Objective:

The edibon Hydraulics Bench is to be used to measure friction factors and local loss coefficients in selected piping arrangements. These include sudden expansions, sudden contractions and bends. Other flow components to be studied in this lab include a Venturi flow meter. The theory for using Venturi tubes for flow rate measurement will also be verified.

The hydraulics bench can be operated in both the laminar flow (Re < 2300) and turbulent flow regimes by adjustment of the fluid velocity. The flow rates are measured directly by a digital flow meter. Calibration of the flow meter is most easily performed by timing liquid accumulation in calibrated containers. An alternative method (and likely more accurate) is to weigh the mass accumulated during a given time interval. This eliminates uncertainties in the calibration of the container. Care should be taken to take data at Reynolds numbers far from the Critical Region in both the laminar and turbulent flow regions.

Theory:

The frictional pressure drop in a straight pipe segment can be correlated in terms of the Darcy friction factor according to the equation

\[ \Delta P_f = \frac{fL \rho v^2}{D_e 2g_c} \]  

where:

- \( f \) = Darcy friction factor
- \( L \) = Pipe length
- \( D_e \) = Equivalent diameter
- \( v \) = Fluid velocity
- \( \rho \) = Fluid density
- \( g_c \) = Conversion factor.

The friction factor is in general a function of Reynolds number and pipe roughness.

The local pressure drop due to flow obstructions (elbows, valves, fittings, etc.) is usually correlated in the form

\[ \Delta P_{local} = K \frac{\rho v^2}{2g_c} \]  

where \( K \) is the local loss coefficient. While in general a function of velocity (Reynolds number), the local loss coefficient is often taken to be constant. In a piping system consisting of both straight pipe segments and local flow obstructions, the total pressure drop is a linear sum of these two components.

Flow rate measurement with the Venturi tube is based on application of Bernoulli’s equation and mass conservation at selected points within the component. In the absence of losses, the volumetric flow rate (\( Q = VA_x \)) of a constant density fluid through the venturi can be shown to be
\[ Q = A_2 \sqrt{\frac{2 g_c (P_1 - P_2)}{\rho \left( 1 - \left( \frac{A_2}{A_1} \right)^2 \right)}} \]

where:
- \( A_1 \) = inlet area
- \( A_2 \) = throat area
- \( P_1 \) = inlet pressure
- \( P_2 \) = throat pressure.

With known Venturi geometry, the system flow rate is found by measuring \( P_1 \) and \( P_2 \). In reality, some irreversible losses within the venturi are to be expected. This is accounted for by an experimentally determined discharge coefficient \( C_d \) such that the actual volumetric flow rate is

\[ Q = C_d A_2 \sqrt{\frac{2 g_c (P_1 - P_2)}{\rho \left( 1 - \left( \frac{A_2}{A_1} \right)^2 \right)}} \]

The equation for volumetric flow rate given above is also commonly used to determine the flow through orifice plates and nozzles.

**Procedure:**

1) Confirm the digital flow meter is correctly calibrated by comparing the output from the flow meter to the flow rate obtained by directly measuring accumulated liquid mass (or volume) as a function of time.

2) Under both laminar and turbulent flow conditions, measure the pressure drop associated with the assigned flow geometries.

3) The friction factor can be obtained directly from the measured pressure drop and flow velocity by

\[ f = \frac{\Delta P}{L \rho v^2 / D} \frac{2g_c}{2g_c} \]

in both the laminar and turbulent regions. Plot friction factor as a function of Reynolds number using different symbols for the individual straight pipe segments. The different symbols will allow you to clearly show the effect of roughness for pipes of the same diameter and Reynolds number. One form of the friction factor that takes into account relative roughness and Reynolds number is

\[ f = 0.25 \left( \log \left( \frac{e}{3.7D} \right) + \frac{5.74}{Re^{0.8}} \right)^2 \]

For the piping segments examined here, the roughness is not generally known. Perform a least squares fit on your friction factor data to determine the roughness of the individual piping segments.
3) Determine the loss coefficients for the assigned flow geometries and investigate any velocity dependence. Compare your results with those in the literature. Note: Be sure and subtract out the friction component (if any) before determining the loss coefficient.

4) Calibrate the venturi for measuring flow rate by determining the discharge coefficient which gives the best fit to measured flow rate data. Determine the loss coefficient for the venturi by measuring the pressure drop across the entire device.