ENE 206 – Fluid Mechanics

WEEK 11

- ## Introduction

➢ **Closed conduit:** A closed conduit is referred to as a pipe if it has a circular cross section and a duct when its cross section is not round. Most of the conduits, which are used to transport a fluid from one location to another, are circular. Water pipes are the typical ones. The qualitative difference between the nature of the laminar and turbulent flows in closed conduits are discussed in this lesson.

- ## Laminar and turbulent flow in pipes

➢ Qualitative difference between the nature of the laminar and turbulent flows are demonstrated by the classical Reynolds experiment due to Osborne Reynolds (1883). In this experiment, a thin filament of dye, which is injected at the centerline of the pipe, allows visual observation of the flow. Following observations are made depending on the volumetric flow rate of the flow in the pipe as demonstrated in Figure 8.1.:

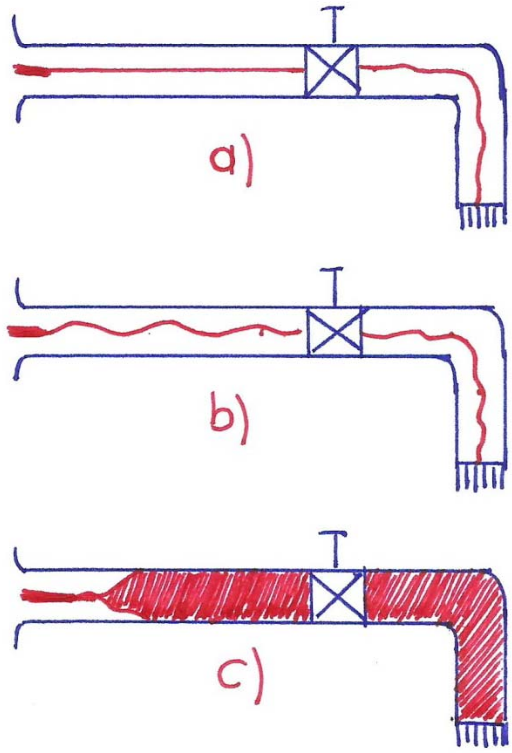

Figure 8.1. Different flow modes in the Reynolds experiment

i) At a very low volumetric flow rate adjusted by the valve at the end of the transparent pipe, a well-defined straight line along the centerline of the transparent pipe is observed as seen in Figure 8.1a. This mode of flow is known as laminar flow.

ii) When the flow rate is increased the dye streak remains straight up to a certain level of flow rate. Beyond a certain volumetric rate, Reynolds number based on the pipe diameter, $\mathrm{Re}_d \; \rho V d/\mu$ exceeds a critical value, transitional nature of the flow occurs as seen in Figure 8.1b.

iii) If the volumetric flow rate is further increased, the dye filament spreads uniformly throughout the pipe as shown in Figure 8.1c. In this mode, the flow is known as turbulent flow. Every fluid particle follows a random path throughout the pipe such that the average motion is along the axis of the pipe.

- Transition from laminar to turbulent flow is, of course, a function of the Reynolds number and occurs at Reynolds number of 2000 to 3000 in pipes. Variation of fluid velocity with time at a point in the pipe can be shown in Figure 8.2.

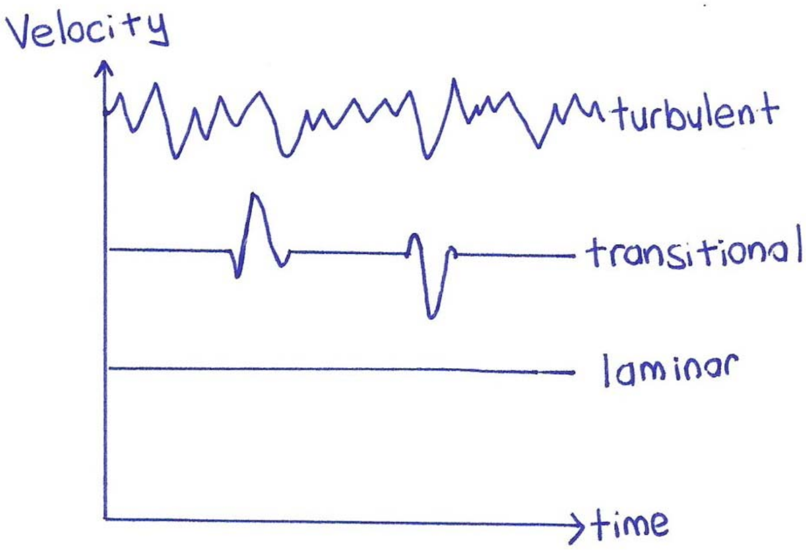

Figure 8.2. Variation of fluid velocity with time at a point in the pipe

- ## Development of the flow in the pipe

- **Boundary layer:** The region, where the viscous affects are important.

- **Entrance region**: It is a region where the flow develops. At the end of the entrance region the flow is no longer function of the flow direction and the radius of the pipe determines the velocity profile. Its length also affected by the nature of the flow. At the entrance region the fluid accelerates or decelerates.

- **Fully developed flow**: At the end of the entrance region, where the fully developed region happens, the velocity profile is only function of the distance from the centerline of the pipe and independent of the distance along the pipe. Hence, the velocity is the same at any cross section of the pipe. Although this fact is true whether the flow is laminar or turbulent, the velocity profile and other flow properties are quite different for these two kinds of flow.

- Once the velocity profile is known, then it is possible to calculate the other useful information such as the pressure drop, head loss, etc.

• The pressure or head losses in pipes:

- The changes in the pressure along the flow direction in the pipe are due to:
  i) changes in elevation,
  ii) changes in the flow velocity due to the changes in the flow cross-sectional area
  iii) viscous effects.

- **Major head losses**:
  It is due to the flow in closed conduits of constant diameter.

- **Major head loss in the laminar flow:**
  The pressure drop, Δp in steady, laminar and fully-developed flow of an incompressible fluid is computed as:

$$\Delta p = f\frac{L}{d}\frac{\rho V^2}{2} \qquad (8.1)$$

where f is the friction factor, L is the length of the pipe, d is the diameter of the pipe, ρ is the fluid density, and V is the average velocity in the pipe. the friction factor can be also determined as follows:

$$f = \frac{64}{\mathrm{Re}_d} \qquad (8.2)$$

The pressure loss, which is given in eqn. 8.1. can now be expressed in terms of the head loss, h_f as :

$$h_f = f\frac{L}{d}\frac{V^2}{2g} \qquad (8.3)$$

In the above equation is known as the Darcy-Weisbach equation.

- **Major head loss in the turbulent flow**:
  Experiments show that the head loss, due to the viscous effects in turbulent flow is:

$$h_f = f\left(\mathrm{Re}_d, \frac{\varepsilon}{d}\right)\frac{L}{d}\frac{V^2}{2g} \qquad (8.4)$$

where friction factor depends on the surface roughness, ε diameter and Reynolds number.

- **Minor head losses**:
  The minor head losses are proportional to the velocity head of the fluid, as it flows though sudden enlargements, gradual enlargements, exits. The experimental values for head losses are usually reported in terms of a head loss coefficient as follows:

$$h_f = k\frac{V^2}{2g} \qquad (8.5)$$

where h_f is the minor head loss, k is the head loss coefficient, and V is the average velocity of the fluid flow in the vicinity where the minor head loss occurs. Minor head losses in variable area parts can be classified as follows.

i) sudden enlargement loss

ii) exit loss

iii) gradual enlargement loss

iv) sudden contraction loss

v) entrance loss

vi) gradual contraction loss

- **References**

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