Fall 2018 Rev 2

MEEG333 Fluids Laboratory

X5. Reynolds Experiment (Laminar and Turbulent Flow)

Objectives

(1) To directly observe and measure laminar, transitional, and turbulent pipe flow, and to quantify the conditions under which these types of flow occur.

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

Apparatus

The equipment used consists of a hydraulic test bench with an apparatus similar to the traditional one used by Osborne Reynolds, dye, a stopwatch, a graduated cylinder, and a thermometer. The inside diameter of the flow visualization pipe is 10 mm, and length is approximately 0.7 m.

Theory

The Reynolds number was introduced briefly in chapter 1 of your textbook, page 27. Before coming to lab, you are <u>required to read section 6.1</u> of your textbook.

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

$$\mathrm{Re} \equiv \frac{\rho V D}{\mu} = VD/\nu$$

where ρ is the density, V the average velocity, D the pipe diameter, and μ the fluid's dynamic viscosity. The Reynolds number can be viewed as the ratio of inertial forces to the viscous damping forces at a point in the fluid continuum; small disturbances in laminar flow are restored toward equilibrium by friction, while inertial forces tend to destabilize the flow. As the Reynolds number increases the inertial forces grow relatively larger and the flow eventually destabilizes into turbulence. There is a finite <u>*interval*</u> between laminar and turbulence called the <u>transition</u> region. 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 is a visual way of describing the pressure drop along a pipe for broad range of flows and surface geometries. For very smooth pipes, there are two different friction factors that are possible, depending on whether the flow is laminar or turbulent.

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

As part of the experimental analysis, we will investigate the effect of transition to turbulence on pressure drops in pipes.

<u>Procedure</u>

1. Fill the reservoir of the dye injector with dye and lower it until it is just above the bellmouth inlet. With the flow control valve closed, *slowly* fill the head tank with water to the overflow level then close the inlet valve. Adjust the flow control valve to admit water to the flow visualization pipe. Allow the apparatus to stand at least five minutes before proceeding so that currents and the circulation from filling decay away.

2. Measure and record the temperature of the water so that you can determine density and viscosity.

3. Slightly open the flow control valve so that a low speed flow occurs in the pipe. Turn on the valve controlling the dye injection (you do not need very much!). You should now be able to visualize the nature of the flow. You should be at a low enough flowrate that your initial observations are of laminar flow. We will now take about 9 observations at different flow rates.

4. To measure flow rate, collect the water discharging from the flow visualization pipe in a graduated cylinder and record the volume and time required to collect it. Volume flow rate can be calculated (as well as the mean velocity). Try to get the flow rate for your first observation set to <u>*approximately*</u> 200 mL/min. Record any observations about the flow (laminar, transition, turbulent as well as any other helpful notes).

5. You will now do this ~8 more times at higher flow rates. Try to set each flow rate ~50% higher than the previous (It does not need to be exactly 50%! We are just trying to create logarithmic spaced data points). For each point,

open the valve slightly more to achieved the desired flow rate and record the relevant data: (volume)/(collection time)/(observation of the flow).

6. You will likely have few points in the transition region in step 4. Try to get more detailed data near the transition region: Take about 5 more observations with flow rate spaced between your last "laminar" and first clearly "turbulent" observation in step 4.

7. Measure and record the temperature of the water (again) so that you can determine whether the density and viscosity changed during the course of the experiment.

Analysis

Use your data to calculate the volumetric flow rate and velocity for each observation and the corresponding Reynolds number. When determining the density and dynamic viscosity of the water (or equivalently kinematic viscosity), lookup the value(s) corresponding to your measured temperature (see Table A.1 in the textbook for example). Note how viscosity changes with temperature.

Your results should include, in tabular form, your measurements of volume, time, computed average velocity, Reynolds number, plus your observational note of the state of the fluid: laminar, transitional, or turbulent.

For each observation calculate the expected pressure drop (eqn 1)along the pipe, using the friction factors corresponding to laminar and turbulent flow (Eqn 2): *On a log_{10}-log_{10} plot*, show the calculated pressure drop, ΔP , vs. average velocity, V. This plot should be qualitatively similar to Mr. Reynolds' plot as he reported and shown in the Discussion notes. You may omit any points you regarded as transitional.

Uncertainty analysis

There are uncertainties in all the parameters in the Reynolds number. Determine the relative error, $\Delta\mathrm{Re}/\mathrm{Re}$, in the Reynolds number by applying the propagation of statistical errors method to the definition of Reynolds number. You must specify the uncertainty of each parameter based on your observations in the lab. For example, note that tabulated property values like density are often assumed to be perfect, when in fact they are not. Values of viscosity and density are temperature dependent which could have varied during your experiment. Also, how closely can you read the temperature scale on the thermometer? Look at the table in the book and estimate the $\Delta\rho$ and $\Delta\eta$ per degree in the temperature range of the lab water. Then derive uncertainty in each and show your calculated uncertainty in the Reynolds number.

<u>Discussion</u>
You may agree by now that identification of the exact transition region is not easy. Qualitatively describe any difficulties. Outside a lab, as a practicing engineer, how closely would you expect to estimate the Reynolds number? How closely do you need to know (e.g., for building plumbing, or for fuel flow to a rocket engine, or cooling flow to a hot unit operation). Does a Re = 3498.2398 make any sense? Would rounding to 3500 do as well?

<u>Design objective</u>

You are an engineer in charge of designing an eyewash station. Legally, the station must meet ANSI Standard Z358.1 to guarantee OSHA compliance. This standard gives specifications for the required "tepid" water temperatures (officially defined as the range 60F (16C)-100F (38C)) and flow rate (must be >1.5 L/min). To guarantee that the water is in the correct temperature range, cold water (which is often below 60F in winter) should be combined and mixed with a hot water stream (typically 140F (60C)) in a common section of pipe before being diverted to the eye wash nozzles. However, if "hot" and "cold" streams are combined and the resulting flow is laminar, then the water will not be mixed at the outlet, potentially resulting in one of the eye wash outlets being scolding hot while the other is freezing cold!

To account for this potential issue, specify a <u>diameter of the common pipe</u> that would *ensure* turbulent mixing for all possible outlet temperatures and flow rates satisfying the standard. Use your experimental data to help choose the criteria, and be conservative in your estimates. Think carefully about which estimates are conservative: Should you design for the lower end of the temperature range or higher? Should you design a smaller pipe or a bigger pipe than for the "exact" onset of turbulent flow?

Summary Letter:

American National Standards Institute
2000 Z-Street NW
Washington, DC

We have designed and developed a method for insuring that tepid water in the required OSHA temperature range will assured through natural turbulent mixing, without requiring manual adjustment by the user, or using thermostatically control devices that might fail if power is lost.

Please review and advise what further action or information will be required for our system to be included in the Standard. Patent applied for.

Sincerely,