Experiment No. 4: venturi meter

Introduction:

Venturi meters are flow measurement instruments which use a converging section of pipe to give an increase in the flow velocity and a corresponding pressure drop from which the flow rate can be deduced. They have been in common use for many years, especially in the water supply industry. A venturi meter is shown in figure 1.

Fig. 1: venturi meter

Flow meters are used in the industry to measure the volumetric flow rate of fluids. Differential pressure type flow meters (Head flow meters)measure flow rate by introducing a constriction in the flow. The pressure difference caused by the constriction is correlated to the flow rate using Bernoulli's theorem.

If a constriction is placed in a pipe carrying a stream of fluid, there will be an increase in velocity, and hence an increase in kinetic energy, at the point of constriction. From an energy balance as given by Bernoulli's theorem, there must be a corresponding reduction in pressure. Rate of discharge from the constriction can be calculated by knowing this pressure reduction, the area available for flow at the constriction, the density of the fluid and the coefficient of discharge C. Coefficient of discharge is the ratio of actual flow to the theoretical flow.

The Venturi is widely used particularly for large volume liquid and gas flows since it exhibits little pressure loss.

Objectives:

This experiment allows the student to:.

1. To use the venturi meter instrument and calculating volumetric flow rate theoretically applying Bernoulli equation, also finding the actual value of volumetric flow rate through a volumetric tank and a stopwatch, comparing it with the theoretical one.
2. To determine the coefficient of discharge of venturi meter.
3. To realize the relationship between the cross sectional area, fluid velocity, and fluid pressure through the venturi (venturi effect).
4. To plot the velocity and pressure distribution along venturi meter.

Parts needed:

1. H5 venturi meter apparatus, (fig.*2a*).
2. H1D volumetric bench, (fig.*2b*)
3. Hand pump.
4. Stopwatch.
5. Colored water.

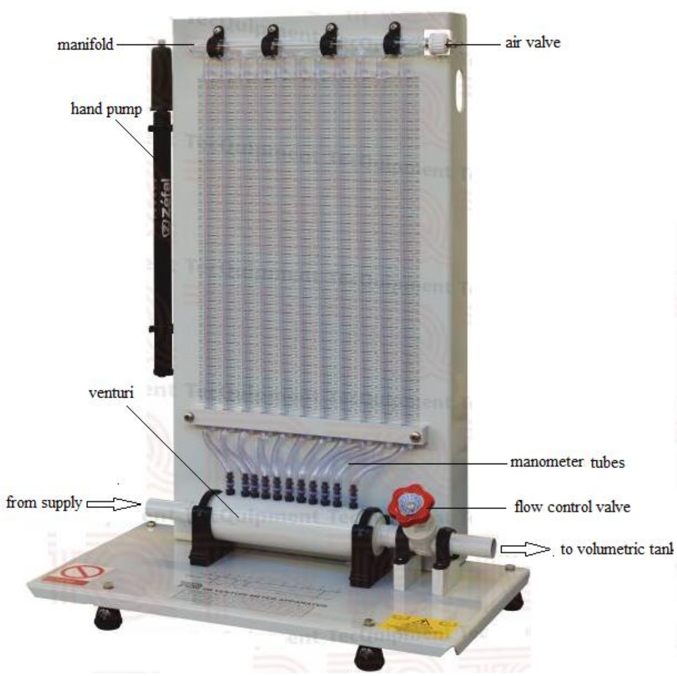

Fig.2a: H5 venturi meter apparatus

Fig. 2b:H1D volumetric bench

Theory:

An incompressible, inviscid fluid flow through the Venturi meter is shown in Figure 3, The cross sectional area at the inlet is A_1 , at the throat section is A_2, and at any other arbitrary section is A_n, and the manometric head related to these sections are denoted as h_1, h_2 and h_n respectively as shown in figure 3. Assuming that the instrument is placed on a level table, and both the velocity and the manometric head are remains constant for each section, so that the venturi can be treated as a stream tube and no energy loss along the pipe then Bernoulli's theorem states that:

$$\frac{p_1}{\rho g}+\frac{u_1^2}{2g}+z_1=\frac{p_2}{\rho g}+\frac{u_2^2}{2g}+z_2$$

$\frac{p_1}{\rho g}$ = Pressure head at 1 = h_1 $\qquad \frac{u_1^2}{2g}$ = kinetic head at 1 $\qquad z_1$ = potential head at 1

$\frac{p_2}{\rho g}$ = Pressure head at 2 = h_2 $\qquad \frac{u_2^2}{2g}$ =kinetic head at 2 $\qquad z_2$ = potential head at 2

But

$$z_1 = z_2$$

and

$$\frac{u_1^2}{2g}+h_1 = \frac{u_2^2}{2g}+h_2 = \frac{u_n^2}{2g}+h_n \qquad (1)$$

where u_1, u_2 and u_n are the velocities of flow through sections 1, 2 and n.

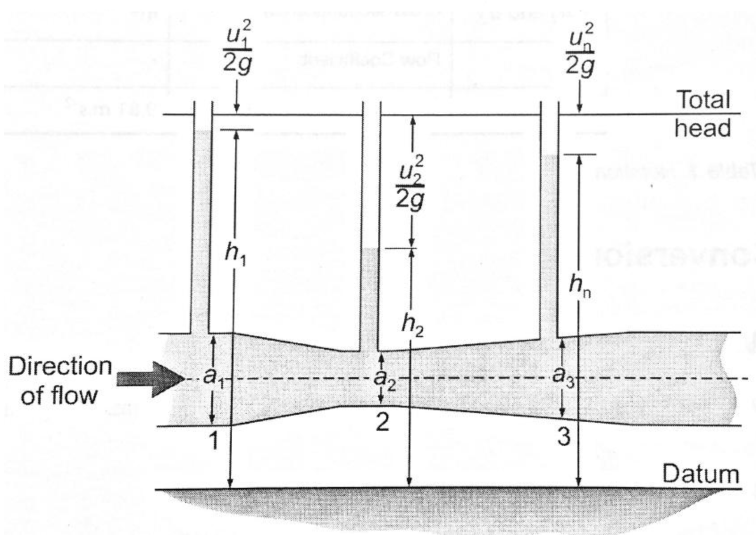

Fig. 3: ideal conditions in a venturi

The equation of continuity assumes constant flow ***volume*** (not velocity) along the pipe, so:

$$u_1 a_1 = u_2 a_2 = u_n a_n = Q \qquad (2)$$

Substituting in Equation 1 for u_1 from Equation 2:

$$\frac{u_2^2}{2g}\left(\frac{a_2}{a_1}\right)^2 + h_1 = \frac{u_2^2}{2g} + h_2$$

and solving this equation for u_2 leads to:

$$u_2 = \sqrt{\frac{2g(h_1 - h_2)}{1 - (a_2/a_1)^2}}$$

so that the discharge rate (volume flow), from Equation (2) becomes:

$$Q = a_2 \times \sqrt{\frac{2g(h_1 - h_2)}{1 - (a_2/a_1)^2}} \qquad (3)$$

The flow actually loses some energy between sections 1 and 2, and the velocity is not absolutely constant across either of these sections. As a result, the measured value of Q is always slightly less than the value calculated from theory - Equation (3). To allow for this, the equation becomes:

$$Q = Ca_2 \times \sqrt{\frac{2g(h_1 - h_2)}{1 - (a_2/a_1)^2}} \qquad (4)$$

where C is an adjustment factor called the ***coefficient of discharge*** for the meter, which you can find by experiment. Its value varies slightly from one meter to another and, even for a given meter it may vary slightly with the discharge, but is usually between 0.92 to 0.99 for a convergent-divergent (Venturi) meter.

Finding the Coefficient of Discharge (C)

Equation 4 can be re-arranged to give:

$$Q = C \times a_2 \sqrt{\frac{2g}{1 - (a_2/a_1)^2}} \times \sqrt{(h_1 - h_2)} \qquad (5)$$

As the dimensions of the Venturi (a_1 and a_2) and gravity (g) remain constant, the middle of the equation can simplify to a constant (k), so that:

$$k = a_2 \sqrt{\frac{2g}{1 - (a_2/a_1)^2}}$$

So:

$$Q = C \times k \times \sqrt{h_1 - h_2} \tag{6}$$

and therefore:

$$C = \frac{1}{k} \times \frac{Q}{\sqrt{h_1 - h_2}} \tag{7}$$

Showing a linear relationship between flow, flow coefficient and the square root of head difference.

Average Coefficient of Discharge

From Equation 7, assuming C and k remain constant, a chart of $\sqrt{h_1 - h_2}$ against Q (see Figure 4) should produce linear results. You can then use ***the inverse gradient*** of the results to give an average value that you can substitute for the right hand side in Equation 7.

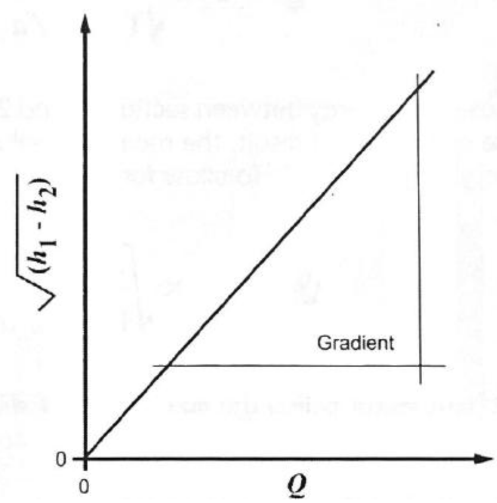

Fig. 4: using chart to find average C

Dimensionless Calculations of Pressure

From Bernoulli's equation the difference in head between any point and the inlet pressure may be found from:

$$h_n - h_1 = \frac{u_1^2 - u_n^2}{2g}$$

To easily compare actual results with theory, you must convert these terms into dimensionless calculations. To do this, dividing through by $(u_2^2/2g)$ gives:

$$\frac{h_n - h_1}{(u_2^2/2g)} = \frac{u_1^2 - u_n^2}{u_2^2}$$

Using the equation of continuity (2) to substitute area ratios in place of velocity ratios, this becomes:

$$\frac{h_n - h_1}{(u_2^2/2g)} = \left(\frac{a_2}{a_1}\right)^2 - \left(\frac{a_2}{a_n}\right)^2 \tag{8}$$

Therefore, calculating the area ratios gives the ***theoretical or 'ideal'*** dimensionless pressure difference, otherwise known as ***ideal piezometric head coefficient***:

$$\left(\frac{a_2}{a_1}\right)^2 - \left(\frac{a_2}{a_n}\right)^2 \tag{9}$$

and the ***actual*** dimensionless pressure distribution (otherwise known as ***actual piezometric head coefficient)*** is found from:

$$\frac{h_n - h_1}{(u_2^2/2g)} \tag{10}$$

Procedure:

1. Create a blank results table, similar to table 1.
2. Setup the apparatus, so you can read all the water levels at full flow.
3. Now slightly reduce the flow rate through the meter, and wait for it to stabilize. Use the hydraulic bench to measure the flow.
4. Record the pressure tapping readings and the flow. Remember to convert flow into volume flow of m^3 /s.
5. Repeat for several more (lower) flow rates down to the minimum flow that gives you reasonable set of pressure levels along the meter.

<table>
<tr><th rowspan="2">Tapping</th><th colspan="6">Head (h) (mm)</th><th rowspan="2">Distance Along Venturi</th><th rowspan="2">Area (m^2)</th><th rowspan="2">$(a2/an)^2$</th><th rowspan="2">Ideal Dimensionless Pressure</th><th rowspan="2">Actual Dimensionless Pressure</th></tr>
<tr><th>1st</th><th>2nd</th><th>3rd</th><th>4th</th><th>5th</th><th>6th</th></tr>
<tr><td>A (Upstream) (h1)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>B</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>C</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>D (Throat) (h2)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>E</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>F</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>G</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>H</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>I</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>J</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>K</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Volume m^3</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Time t</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>$\sqrt{h1-h2}$ ($m^{1/2}$)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td rowspan="5" colspan="4">$(a2/a1)^2$ =
$u2^2/2g$ =
K =
Average value of C =</td></tr>
<tr><td>u2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Actual Flow (m^3/s)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Calculated Flow (m^3/s)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Coefficient Of Discharge (C)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table 1: a blank results table

Typical results:

All results are for reference only. Actual results may differ slightly.

Dimensionless pressure distribution

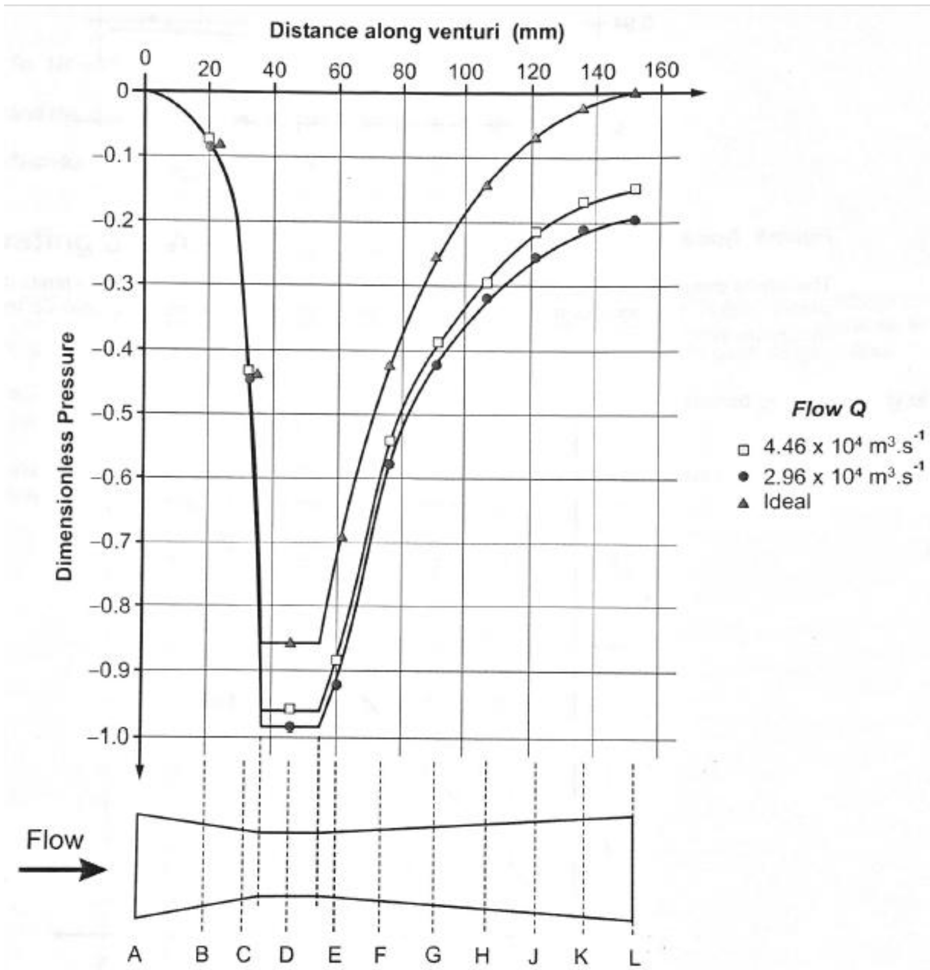

Figure 5 Typical Pressure Distribution Results

The result show that the theoretical and actual curves agree until the flow reaches the throat. At the throat and further downstream, actual results give lower dimensionless pressure results than theory. It also shows that this gets worse with lower flow. This suggests that in the actual Venturi, there is head loss (and therefore energy loss) in the throat and the diffuser. This shows the need to find and allow for the losses using the coefficient of discharge for the Venturi.

Finding the Coefficient of Discharge

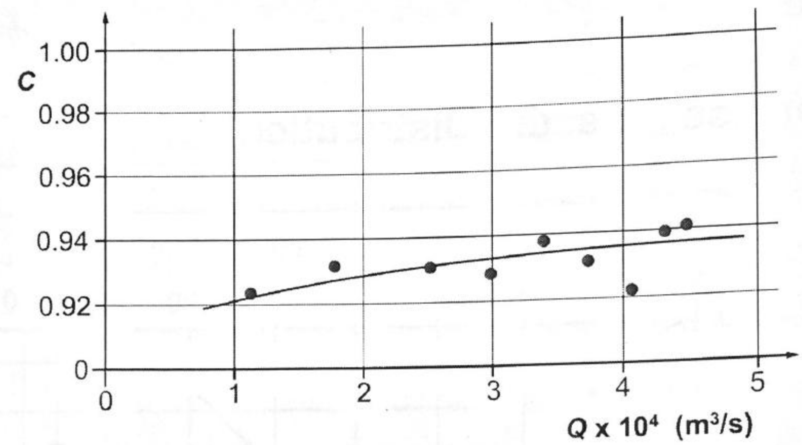

Figure 6 Typical Variation of C with Flow

The results should show that C varies slightly with flow, but generally stay within the limits stated in the theory section. The value for this meter shows a trend of increasing slightly with flow, up to the maximum available flow.

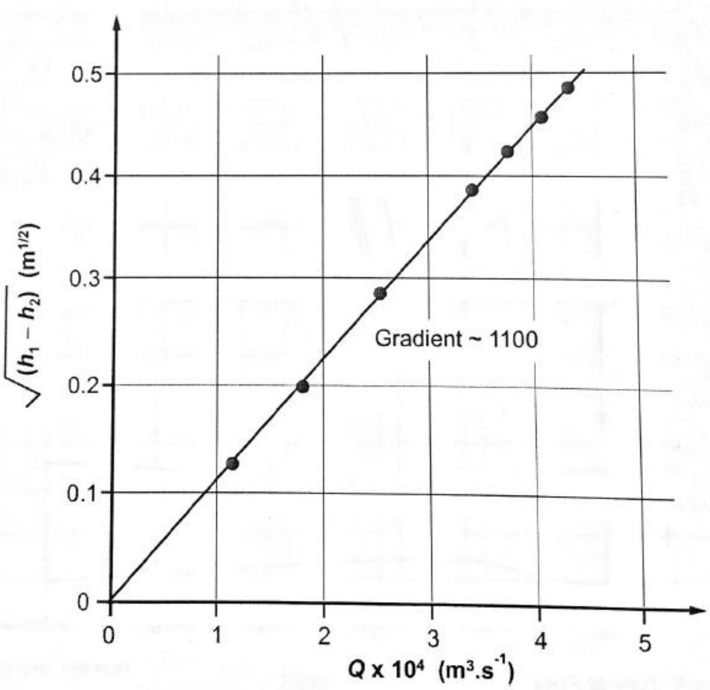

Figure 7 Typical Square Root of Head Change Over Flow Results

With nominal values of:

Inlet area (a_1) = 0.00053 m^2

Throat area (a_2) = 0.000201 m^2

The value of k gives:

$$0.000201\sqrt{\left(\frac{19.62}{1-(0.379)^2}\right)} = 0.000201\sqrt{(22.91)} = 0.000962$$

So, $1/k$ = 1039.5

and the inverse of the chart's gradient gives 1/1100 = 0.000909

Therefore average C = 1039.5 x 0.000909 = 0.945

Calibrating the Venturi

Using Equation 6 with the average value of C, the calculated value of k and the actual head differences gave typical errors of less than 3% through the flow range. This shows that using the average value for C gives reasonably accurate predictions of flow for the Venturi meter over the given range of flow.

Remember that the accuracy measurements can be slightly subjective, determined by the accuracy of your flow measurement technique using the Hydraulic Bench.

Also remember that the theory is based on fluid that has no viscosity, but water does have viscosity (but low), and its value changes slightly with temperature.

Questions for further discussion:

1. Does Bernoulli's equation give you a good approximation of your calculations for flow rate?
2. According to your calculations In what range the value of discharge coefficient C fall?
3. Mention some of venturi meter advantages?

Conclusion: does the objectives of the experiment achieved? How?