Laminar Flow and Turbulent Flow of Fluids

Resistance to flow in a pipe

When a fluid flows through a pipe the internal roughness (e) of the pipe wall can create local eddy currents within the fluid adding a resistance to flow of the fluid. Pipes with smooth walls such as glass, copper, brass and polyethylene have only a small effect on the frictional resistance. Pipes with less smooth walls such as concrete, cast iron and steel will create larger eddy currents which will sometimes have a significant effect on the frictional resistance.

The velocity profile in a pipe will show that the fluid at the centre of the stream will move more quickly than the fluid towards the edge of the stream. Therefore friction will occur between layers within the fluid.

Fluids with a high viscosity will flow more slowly and will generally not support eddy currents and therefore the internal roughness of the pipe will have no effect on the frictional resistance. This condition is known as laminar flow.

Reynolds Number

The Reynolds number (Re) of a flowing fluid is obtained by dividing the kinematic viscosity (viscous force per unit length) into the inertia force of the fluid (velocity x diameter)

Kinematic viscosity = $\dfrac{\text{dynamic viscosity}}{\text{fluid density}}$

Reynolds number = $\dfrac{\text{Fluid velocity x Internal pipe diameter}}{\text{Kinematic viscosity}}$

Laminar Flow

Where the Reynolds number is less than 2300 laminar flow will occur and the resistance to flow will be independent of the pipe wall roughness.

The friction factor for laminar flow can be calculated from 64 / Re.

Turbulent Flow

Turbulent flow occurs when the Reynolds number exceeds 4000.
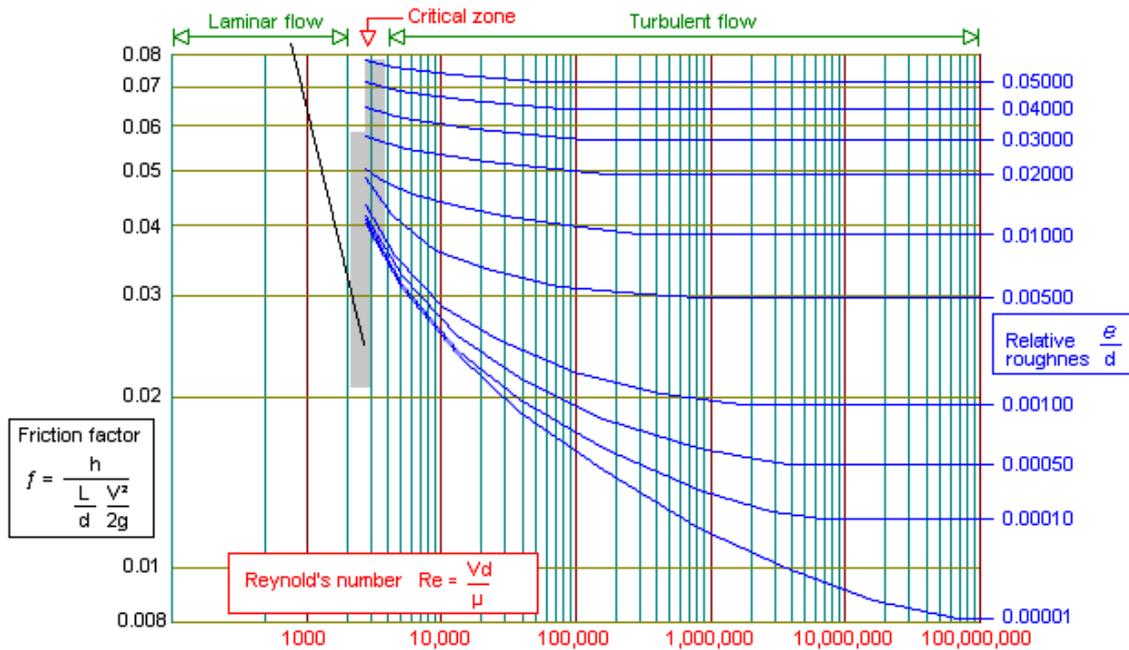
Eddy currents are present within the flow and the ratio of the internal roughness of the pipe to the internal diameter of the pipe needs to be considered to be able to determine the friction factor. In large diameter pipes the overall effect of the eddy currents is less significant. In small diameter pipes the internal roughness can have a major influence on the friction factor.

The 'relative roughness' of the pipe and the Reynolds number can be used to plot the friction factor on a friction factor chart.

The friction factor can be used with the **Darcy-Weisbach formula** to calculate the frictional resistance in the pipe. (See separate article on the Darcy-Weisbach Formula).

Between the Laminar and Turbulent flow conditions (Re 2300 to Re 4000) the flow condition is known as critical. The flow is neither wholly laminar nor wholly turbulent. It may be considered as a combination of the two flow conditions.

The friction factor for turbulent flow can be calculated from the Colebrook-White equation:

$$1/\sqrt{f} = 1.14 - 2\log_{10}\left(\frac{e}{D} + \frac{9.35}{\mathrm{Re}\sqrt{f}}\right) \quad \text{for Re > 4000}$$

2

Internal roughness (e) of common pipe materials.

Cast iron (Asphalt dipped)	0.1220 mm	0.004800"
Cast iron	0.4000 mm	0.001575"
Concrete	0.3000 mm	0.011811"
Copper	0.0015 mm	0.000059"
PVC	0.0050 mm	0.000197"
Steel	0.0450 mm	0.001811"
Steel (Galvanised)	0.1500 mm	0.005906"