57:020 EFD Lab 2 and CFD Lab 1 Concepts

1. Background

EFD Lab 2 (**Measurement of Flow Rate, Velocity Profile and Friction Factor in Pipe Flows) will** provide students *hands-on* experience with Pipe stand test facility and modern measurement systems including pressure transducers and Pitot probes and computerized data acquisition using Labview. To measure flow rate, velocity profiles and friction factors in smooth and rough pipes, determine the measurement uncertainties, and compare the results with benchmark data. CFD PreLab 1 (**Simulation of Laminar Pipe Flow**) and CFD Lab 1 (**Simulation and Validation of Turbulent Pipe Flow**) will provide students "hands-on" experiences using the CFD Educational Interface to compute axial velocity profile, centerline velocity, centerline pressure and friction factor. Students will compare simulation results with AFD data for laminar pipe flow, with their own EFD data for turbulent pipe flows.

2. Concepts covered

2.1 Averaged velocity

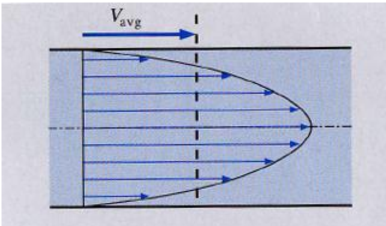
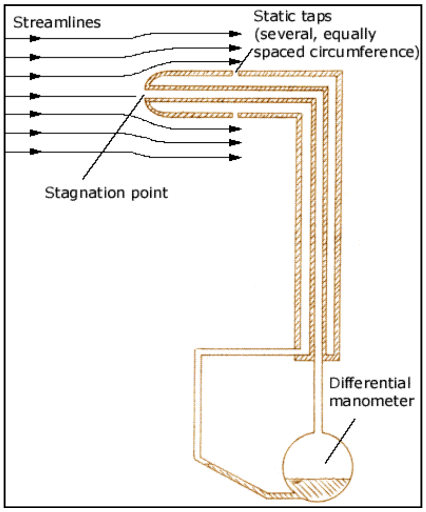


FIGURE 8–2
Average velocity V_{avg} is defined as the average speed through a cross section. For fully developed laminar pipe flow, V_{avg} is half of maximum velocity.

The fluid velocity in a pipe changes from zero at the pipe wall to a maximum at the pipe centerline. By conservation of mass:

$$\dot{m} = \rho V_{avg} A_c = \int_{A_c} \rho u(r) dA_c$$

Where A_c is the cross-section area and $u(r)$ is the velocity profile.



$$p_0 = p_{stat} + \frac{1}{2}\rho V^2, (Bernoulli)$$

$$V = \sqrt{2(p_0 - p_{stat})/\rho}$$

$$V = C\sqrt{2(p_0 - p_{stat})/\rho}$$

The tubes sensing static and stagnation pressures are usually combined into one instrument known as pitot static tube.

2.2 Reynolds number

The ratio of the inertial forces to viscous forces in the fluid is called the **Reynolds number**

$$\mathrm{Re} = \frac{Inertial \quad forces}{Viscous \quad forces} = \frac{V_{avg} D}{\nu} = \frac{\rho V_{avg} D}{\mu}$$

2.3 Laminar vs. turbulent pipe flows

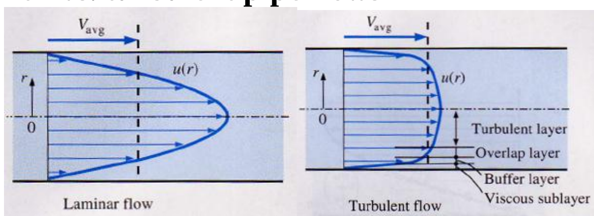


FIGURE 8–24
The velocity profile in fully developed pipe flow is parabolic in laminar flow, but much fuller in turbulent flow.

$\mathrm{Re} \le 2300$	laminar flow
$2300 \le \mathrm{Re} \le 4000$	transitional flow
$\mathrm{Re} \ge 4000$	turbulent flow

For fully developed region in laminar pipe flow, the velocity profile has analytical solution:

$$u(r) = 2V_{avg}\left(1 - \frac{r^2}{R^2}\right)$$

2.4 Developing vs. developed flows

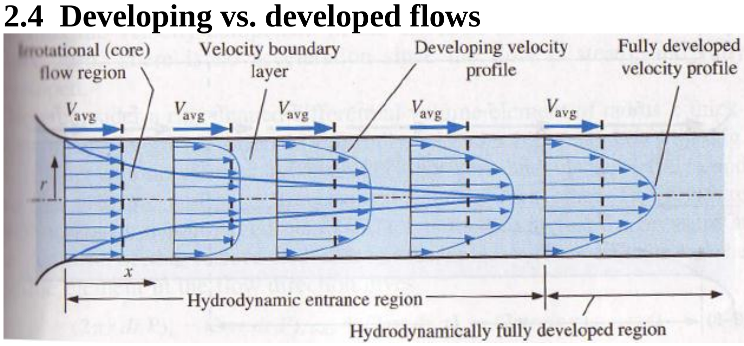
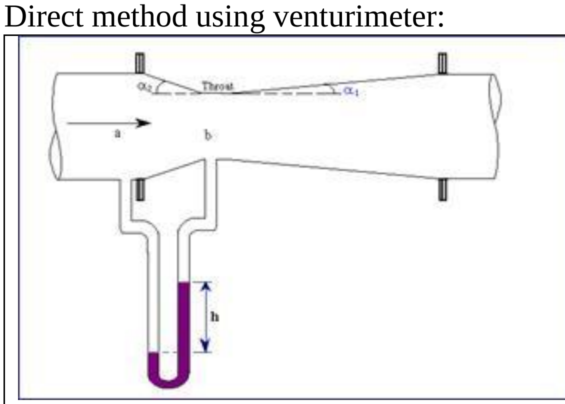


FIGURE 8–8
The development of the velocity boundary layer in a pipe. (The developed average velocity profile is parabolic in laminar flow, as shown, but somewhat flatter or fuller in turbulent flow.)

2.5 Flow rate computation

Direct method using venturimeter:



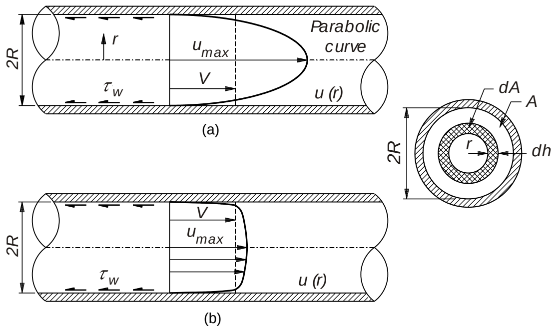
$$\frac{p_a}{\rho g} + \frac{V_a^2}{2g} = \frac{p_b}{\rho g} + \frac{V_b^2}{2g} \quad \mathbf{(Bernoulli)}$$

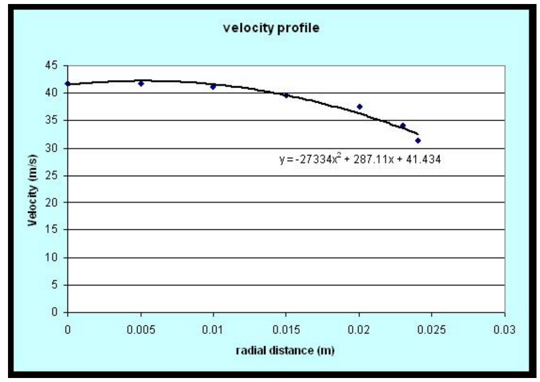
$$\textbf{where, } p_a - p_b = \rho_m g h$$

$$V_a A_a = V_b A_b \,(Continuity)$$

$$Q = \rho A_b V_b$$

Integration method:



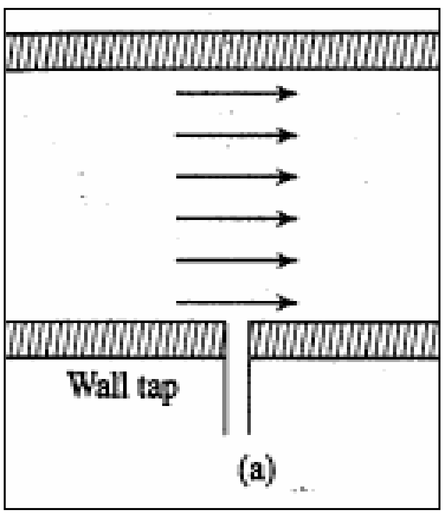


$$Q = 2\pi \int_0^{Rmas} (-2733x^2 + 287.11x + 41.434)x\,dx$$

2.6 Pressure drop

The fluids in pipes are driven by the pressure gradient, which is related to the power requirements of the pump to maintain the flow:

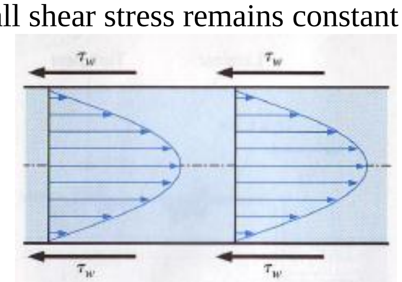
$$\Delta P_L = f\,\frac{L}{D}\,\frac{\rho V_{avg}^2}{2}$$



1) Pressure caused only by molecular collisions is known as **static** pressure.
2) The **pressure tap** is a small opening in the wall of a duct (Fig a.)
3) Pressure tap connected to any pressure measuring device indicates the static pressure. (note: there is no component of velocity along the tap axis).
4) The stagnation pressure at a point in a fluid flow is the pressure that could result if the fluid was brought to rest **isentropically** (i.e., the entire kinetic energy of the fluid is utilized to increase its pressure only).

2.7 Friction factor

In the fully developed flow region of a pipe, the velocity profile does not change downstream, and thus the wall shear stress remains constant as well



Friction factor *f* is $f = \dfrac{8\tau_w}{\rho V_{avg}^2}$, laminar pipe flow: $f = \dfrac{64}{\text{Re}}$