**Experiment: Bernoulli Equation applied to a Venturi Meter**

**Purpose**

The objective of this experiment is to measure the fluid head through a Venturi meter constriction for various flow rates and examine the validity of Bernoulli’s equation as a function of position along the meter.

**Learning Objectives**

The Bernoulli exercise involves measurements of static pressure heads and examines the validity of Bernoulli’s Eqn. along a duct of variable cross section. After successfully completing the exercise students should be able to

* Apply Bernoulli’s Eqn. along a pipe of varying cross section.
* Identify any discrepancies within the experimental results and provide a plausible explanation for observed discrepancies.

**Apparatus**

Figure 1 is a schematic of the TecQuipment Venturi Meter apparatus. Water is pumped into the meter through a flexible hose. Inserted in the hose is a valve for controlling the flow rate and a flow meter to measure the flow rate. Water passes through the Venturi device and a secondary valve before discharging into the reservoir tank. A set of pressure taps along the Venturi wall provide the pressure distribution along the length of the convergent-divergent passage. Each tap is connected to a vertical manometer tube mounted in front of a scale for direct readings of pressure head difference in millimeters of water. The manometer tubes connect at their top ends to a common manifold that has a small air valve. The hand pump (attached to the side of the apparatus) can be used to adjust the air pressure in the manifold to adjust the uniformity of the water levels in the manometer at higher flow rates so that the water levels fit within the measuring scale of the manometers scales. The secondary valve adjusts the overall pressure in the system to control the location of the static pressure manometer interfaces.

Figure 1. Schematic of the Venturi meter apparatus. (taken from TecQuipment H5 user guide)

**Theory**

The Venturi Effect is named after the Italian physicist Giovanni Venturi from the 18th century. He found that the pressure of a moving fluid drops when it passes through a constriction in a pipe. Around the same time, a Dutch-Swiss mathematician, Daniel Bernoulli, showed that the change in velocity of a fluid is directly related to the change in its pressure (potential energy) assuming that the flow is steady, incompressible, inviscid, without losses, and with no work.

Figure 2 shows an incompressible fluid flowing along a convergent-divergent pipe with three pressure taps. One tap measures the upstream pressure at section 1, the second measures the pressure at the throat (section 2) and the third measures pressure downstream at an arbitrary section 3. The cross-sectional area at the upstream section is *a1*, at the throat is *a2*, and at the arbitrary location is *an*. Piezometer tubes at these sections register *h1*, *h2*, and *hn* as shown. Assuming Bernoulli’s Equation is valid and expressing the pressure in terms of the manometer readings yields

Figure 2. Idealized depiction of the relative magnitude of the velocity head and pressure head along a convergent-divergent pipe. (taken from TecQuipment H5 user guide)

$$\frac{u\_{1}^{2}}{2g}+h\_{1}=\frac{u\_{2}^{2}}{2g}+h\_{2}=\frac{u\_{n}^{2}}{2g}+h\_{n}$$

[1]

where *u1*, *u2*, and *un* are the velocities through sections *1*, *2*, and *n*. The velocities at *1*, *2*, and *n* are further related through the continuity equation (conservation of mass) which states that the mass flow rate through each section is constant (no accumulation of mass) or

[2]

$$\dot{m}\_{1}=\dot{m}\_{2}=\dot{m}\_{n}$$

or

[3]

$$ρ\_{1}\dot{Q}\_{1}=ρ\_{2}\dot{Q}\_{2}=ρ\_{n}\dot{Q}\_{n}$$

where $\dot{m}$ is the mass flow rate,  is the density, and $\dot{Q}$ is the volume flow rate. If the fluid is incompressible then

[4]

$$\dot{Q}\_{1}=\dot{Q}\_{2}=\dot{Q}\_{n}$$

and if *u1*, *u2*, and *un* represent the average velocity through each section then Eqn. 4 becomes

[5]

$$u\_{1}A\_{1}=u\_{2}A\_{2}=u\_{n}A\_{n}$$

where A is the cross sectional area at a given point. Thus the velocity at each section may be determined from the measured flow rate knowing the cross sectional area at each point along the length of the Venturi meter.

**Procedure**

1. Record dimensions of the Venturi apparatus at all locations along the convergent-divergent section.
2. First close the valve attached to the pump then open the valve 1.5 to 2 full turns.
3. Open the secondary valve (valve downstream of the Venturi meter) completely.
4. Turn on the pump. It may take a few seconds to for the pump to prime and the water to begin flowing through the Venturi meter.
5. As water begins to flow through the apparatus, water should rise up into the manometer tubes. Make sure the fluid does not rise completely to the top an any tube. If it appears as though it will rise to the top, make sure the secondary valve is completely open then close the valve near the pump to reduce the flow rate.
6. Once steady state is reached you may notice air bubbles trapped in the manometers. These need to be removed. Tilt the entire Venturi meter and gently pluck each manometer to dislodge the bubbles. Repeat until all the bubbles have risen to the top.
7. Increase the flow rate (to about 10gpm) until the far left manometer is a couple of inches from the top. You may notice that not all of the manometers are filled.
8. To fill all manometers slowly close the secondary valve until liquid is present in all tubes. Be careful that the fluid in the other manometers does not exceed the scale maximum. If it appears as though it will, either decrease the flow rate or increase the back pressure with the hand pump provided (Note: it is unlikely you will need to do this).
9. The device should now be ready. Measure the manometer readings at each position for multiple flow rates between 1 and 10 gpm (increments of 1gpm).

**Data Analysis**

For the measured flow rates, calculate the velocity at each point along the Venturi meter. With the velocities and manometers readings calculate the total fluid head along the length of the Venturi meter for each flow rate and plot the results. Are trends consistent with Bernoulli’s Eqn observed.

Additionally plot the dimensionless pressure as a function of position along the Venturi Meter. From Bernoulli’s equation the difference in head between any point may be found from

[6]

$$h\_{n}-h\_{1}=\frac{u\_{1}^{2}-u\_{n}^{2}}{2g}$$

Dividing Equation 6 by the characteristic head $u\_{max}^{2}/2g$ yields the dimensionless terms

[7]

$$\frac{h\_{n}-h\_{1}}{\left(\frac{u\_{max}^{2}}{2g}\right)}=\frac{u\_{1}^{2}-u\_{n}^{2}}{u\_{max}^{2}}$$

By applying continuity the velocity ratios are replaced by the area ratios such that

[8]

$$\frac{h\_{n}-h\_{1}}{\left(\frac{u\_{max}^{2}}{2g}\right)}=\left(\frac{A\_{min}}{A\_{1}}\right)^{2}-\left(\frac{A\_{min}}{A\_{n}}\right)^{2}$$

Equation 8 indicates that theoretically the dimensionless head difference theoretically depends only on the area ratios (right hand side of Eqn 8.) Thus, the measured dimensionless head difference (also known as the dimensionless pressure distribution or the actual piezometric head coefficient) may be calculated from the left hand side of Eqn. 8 and compared to the theoretical or ideal piezometric head coefficient (the right hand side of the Eqn. 8). Compare the actual and ideal piezometric head coefficient as a function of position along the Venturi meter. Note umax and Amin are usually defined at the throat of the Venturi meter however is may be defined at a location downstream of the constriction for comparison of head coefficients along the discharge.

**Possible Discussion Points**

If Bernoulli’s Equation is valid along the length of the Venturi meter then the total head at each point should be constant. If the total head is not constant, head loss (and therefore energy loss) is present in the system. It is possible that Bernoulli’s Equation is satisfied in sections of the Venturi meter but not necessarily across the entire meter. Is this observed? If so does the region of validity vary with flow rate? Would we expect this to be the case considering the assumptions inherent in Bernoulli’s Equation? Are the measured and theoretical head coefficients consistent in the converging section, at the throat, or in the discharge region?