Experimental Analysis of a Venturimeter Flow Rig

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Abstract- *This paper presents the performance analysis of a Venturimeter flow rig; designed and manufactured for use in the Mechanical Engineering Laboratory of the Akwa Ibom State University (AKSU), Ikot Akpaden, Nigeria. The project provides a portable flow measurement apparatus for flow measurement in the laboratory. The students will use this apparatus during their fluid mechanics practical, to determine the discharge of a flowing liquid through the meter, hence the measurement of flow rate across the Venturimeter. The idea will be essential to flow discharge measurement in petroleum pipeline, irrigation facilities, automotive industry, wastewater collection systems and treatment plants. The rig consists essentially of measuring tank reservoirs, the Venturimeter, sump tank, an electric motor, cable, plug, valves, Polyvinyl Chloride (PVC) piping connections and a U-tube manometer. The design and construction were done with strict compliance to international standards to provide a high precision target for the measurement of flow rate; the length of the divergent cone of the Venturimeter is three (3) times that of convergent cone. The ratio of the diameter at throat to that of the pipe was ½. The manometer was used to measure pressures in the pipe, expressed in terms of head of water in metres. The Bernoulli's equation and the continuity equation were applied for the flow analysis. The values generated from the Venturimeter were validated against the standard Khurmi discharge values and were in good agreement as both plots shows similar trends; because, by increasing the value of the pressure head, there was a corresponding increase in discharge, hence confirming the efficacy of the Bernoulli's principles and continuity equation in the analysis of flow discharge through Venturimeter. This project is produced at a reduced cost since the materials used were sourced locally. The manufacturing cost will further reduce significantly if the Venturimeter flow rig is mass produced.*

I. INTRODUCTION

A Venturimeter is a device used for measuring the rate of flow of a fluid flowing through a pipe. It is also an apparatus for finding out the discharge of a liquid flowing in a pipe. It consist of three main parts; convergent cone, throat and divergent cone. The convergent cone is a short pipe which converges from section 1 to a small diameter and it is known as the inlet of the Venturimeter. Divergent cone is the long pipe which diverges from the throat to a large diameter while the throat is the small portion of the circular pipe at which the convergent cone converges and the divergent cone diverges respectively as shown in Figure 1.1. It is vital to note that the short converging part of the Venturi is where the fluid gets converges, the throat section lies in between the converging and diverging part of the venture. The cross section of the throat is much less than the cross section of the converging and diverging section. When the fluid enters the throat its velocity increases and the pressure decrease. The length of the divergent cone is about three (3) to four (4) times than that of the convergent cone.

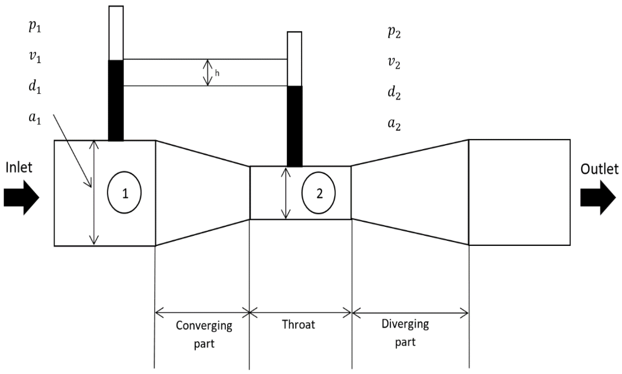


Figure 1.1: Cross section of Venturimeter showing variations in pressure (p), velocity (v), diameter (d) and area (a)

A Venturimeter uses 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 (Harris, 2011).

This flow measurement apparatus is used in the practical application of Bernoulli's theorem to the measurement of fluids flowing in pipes under pressure. Hence, the working of Venturimeter is based on the principle of Bernoulli's and continuity equations. The Bernoulli's principle states that in a steady, ideal flow of an incompressible fluid, the total energy at any point of the fluid is constant. The total energy consists of pressure energy, kinetic energy and potential energy.

A Venturimeter fit into the same class of flow measuring instruments known as Head meters such as the orifice meter. The short converging part is a tapered portion, whose radius decreases as we move forward. The middle portion of the Venturi is known as the throat. At the throat, the velocity of the fluid increases and pressure decreases. It possesses the least cross section area. After the throat, is the diverging part, where the fluid diverges.

The upstream section is a contracting portion with included an angle of from 19 to 23 degrees while the downstream section is a portion of a cone diverging with include an angle of 5 to 15 degrees. The throat can also be described as the junction of the two reduced sections of the Venturi. There are two pressure taps located in the Venturi.

Figure 1.2: Shows the manufactured Venturimeter flow rig being integrated alongside other fluid mechanics equipment in the fluid mechanics laboratory

II. A REVIEW OF SOME WORK USING VENTURIMETER

In fluid dynamics, Bernoulli's principle states that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy (Clancy, 1975; Batchelor, 1967). Bernoulli's principle can also be derived directly from Isaac Newton's Second Law of Motion. If a small volume of fluid is flowing horizontally from a region of high pressure to a region of low pressure, then there is more pressure behind than in front. This gives a net force on the volume, accelerating it along the streamline (Babinsky, 2003; Weltner and Ingelman-Sundberg, 2009). Fluid particles are subject only to pressure and their own weight. If a fluid is flowing horizontally and along a section of a streamline, where the speed increases, it can only be because the fluid on that section has moved from a region of higher pressure to a region of lower pressure; and if its speed decreases, it can only be because it has moved from a region of lower pressure to a region of higher pressure. Consequently, within a fluid flowing horizontally, the highest speed occurs where the pressure is lowest, and the lowest speed occurs where the pressure is highest (Resnick and Halliday, 1960).

III. METHODOLOGY

The methodology uses Bernoulli's theorem and Continuity equation in the analysis of the Venturimeter. The design principle of the Venturimeter is based on the theory of discharge of a liquid flowing in a pipe. During the flow of liquid through a pipe, there is an effect known as the Venturi effect. This effect is the reduction in fluid pressure that results when a fluid flows through a constricted section of the pipe. The fluid velocity must increase through the constriction to satisfy the equation of continuity, while its pressure must decrease due to conservation of energy: the gain in kinetic energy is balanced by a drop in pressure or a pressure gradient force. An equation for the drop in pressure due to Venturi effect is governed by Bernoulli's and continuity equations.

3.1 Discharges through a Venturimeter

In this study, the performance characteristics of a Veturimeter are determined. Applying Bernoulli's theorem and Continuity equation; and according to Khurmi (2006) to a Venturimeter through which some liquid is flowing as shown in Figure 3.1 and for completeness,

Let

p_1 = Pressure at section 1
v_1 = Velocity of water at section 1
Z_1 = Datum head at section 1
a_1 = Area of the Venturimeter at section 1
p_2, v_2, Z_2, a_2 = *Corresponding values at section 2*

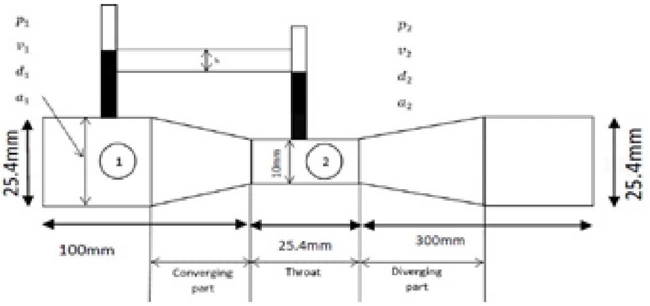


Figure 3.1: Venturimeter with dimensions as designed for the analysis

Applying Bernoulli's equation at section 1 and 2, we have that,

$$Z_1 + \frac{v_1^2}{2g} + \frac{p_1}{w} = Z_2 + \frac{v_2^2}{2g} + \frac{p_2}{w} \quad 3.1$$

Applying the Continuity equation at section 1 and 2, since the discharge is continuous, then,

$$v_1^2 = \frac{a_2^2 v_2^2}{a_1^2} \qquad 3.2$$

Noting that the pipe is horizontal, then the difference between the pressure heads at sections 1 and 2 represents the Venturi head, denoted as h, hence the relationship between the velocity and the Venturi head is given as,

$$v_2 = \sqrt{2gh}\left(\frac{a_1^2}{a_1^2 - a_2^2}\right) \qquad 3.3$$

Having been acquainted with the discharge through a Venturimeter as,

$$Q = C\ x\ a_2\ x\ v_2 \qquad 3.4$$

Where C = coefficient of Venturimeter

By substituting the values of v_2 of Equation 3.3 in Equation 3.4 and simplifying the equation, we have the discharge through a Venturimeter as,

$$Q = \frac{C.a_1\,a_2}{\sqrt{a_1^2 - a_2^2}}\sqrt{2gh} \qquad 3.5$$

IV. RESULTS AND DISCUSSION

This section presents the results and discussion of this work; the performance evaluation of the Venturimeter using Bernoulli’s and Continuity equations as stated in section 3 are presented.

Analysis of the Venturimeter Flow Rig

In this study, the analysis of the discharge of the Venturimeter flow rig was performed with the following data: A Venturimeter with a 25.4mm diameter at inlet and 10mm at the throat is laid with its axis horizontal shown in Figure 3.1. During the flow, the recorded pressure head of the large section is 6.5 millimetres and that at the throat is 4.25 millimetres. Assuming the metre coefficient, C is 0.99, then:
We know that the area at the inlet,

$$a_1 = \frac{\pi}{4}\ x\ \left(d_1^2\right) = \frac{\pi}{4}\ x\ \left(0.0254^2\right) = 5.07\ x\ 10^{-4}\ m^2$$

And the area at throat

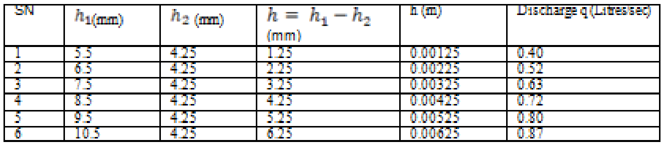
$$a_2 = \frac{\pi}{4}\ x\ \left(d_2^2\right) = \frac{\pi}{4}\ x\ \left(0.01^2\right) = 7.86\ x\ 10^{-4}\ m^2$$

and the discharge through the Venturimeter is given as Equation 3.5,

$$Q = \frac{C.a_1 a_2}{\sqrt{a_1^2 - a_2^2}}\sqrt{2gh}$$

Substituting the values in the equation for Q, we have that, the discharge at the pressure head (h) of 0.00225 m is Q = 0.52 litres/s. The excel spreadsheet program was used to compute and analyse the relationship between discharge and head of the flow discharge from the Venturimeter flow rig is presented in Figure 4.1. In the analysis, a fixed value of h_2 was employed while varying the value of h_1 and the difference between $(h_1 - h_2)$ equals to h as shown in Table 4.1.

Table 4.1: Showing differences in heads by varying h_1 and the corresponding discharge



SN	h_1(mm)	h_2 (mm)	$h = h_1 - h_2$ (mm)	h (m)	Discharge q (Litres/sec)
1	5.5	4.25	1.25	0.00125	0.40
2	6.5	4.25	2.25	0.00225	0.52
3	7.5	4.25	3.25	0.00325	0.63
4	8.5	4.25	4.25	0.00425	0.72
5	9.5	4.25	5.25	0.00525	0.80
6	10.5	4.25	6.25	0.00625	0.87

The corresponding values for the discharge q was recorded and plotted on a graph of discharge q against h as shown in Figure 4.1 as scatter plots and Figure 4.2 a 3D plot as a linear relationship between discharge and head.

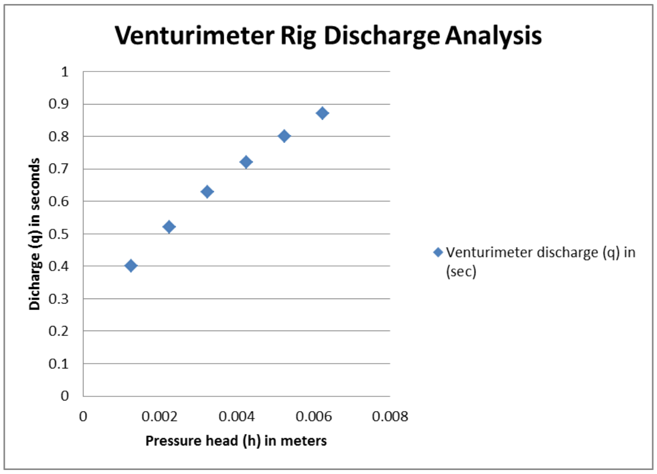


Figure 4.1: Shows the relationship between the pressure head and the discharge.

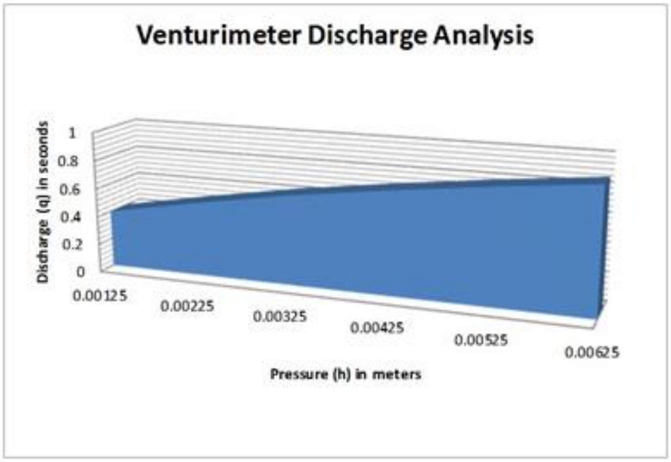


Figure 4.2: Shows a 3D linear relationship between the pressure head and the discharge of the Venturimeter flow rig.

Computation Analysis of a Standard Khurmi Venturimeter

The standard KHURMI (2006) experimental data are as follows: A Venturimeter has an area ratio of 9 to 1, the larger diameter being 300 mm. during the flow, the recorded pressure head in the large section is 6.5 metres and that at the throat is 4.25 metres. Assuming the metre coefficient, C is 0.99, the computated result of the discharge through the Venturimeter is presented as follows:

$$h = h1 - h2 = 6.5 - 4.25 = 2.25 \text{ m}$$

where h = difference in pressure head

h1 = pressure head in the large section h2 = pressure head at the throat

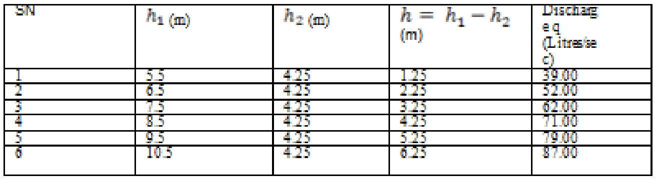
Applying the discharge equation which is given in Equation 3.5 as,

$$Q = \frac{C.a_1a_2}{\sqrt{{a_1}^2 - {a_2}^2}}\sqrt{2gh}$$

The discharge through the metre is equal to **52 litres/s** at the pressure head (h) of 2.25m (see Khurmi, 2006) an excel spreadsheet program was used for the computation.

However, increasing the value of the pressure head produces a corresponding increase in discharge as shown in Table 4.1. And if these values are plotted on a graph, the result is as shown in Figure 4.3 and Figure 4.4 as scatter plots and 3D plot respectively.

Table 4.2: Showing differences in heads by varying h_1 and the corresponding discharge



SN	h_1 (m)	h_2 (m)	$h = h_1 - h_2$ (m)	Discharg e q (Litres/se c)
1	5.5	4.25	1.25	39.00
2	6.5	4.25	2.25	52.00
3	7.5	4.25	3.25	62.00
4	8.5	4.25	4.25	71.00
5	9.5	4.25	5.25	79.00
6	10.5	4.25	6.25	87.00

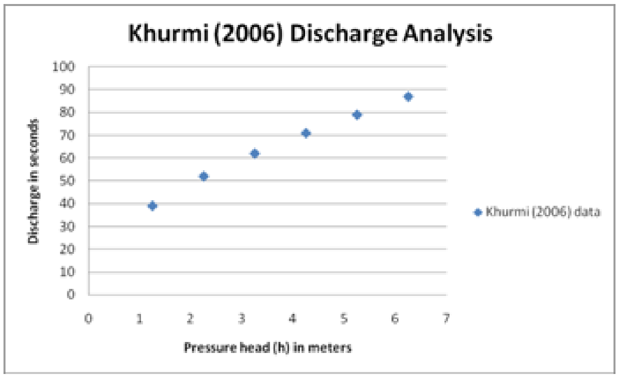


Figure 4.3: Shows the relationship between the pressure head and the discharge.

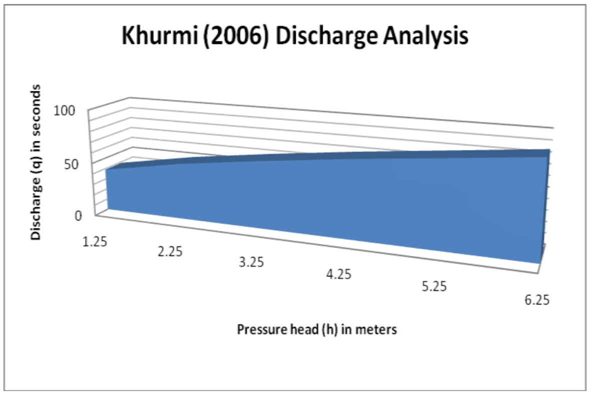


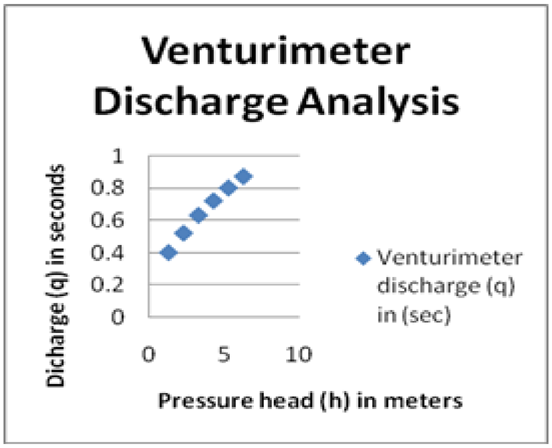
Figure 4.4: Shows a 3D linear relationship between the pressure head and the discharge of the Khurmi Venturimeter.

4.4 VALIDATION AND DISCUSSION OF RESULTS

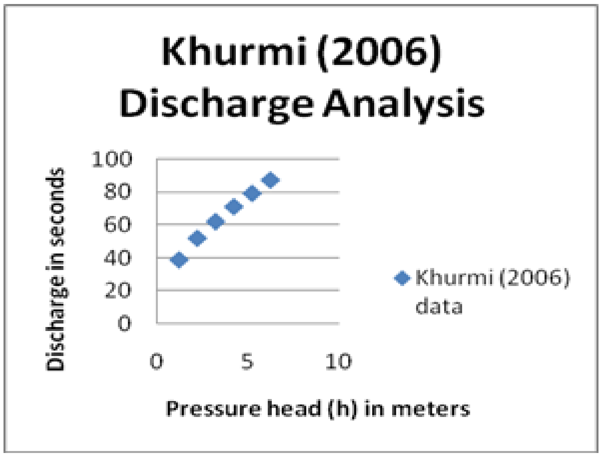
The results of the Venturimeter flow rig were validated against the standard Khurmi (2006) results and they were in good agreement since the trends were the same. In each case, as the pressure head increases, there was an increase in discharge in both results as shown in Table 4.3. The characteristic curve of both plots is parabolic as shown in Figure 4.5a and Figure 4.5b respectively. This indicated that the higher the head, the higher the flow discharge as presented in Figure 4.5; hence confirming the effectiveness of the Bernoulli's principles and continuity equation in the analysis of flow discharge through Venturimeter.

Table 4.3: Shows the Venturimeter flow rig data against the Khurmi (2006) data

SN	$h = h_1 - h_2$ (m)	Venturimeter rig discharge q (sec)	$h = h_1 - h_2$ (m)	KHURMI discharge q (sec)
1	0.00125	0.40	1.25	39.00
2	0.00225	0.52	2.25	52.00
3	0.00325	0.63	3.25	62.00
4	0.00425	0.72	4.25	71.00
5	0.00525	0.80	5.25	79.00
6	0.00625	0.87	6.25	87.00



a) AKSU Venturimeter Flow Rig discharge analysis graph



b) Khurmi (2006) discharge analysis graph

Figure 4.5: Validation of Venturimeter Flow Rig discharge against discharge analysis

V. CONCLUSION

The Venturimeter flow rig was designed, constructed and tested. The project was successfully completed and the aims achieved. The results were analysed and compared with a standard Khurmi (2006) analysis of flow discharge through Venturimeter and was in good agreement; hence confirming the usefulness of the Bernoulli's principles and continuity equation in the analysis of flow discharge through Venturimeter. The idea will be effective applied in the control and measurement of flow alone pipeline in oil field, for irrigation purposes, automotive industry, wastewater collection systems and treatment plants. The Venturimeter flow rig manufactured is portable with the capability of easy assembly and disassembly. This flow system is valuable for practical demonstration of fluid measurement and control in Fluid mechanics studies in Mechanical Engineering Laboratory. The cost is affordable due the used of locally available material; and the cost will further reduce significantly if the Venturimeter flow rig is mass produced.

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