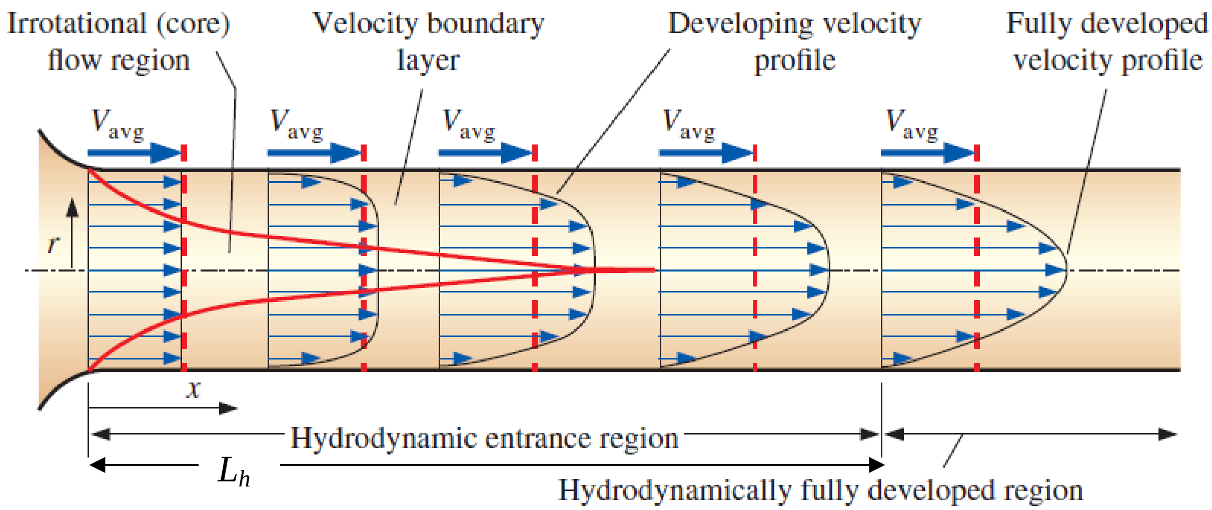
Today, we will:

- Continue discussing the entrance region and the fully developed region for pipe flows
- Discuss the Darcy friction factor, the Moody Chart, and the Colebrook Equation
- Do some example problems – head losses in pipe flows

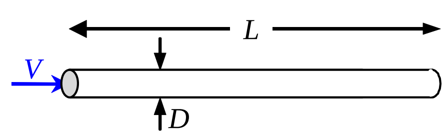
d. The entrance region (continued)



Last time, we said that L_h is a function of (ρ, μ, D, V_{avg}). Dimensional analysis yields:

Example: Hydrodynamic entrance length

Given: Water with $\nu = 1.00 \times 10^{-6}$ m^2/s flows at a steady average speed of 5.70 m/s through a long pipe of diameter 25.4 cm. The pipe is 1.80 km long.



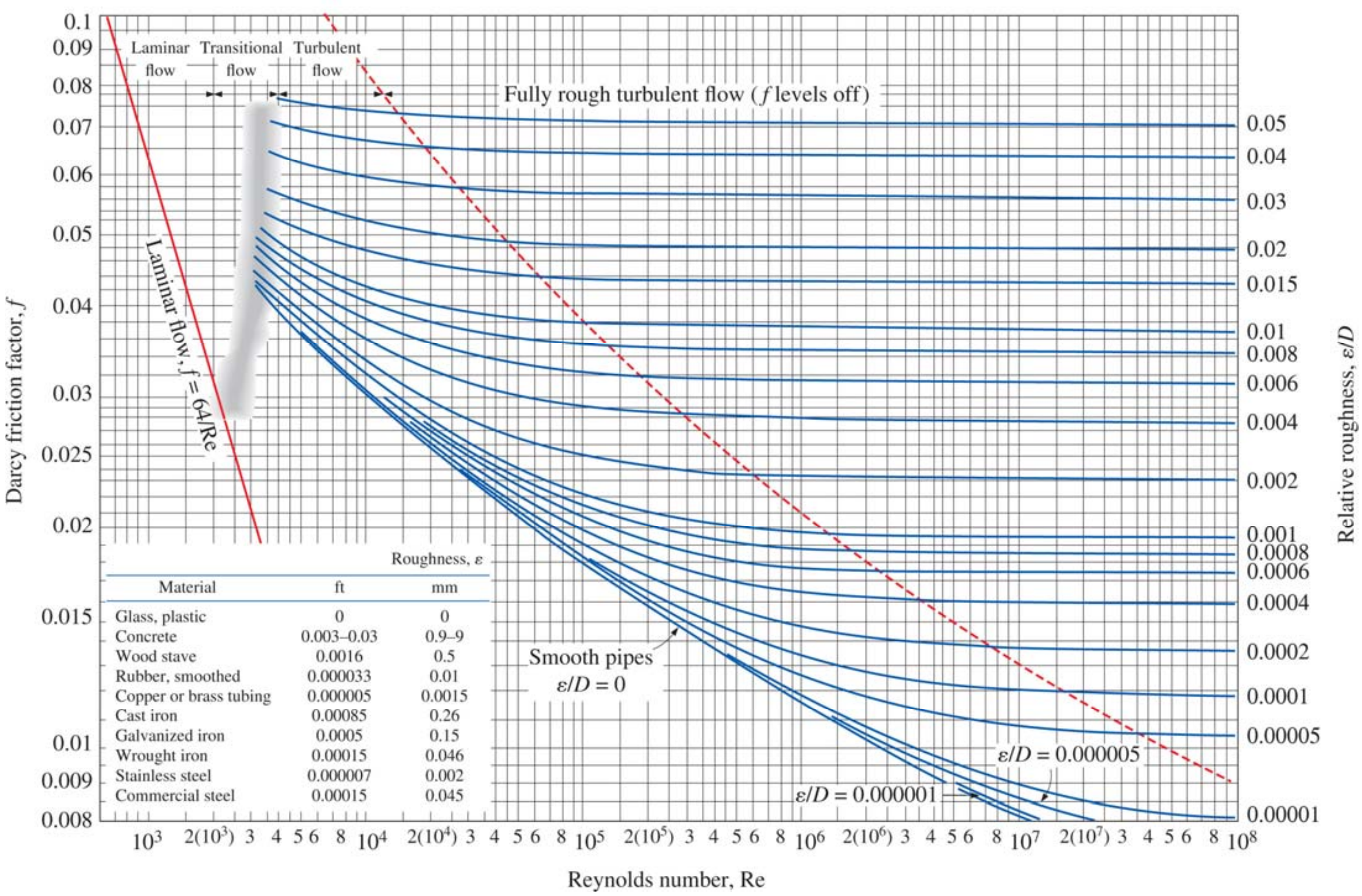
To do: What percent of the pipe length can be considered to be fully developed?

Solution:

B. Fully Developed Pipe Flow

1. Comparison of laminar and turbulent velocity profiles

The Moody Chart (From Appendix, Figure A-12, in the textbook)



Fully Developed Pipe Flow Equations

There are empirical equations available to use in place of the Moody chart. The most useful one (in fact, the equation with which the turbulent portion of the Moody chart is drawn) is:

The Colebrook equation

$$\frac{1}{\sqrt{f}} \approx -2.0\log_{10}\left(\frac{\varepsilon/D}{3.7}+\frac{2.51}{\mathrm{Re}\sqrt{f}}\right)$$

Note: This is $\log_{10}$, not the natural log, ln.

Unfortunately, the Colebrook equation is ***implicit*** in *f* (since *f* appears on both sides of the equation), and the equation must be solved by *iteration*. An approximation to the Colebrook equation was created by Haaland, accurate to ±2% compared to the Colebrook equation, and can be used as a quick estimate or as a "first guess" to begin a Colebrook equation iteration:

The Haaland equation

$$\frac{1}{\sqrt{f}} \approx -1.8\log_{10}\left[\frac{6.9}{\mathrm{Re}}+\left(\frac{\varepsilon/D}{3.7}\right)^{1.11}\right]$$

Also $\log_{10}$, not ln.

Finally, there are some other approximations in the textbook, e.g., those of Swamee and Jain. **In this course, we will always use the Colebrook equation or the Moody chart.**