TECHNICAL INFORMATION

POLIPLEX® PE100

HYDRAULIC DESIGN

SELECTION OF PIPE DIAMETER AND CLASS

The choice of pipe diameter and pressure class will depend on the following factors:

- The required flow rate including any planned future increases.
- The friction losses caused by the pipes and fittings.
- The longitudinal section of the proposed pipeline route.
- In the case of pressurised gravity systems, the available head differential.
- The relative cost of different pipe diameters and classes.
- Financial parameters such as expected interest rate and repayment term.
- For pumped systems - the cost of power and anticipated inflation rate for energy costs.
- Estimated water hammer and surges caused during normal operation and due to power failure.
- Specified field test pressures.

FORMULAE FOR FLOW RESISTANCE

Notation

C = Hazen-Williams co-efficient

C_z = Chezy number

d = internal diameter (m)

f = Darcy friction co-efficient

g = acceleration due to gravity (m/sec^2)

k = equivalent hydraulic roughness (m)

L = length of pipeline (m)

n = Manning ‘n’

S = hydraulic gradient (m/m)

R = hydraulic mean radius (m)
(R = d/4 for circular conduits)

R_e = Reynolds number

S = hydraulic gradient (m/m)

V = mean velocity (m/sec) $\frac{Vd}{\nu}$
ie flow + pipe cross sectional area

ΔH = friction head loss (m)

ΔP = pressure loss (Pa)

ρ = fluid density (kg/m^3)

μ = dynamic viscosity (N.s)

ν = kinematic viscosity (m^2/sec) ie $\nu = \mu/\rho$

HYDRAULIC DESIGN

As early as 1840 Poiseuille had established that under certain flow conditions (now described as laminar) the resistance or friction loss in a pipeline is directly proportional to the mean velocity. By 1858 Darcy had shown that for other conditions (ie turbulent flow) the friction loss was approximately proportional to the square of the mean velocity. It was Reynolds in 1883 who as a result of extensive experimentation provided a means of identifying these two quite distinct flow conditions. He found that laminar flow occurs whenever Reynold's Number $R_e = Vdl_v$ is less than approximately 2000 ie the 'lower critical' value. Where R_e exceeds an 'upper critical value' of say 2500, the flow is likely to be turbulent and the Darcy equation is then applicable. However the upper critical R_e is the result of instability and will vary between installations. Typical values range from 2300 to 4000.

Figure 1.1 shows the difference in velocity profile between the two flow types. Figures 1.2 & 1.3 show the Reynolds Number relationship to Darcy 'f' and the friction head loss relationships to velocity for the two distinct flow conditions.

POISEUILLE EQUATION

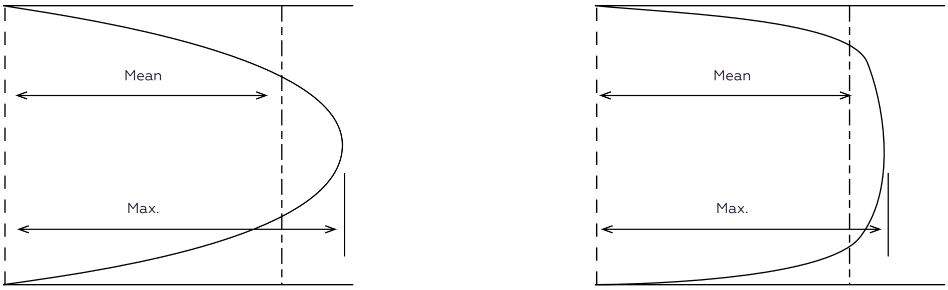
For viscous flow the Poiseuille equation is an exact relationship for Newtonian fluids where R_e is less than 2000. It can be written:

$$AP = \frac{32\mu.\,VL}{d^2} \qquad \text{AND} \qquad AH = \frac{32\,.\nu.VL}{d^2g} \qquad \textit{Eqn. 1.1}$$

$$= \frac{32p.\nu\,.VL}{d^2}$$

OR REARRANGING THIS EQUATION

$$V = \frac{gd^2S}{32\nu} \qquad \textit{Eqn. 1.2}$$



Laminar

Turbulent

Figure 1.1 Velocity profiles in pipes for laminar and turbulent flows

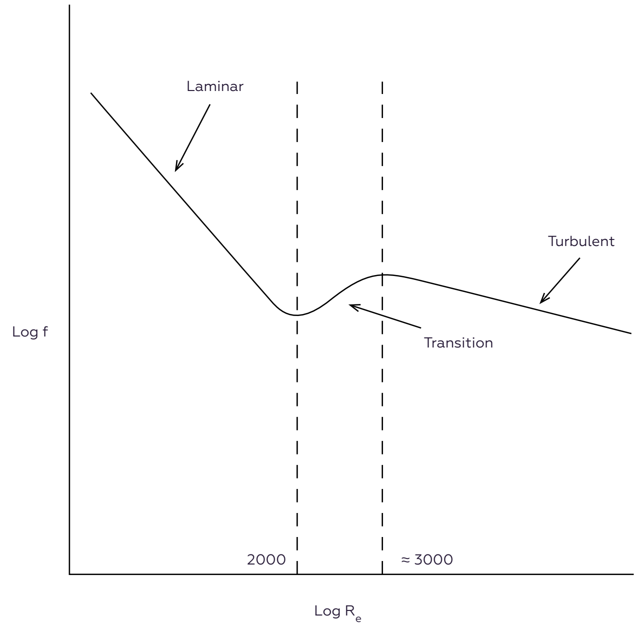


Figure 1.2 Variation in the Darcy Friction Factor with Reynolds Number for smooth pipes

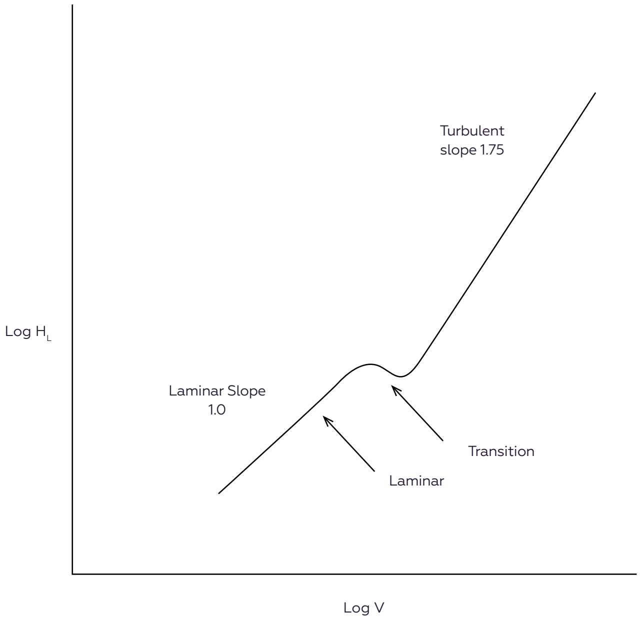


Figure 1.3 Headloss to velocity characteristics for the full range of flows

HYDRAULIC DESIGN

DARCY – WEISBACH EQUATION

The Darcy equation relies on the selection of the appropriate value of ‘f’ which is in turn a function of the Reynolds Number and pipe roughness.

- For laminar flow where $R_e < 2000$, use $f = 64/R_e$ (irrespective of pipe roughness). This substitution converts the Darcy equation into the Poiseuille form.

- For $2000 < R_e < 100{,}000$ and a smooth pipe the empirical relationship of Blasius applies,

  ie $$f = \frac{0.316}{R_e^{0.25}}$$

  (Note that owing to instability in the $2000 < R_e < 4000$ range flow resistance calculations will not give precise results regardless of the equation used)

- For transitional and turbulent flow in rough pipes where $2000 < R_e <$ very large use the ‘f’ value obtained from the Swamee & Jain modification to the Colebrook White equation given as Eqn 1.10 on the next page. This relationship includes the effect of pipe roughness. At large values of R_e, the key variable is roughness, with changes to R_e having negligible effect.

  The Darcy equation is written:

$$\Delta H = \frac{f \,.\, L}{d} \,.\, \frac{V^2}{2g}$$ *Eqn. 1.3*

$$\Delta P = \frac{f \,.\, L}{d} \,.\, \rho \,.\, \frac{V^2}{2}$$ *Eqn. 1.4*

Many other empirical formulae, exponential in form, have been developed over the years for turbulent flow as this almost always occurs in the design of water schemes. Being relatively easy to use they are still favoured by hydraulic engineers, especially where network analyses are involved. They include the following equations (all expressed in SI units):

Hazen-Williams Equation

$$V = 0.354C.d^{0.63}.S^{0.54}$$ *Eqn. 1.5*

Manning Equation

$$V = \frac{1}{n} R^{0.66}.S^{0.5}$$ *Eqn. 1.6*

Chezy Equation

$$V = 0.55\ Cz.\ R^{0.5}.S^{0.5}$$ *Eqn. 1.7*

Darcy Equation

$$V = \left(\frac{2gSd}{f}\right)^{0.5}$$ *Eqn. 1.8*

HYDRAULIC DESIGN

COLEBROOK-WHITE TRANSITION EQUATION

Although the above equations are convenient to use, the Colebrook-White transition formula which was developed in the 1930s, takes account of Reynolds Number, liquid viscosity and pipe roughness, and is recognised as being more accurate.

$$V = -2\sqrt{2g.d.S.}\left(\log \frac{k}{3.7d} + \frac{2.51v}{d\sqrt{2gdS}}\right)$$

Eqn. 1.9

Equation 1.9 requires an iterative solution and it is sometimes more convenient to use the Darcy head loss expression with ‘f’, the friction co-efficient, obtained from the equation developed by P. Swamee and A. Jain:

$$f = \frac{0.25}{\left[\log\left(\frac{k}{3.7d} + \frac{5.74}{R_e^{0.9}}\right)\right]^2}$$

Eqn. 1.10

FLOW RESISTANCE CHARTS

The roughness of the bore of a PE pipeline can vary due to various factors, which include:

- growth of slime which will vary with the age of the pipeline and available nutriment in the water
- roughening, due to the carrying of abrasive solids
- joint imperfections such as weld beads or gaps

To assist the designer in the selection of the appropriate diameter pipe without applying complex formulae, charts covering friction loss in the full range of POLIplex® polyethylene pipes have been included in this Section, together with a table giving the head loss co-efficients in various fittings. Occasionally higher roughness co-efficients for the pipes may be used by some authorities to cover losses in fittings rather than quantifying individual fitting losses.

These flow resistance charts have been prepared using the Colebrook-White transition formula for the following flow conditions:

Temperature = 20°C

$k = 0.007$mm

$R_e = > 2000$

This value of the equivalent roughness co-efficient ‘k’ assumes the PE pipeline is straight, clean and concentrically jointed. It is consistent with the range of between 0.003 to 0.015 mm given in AS 2200 ‘Design Charts for Water Supply and Sewerage’.

Temperature Correction

An approximate allowance for the effect on the variation in water temperature on the viscosity can be made by increasing the chart value of the head loss by 1% for each 3°C below 20°C and by decreasing it by 1% for each 3°C in excess of 20°C.

HYDRAULIC DESIGN

TABLE 1.1 VARIATION OF WATER DENSITY & VISCOSITY

TEMPERATURE °C	DENSITY ρ (kg/m³)	VISCOSITY ν (m²/sec)
0	1000	1.79×10^{-6}
5	1000	1.52×10^{-6}
10	1000	1.31×10^{-6}
15	999	1.14×10^{-6}
20	998	1.01×10^{-6}
25	997	0.87×10^{-6}
30	996	0.81×10^{-6}
35	995	0.73×10^{-6}
40	992	0.66×10^{-6}
45	990	0.60×10^{-6}
50	988	0.55×10^{-6}
55	985	0.52×10^{-6}

RESISTANCE LOSSES IN FITTINGS

Any change in direction or cross section in a pipeline can cause further flow resistance losses. In a long pipeline, these losses are usually insignificant, and are commonly ignored. However, where there are a large number of fittings in a short pipeline, such as might be found on an industrial site, they should be taken into account.

Head losses in fittings can be estimated from the following equation:

$$H = K_L \frac{V^2}{2g} \qquad \textit{Eqn. 1.11}$$

where

K_L = resistance co-efficient for a particular type of fitting, from Table 1.2.

Resistance co-efficients will vary in magnitude according to the value of the Reynolds Number and the relative proximity of other fittings. In normal water supply where the Reynolds Number exceeds 2×10^5 the following tabulated values of K_L are typical.

HYDRAULIC DESIGN

TABLE 1.2 HEAD LOSS CO-EFFICIENTS “K_L” FOR FITTINGS

TYPE OF FITTING				
Elbows	DN 20	DN 32	DN 50	DN > = 63
90°	2.0	1.7	1.1	0.8
Bends (sweep)				
90°	1.5	1.0	0.6	0.5
45°				0.3
22 $^1/_2$°				0.1
11 $^1/_4$°				0.05
Bends (mitred)				
90°				0.45
60°				0.30
30°				0.12
Tees				
Through flow				0.8
Full flow to branch				1.8
Full flow from branch				1.5
Entries				
Square				0.5
Rounded				0.25
Protruding				0.8
Bell mouth				0.06
Outlets (all types)				1.0
Tapers				
Flow to small end				0.01
Flow to large end				
I/O Ration 4:5				0.03
I/O Ration 3:4				0.04
I/O Ration 1:2				0.12
Sluice Valve				
Fully open				0.20
Half open				6.00
Quarter Open				24