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(Storage and transportation of petroleum products)

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Lecture (3)

Fluid Flow in Pipes

We will be looking here at the flow of real fluid in pipes – *real* meaning a fluid that possesses viscosity hence loses energy due to friction as fluid particles interact with one another and the pipe wall. Newton's law of viscosity gives the shear stress induced in a fluid flowing near a boundary:

$$\tau \propto du/dy$$

This tells us that the shear stress, τ, in a fluid is proportional to the velocity gradient - the rate of change of velocity across the fluid path. For a "Newtonian" fluid, we can write:

$$\tau = \mu \, du/dy$$

Where the constant of proportionality, μ, known as the coefficient of viscosity (or simply viscosity). Recall also that flow can be classified into one of two types, **laminar** or **turbulent** flow (with a small transitional region between these two). The non-dimensional number, the Reynolds number, Re, is used to determine which type of flow occurs:

$$\mathrm{Re} = \rho u d / \mu$$

For a pipe

Laminar flow: Re < 2000

Transitional flow: 2000 < Re < 4000

Turbulent flow: Re > 4000

It is important to determine the flow type as this governs how the amount of energy lost to friction relates to the velocity of the flow. And hence how much energy must be used to move the fluid.

Q: - Derive Darcy or Weisbach Equation
Q: - Derive General Equation for head loss in pipe due to friction
Q: - Derive an Equation for pressure drop along circular pipe

Consider a cylindrical element of incompressible fluid flowing in the

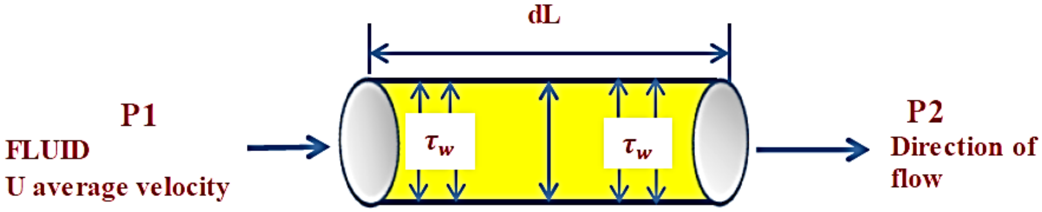


Figure: Element of fluid in a pipe

The pressure at the upstream end, 1, is p, and at the downstream end, 2, the pressure has fallen by Δp to (p-Δp).

The driving force due to pressure (F = Pressure x Area) can then be

Written driving: Force = Pressure force at 1 - pressure force at 2

$$pA \;-(p-\Delta p)A = \Delta pA = \Delta p \times \frac{\pi d^2}{4}$$

The retarding force is that due to the shear stress by the walls
= shear stress × area over which it acts
= τw × area of pipe wall
= τw π *dL*
As the flow is in equilibrium,

$$\textit{driving force} = \textit{retarding force}$$

$$\Delta p \times \frac{\pi d^2}{4} = \tau_w \pi\, dL$$

$$\Delta p = \frac{4\tau_w L}{d} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

This equation (1) giving an expression for pressure loss in a pipe in terms of the pipe diameter and the shear stress at the wall on the pipe.

$$\Delta p = \frac{4\tau_w L}{d} \qquad \text{Multiply and divided} \quad \frac{\rho U^2/2}{\rho U^2/2}$$

$$\Delta p = \frac{8\tau_w}{\rho U^2} \times \frac{L}{D} \times \frac{\rho U^2}{2}$$

$$\Delta p = 8j_F \times \frac{L}{D} \times \frac{\rho U^2}{2}$$

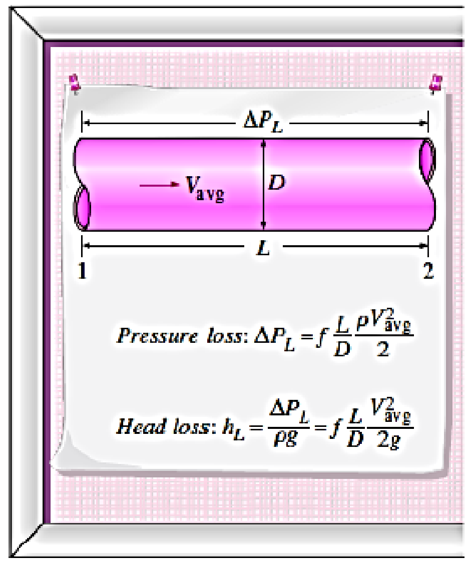
$$j_{F\ Moday\ fraction\ factor} = \frac{1}{2f(fanning\ fraction, Darcy-Weisbach} = \frac{\tau_w}{\rho U^2}$$

$$\Delta p = 4f \times \frac{L}{D} \times \frac{\rho U^2}{2}$$

but $\Delta p = \rho \times g \times \Delta h$

$$\Delta h = 4f \times \frac{L}{D} \times \frac{U^2}{2g}$$

$$\Delta p = 4f \times \frac{L}{D} \times \frac{\rho U^2}{2g_c}$$



SI readers may ignore g_c in all equations, if they wish.

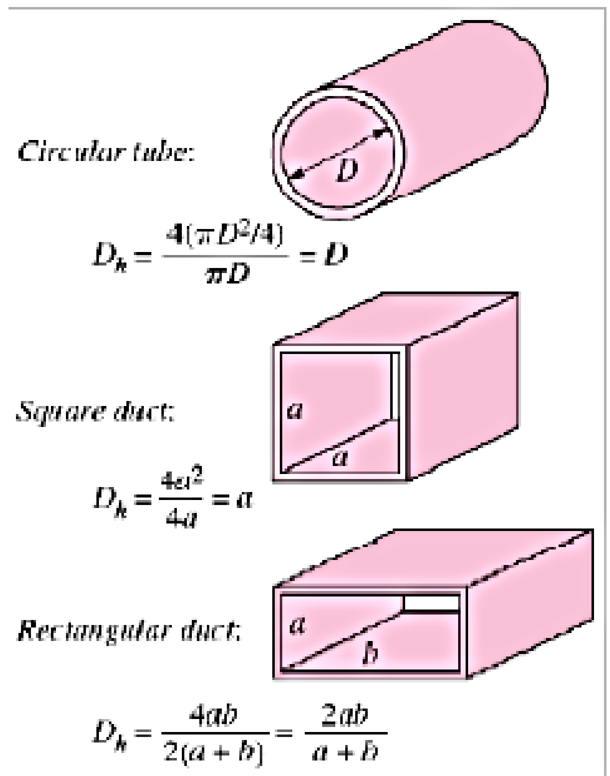
When a fluid flows in a pipe, some of its mechanical energy is dissipated by friction. The ratio of this frictional loss to the kinetic energy of the flowing fluid is defined as the Fanning friction factor, ft. Thus

$$f_F = \left(\frac{\text{frictional drag force} / \text{area of pipe surface}}{\text{kinetic energy/m}^3 \text{ of fluid}} \right) = \frac{\tau_w}{\rho \frac{u^2}{2}} \quad [-]$$

معلومة مهمة :- اذا اعطاني shear stress τ او R بسؤال ال friction معناه نحسب
Jf from $J_f = \frac{\tau}{\rho \bar{u}^2}$

For flow through noncircular pipes, the Reynolds number is based on the **hydraulic diameter**

$$D_h = \frac{4A_c}{p}$$



$$d_H = 4 * \frac{\text{cross sectional area for fluid flow}}{\text{wetted perimeter for fluid flow}}$$

Table: Flow Quantities, Reynolds Number, and Friction Factor

Flow Quantity	Symbol and Equivalent	Typical Units: Common	Typical Units: SI
Linear	u	ft/sec	m/sec
Volumetric	$Q = uA = \pi D^2 u/4$	cuft/sec	m^3/sec
Mass	$\dot{m} = \rho Q = \rho A u$	lb/sec	kg/sec
Weight	$\dot{w} = \gamma Q = \gamma A u$	lbf/sec	N/sec
Mass/area	$G = \rho u$	lb/(sqft)(sec)	kg/m* sec
Weight/area	$G_\gamma = \gamma u$	lbf/(sqft)(sec)	N/m^2 sec

Reynolds Number (with $A = \pi D^2/4$)

$$\mathrm{Re} = \frac{Du\rho}{\mu} = \frac{Du}{\nu} = \frac{DG}{\mu} = \frac{4Q\rho}{\pi D\mu} = \frac{4\dot{m}}{\pi D\mu} \quad (1)$$

Friction Factor

$$f = \frac{\Delta P}{\rho} \Big/ \left(\frac{L}{D}\frac{u^2}{2g_c}\right) = 2g_c D\Delta P/L\rho u^2 = 1.6364 \Big/ \left[\ln\left(\frac{0.135\varepsilon}{D} + \frac{6.5}{\mathrm{Re}}\right)\right]^2 \quad (2)$$

(Round's equation)

$$\frac{\Delta P}{\rho} = \frac{L}{D}\frac{u^2}{2g_c} f = \frac{8LQ^2}{g_c\pi^2 D^5} f = \frac{8L\dot{m}^2}{g_c\pi^2\rho^2 D^5} f = \frac{LG^2}{2g_c D\rho^2} f \quad (3)$$

D = in., $\dot{m}$ = lb/hr

Q = cuft/sec, μ = cP

ρ = specific gravity

$$\mathrm{Re} = \frac{6.314\dot{m}}{D\mu} = \frac{1.418(10^6)\rho Q}{D\mu} \quad (4)$$

$$\frac{\Delta P}{L} = \frac{3.663(10^{-9})\dot{m}^2}{\rho D^5} f, \quad \text{atm/ft} \quad (5)$$

$$= \frac{5.385(10^{-8})\dot{m}^2}{\rho D^5} f, \quad \text{psi/ft} \quad (6)$$

$$= \frac{0.6979\rho Q^2}{D^5} f \quad \text{psi/ft} \quad (7)$$