MEEG331 Incompressible Fluids Laboratory

2. Reynolds Experiment (Laminar and Turbulent Flow)

Objective and Apparatus

The purpose of the Reynolds Experiment is to illustrate laminar, transitional (intermittently turbulent), and fully turbulent pipe flows, and to determine the conditions under which these types of flow occur. The equipment consists of a hydraulics bench, an Osborne Reynolds apparatus, dye, a stopwatch, a graduated cylinder, and a thermometer. The diameter of the flow visualization pipe is \( d = 10 \text{ mm} \).

Theory

The critical velocity \( V \) averaged over the cross section at which laminar pipe flow changes to transitional flow, or transitional flow changes to turbulent flow, is believed to be a function primarily of the pipe diameter \( d \), the fluid density \( \rho \), and the fluid dynamic viscosity \( \mu \). In mathematical terms, \( V = V(d, \rho, \mu) \). Using dimensional reasoning, one can show that the relation among the parameters must be

\[
R \equiv \frac{\rho V d}{\mu} = \text{dimensionless parameter}
\] (1)

The dimensionless parameter \( R \) is called the Reynolds number. It is a ratio of the inertial (destabilizing) force to the viscous damping (stabilizing) force. As \( R \) increases, the inertial forces grow relatively larger, and the flow gets destabilized into full-blown turbulence.

The Reynolds Experiment determines the critical Reynolds number at which laminar flow becomes transitional, and transitional flow becomes turbulent. The advantage of using a critical Reynolds number, instead of a critical velocity, is that the results of the experiment are applicable to all Newtonian fluid flows in round pipes of all diameters.

Procedure

- 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. Open and close flow control valve to admit water to the flow visualization pipe. Allow the apparatus to stand at least ten minutes before proceeding.

- Open the inlet valve slightly until water trickles from the outlet pipe. Then open the control valve for a small amount, so that a low-speed flow occurs in the pipe. Turn on the valve controlling the dye injection. The traces of the dye in the flow visualization pipe illustrate the character of the flow. Initially, the dye should remain in a steady, narrow stream, indicating laminar flow.
• Next, open the control valve in small increments, so that the flow speed gradually increases. At a certain flow speed, the flow will become transitional and finally reach a fully turbulent state. For each flow state, collect water discharging from the flow visualization pipe in the graduated cylinder and record the time required to collect it. Record the nature of the flow, the volume of water collected. Also record the water temperature.

• Repeat the procedure so that you have at least two sets of data for laminar, transitional, and turbulent flow states.

Data analysis and discussion
Use the continuity equation for incompressible flows to determine the average velocity \( V \) from the measurements. If \( A = \) cross-sectional area of the pipe, \( V = \) volume of water collected, and \( t = \) time required to collect it, then show that

\[
V = \frac{Vol}{tA}
\]  

(2)

To determine the density and viscosity of water, use the measured temperature in tables available in your fluid mechanics textbook.

• The theoretical background section of your report should contain a discussion of Equation 1. Show that the Reynolds number is the only dimensionless grouping possible from the relevant parameter list \((\rho, V, d, \mu)\) by computing the dimensions for all other possible arrangements.

• Your results should include, in tabular form, measurements of volume, time and fluid temperature, computed velocity, and Reynolds number, and a description with illustrative sketches of the flow characteristics for each experimental run. Discuss your observation and compare it with that described in the textbook.

• All dimensionless numbers are ratios of like quantities. What two quantities does the Reynolds number incorporate? Discuss the significance of the Reynolds number.

• There is a long list of dimensionless numbers in fluid mechanics. Read up on several that are important to us (Chapter 5), provide their names, their definition (similar to Equation 1) and discuss what ratios they represent.

Error analysis
Determine the error in \( R \) by applying the propagation of statistical errors method to Equation 1. Obviously, the error in \( R \) depends on the error in the velocity \( V \), which can be similarly determined from Equation 2. Include the relative error alongside each \( R \) in your table.