Flow in Closed Conduits (Pipes)

In turbulent flow there is considerable mixing between layers. A dye injected into the

7.0 PARAMETERS INVOLVED IN THE STUDY OF FLOW THROUGH CLOSED CONDUITS

In the previous chapter, the energy level changes along the flow was discussed. The losses due to wall friction in flows was not discussed. In this chapter the determination of drop in pressure in pipe flow systems due to friction is attempted.

Fluids are conveyed (transported) through closed conduits in numerous industrial processes. It is found necessary to design the pipe system to carry a specified quantity of fluid between specified locations with minimum pressure loss. It is also necessary to consider the initial cost of the piping system.

The flow may be laminar with fluid flowing in an orderly way, with layers not mixing macroscopically. The momentum transfer and consequent shear induced is at the molecular level by pure diffusion. Such flow is encountered with very viscous fluids. Blood flow through the arteries and veins is generally laminar. Laminar condition prevails up to a certain velocity in fluids flowing in pipes.

The flow turns turbulent under certain conditions with macroscopic mixing of fluid layers in the flow. At any location the velocity varies about a mean value. Air flow and water flow in pipes are generally turbulent.

The flow is controlled by (i) pressure gradient (ii) the pipe diameter or hydraulic mean diameter (iii) the fluid properties like viscosity and density and (iv) the pipe roughness. The velocity distribution in the flow and the state of the flow namely laminar or turbulent also influence the design. Pressure drop for a given flow rate through a duct for a specified fluid is the main quantity to be calculated. The inverse—namely the quantity flow for a specified pressure drop is to be also worked out on occasions.

The basic laws involved in the study of incompressible flow are (i) Law of conservation of mass and (ii) Newton's laws of motion. Besides these laws, modified Bernoulli equation is applicable in these flows.

7.4 FEATURES OF LAMINAR AND TURBULENT FLOWS

In laminar region the flow is smooth and regular. The fluid layers do not mix macroscopically (more than a molecule at a time). If a dye is injected into the flow, the dye will travel along a straight line. Laminar flow will be maintained till the value of Reynolds number is less than of the critical value (2300 in conduits and $5 \times 10^5$ in flow over plates). In this region the viscous forces are able to damp out any disturbance.

The friction factor, $f$ for pipe flow defined as $4 \tau_w / (\rho u^2 g)$ is obtainable as $f = 64 / Re$ where $\tau_w$ is the wall shear stress, $u$ is the average velocity and Re is the Reynolds number. In the case of flow through pipes, the average velocity is used to calculate Reynolds number.

The flow will quickly mix with the fluid. Most of the air and water flow in conduits will be turbulent. Turbulence leads to higher frictional losses leading to higher pressure drop. The friction factor is given by the following empirical relations.

$$f = 0.316/Re^{0.25} \quad \text{for } Re < 2 \times 10^4$$

$$f = 0.186/Re^{0.2} \quad \text{for } Re > 2 \times 10^4$$
These expressions apply for smooth pipes. In rough pipes, the flow may turn turbulent below the critical Reynolds number itself. The friction factor in rough pipe of diameter $D$, with a roughness height of $\varepsilon$, is given by

$$f = 1.325/\left[\ln \left(\left(\varepsilon/3.7D\right) + 5.74/\text{Re}\right)\right]$$

(7.4.3)

7.8 Darcy-Weisbach Equation for Calculating Pressure Drop

In the design of piping systems the choice falls between the selection of diameter and the pressure drop. The selection of a larger diameter leads to higher initial cost. But the pressure drop is lower in such a case which leads to lower operating cost. So in the process of design of piping systems it becomes necessary to investigate the pressure drop for various diameters of pipe for a given flow rate. Another factor which affects the pressure drop is the pipe roughness. It is easily seen that the pressure drop will depend directly upon the length and inversely upon the diameter. The velocity will also be a factor and in this case the pressure drop will depend in the square of the velocity (refer Bernoulli equation).

Hence we can say that

$$hL = hf = f(D/L)(V^2/2g)$$