Fluid Mechanics - Course 223

FRICTION IN FLUID FLOW

In fluid flow, where liquids are concerned, we shall consider the flow to be incompressible. That is, there is no change of volume with pressure. The total energy that a fluid possesses when the flow is incompressible is made up of the following energies:

(a) Potential Energy - energy due to position.
(b) Pressure Energy - energy due to pressure.
(c) Kinetic Energy - energy due to motion.

In level 3 we saw that we could express the total energy, a fluid possessed, in a mathematical form:

$$E_T = E_P + E_K + E_{PR}$$

$$= gh + \frac{V^2}{2} + \frac{P}{\gamma}$$

where these values are in Joules/kg.

In an ideal situation the total energy at one point in the system is equal to the total energy at another point in the system. In practice this is not the case. Some of the energy possessed by the fluid is converted into low grade heat, due to fluid internal friction and pipe friction. This heat energy is considered lost because there is no easy method, whereby the heat energy may be reconverted into PE, KE or Pressure Energy.

The energy loss appears as a decrease in pressure energy and has to be replaced. This is done by a pump, where the fluid is given high KE in the impeller which is converted into pressure energy in the pump volute.

It should be understood that any changes in KE, PE or friction loss - all appear as a change in static pressure.

There are several factors upon which the friction loss depends. In practice, there are very few laminar flow conditions and turbulent flow is the most frequently encountered condition.

The friction loss in turbulent flow varies as follows:

(a) Directly with the length of the pipe.
(b) Almost as the square of the velocity.
(c) Almost inversely as the diameter.

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(c) Almost inversely as the diameter.
(d) Depends upon the surface roughness of the interior pipe wall.
(e) Depends upon the fluid properties of density and viscosity.
(f) Is independant of the pressure.

By now, it has become obvious that friction is a complicated function with many variables and we will now have a closer look to determine how we may account for friction mathematically.

We must be able to select a factor correctly so that it accounts for the system pressure loss due to friction. This factor, called the "friction factor" is not constant but varies with

velocity	V
diameter	D
density	ℓ
dynamic viscosity	μ and

certain characteristics of the wall roughness, signified by ε where ε is a measure of the SIZE of the roughness projections and has the dimensions of length.

Thus the friction factor "f" is a function of (V, D, ℓ, μ, ε). Since "f" is a dimensionless quantity, the dependent variables must be arranged to present a dimensionless ratio.

In a smooth pipe $\varepsilon = 0$ which leaves "f" dependant upon the first four quantities. These quantities may only be arranged in one way to give a dimensionless ratio, $\frac{VD\ell}{\mu}$ - which as you will recognize is Reynolds' Number.

For rough pipes ε may be made dimensionless by dividing by the diameter D. Thus in the general case "f" is a function of $(\frac{VD\ell}{\mu}, \frac{\varepsilon}{D})$.

In rough pipes, ε/D is called the "relative roughness" Charts of relative roughness against pipe diameter are available to determine the friction factor at fully turbulent flow. Figure 3.1 shows a typical chart.

Experimental results have allowed the friction factor to be expressed as a function of the relative roughness and the Reynolds' Number. This chart is called a "Moody Diagram" and is illustrated in Figure 3.2.

Relative Roughness of Pipe Materials and Friction Factors For Complete Turbulence[18]

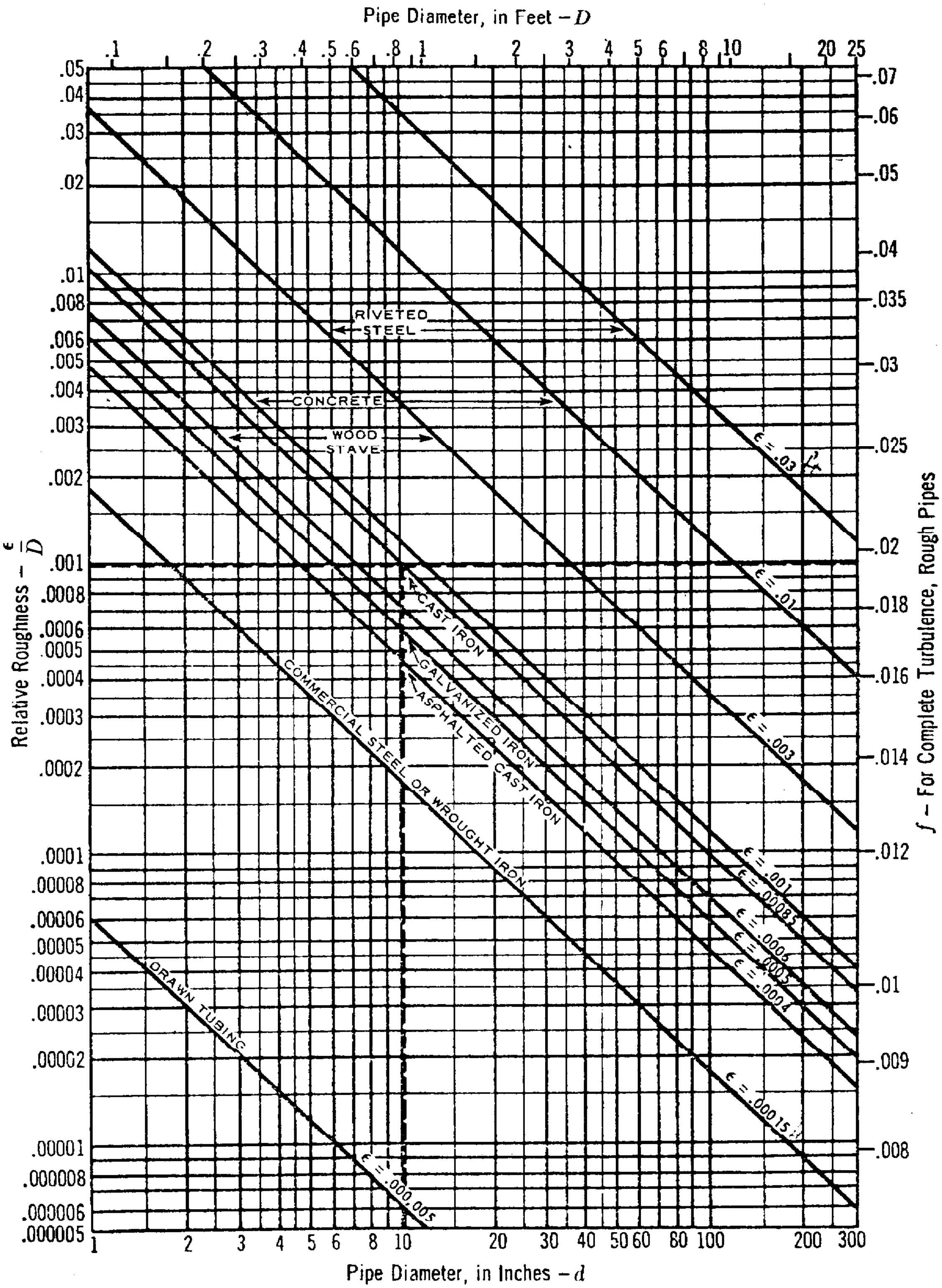

Figure 3.1

Friction Factors for Any Type of Commercial Pipe[18]

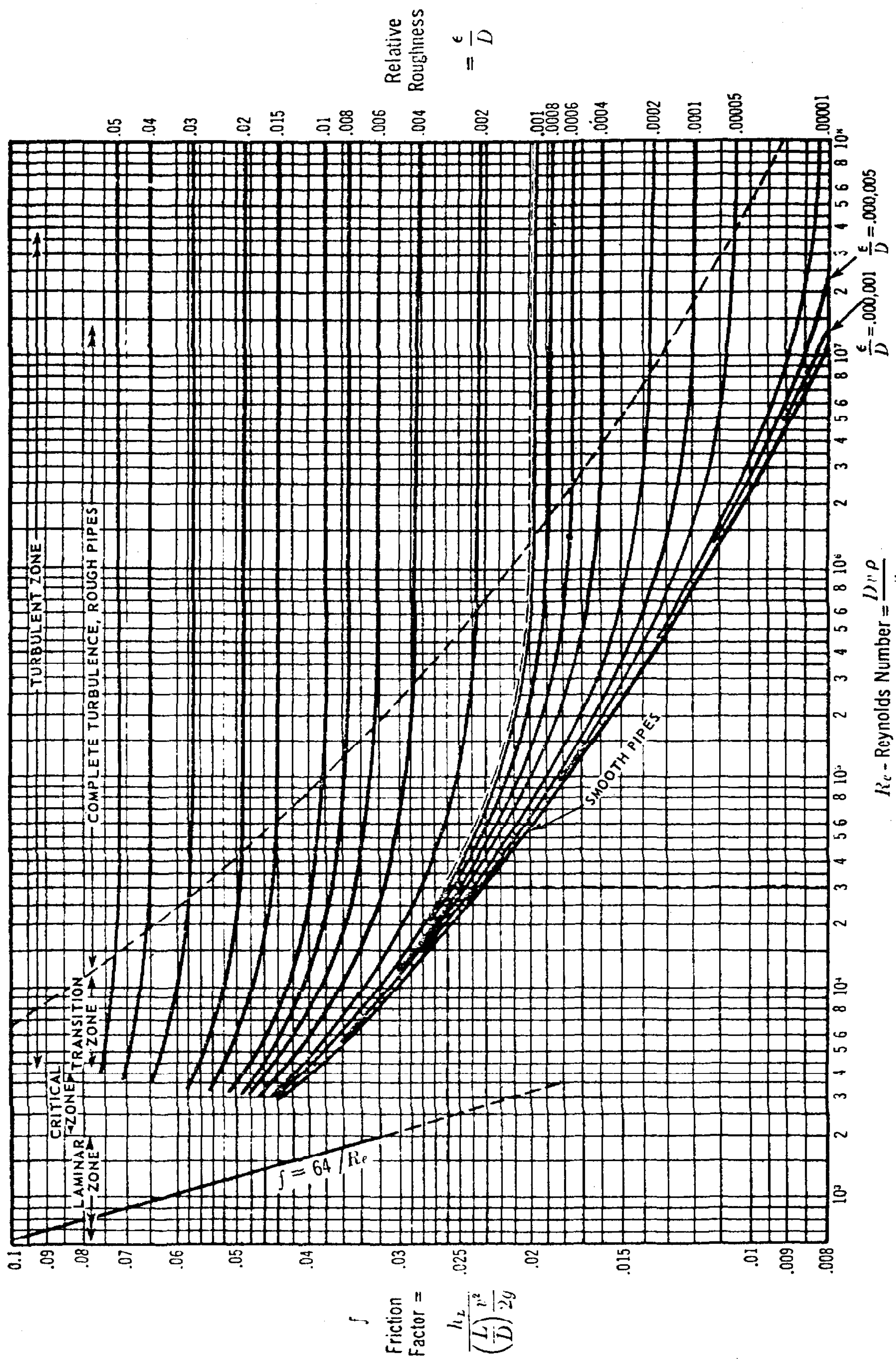

Figure 3.2

We will be using these charts later in the course - Figures 3.1 and 3.2.

We have determined a means of accounting for friction. We still have to work out how much energy will be lost due to friction.

The energy loss, per unit mass of liquid, flowing in a circular pipe is as follows:

$$E_{LOSS} = \frac{fL}{D} \cdot \frac{V^2}{2} \qquad \text{J/kg}$$

where E_{LOSS} = loss in J/kg, due to frictional resistance over a length L metres.

D = diameter of pipe in metres.

$\frac{V^2}{2}$ = kinetic energy in J/kg.

"f" = the dimensionless friction factor found from the Moody diagram.

There are three simple pipe-flow cases that are basic to the solutions of more complex problems.

I Given Q, L, D, ν, E find E_{LOSS}.

II Given E_{LOSS}, L, D, ν, E find Q.

III Given E_{LOSS}, Q, L, ν, E find D.

In each of these cases the following are used to determine the unknown quantity.

(a) $E_{LOSS} = \frac{\text{"f"}L}{D} \cdot \frac{V^2}{2}$ J/kg.

(b) Continuity Eqn $Q_V = A_1 \times V_1 = A_2 \times V_2$

(c) Moody diagram.

Examples

1. Determine the absolute and relative roughness and friction factor for a fully turbulent flow in a 10" cast iron pipe.

   Looking at Figure 3.1 - the pipe diameter may be found at the bottom. Follow the line upwards until it intersects the "cast iron" line. The friction factor "f" is read off on the RH scale and the relative roughness off the LH scale. The absolute roughness is marked on the "cast iron" line at the bottom RH corner.

$$\text{Thus} \quad \varepsilon = 0.00085$$
$$\varepsilon/D = 0.001$$
$$\text{"f"} = 0.0196.$$

2. Determine the friction factor for the pipe in the previous question, when the flow gives a Reynolds' Number of 30,000.

Looking at Figure 3.2, relative roughness is on the RH scale. Find the line where $\varepsilon/D = 0.001$. Follow this line to the left until it intersects with the vertical line, representing Reynolds' Number = 3×10^4. Read across to the LH scale to determine the friction factor.

Thus friction factor "f" = 0.026.

3. Determine the energy loss due to the flow of 12 m^3/min of oil in a steel pipe. The 12" SCH 40 pipe is 300 metres long. $\mu = 1 \times 10^{-1}$ N.S./m^2; d = 0.86.

Velocity = Flowrate/Area

Area from SCH 40 pipe chart (Fig 3.3) = $\underline{722.1 \times 10^{-4}\ m^2}$

$$\text{Thus velocity} = \frac{12}{60 \times 722.1 \times 10^{-4}} = 2.77 \text{ m/s.}$$

$$RE = \frac{VD\ell}{\mu} = \frac{2.77 \times 12 \times 2.54 \times 10^{-2} \times 1000 \times 0.86}{1 \times 10^{-1}}$$

$$= \underline{\underline{7261}}$$

From Figure 3.1 $\varepsilon/D = 0.00015$.

From Figure 3.2 using $\varepsilon/D = 0.00015$ and RE = 7261
"f" = $\underline{\underline{0.033}}$.

$$\text{Thus} \quad E_{LOSS} = \frac{fLV^2}{2D}$$

$$= \frac{0.033 \times 300 \times 2.77^2}{12 \times 2.54 \times 10^{-2} \times 2}$$

$$= \underline{\underline{124}} \text{ J/kg.}$$

4. What is the minimum power required to maintain flow in the previous question?

$E_{LOSS} = 124$ J/kg

$Q_V = 12$ m^3/min

$Q_M = \ell \times A \times V = \ell \times Q_V$

$$= \frac{0.86 \times 1000 \times 12}{60}$$

$$= \underline{172} \text{ kg/s}$$

Thus $J/s = \text{watts} = \text{mass flow} \times E_{LOSS}$

$$= 170 \times 124$$

$$= \underline{\underline{21.08}} \text{ kW}$$

5. Water at 20°C flows through a 10" SCH 80 pipe. $\varepsilon = 3$ mm. E_{LOSS} for 1000 m length is 1500 J/kg. Determine the flow.

In this case both the velocity and the friction factors are unknown. We know ε/D and can obtain a rough value of "f" from Figure 3.1. Using this value, in the energy loss equation, we may obtain RE and thus be able to get a closer value of "f". Having found "f" we can determine V and Q_V.

Relative roughness $\varepsilon/D = \dfrac{3 \times 10^{-3}}{9.56 \times 2.54 \times 10^{-2}} = \underline{0.012}$

From Figure 3.1 for a 10" pipe with $\varepsilon/D = 0.012$

$$f = \underline{0.039}$$

Using the E_{LOSS} eqn.

$$E_{LOSS} = \frac{fLV^2}{2D}$$

$$V^2 = \frac{E_{LOSS} \times 2D}{f \times L}$$

$$= \frac{1500 \times 2 \times 9.56 \times 2.54 \times 10^{-2}}{0.039 \times 1000}$$

$$= 18.68$$

$$\text{Thus } V = \underline{\underline{4.32}} \text{ m/s}$$

5. Continued.

From table C2 - $\nu = 1.007 \times 10^{-6}$

$$RE = \frac{VD}{\nu} = \frac{4.32 \times 2.54 \times 10^{-2} \times 9.56}{1.007 \times 10^{6}}$$

$$= \underline{\underline{1.04 \times 10^{6}}}$$

Using the relative roughness and the RE with Figure 3.2 check the value of "f" = 0.038. It if agrees within two decimal places this is accurate enough.

$$Q_V = A \times V$$

$$= 463.5 \times 10^{-4} \times 4.32$$

$$= \underline{\underline{0.2}} \ m^3/s$$

ASSIGNMENT

1. Show that the expression $\frac{VD\ell}{\mu}$ = RE is dimensionless.

2. Show that $E_{LOSS} = \frac{fLV^2}{2D}$ is in J/kg.

3. What is the friction factor "f"? Upon what parameters does the friction factor depend?

4. Determine the power required to pump water at 15 m^3/min and 15°C along a steel 16" SCH 80 pipe which is 500 metres long.

5. Oil flows through a 10" SCH 40 pipe which is 600 metres long, the energy loss is 1200 J/kg. d = 0.86, $\mu = 1 \times 10^{-1} \frac{N.S.}{m^2}$. Calculate the flowrate.

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