Worksheet: Hydraulic Loss in a Smooth Pipe

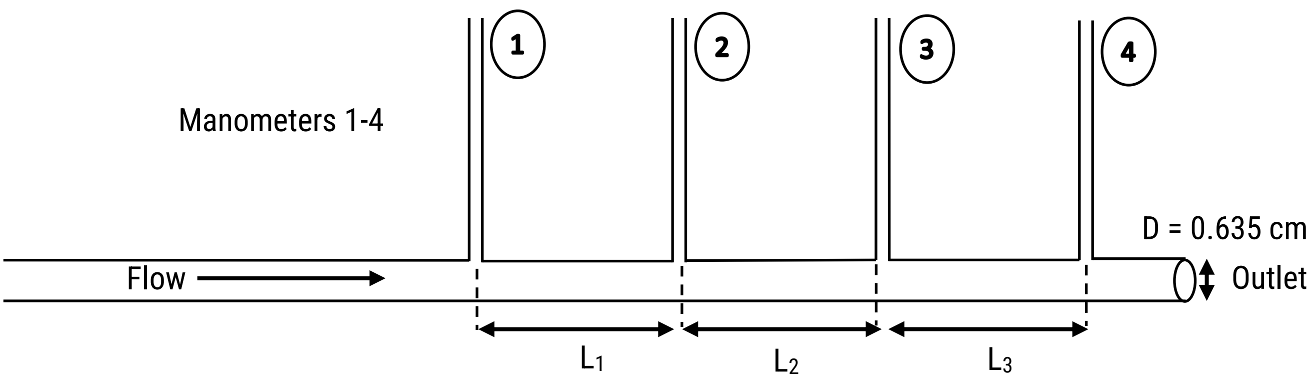
Name(s):____

This experiment measures frictional losses in a smooth pipe for water flow by measuring pressures along the pipe with manometers.

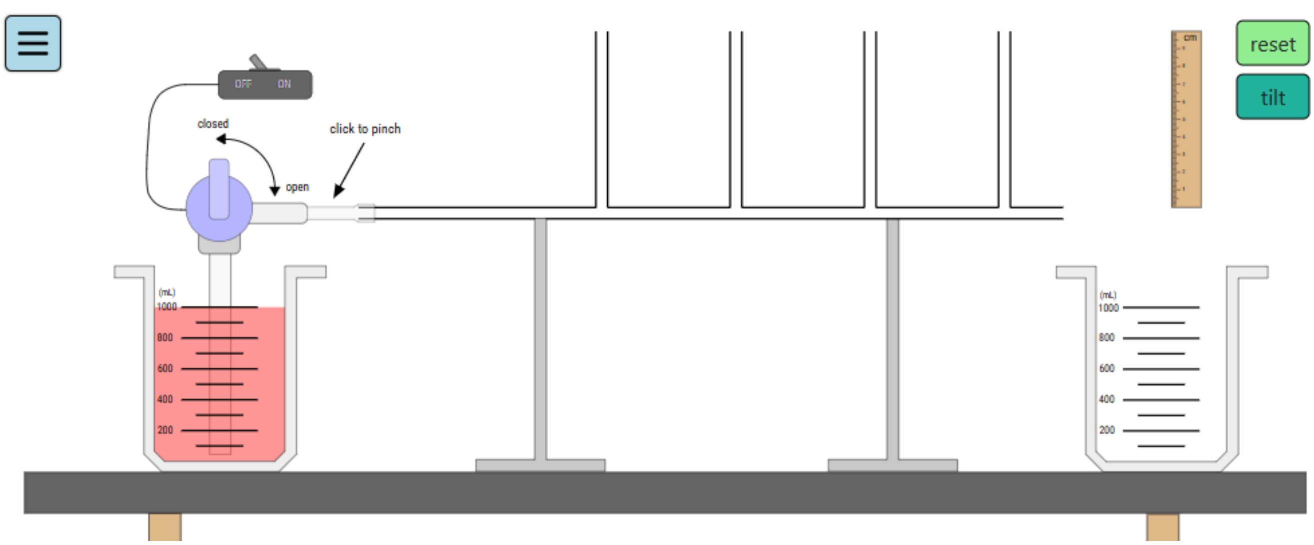
Student Learning Objectives

1. Use the continuity equation and mechanical energy balance to predict velocity and pressure trends in a pipe
2. Measure frictional head loss
3. Demonstrate how Reynolds number, pipe length, and pipe diameter affect frictional head loss
4. Calculate theoretical head loss values and compare to measured head loss values
5. Demonstrate how/if gravity affects the velocity along the length of a tilted pipe

Schematic and Dimensions



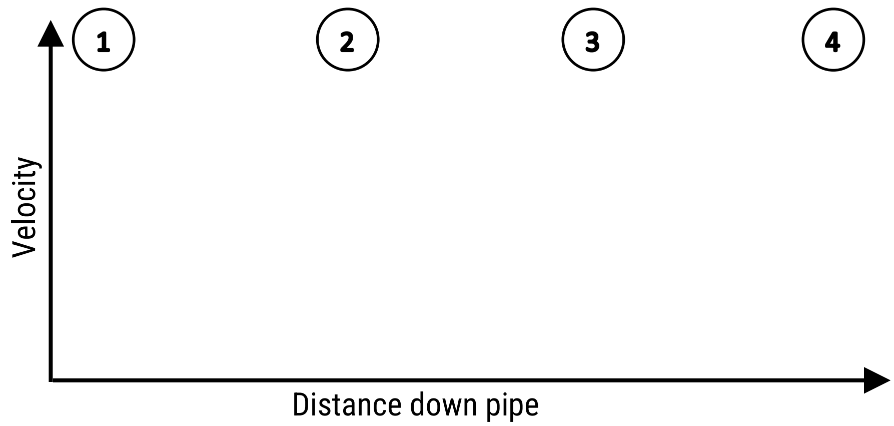
Distance between standpipes: $L_1 = L_2 = L_3 = 7.62$ cm



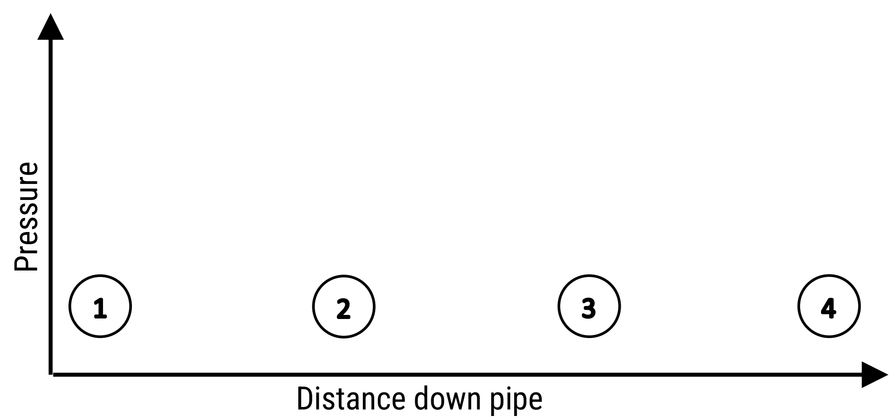
Worksheet: Hydraulic Loss in a Smooth Pipe

Before starting the experiment:

Draw lines for predicted velocity and pressure trends as water travels down the pipe. Explain your reasoning.

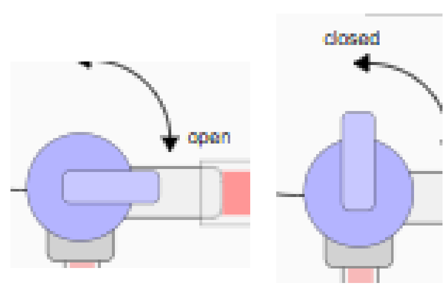


Velocity: ________________________



Pressure ________________________

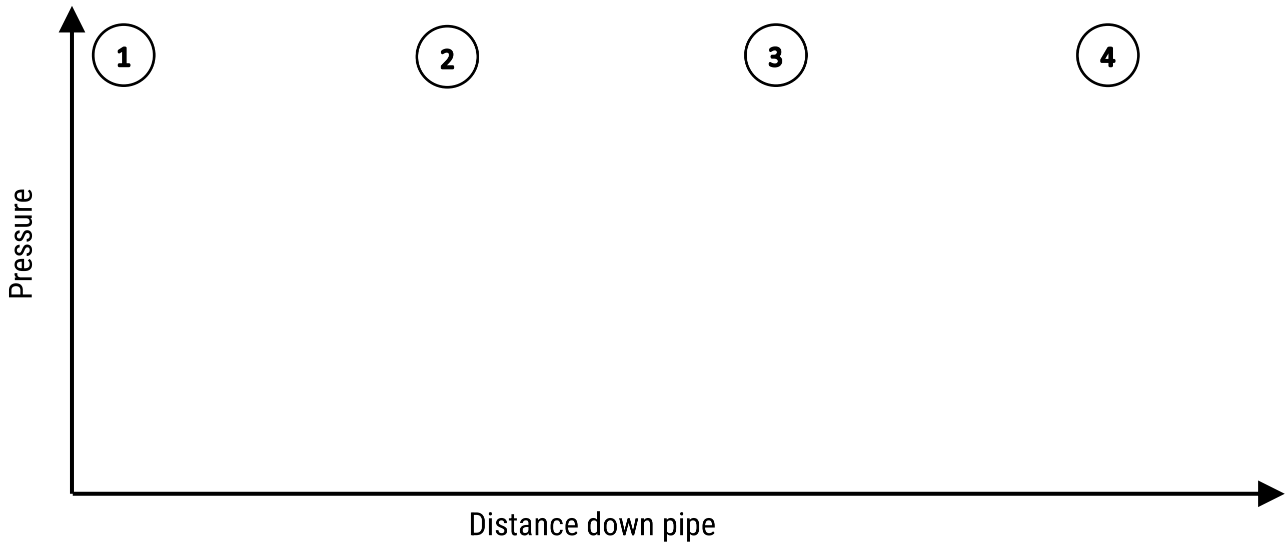
Velocity and Pressure Trends in a Pipe



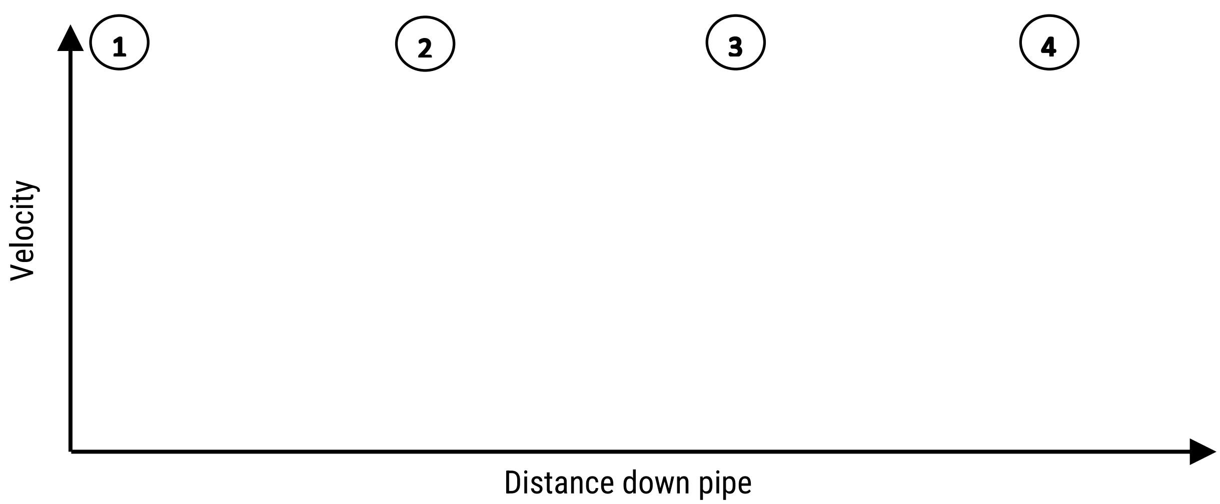
1. Start pump with the valve fully open (figure on right). ***Remove bubbles from the manometers by pinching the inlet tube***.
2. Observe water heights in manometer tubes. Plot the pressure trend below. Remember that pressure is proportional to water column height.
3. Discuss why you observe the pressure trend above. How does pressure vary with pipe length? How does pressure drop vary with pipe diameter? The equation below may help you understand.

$$\Delta P = \frac{fL\rho\bar{v}^2}{2D}$$

f = Darcy friction factor (defined in homework section), $\bar{v}$ = average fluid velocity, D = pipe diameter, L = pipe length, ρ = fluid density



4. Go to https://labs.wsu.edu/educ-ate/tutorial-videos/ and watch "Flow tracing with bubbles (slow-motion cell-phone video)," located near the bottom of the page. Based on the speed of the bubbles as they move through the pipe, plot the velocity trend between points 1-4.



5. Discus why you observe the velocity trend above. Does the velocity vary with pipe length? The continuity equation between two points, *i* and *j*, may help you understand.

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$$\bar{v}_i A_{x,i} \rho_i = \bar{v}_j A_{x,j} \rho_j$$

$\bar{v}$ = average fluid velocity
A_x = cross sectional area
ρ = fluid density

6. The mechanical energy balance for steady, incompressible, one-dimensional flow in terms of energy per unit mass between two points, *i* and *j*, is given below:

$$\frac{P_i}{\rho} + \frac{\bar{v}_i^2}{2} + gZ_i + W_p = \frac{P_j}{\rho} + \frac{\bar{v}_j^2}{2} + gZ_j + h_L$$

where W_p is the pump work, if a pump or turbine exists between points *i* and *j*, h_L is the irreversible headloss, and $\frac{P}{\rho}, \frac{\bar{v}^2}{2}$, and gZ are the flow work, kinetic energy, and potential energy per unit mass, respectively.

Simplify the equation above between manometers 1 and 4 (note there is no pump between 1 and 4). Based on the simplified equation, why does the pressure change from manometer position 1 to 4?

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Flowrate and Frictional Head Loss

7. a. Open the valve till water is not leaking from the top of manometer 1. Measure volumetric flow rate with a beaker and a cell phone timer. Record the water column heights at manometers 1 & 4.

   b. Repeat twice by **partially closing** the valve to *different* positions and record the data in Table 1.

Table 1

Valve setting	t [sec]	V [cm^3]	h_1 (cm)	h_4 (cm)
Fully open				
Partially closed position (1)				
Partially closed position (2)				

8. Based on your data in Table 1, taking h_1-h_4 as the pressure head loss, how do the velocity (related to the volumetric flowrate (V/t) divided by the cross-sectional area) and the Reynolds number affect the pressure loss?

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Gravity and Flowrate

9. Go to https://labs.wsu.edu/educ-ate/tutorial-videos/ and watch “Bubbles in a Tilted Pipe,” located at the bottom of the page. Based on the speed of the bubbles as they move through the tilted pipe, how does gravity affect fluid velocity as flow continues down the pipe? Discuss why velocity changes or remains constant.

Homework Problems **Due:** ____________________

1. Calculate and record the volumetric flow rate, velocity, measured pressure drop (head loss), and Reynolds number for each of the valve positions in Table 1 using data collected during class.

$$Re = \frac{\rho \bar{v} D}{\mu}$$

Table 2

Valve setting	$\dot{V} = \frac{V}{t}$ [cm³/s]	$\bar{v} = \frac{\dot{V}}{A_x}$ [cm/s]	$\Delta P = \rho g(h_1 - h_{4)}$ [Pa]	Re
Fully open				
Partially closed position (1)				
Partially closed position (2)				

2. The pressure drop in a section of pipe can be calculated as a function of the Darcy friction factor:

$$\Delta P = \frac{f L \rho \bar{v}^2}{2D}$$

where f is the Darcy friction factor shown below for laminar flow, as derived from first principles, and for turbulent flow using one of the common correlations.

For laminar flow: $f = \frac{64}{Re}$

For transitional/turbulent flow: $f = \frac{0.25}{\left[log\left(\frac{\varepsilon/D}{3.7} + \frac{5.74}{Re^{0.9}}\right)\right]^2}$

Note: For this experiment with a smooth pipe, **the relative roughness (ε/D) can be taken as zero. For rough pipes, relative roughness must be included in the friction factor calculation.

Calculate the theoretical pressure loss between manometers 1 and 4 for each valve position in Table 1 using <u>**both**</u> the laminar and turbulent correlations for the friction factor.

Table 3

Valve setting	ΔP_{theory} from $f_{laminar}$	ΔP_{theory} from $f_{turbulent}$	$\Delta P_{measured}$
Fully open			
Partially closed position (1)			
Partially closed position (2)			

3. Which friction factor relationship gives values closest to your experimental values for each experiment? Discuss what you learn from using the applicable and non-applicable friction factor relationships in each case.

4. Summarize in 1-2 sentences what you learned for each of the learning objectives below.
   - Use the continuity and mechanical energy equations to predict velocity and pressure trends in a pipe:
   - Determine how to measure frictional head loss:
   - Demonstrate how Reynolds number, pipe length, and pipe diameter affect frictional head loss:
   - Calculate theoretical head loss values for laminar and turbulent flow; compare to LCDLM measured head loss values:
   - Demonstrate how/if gravity affects the velocity along the length of a tilted pipe: