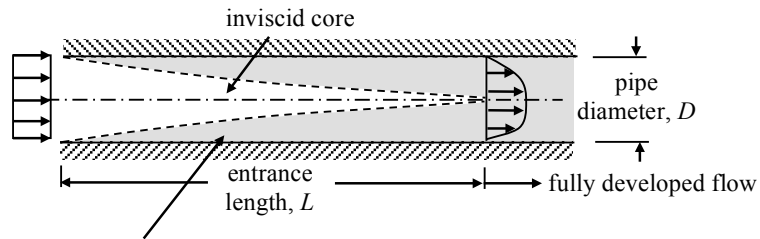


1. Entrance Region



The shaded regions are where viscous stresses are important (the boundary layer).

The flow in the entrance region is complex and will not be investigated here. Experiments have shown that the dimensionless length of the entrance region depends on whether the entering flow is laminar or turbulent, with,

$$\text{laminar flow: } L/D \approx 0.06 \text{ Re}_D, \quad (1)$$

$$\text{turbulent flow: } L/D \approx 4.4 \text{ Re}_D^{1/6}, \quad (2)$$

For many engineering flows,

$$10^4 < \text{Re}_D < 10^5 \Rightarrow 20 < L/D < 30. \quad (3)$$

The shorter entrance region length for turbulent flows is due to the fact that turbulent mixing rapidly averages the flow speeds across the pipe cross-section.