Fall 2018

MEEG333 Fluids Laboratory

X6. Pipe Flow Pressure Loss and the Friction Factor R5

Objectives

(1) To directly observe pressure loss in pipe, and take data to calculate the Darcy friction factor.

(2) To apply your experimental observations to a practical process situation.

Apparatus

The apparatus consists of a centrifugal pump that circulates water around closed loop with known diameter and length. Flow around the loop can be adjusted from low values (Re in the laminar range) to high values (Re in the turbulent range). The system is equipped with flow meters for the different ranges, and a differential pressure transducer.

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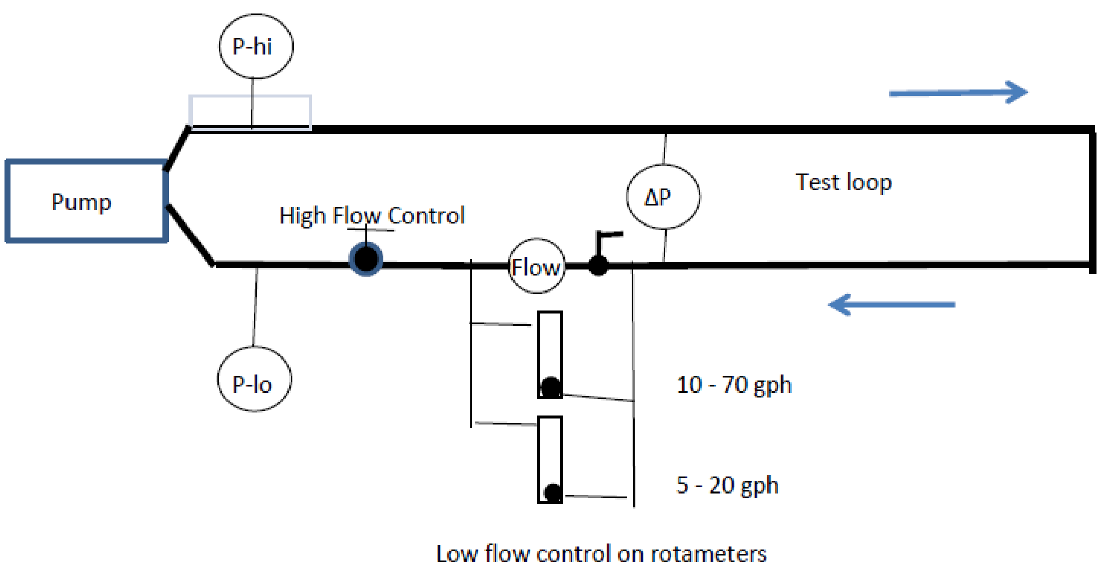

Test loop length L = 7.85 feet. Test loop I.D. = 0.540 inch.

Theory

The Reynolds number was introduced briefly in chapter 1 of your textbook.
In lab experiment X5 you observed laminar and turbulent flow directly.

The Reynolds number, Re, is a dimensionless number defined as

$$\mathrm{Re} \equiv \frac{\rho V D}{\mu}$$

where ρ is the density, V the average velocity, D the pipe diameter, and μ the fluid's dynamic viscosity. In Lab experiment X5 you observed directly how flow transitioned from laminar to turbulent, with a transition region between. The Reynolds was a measure of when this transition can occur. Like all dimensionless numbers, the advantage to using the Reynolds number to predict the state of the fluid is that the results are applicable to all Newtonian fluids in pipes of all diameters.

The friction factor, f, is another dimensionless number that describes the pressure drop along a pipe. The friction factor is defined as

$$f \equiv \frac{\Delta P}{\left(\tfrac{1}{2}\rho V^2\right)\left(L/D\right)} \text{ or } f = \frac{\rho g h_L}{\left(\tfrac{1}{2}\rho V^2\right)\left(L/D\right)} \qquad (1)$$

The friction factor is a function of the Reynolds number and for non-smooth pipes is also a function of roughness, ϵ. A Moody diagram (named after a mechanical engineer in the 1940's) is a visual way of describing the pressure drop along a pipe for broad range of flows and surface geometries. For <u>very smooth</u> pipes, there are two different friction factor expressions that are possible, depending on whether the flow is laminar or turbulent.

$$f = \begin{cases} 64/\mathrm{Re}_D & \text{(laminar)} \\ 0.316\,\mathrm{Re}_D^{-1/4} & \text{(turbulent)} \end{cases} \qquad (2)$$

The laminar expression is an exact solution to the Navier-Stokes equation for a circular pipe. The turbulent expression is a best fit to data and limited to $\mathrm{Re}_D < 10^5$. There are other expressions with a wider range, and for non-circular pipes. As part of the experimental analysis, we will compare our measurements to these. You are provided with an enlarged copy of the Moody diagram to plot your data on.

Note that ALL parameters on the Moody diagram are dimensionless. Therefore, it can be used with any Newtonian fluid, not just water, and with any unit system. Just be sure you check and get your units right. In this lab, instruments are in fps (foot/pound/second), not SI. You can convert to SI for your analysis; just do it right.

Procedure

1. Examine the apparatus and identify all of its parts. Note the vent pipes on the intake ("suction") side of the pump. The water level with the pump off should be at about the half way point. If not, add water with the funnel provided. Why do you need a vent at all? (This is a non-trivial question: learn the answer.)

2. Record the temperature of the water so that you can determine density and viscosity. Important: the water in the loop will get warm fast as you begin the experiment. At each data point, record the associated temperature. Why does it get warm? (Another non-trivial question: know the answer).

3. Also record the differential pressure reading before starting. The TA will usually have zeroed the pressure before the lab starts, but it may have drifted. If so, record the value shown before start up to use as a correction.

4. The apparatus has three different flow meters: two small rotameters and one turbine meter. The turbine meter is not accurate below about 1 gpm, but good after that. The two rotameters are more accurate at flows between about 0.1 gpm and 1 gpm. We will use each one accordingly.

5. To begin, be sure that both the main flow control valve and the main flow cutoff valve are open. Then turn on the pump. Open the small rotameter, Then close the main flow cutoff valve. Set the flow for the first data point by adjusting the flow through the small rotameter.

6. The differential pressure gage has nominal range from 0 to 10 psi. However, the manufacturer states accuracy of +/- 1% , so that at 10 psi, that is +/- 0.1 psi. At the lowest flow we will test, the differential pressure readings will be on the order of 0.001, and fluctuating from fluid and electronic noise. Take a reading as best you can (photo might help), but consider the analytical result to be uncertain. In practice, adding a low range ΔP meter is possible, but has not been done at this time.

7. Because the Moody diagram is logarithmic, we will take flow data at spaced points each approximately 50% bigger than the one before, beginning with 10 gph (0.17 gpm). For example, 10, 15, 25, 40 gph using the rotometers, then 1, 1.5, 2.5, 3.7, 5.6, 7 gpm using the main control valve (these are approximate). Values in this range will give Re from approximately 1000 to 60,000, from laminar through transition to turbulent.

8. When moving from one flow meter to the next, OPEN THE FLOW TO THE NEXT METER BEFORE CLOSING THE PREVIOUS. This insures that there is always flow through the pump.

9. When you reach the maximum flow, reverse the procedure and take data for about 9 points, moving from high flow to low.

10. For each flow rate, the following data needs to be recorded:

    1. Flow rate (gph or gpm depending on meter used)
    2. Water temperature (for every point. It changes)
    3. Observed ΔP reading

Analysis

Use your data to calculate the friction factor from Eqn (1) and the corresponding Reynolds number for each flow rate. When determining the density and dynamic viscosity of the water (or equivalently kinematic viscosity), lookup the value(s) corresponding to your measured temperature (e.g., see Table A in the textbook). Note how viscosity changes with temperature. Viscosity is in the denominator, and can affect the calculated Reynolds number significantly. Be careful of the units!

The flow loop has two elbow fittings. In a pipe flow, fittings cause an additional pressure loss that must be accounted for. The correction usually has the form of

$$\Delta P = K * \rho V^2/2$$

where K is an empirically determined factor that varies with the type of fitting. Manufacturers or handbooks provide values for their products. For this apparatus, we have determined that K=0.2 is a reasonable value. There is significant uncertainty in this value. K is dimensionless. Be sure your calculation gives the correct pressure dimension. Then correct your measured ΔP accordingly.

Your reported results should include, in tabular form, your measurements of flow, temperature, and ΔP, plus your calculated average velocity, Reynolds number, and friction factor using Eqn (1). Also show the friction factor as calculated with the fitted equations (2). Calculate and report the differences.

The Moody diagram is shown in the inside back cover of your textbook. However, you are being provided with a large scale reproduction for easier reading. As part of your report, plot clearly all of your data points on this large chart. Not easy, is it? Append the chart with your data plotted to your lab report.

Uncertainty analysis

Calculate the uncertainty in computing the friction factor by applying the propagation of statistical errors method to the definition (Eqn 1). You did this for the Reynolds number in experiment X5, but the water temperature in X5 was nearly constant. In X6, the temperature varied, hence the density varies. Account for this.

You may treat the (L/D) parameter as constant. However, ΔP, especially for lower flow values had considerable variation, as did the flow rate. Being digital instead of analog does not make data more accurate.

Discussion

The Moody diagram has been checked, used, and improved by engineers for many years. It still has an accepted uncertainty in use of 10%. How does your data compare? If your data points do not fall in range, discuss why not. It is not from human error unless you make a math error. Consider the apparatus, the instruments used, and the procedure. Now use the Moody diagram for the Design Objective.

Design Objective

One of the most basic calculations in practical fluid dynamics is the pressure loss in a pipe transporting a fluid, whether it is a multistate oil pipeline, a domestic water supply, rocket fuel, or anything in between. The simplest case may be, given flow rate and pipe diameter, what is the pressure loss. Eqn(1) is used. An alternative is, given required flow, pump pressure, and L, what diameter pipe D should be specified.

DESIGN OBJECTIVE - Commercial companies such as SpaceX and Blue Origin are already launching, recovering, and planning to fly people soon. Smaller companies are anxious to get involved, but many lack resources and technical expertise. One company, UDinSPACE, is considering a small launch site on the STAR campus. The University has serious safety issues and wants expert advice. You have been requested to provide launch system design safety consulting for fuel loading. Their rocket's first stage may be fueled by refined kerosene and liquid oxygen (LOX). The volatile LOX has to be rapidly pumped from a railroad tank car, 2000 feet to the rocket's LOX tank just before launch. You have been asked to size the LOX insulated piping.

It must be pumped at a high rate, yet the internal pressure must be kept high so that the LOX does not flash to vapor before reaching the rocket LOX tank. The data below is for LOX at 200 psia and 160 R. It is liquid phase at these conditions. It must reach the rocket before the pressure drops below 100 psia, dangerously close to its vaporization point. Specify the minimum inside diameter of a Standard Sch 40 steel pipe that will allow this at the required mass flow rate. (Assume pipe is insulated so that only pressure change is from fluid wall friction).

Pipe length = 2000 feet	(609.6 m)
Inlet pressure = 200 psia	(1379 kPa)
Outlet pressure >100 psia	(690 kPa)
Flow rate 20 lbm/sec	(9.07 kg/sec)
LOX density = 21.6 lbm/ft3	(346 kg/m3)
LOX viscosity=6.1E-05 lbm/ft-s)	(9.08E-05 N-s/m^2)

Pipe Diameter = ?
Suggested Summary Letter:

Mr. David Graham, P.E.
Facilities Planning and Engineering
Re: UDinSpace Launch Safety
200 Academy St
Newark, DE

We calculate…

We would be pleased to provide additional safety consulting services, such as RP1 (kerosene) fuel storage and delivery, protection for existing buildings, …

Sincerely,