Guided Practice for Experiment 1: Reynolds Number and Reynolds Experiment

Time estimate to complete this assignment: 1 to 1.5 hours

Overview

Fluid flows can be classified as laminar, turbulent, or transitional. The type of flow regime determines important fluid behavior and, as a civil engineer, you will be required to determine the flow regime. In fact, determining the flow regime is often the first step when solving a fluid dynamics problem. The first experiments on this topic were carried out by Osborne Reynolds (1842-1912) and published in 1883 as "An experimental investigation of the circumstances which determine whether the motion of water shall be direct or sinuous, and of the law of resistance in parallel channels" (how's that for a title!) in the Proceedings of the Royal Society of London. These experiments are amongst the most famous in fluid mechanics.

In this lab, you will reproduce Reynolds' experiment and observe laminar, transitional, and turbulent flows. We will inject dye into water flowing in a clear pipe and observe the dye streaks for different flow conditions. In most practical applications, you will not be able to inject dye into the fluid. Instead, the dimensionless quantity known as the Reynolds number is used to classify flows. Following this experiment, you will be able to classify flows using the Reynolds number. In subsequent experiments, we will investigate the role of Reynolds number on fluid behavior such as energy losses in pipe flows. Beyond this course, knowledge of Reynolds numbers is needed when working with water supply and other pipe networks, mixing of pollutants in water bodies (rivers, lakes, coastal waters), groundwater flow, drag force on buildings, transport of sediment by water, and many other civil engineering applications (any problem with a fluid flow!).

Learning Objectives

Basic objectives

1. (*Fluid mechanics review*) Define the viscosity of a fluid.
2. (*Fluid mechanics review*) Define the flow rate and average velocity for flow in a circular pipe.
3. Define the Reynolds number for a pipe flow.
4. Classify a pipe flow as laminar, turbulent, or transitional by observing a dye streak in the flow.
5. Classify a pipe flow as laminar, turbulent, or transitional using the Reynolds Number.

Advanced objectives

1. Collect experimental data to classify flows visually and using Reynolds number.
2. Interpret qualitative and quantitative experimental data to determine the flow regime.
3. Design a pipe system (fluid, flow rate, and diameter) to produce a desired flow regime.
4. Develop a physical interpretation of the Reynolds number.

Learning Resources

- **Reading:** Read the *Reynolds Number Background* document posted on the course Canvas site.
- **Video:** Watch the following short videos and think about how you would describe the dye streaks in plain English:

  https://www.youtube.com/watch?v=-qcdcvxNDHQ
  https://www.youtube.com/watch?v=BBiR6FWmyv4

Exercises

Reminder: Perform the work for each exercise in your notes first, then put your responses in the Google Form linked in the "Submission Instructions" area below.

1. Describe in your own words flow in a pipe that is (1) laminar, (2) turbulent, and (3) transitional.

2. Write the equation for the Reynolds number in a pipe flow using the kinematic viscosity. Using this equation, answer the following questions for water flowing in a pipe:

   (a) How does the Reynolds number change (increase, decrease, or stay the same) if the pipe diameter increases?
   (b) How does the Reynolds number change (increase, decrease, or stay the same) if the flow rate in the pipe increases?
   (c) How does the Reynolds number change (increase, decrease, or stay the same) if the temperature of the water increases?

3. Write the approximate range of Reynolds numbers for each flow regime: laminar, transitional, and turbulent.

4. For water at 60°F flowing in a 2-inch diameter pipe:

   (a) Find the maximum average velocity (in ft/sec) to maintain laminar flow.
   (b) What flow rate does this velocity produce?
   (c) The recommended minimum flow to a household is about 6 gpm (gallons per minute). How does this minimum flow compare with your finding in Part (b)? What does this result say about flow in pipe networks and water supply systems?

Submission Instructions

Please do the work in your notes, and then submit the results using this form:
Insert link to Canvas or Google forms

In-class Activity for Experiment 1: Reynolds Experiment

Class time: 2.5 hours

Topic or concept: Reynolds Number and Reynolds Experiment

Basic objectives for preparatory work:	Advanced objectives for classwork & after class work:
1. (*Fluid mechanics review*) Define the viscosity of a fluid. 2. (*Fluid mechanics review*) Define the flow rate and average velocity for flow in a circular pipe. 3. Define the Reynolds number for a pipe flow. 4. Classify a pipe flow as laminar, turbulent, or transitional by observing a dye streak in the flow. 5. Classify a pipe flow as laminar, turbulent, or transitional using the Reynolds Number.	1. Collect experimental data to classify flows visually and using Reynolds number. 2. Interpret experimental data to determine the flow regime. 3. Design a pipe system (fluid, flow rate, and diameter) to produce a desired flow regime. 4. Develop a physical interpretation of the Reynolds number.

	Time planned	Activity and rationale	Resources needed
Beginning of class period	10 mins	"Memory exercise"* to activate knowledge from the preparatory activities and lead into the physical interpretation of the Reynolds number. * Ask student to write down the 2-3 key items they remember from the preparatory activity.	Paper and pencil/pen
Middle of period	15 mins	Mini-lecture on the physical interpretation of the Reynolds number including example from pipe flow (Moody diagram)	Whiteboard and handout of Moody diagram

	Time planned	Activity and rationale	Resources needed
Middle of period	120 mins	Perform experiment Class is divided into 4 teams (4 students/team). Each team will have 30 minutes to collect data. Teams waiting to collect data or finished collecting data will develop spreadsheet for data analysis.	Reynolds experiment apparatus Graduated cylinder and stopwatch Experimental procedure and datasheet handout Laptop (for when teams are waiting to take data or have finished taking data)
End of period	5 mins	Mini-lecture reviewing collected data and reminder of calculation procedure.	Whiteboard

Post-class Activity for Experiment 1: Reynolds Number and Reynolds Experiment

Time estimate to complete this assignment: 1.5 to 2 hours

Instructions

Complete the following exercises with your team. Include the names of each team member that contributes to this assignment (including performing the experiment) on the cover sheet. An example cover sheet is provided on the course Canvas site. All team members are responsible for the work submitted.

Reminder: Following your responses to the exercises, include a scan of your raw experimental data, sample calculations for *all* calculated quantities, a screen capture showing your spreadsheet with all calculations, and a table showing the designated role for each team member for this experiment.

Exercises

1. Using the recorded temperature, find the kinematic viscosity of water for your experiment. Include a citation for the source of the viscosity value.

2. For each experimental run, calculate the flow rate, average velocity, and Reynolds number. Create a summary table of your results containing these three quantities as well as the visual description of the flow using the dye streak, visual classification of the flow regime, and classification of the flow regime using the Reynolds number. A suggested format for this table is provided below. *Remember to include sample calculations for Run 1 in your Sample Calculations section and report the appropriate number of significant figures.*

					Flow Regime Classification	
Run	**Visual description of flow**	***Q*** **(m^3/s)**	***V*** **(m/s)**	R_e	**Visual**	R_e
1						
…						

3. For the experimental apparatus, calculate the range of flow rates and velocities expected to produce laminar, transitional, and turbulent flow. How do these calculated values compare with your observations? What are the possible reasons for any discrepancies?

4. Determine the experimental uncertainty in the calculated Reynolds number using the following steps.

   (a) What quantities were measured in this experiment? Estimate the uncertainty in the measurement of each quantity.

(b) Determine the uncertainty in the calculated flow rate, average velocity, and Reynolds number. Report your findings as a relative uncertainty and a standard uncertainty. You may assume the pipe diameter and fluid viscosity are known exactly.

(c) Using the error propagation procedure presented in class, demonstrate that the above equation for the uncertainty in the Reynolds number is correct.

5. Consider an industrial processing plant located next to a river. This plant discharges a pollutant through a pipe into the river. Describe what happens to the pollutant if the flow in the river is (a) laminar or (b) turbulent. Which flow regime do fish prefer and why? *Hint*: a plan view sketch of the river may be helpful.

Submission Instructions

Submit your response to these exercises as a single pdf document on Canvas (under Experiment 1). Only one response is submitted per team.