

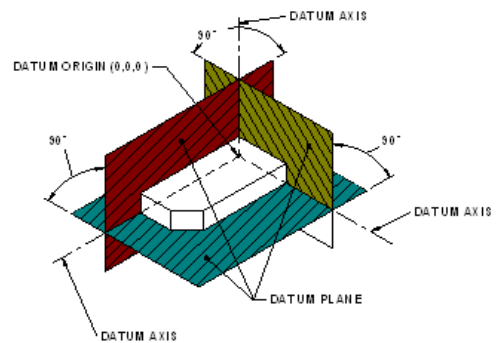


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Pipe Flow-Friction Factor Calculations with Excel

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COURSE CONTENT

1. Introduction

Several kinds of pipe flow calculations can be made with the Darcy-Weisbach equation and the Moody friction factor. These calculations can be conveniently carried out with an Excel spreadsheet. Many of the calculations require an iterative solution, so they are especially suitable for an Excel spreadsheet solution.

This course includes discussion of the Darcy-Weisbach equation and the parameters in the equation along with the U.S. and S.I. units to be used. Example calculations and sample Excel spreadsheets for making the calculations are presented and discussed.



Image Credit: [Wikimedia Commons](#)

2. Learning Objectives

At the conclusion of this course, the student will

- Be able to calculate the Reynolds number for pipe flow with specified flow conditions
- Be able to determine whether a specified pipe flow is laminar or turbulent flow for specified flow conditions
- Be able to calculate the entrance length for pipe flow with specified flow conditions
- Be able to obtain a value for the friction factor using the Moody diagram for given Re and ϵ/D .
- Be able to calculate a value for the friction factor for specified Re and ϵ/D , using the appropriate equation for f .
- Be able to determine a value of the Moody friction factor from the Moody diagram, for given Re and ϵ/D .
- Be able to calculate a value of the Moody friction factor for given Re and ϵ/D , using the Moody friction factor equations.
- Be able to use the Darcy Weisbach equation and the Moody friction factor equations to calculate the frictional head loss and frictional pressure drop for a given flow rate of a specified fluid through a pipe with known diameter, length and roughness.
- Be able to use the Darcy Weisbach equation and the Moody friction factor equations to calculate the required diameter for a given flow rate of a specified fluid through a pipe with known length and roughness, with specified allowable head loss.
- Be able to use the Darcy Weisbach equation and the Moody friction factor equations to calculate the fluid flow rate through a pipe with known diameter, length and roughness, with specified frictional head loss.

3. Topics Covered in this Course

- I. Pipe Flow Background
- II. Laminar and Turbulent Flow in Pipes
- III. The Entrance Length and Fully Developed Flow
- IV. The Darcy Weisbach Equation
- V. Obtaining a Value for the Friction Factor
- VI. Calculation of Frictional Head Loss/Pressure Drop – Excel Spreadsheet
 - A. Straight Pipe Head Loss
 - B. Minor Losses
- VII. Calculation of Flow Rate – Excel Spreadsheet
- VIII. Calculation of Required Pipe Diameter – Excel Spreadsheet
- IX. Summary
- X. References and Websites

4. Pipe Flow Background

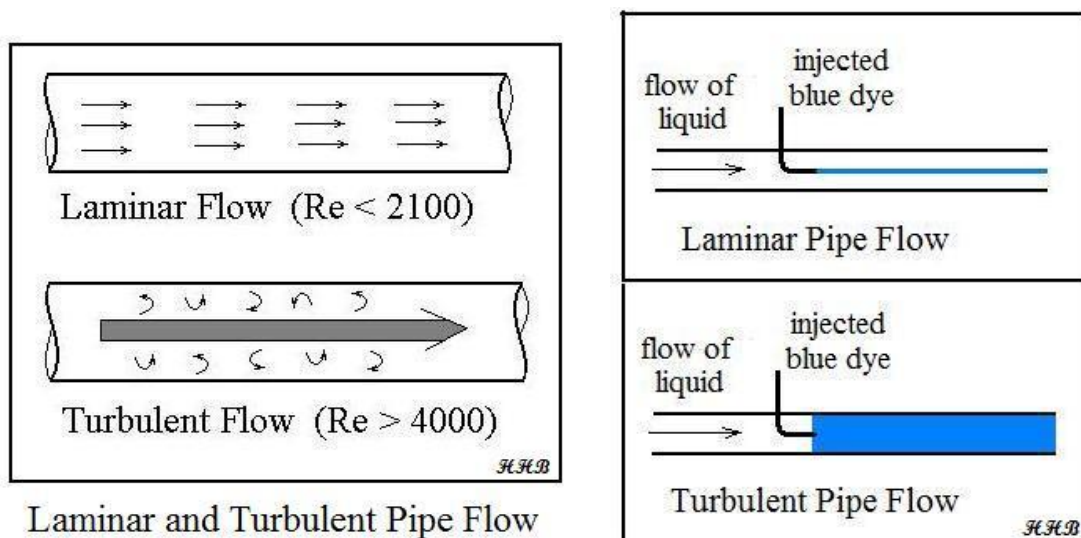
The term pipe flow in this course is being taken to mean flow under pressure in a pipe, piping system, or closed conduit with a non-circular cross-section. Calculations for gravity flow in a circular pipe, like a storm sewer, are done with open channel flow equations, and will not be discussed in this course.

The driving force for pressure pipe flow is typically pressure generated by a pump and/or flow from an elevated tank.

5. Laminar and Turbulent Flow in Pipes

It is often useful to be able to determine whether a given pipe flow is laminar or turbulent. This is necessary, because different methods of analysis or different equations are sometimes needed for the two different flow regimes.

Laminar flow takes place for flow situations with low fluid velocity and high fluid viscosity. In laminar flow, all of the fluid velocity vectors line up in the direction of flow. Turbulent flow, on the other hand, is characterized by turbulence and mixing in the flow. It has point velocity vectors in all directions, but the overall flow is in one direction. Turbulent flow takes place in flow situations with high fluid velocity and low fluid viscosity. The figures below illustrate differences between laminar and turbulent flow in a pipe.



The figure at the right above illustrates the classic experiments of Osborne Reynolds, in which he injected dye into fluids flowing under a variety of conditions and identified the group of parameters now known as the Reynolds Number for determining whether pipe flow will be laminar or turbulent. He observed that under laminar flow conditions, the dye flows in a streamline and doesn't mix into the rest of the flowing fluid. Under turbulent flow conditions, the turbulence mixes dye into all of the flowing fluid. Based on Reynolds' experiments and subsequent measurements, the

criteria now in widespread use is that **pipe flow will be laminar for a Reynolds Number (Re) less than 2100 and it will be turbulent for a Re greater than 4000**. For $2100 < Re < 4000$, called the transition region, the flow may be either laminar or turbulent, depending upon factors like the entrance conditions into the pipe and the roughness of the pipe surface.

The Reynolds Number for flow in pipes is defined as: $Re = DV\rho/\mu$, where

- D is the diameter of the pipe in ft (m for S.I.)
- V is the average fluid velocity in the pipe in ft/sec (m/s for S.I.) (The definition of average velocity is: $V = Q/A$, where Q = volumetric flow rate and A = cross-sectional area of flow)
- ρ is the density of the fluid in slugs/ft³ (kg/m³ for S.I.)
- μ is the viscosity of the fluid in lb-sec/ft² (N-s/m² for S.I.)

Transport of water or air in a pipe is usually turbulent flow. Also pipe flow of other gases or liquids whose viscosity is similar to water will typically be turbulent flow. Laminar flow typically takes place with liquids of high viscosity, like lubricating oils.

Example #1: Water at 50°F is flowing at 0.6 cfs through a 4" diameter pipe. What is the Reynolds number of this flow? Is the flow laminar or turbulent?

Solution: From the table below the density and viscosity of water at 50°F are: $\rho = 1.94$ slugs/ft³ and $\mu = 2.73 \times 10^{-5}$ lb-sec/ft².

The water velocity, V, can be calculated from $V = Q/A = Q/(\pi D^2/4) = 0.6/[\pi(1/3)^2/4] = 6.9$ ft/sec.

Substituting values into $Re = DV\rho/\mu$ gives:

$$Re = (1/3)(6.9)(1.94)/(2.73 \times 10^{-5}), \text{ or } Re = 1.6 \times 10^5.$$

The Reynolds Number is greater than 4000, so **the flow is turbulent**.

The density and viscosity of the flowing fluid are often needed for pipe flow calculations. Values of density and viscosity of many fluids can be found in handbooks, textbooks and websites. Table 1, below gives values of density and viscosity for water over a range of temperatures from 32 to 70°F.

Table 1. Density and Viscosity of Water

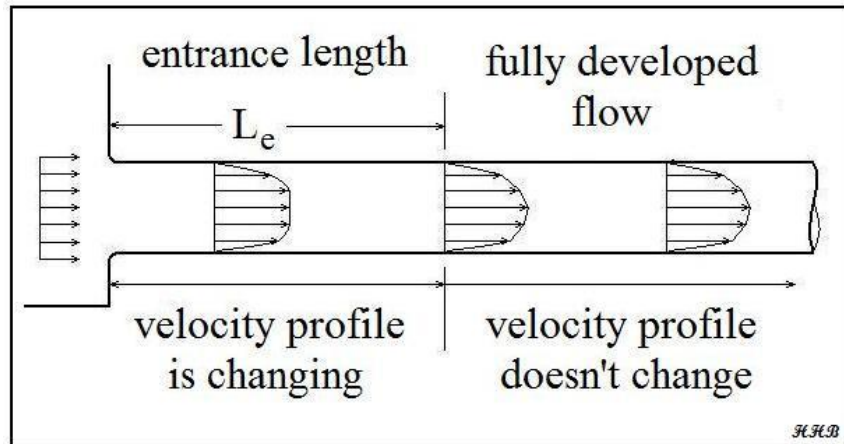
<u>Temperature, °F</u>	<u>Density, slugs/ft³</u>	<u>Dynamic Viscosity, lb-s/ft²</u>
32	1.940	3.732×10^{-5}
40	1.940	3.228×10^{-5}
50	1.940	2.730×10^{-5}
60	1.938	2.334×10^{-5}
70	1.936	2.037×10^{-5}

6. The Entrance Length and Fully Developed Flow

The Darcy Weisbach equation, which will be discussed in the next section, applies only to the fully developed portion of the pipe flow. If the pipe in question is long in comparison with its entrance length, then the entrance length effect is often neglected and the total length of the pipe is used for calculations. If the entrance length is a significant part of the total pipe length, however, then it may be necessary to make separate calculations for the entrance region.

The entrance region refers to the initial portion of the pipe in which the velocity profile is not “fully developed,” as shown in the diagram below. At the entrance to the pipe, the flow is often constant over the pipe cross-section. In the region near the entrance, the flow in the center of the pipe is unaffected by the friction between the pipe wall and the fluid. At the end of

the entrance region, the pattern of velocity across the pipe (the velocity profile) has reached its final shape.



The entrance length, L_e , can be estimated if the Reynolds Number, Re , is known.

For turbulent flow ($Re > 4000$): $L_e/D = 4.4 Re^{1/6}$.

For laminar flow ($Re < 2100$): $L_e/D = 0.06 Re$.

Example #2: Estimate the entrance length for the water flow described in example #1: (1.2 cfs of water at 50°F, flowing through a 4" diameter pipe).

Solution: From Example # 1, $Re = 1.6 \times 10^5$. Since $Re > 4000$, so this is turbulent flow, and $L_e/D = L_e/(1/3) = 4.4(1.6 \times 10^5)^{1/6} = 32.4$

Thus $L_e = (1/3)(32.4) = 10.8 \text{ ft} = L_e$

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typical set of U.S. units and a typical set of S.I. units are shown in the list above.

Table 2, below, shows some typical values of pipe roughness for common pipe materials, drawn from information on several websites.