1 Part A Background and Theory

a. Symbol Directory:

Experimental Quantities:		
d	Pipe Diameter	m
L	Length of Tube across which Head Loss is Measured	m
Q	Volumetric Flow Rate	$\frac{m^3}{s}$
h_1	Upstream Head	m
h_2	Downstream Head	m
T	Fluid Temperature	$°C$

Computed Quantities:		
V_{av}	Average Fluid Velocity	$\frac{m}{s}$
$[Re]$	Reynold's Number	
h_e	Empirical Head Loss	m
h_c	Theoretical Head Loss	m
f_e	Empirical Friction Factor	
f_c	Theoretical Friction Factor	

Constants and Thermophysical Properties:		
g	Acceleration due to Gravity	$9.807\frac{m}{s^2}$
ρ	Fluid Density	$\frac{kg}{m^3}$
μ	Fluid Dynamic Viscosity	$\frac{N}{m^2 s}$
ν	Fluid Kinematic Viscosity	$1.003 \times 10^{-6}\frac{m^2}{s}$
ε	Surface Roughness of Pipe	m
ε_s	Surface Roughness of the Smooth Pipe	$4.6 \times 10^{-5}m$
ε_r	Surface Roughness of the Rough Pipe	$2.5 \times 10^{-4}m$

**All non-standard values extracted from relevant sections of assignment.*
Values not provided were not needed.

b. Basic Calculations:

Average Velocity Assuming an incompressible fluid, for flow through a given tube, the average velocity, V_{av} at any cross-section can be determined from the volumetric flow rate, Q, anywhere in the stream and the diameter of the tube, d at the cross-section of interest as:

$$V_{av} = \frac{Q}{A_c} = \frac{4Q}{\pi d^2} \tag{1}$$

Reynold's Number As given in equation 8 of the assignment, the Reynold's Number can be determined by:

$$[Re] = \frac{\rho V_{av} d}{\mu} = \frac{V_{av} d}{\nu} \tag{2}$$

Head Loss and Empirical Friction Factor To determine the friction factor, f_e from experimental data, the head loss must first be determined as

$$h_e = h_1 - h_2$$

With this determined, the friction factor can be found from the formula for major head loss set out in equation 4 of the assignment:

$$f_e = \frac{2gdh_e}{LV_{av}^2} \tag{3}$$

This, of course, assumes that any minor head losses are negligible which is the for fluid running through an straight uninterrupted section of tube as is the case in set up of Part A.

Theoretical Friction Factor and Head Loss Accordingly, the theoretical head loss for a fluid moving through a straight section of pipe with a given velocity can be determined by first finding the friction factor based on either equation 7 or 10 of the assignment:

$$f_c = \begin{cases} \frac{64}{Re} & Re \leq 2500 \\ \left[-1.8 \ln\left(\frac{6.9}{Re} + \left(\frac{\varepsilon/d}{3.7}\right)^{1.11}\right)\right]^{-2} & Re > 2500 \end{cases} \tag{4}$$

Based on the nature of the experimental setup, values for the pipe surface roughness are used in accordance with the values provided in the assignment as an overlay on the Moody's chart. Namely:
Assuming Commercial Steel: $\varepsilon_{smooth} = 4.6 \times 10^{-5}m$
Assuming Roughened to Degree of Cast Iron: $\varepsilon_{rough} = 2.5 \times 10^{-4}m$

With this value, the expected head loss can be computed based on equation 4 of the assignment:

$$h_c = f_c \frac{LV_{av}^2}{2gd} \tag{5}$$

Uncertainties: Since all values were sampled 5 times, uncertainty in any given parameter can be calculated using $\delta X = 2\sigma_X$, where σ_X is the standard deviation in X, given by:

$$\sigma_X = \sqrt{\frac{1}{N_X - 1}\sum_i (X_i - \mu_X)^2} \quad | \quad \mu_x = \frac{1}{N_X}\sum_i X_i \tag{6}$$

Note: In plots, this process is applied to the Y *and* X values around certain target values to create X and Y error bars.
For example in the plot of h_e vs Q, this is used to create error bars for each set of $\{Q, h_e\}$ where the flow rate was within $0.03{}^L/_s$ of the desired test values $0.75{}^L/_s, 0.65{}^L/_s$, *etc.*