq Re \leq 38 \cdot 10^3$

for Reynolds number 'Re' lower than 500 or greater than $38 \cdot 10^3$, the coefficient ' λ_{el} ' is linearly extrapolated.

Example of application:

HydrauCalc 2020a - [Smooth bend with rectangular cross-section - IDELCHIK (3rd Ed.)]

File Edit Preferences Calculation method Database Tools Help

Fluid characteristics
 Fluid : Water @ 1 atm [HC]
 Ref.: IAPWS IF97
 Temperature : T 20 °C
 Pressure : P 1.013 bar
 Density : ρ 998.2061 kg/m³
 Dynamic Viscosity : μ 0.00100159 N.s/m²
 Kinematic Viscosity : ν 1.00340E-06 m²/s
 Density Dyn. Visc. Kin. Visc.

Geometrical characteristics
 Help
 Info
 Calculate
 b0 0.05 m
 a0 0.1 m
 R0 0.175 m
 Δ 1.0E-05 m
 δ 90 °
 Pressure loss
 ΔP 0.001110375 bar
 ΔH 0.0113 m of fluid
 G 4.9910 kg/s
 Q 0.005 m³/s
 w0 1.0 m/s (Turbulent)

Complementary results

Designation	Symbol	Value	Unit
Hydraulic diameter	Dh	0.06666667	m
Passage cross-section area	F0	0.005	m²
Sides ratio	b0/a0	0.5	
Relative radius of curvature	R0/b0	3.5	
Relative roughness	Δ	0.00015	
Reynolds number	Re	66440.97	
Friction factor (Diagram 6-2)	λ _{rel}	0.05230567	
Darcy friction factor (roughness pipe)	λ _r	0.02024362	
Darcy friction factor (hydraulically smooth pipe)	λ _s	0.01962486	
Roughness correction	Cf	1.031529	
Pressure loss coefficient (based on the mean bend velocity)	ζ	0.2224741	
Hydraulic power loss	Wh	0.5551873	W
Straight length of equivalent pressure loss	Leq	0.7326559	m

Density (kg/m³) vs Temperature (°C) graph showing a decreasing trend from 1000 kg/m³ at 20°C to approximately 970 kg/m³ at 100°C.

Divers HC

References:

- [1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- [2] Internal Flow System, Second Edition, D.S. Miller