Fundamentals of Liquid Flow Measurement

An Online Continuing Education Course for Engineers

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Fundamentals of Liquid Flow Measurement

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This course covers the basic methods used to measure the flow rate of liquids in commercial, municipal and industrial applications. It is intended to be an introductory course and somewhat broad in discussing a range of current methods of measurement such as differential pressure flow meters, vortex shedding flow meters, ultrasonic flow meters, magnetic flow meters, Coriolis flow meters, positive displacement meters, and turbine flow meters; as well as open-channel flow meters, such as weirs and flumes. In addition, we will discuss applications using these meters, the advantages and disadvantages of each; and conditions that can influence flow meter accuracy, repeatability and reliability.

All of the flow meters that we will be discussing in this course are commercially available, calibrated instruments that use various methods to indirectly measure the velocity of a flowing liquid within a closed system such as pipe, or open channel flow, such as in a culvert or trough.

Flow Characteristics in Filled Pipe Systems

One cannot discuss flow measurement, select or specify the proper flow meter without an understanding of the characteristics of liquid flow within a filled pipe system, and its related terminology.

The primary objective of a stationary (fixed-position) flow measurement instrument is to determine the velocity of the liquid that is passing by it. Once the velocity of the liquid and the inside diameter (I.D.) or cross-sectional "free area" of the pipe or conduit through which it is flowing are known, one can easily calculate the volumetric flow rate of the liquid.

For example, if the velocity of water flowing through a 1-inch I.D. hose is measured to be 30 feet per minute, then we can determine the volumetric flow rate of the water that is passing through the hose in gallons-per-minute using the following calculation:

Volumetric Flow Rate (GPM) = cross-sectional area x fluid velocity where:

GPM = gallons per minute diameter (d) = 1 inch

one gallon of water = 231 cubic inches of water

velocity (v) = 60 feet/min. x 12 inches/foot = 720 inches per minute the equation becomes:

GPM = 720 inches/min. x (πr2) x 1 gallon/231 cubic inches =
720 x (3.14 x 0.52) x 0.004 = <u>2.26 gallons per minute</u>

The volumetric rate of water flowing out of the hose will be 2.26 gallons per minute if the measured flow velocity of the water is 720 feet per minute.

Friction Loss in Pipe

Friction loss of fluid flow within a filled pipe refers to the friction that occurs between the flowing liquid that contacts the stationary inside surfaces of the pipe as it flows.

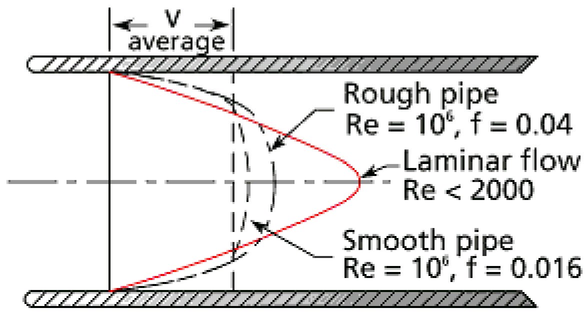


Figure No. 1 – Liquid Flow Profile in Pipe

The most accurate method of estimating frictional head loss in steady pipe flow due to friction is generally considered to be the Darcy-Weisbach Equation (developed by Henry Darcy and later refined by Julius Weisbach in 1845) used in conjunction with the Moody Diagram (developed by L.F. Moody in 1944) .

The Darcy-Weisbach Equation is:

$$\Delta h_f = f \frac{L}{D} \frac{V^2}{2g}$$

where:

h_f = friction head

Note: the term "head" is an engineering unit of hydraulic pressure used commonly in discussing liquid statics and dynamics. "Head" is the pressure equivalent produced by a stationary column of water, typically measured in inches or feet of head. One foot of head is equal to 0.4335 psi.

f = coefficient of friction (obtained from the Moody Chart below) L = length of pipe
V = liquid velocity
D = inside pipe diameter (I.D.)
g = gravity (32 ft/sec^2)

Another formula often used to calculate head (pressure) loss due to friction is the Hazen-Williams Equation that was developed in

$$P_d = \frac{4.52\ Q^{1.85}}{C^{1.85}\ d^{4.87}}$$

where:

P_d = pressure drop (psi per foot)

Q = volumetric flow rate (gallons per minute)

C = friction loss coefficient (the greater the C factor, the smoother the pipe)

d = inside diameter of pipe (inches)

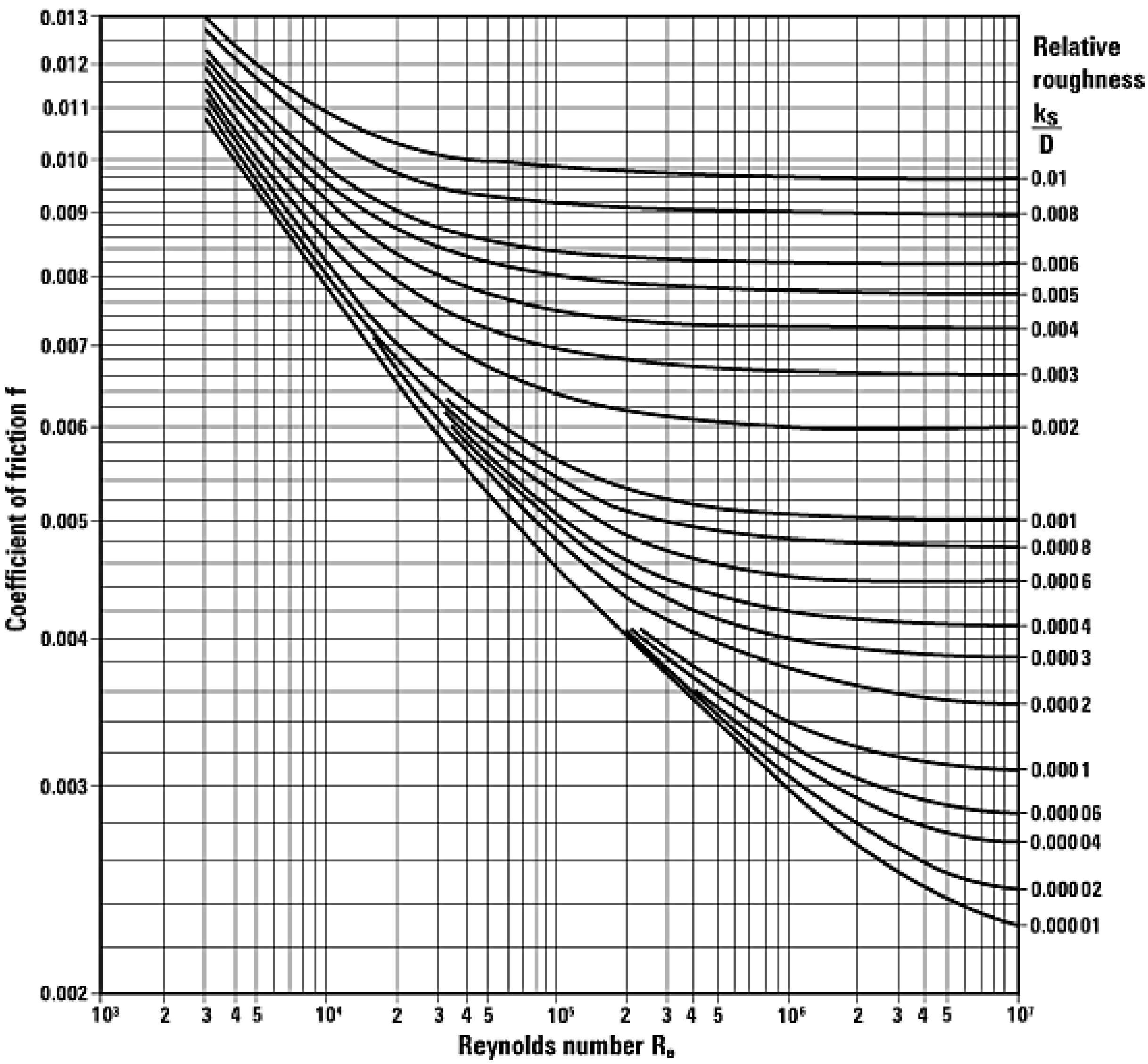


Chart No. 1 – Moody Chart

Examples of the relative roughness of the interior wall of some of the more common pipe materials are as follows:

- Concrete 0.001 to 0.01
- Cast Iron 0.00085
- Commercial Steel 0.00015
- Drawn Copper Tubing 0.0000005

(Source: Pump Handbook, 2nd Ed., 1986, Igor Karassik, McGraw-Hill Book Co.)

Liquid Turbulence in Pipes and Reynolds Number

The accuracy of many of the flow meters that we will be discussing in this course is directly affected by turbulence of the liquid. Therefore, it is important that we determine whether or not turbulence will occur at the point of measurement in the pipe system.

A basis for determining at what point liquid turbulence occurs in a pipe and why, resulted in the establishment of The Reynolds Number (Re), named after Osborne Reynolds, who experimented with flow variations approximately one hundred years ago. Dr. Reynolds determined that if the liquid velocity or pipe diameter is relatively small and the viscosity of the liquid is relatively large, the Re will be small and the flow will tend to be laminar (non-turbulent). Increasing the pipe diameter or liquid velocity, or decreasing the liquid's viscosity, will result in a higher Re. Reynolds concluded that, for a given flow rate in a pipe, regardless of which of the three particular parameters he varied, as long as the Re value was *less than approximately 2300*, the flow in the pipe remained laminar. Above that value, turbulence would consistently occur.

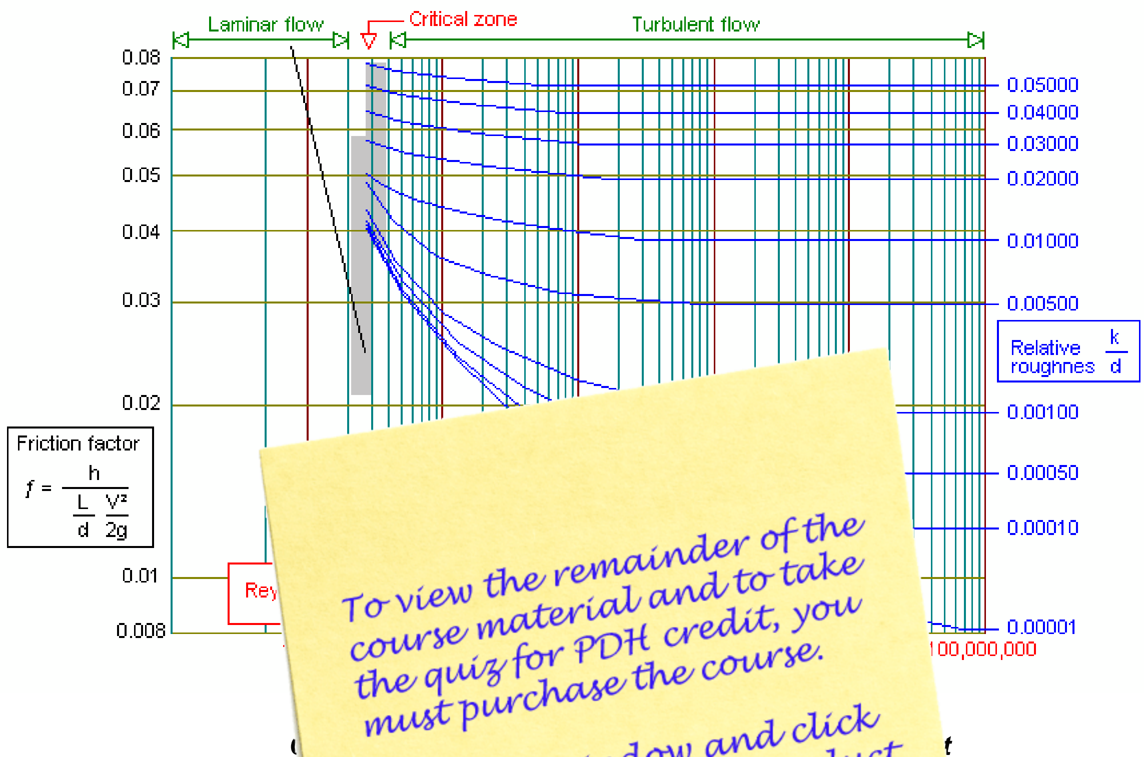
The formula for calculating the Reynolds Number (Re) for flow within a pipe is:

$$Re = u\, d / v$$

where:

u = kinematic viscosity of the liquid
v = liquid velocity in feet per minute
d = diameter in feet

Therefore, when selecting the proper meter for an application, the Reynolds number must be calculated in order to determine if a turbulent flow condition will exist at the point of measurement; and that the meter is suitable for that condition.



Revisiting the Moody C... hip between friction factor, Reynolds Numbe... condition transitions from laminar flow to turb...

Flow Straighteners

A flow straightener, such ... No.1, is, as its name implies: a device that straightens the flow p... a pipe. They introduce further restriction in flow; and a greater potential for fouling (accumulation of particulate or debris at the tube inlets). However, they provide an effective means of eliminating turbulence when there is insufficient space available ahead of the flow meter location for a sufficiently long run of straight pipe. In other words, you may have no choice but to specify such a device if there are space constraints. When the pump system producing the flow that is being measured is initially sized, or the flow straighteners are added to an existing pipe system, the additional system pressure drop produced by the flow straighteners will need to be considered.