BU College of Engineering

ME 303 Fluid Mechanics

Laboratory Exercise No. 1 – Instruction Manual

Flow Visualization using Osborne Reynolds Apparatus

Fall 2011 Revision

Revision History

Name	Date	Notes
Prof. Bala Bharadvaj	1984	Original Document
Steven P. Weibel and Sam Bogan	1989	Instructions revised
R. Adam Rugg	1991	Revised
Mikhail Dvilyanskiy, David Kelly and Mitchell Raymond		Instructions revised
Profs. Wroblewski and Isaacson	2001	
Prof. Barba and Simon Layton	2009	Transferred to LaTeX by Simon Layton
Prof. Grace	2011	Document revised

1 Purpose

One of the most interesting phenomena in fluid mechanics is the transition from laminar to turbulent flow. Laminar flow is characterized by well defined, steady streamlines, whereas turbulent flow is characterized by random and intermixed flow paths. One measure of the state of a fluid flow is the Reynolds number, with which we can make a qualitative judgement on the state of any flow by considering its magnitude. This lab will investigate the transition of simple pipe flow in a transparent sight tube from laminar to turbulent by means of flow visualization. Using the Reynolds apparatus we will observe the behavior of a streak of dye in the sight tube and will have to decide where and when the transition between the two types of flow occurs as the flow speed is varied.

2 Theory

The dimensionless parameter called the Reynolds number is a primary measure of the laminar or turbulent nature of a flow. The Reynolds number (Re) is defined as:

$$Re = \frac{\rho V L}{\mu}, \tag{1}$$

where ρ is the fluid density, V is the characteristic flow velocity, L is the characteristic length of the flow and μ is the dynamic viscosity. Also,

$$\nu = \frac{\mu}{\rho}, \tag{2}$$

where ν is the kinematic viscosity. Thus Re may also be expressed as

$$Re = \frac{VL}{\nu}. \tag{3}$$

For pipe flows, V is taken to be the mean flow velocity across the cross section and L is the diameter of the pipe.

On inspection of the relations for the Reynolds number, one can see that the Reynolds number is actually the ratio of the inertial flow forces to the viscous flow forces. Flow is laminar when the inertial forces are of the same order of magnitude as, or smaller than, the viscous forces, i.e. for low Reynolds numbers. Flow is turbulent, however, when the viscous forces are small when compared to the inertial forces, i.e. at high Reynolds numbers. What is meant by a “low” value or “high” value for the Reynolds number depends on what dimension is used for L and what velocity is used for V in a particular application. For example, for pipe flows $Re = 1000$ is considered low enough for laminar flow, while $Re = 10,000$ is usually considered high enough for turbulent flow. Also, contrary to the impression conveyed in some text books, the transition from purely laminar to purely turbulent flow does not occur suddenly at a unique Reynolds number (e.g. $2,300$ for straight, circular cross section tubes). Instead, the transition occurs gradually, over a range of Reynolds numbers. At very low Re, the streamlines are smooth and straight and the flow is purely laminar. As Re is increased, disturbances cause waviness in the streamlines, but the flow is still laminar. At higher Re, intermittent "bursting" of the streamlines occurs in which a portion of the flow in the pipe becomes turbulent for a short period of time and then reverts back to laminar flow. This turbulent flow is so well mixed that individual die streaks cannot be seen and the flow appears almost uniform in color. At still higher Re, the flow remains turbulent for longer periods of time until, finally, at some Re that is high enough, the flow remains purely turbulent and no longer reverts to the laminar state. The range of Reynolds numbers over which this transition occurs depends on the amount of disturbances the flow is subjected to. For very high degrees of disturbance the transition can begin as low as $Re = 2,000$, while for extremely low degrees of disturbance, transition can be postponed up to about $Re \approx 20,000$.

3 Prelab

1. Explain the significance of the Reynolds number. Show that it is dimensionless by plugging in the units of the dimensioned variables and canceling units. Show all work.

2. Why are there marbles in the tank of the Reynolds apparatus (See Figure 2)?

3. What are the dynamic and kinematic viscosities of water at the calibration temperature? (see Calibration Data page, attached). Which is more viscous, water or air?

4. The diameter of the sight tube in the Reynolds apparatus is 13mm. Based on that, what is the maximum volume flow rate that will give fully laminar flow ($Re \approx< 2000$)? What is the minimum volume flow rate for fully turbulent flow ($Re >\approx 3000$)? Show your answers in units of gallons per minute.

5. A calibration curve and equation for the flowmeter are given at the end of this manual. Using this data, fill in the values for volume flow rate corresponding to the different flowmeter scale settings in Table 1. Fill in both gal/min and m/s columns.

6. Knowing that

$$V = \frac{\dot{Q}}{A}, \tag{4}$$

where V is mean flow velocity, $\dot{Q}$ is the volume flow rate and A is the cross-sectional area of the pipe, calculate flow velocities corresponding to each scale setting and write them down in the appropriate column in Table 1.

7. Calculate and fill in the Reynolds numbers corresponding to each scale setting.

4 Procedure

1. Connect the inlet tube of the apparatus to the faucet and take all the drain lines to the sink. Make sure that the drain valve is closed (bottom right valve, it should be turned all the way clockwise). See Figure 2 for schematic representation of the apparatus.

2. Open the faucet and adjust the water level in the stilling tank so that it is overflowing slightly in the drain (this will keep the water level constant).

3. Measure the temperature of the water in the tank by inserting a thermometer through the opening at the top of the tank. This temperature must be maintained at the calibration temperature (why?). Calibration values for the flow meter are given in Section 6.

4. The teaching fellow will pour dye into the dye reservoir. Adjust the outflow control valve so that the reading is 10 (10% of maximum flow). The center of the float should be at the 10% line. Then open the dye flow control just a little, so that you can see a thin line of dye in the sight tube. If the water in the flowmeter is too dark to allow accurate readings, you should adjust the dye flow valve. Comment on the behavior of the dye line.

5. Continue slowly increasing the flow rate up to 100% and observing the behavior of the flow. You may have to increase the dye flow rate in order to clearly see the dye line. Write down comments on the state of the dye streak in Table 1. Then, using the following scale, assign a numerical value to each of the readings and write it down in the last column of Table 1.

6. Repeat the experiment now starting at 100% flow rate and slowly decreasing it to about 10%. Record your observations in Table 2 along with Reynolds numbers corresponding to each flow rate percentage (same as in Table 1).

7. After you are finished, turn off the dye control valve and turn water faucet off. Drain the tank completely by opening the drain valve.

		Key:
0		Completely laminar behavior, no wavering.
1		Intermittent wavering.
2		Constant wavering
3		Line of dye begins to break up (“burst”) in spots. When the dye line bursts it is no longer distinguishable as a distinct line or lines.
4		Completely turbulent behavior, line is not visible
Note:		Use decimal fractions to describe behavior between two different types of flow.
Example		
	2.5	constant wavering, large amplitude.
	3.0	first evidence of dye streak breaking up (also first evidence of turbulent behavior).
	3.5	line of dye is visible approximately half the time

5 Required analysis

1. For each set of data, plot the numerical description of flow (last column of Tables 1 and 2) versus Reynolds number.

2. You start to see turbulent behavior when the distinct line of dye begins to break up (not just become wavy). At what values of Re did that occur? Does that correspond to the “accepted” value?

3. Discuss any variation in the Reynolds numbers you determined at transition and at full turbulence (numerical description of 4.0) in the two runs of the experiment. Why might the Reynolds numbers you determined while increasing the flow rate differ from those you determined while decreasing the flow rate for both the start of transition and full turbulence?

4. Would you say that it is possible to accurately predict flow transition? What environmental sources introduce error into this experiment? Consider this apparatus in its environment and be precise in your answer.

6 Calibration Data

$T = 17°C$

$$\boxed{\text{Flow Rate} = \dot{Q} = 0.1155x^2 + 0.4433x - 0.0073 \text{ gal/min}} \tag{5}$$

Note: When using this equation use decimal values instead of percent values (i.e. use 0.45 instead of 45%). $\dot{Q}$ is flow rate in gal/min; x is flowmeter scale reading in decimal form.

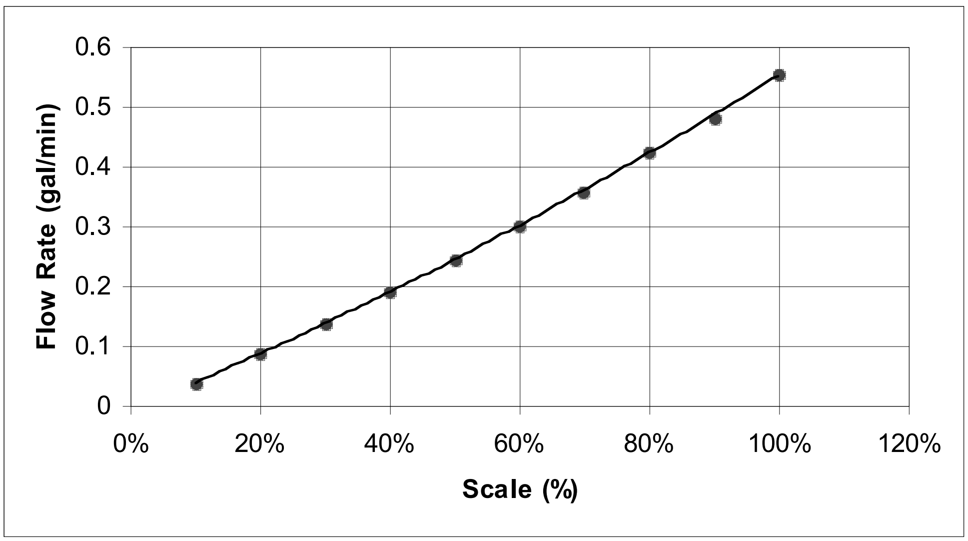

Figure 1: Calibration Curve for Reynolds Experiment

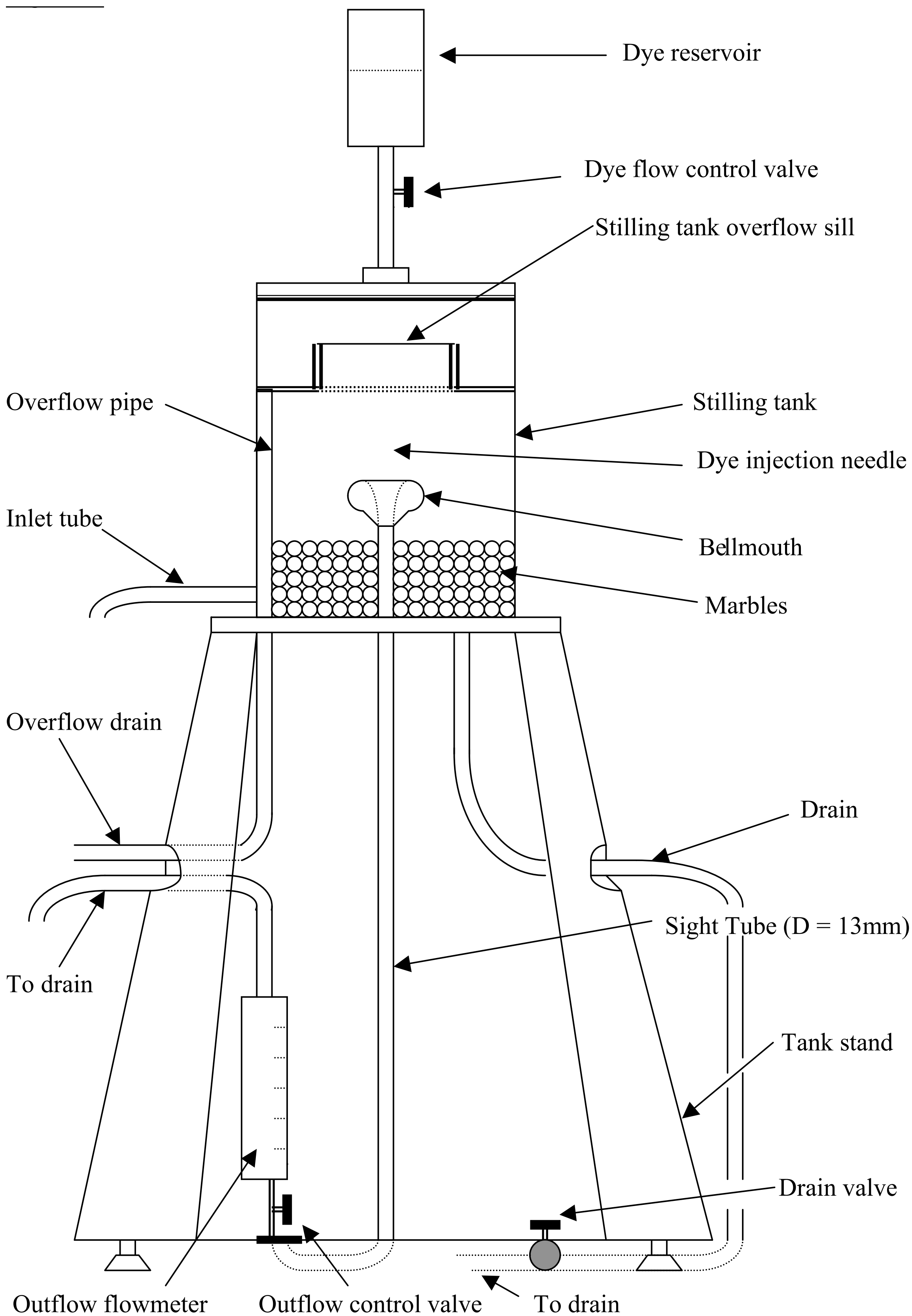

Figure 2: Reynolds Apparatus

Table 1.

Scale	Flow Rate (gal/min)	Flow Rate (m^3/s)	Flow Velocity (m/s)	Reynolds Number	Description of Flow Behavior	Numeric description
10%						
20%						
30%						
40%						
45%						
50%						
55%						
60%						
65%						
70%						
75%						
80%						
85%						
90%						
95%						
100%						

Table 2.

Scale	Reynolds Number	Description of Flow Behavior	Numeric description
100%			
95%			
90%			
85%			
80%			
75%			
70%			
65%			
60%			
55%			
50%			
45%			
40%			
30%			
20%			
10%			