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Research Paper

Parametric Effect on the Discharge of a Venturimeter Flow RIG

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ABSTRACT
This project presents the parametric effect on the discharge of a Venturimeter flow rig. The Venturimeter provide a method of measuring the discharge of a flow through the meter, hence the measurement of flow rate across the Venturimeter. A Venturimeter flow rig which was design in Akwa Ibom State University (AKSU) for the Fluid mechanic laboratory is employed in this study. The flow equipment comprises basically of measuring tank reservoirs, the Venturi flow meter, sump tank, an electric motor, cable, plug, valves, Polyvinyl Chloride (PVC) piping connections and a U-tube manometer. International Standard conventions were employed in the design of this flow measurement apparatus such as the length of the divergent cone of the Venturimeter being three (3) times that of the convergent cone with the ratio of the diameter at throat to that of the pipe being halved (½). The pressures in the pipe were measured using a manometer. Materials were sourced locally for the flow rig manufacturing to reduce cost when compared to similar equipment in the market. The methodology employed includes the application of the Bernoulli's theorem and the Continuity equations in the flow analysis. The experimental values produced with this Venturimeter; along with the computed values using spreadsheet software were used to determine the accuracy level of the flow meter rig. The results indicated that the discharge increases with an increase in the converging head and differences in the pressure head. The parametric analyses of the AKSU Venturimeter flow rig were validated against the standard Khurmi (2006) analyses, and they were in good agreement since the trends and profiles were the same.
Keywords: *Venturimeter, Flow, Measurement, Rig, Pressure and Head.*

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I. Introduction

A Venturimeter which is flow control and measurement equipment for measuring the rate of flow of a fluid flowing through a pipe can also be employed to determine the discharge of a liquid flowing in a pipe. The knowledge is necessary for flow discharge measurement in petroleum pipeline, irrigation facilities, automotive industries, wastewater collection systems and treatment plants. The Venturimeter is classified into three types namely horizontal Venturimeter, inclined Venturimeter and vertical Venturimeter respectively.

The Venturimeter consist essentially of three essential parts; the convergent cone, throat and divergent cone. Following international standard, the convergent cone is a short pipe known as the inlet of the Venturimeter which converges at the throat. 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 presented in Figure 1.1.

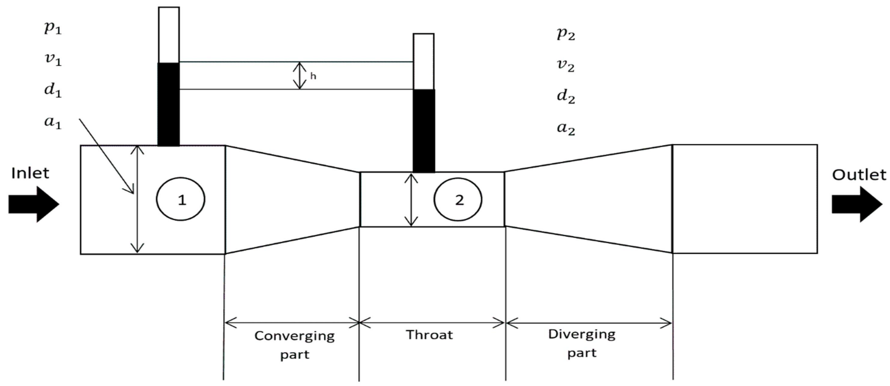


Figure 1.1: Cross section of Venturimeter showing variations in pressure (p), velocity (v), diameter (d) and area (a) (Effiong, W. C. 2017)

Technically, the length of the divergent cone is about three (3) to four (4) times than that of the convergent cone. 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. Hence, when the fluid enters the throat its velocity increases and the pressure decrease. The angle of upstream section which is a contracting portion is from 19 to 23 degrees while the downstream section is a portion of diverging cone with an angle of 5 to 15 degrees. The throat is the junction of the two reduced sections of the Venturi. There are two pressure taps located at the converging side and the throat of the Venturi respectively. Table 1.1 indicates the part list for the Venturimeter Flow Rig. Figure 1.2 shows a Venturimeter flow rig with major parts, while Figure 1.3 shows the manufactured Venturimeter flow rig being integrated alongside other fluid mechanics equipment in the fluid mechanics laboratory in AKSU, hence it known as AKSU Venturimeter flow rig. For further details on the technical description of the AKSU Venturimeter, the reader is referred to Ekong (2020) for details.

This flow measurement equipment is employed in the practical application of Bernoulli's theorem as applied in the measurement fluids flowing in pipes under pressure, therefore, the Venturimeter analysis is based on the principle of Bernoulli's and continuity equations. It is important to recall the Bernoulli's principle, which 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. There are so many real life applications of this appliances such as the measurement of the speed of air around the aircraft, for the measurement fuel and air distribution in carburetors in cars, for measuring the volume flow of blood through vessels, flow rate measurement of chemical in pipes and for the measurement of the discharge rate of irrigation systems on farmlands, among others.

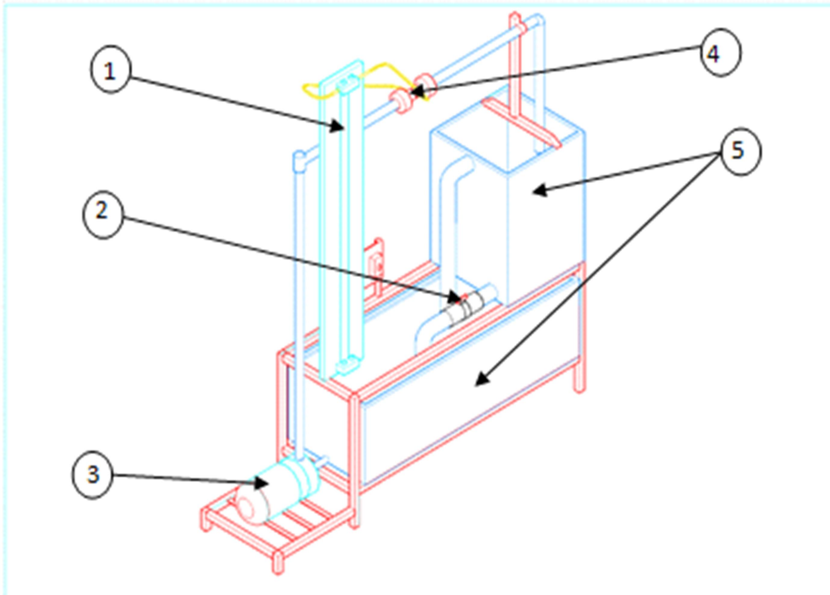


Figure 1.2: A Venturimeter flow rig showing major parts.

Table 1.1 Part List for Venturimeter Flow Rig

PART LIST FOR THE VENTURI METER FLOW RIG	
1.	Manometer (Mercury filled)
2.	Valve
3.	Pump 1.5HP
4.	Venturimeter
5.	Reservoir for Fluid

Figure 1.3: The AKSU Venturimeter flow rig being integrated alongside other fluid mechanics equipment in the fluid mechanics laboratory in AKSU, Nigeria (Ekong, G. I. 2020)

II. A REVIEW OF SOME WORK USING VENTURIMETER

The application of a Venturimeter in laboratories and industries for flow rate monitoring, simulation of real life flow scenarios which are very necessary had been performed by different authors. This has given rise to effective flow measurement and analysis in petroleum pipeline, irrigation facilities, automotive industries, wastewater collection systems and treatment plants, among others. Clancy (1975) and Batchelor (1967) in their separate works confirmed Bernoulli's principle 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.

The application of Venturimeter for the measurement of flow rate of multiphase flows, where two or even three fluids flow simultaneously in a pipe was studied by Hasan (2010) and came out with conclusion that its new separated flow model does not rely on prior knowledge of the mass flow quality, but is based on the measurement of the gas volume fraction at the inlet and the throat of the Venturimeter. It should note that Venturimeter is proficient in the measurement of the gas volume fractions at the inlet and the throat of the Venturi. However, to study the annular flow using a Venturi with conductance sensors, the reader is referred to the works by Prasanna et al. (2016), Ameresh (2017), Musbah and Lucas (2012) respectively. Further application of Venturimeter in industries, pipelines and other real life situations, the reader is referred to works by Kala et al. (2015), Babinsky, (2003); Weltner and Ingelman-Sundberg, (2009), Resnick and Halliday, 1960). Arun. et al. (2015).

III. METHODOLOGY

The Venturimeter make use of the principles of Bernoulli's theorem and Continuity equation, to analysis the theory of discharge of a liquid flowing in a pipe. A Venturi effect is experienced when a liquid flow through a pipe. This is noticed when a fluid flows through a constricted section of the pipe. The fluid velocity increases through the constriction to resolve the equation of continuity, while its pressure decreases due to conservation of energy. At this point, the gain in kinetic energy is balanced by a drop in pressure or a pressure gradient. The effect is governed by Bernoulli's and Continuity equations.

According to Ekong (2020), and by applying Bernoulli's theorem and Continuity equation; and for completeness of the study, Figure 1 is used for the analysis, where all symbols retain their usual nomenclatures:

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

$p_2, v_2, Z_2, a_2 = Corresponding\ values\ at\ section\ 2$

When, Bernoulli's equation is applied at section 1 and 2, the resultant equation is,

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

Since the discharge is continuous and by applying the Continuity equation at section 1 and 2, we have that,

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

Considering that the pipe is horizontal and the difference between the pressure heads at sections 1 and 2 being denoted as **h** which is the Venturi head, then, the link between the velocity and the Venturi head is given as,

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

Let recall that the discharge through a Venturimeter is,

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

Where C = coefficient of Venturimeter

Hence, if the value of v_2 of Equation 3.3 is substituted in Equation 3.4, then, the discharge through a Venturimeter is,

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

IV. RESULTS AND DISCUSSION

This section presents the results and discussion of this work; the parametric effect on the performance evaluation of the Venturimeter using Bernoulli's and Continuity equation as stated in section 3.

4.1 Analysis of the AKSU Venturimeter Flow Rig

In this analysis, the discharge of the AKSU Venturimeter flow rig was performed with the following data: A Venturimeter with a 25.4mm diameter at the inlet and 10mm at the throat is laid with its axis horizontal shown in Figure 1.1. During the flow, the recorded pressure head of the large section is 6.5 mm and that at the throat is 4.25 mm. Assuming the meter coefficient, C is 0.99, then: By considering the converging head, pressure head, area at the inlet, an area at the throat and the discharge through the Venturimeter, an excel spreadsheet program was used to compute and analyse the relationship between the converging head and the pressure head; and the resulting effect on the discharge from the Venturimeter flow rig. The results are presented graphically as Figure 4.1, Figure 4.2 and Figure 4.3 respectively. During 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 is tabulated in Table 4.1. The corresponding values for the discharge (q) was documented and plotted on a graph of discharge (q) against the converging head (h_1), as shown in Figure 4.1 A further plot is presented in Figure 4.2, showing a linear relationship between the converging head (h_1) and the pressure head (h), while Figure 4.3 is the relationship between the discharge (q) of the Venturimeter and the pressure head (h). The analysis is extended to include the effect of inlet diameter increase on the area ratio of this Venturimeter as presented in Figure 4.4. Figure 4.4 indicate that by increasing the inlet diameter, there is a corresponding increase in the area ratio of the flow rig.

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

SN	h_1(m)	h_2 (m)	$h = h_1 - h_2$ (m)	h (m)	Discharge q (Litres/sec)
1	0.0055	0.00425	0.00125	0.00125	0.40
2	0.0065	0.00425	0.00225	0.00225	0.52
3	0.0075	0.00425	0.00325	0.00325	0.63
4	0.0085	0.00425	0.00425	0.00425	0.72
5	0.0095	0.00425	0.00525	0.00525	0.80
6	0.0105	0.00425	0.00625	0.00625	0.87

Figure 4.1 is the relationship between the discharge through a Venturimeter and the converging head, while Figure 4.2 indicates the relationship between the converging head and the pressure head of this Venturimeter flow rig.

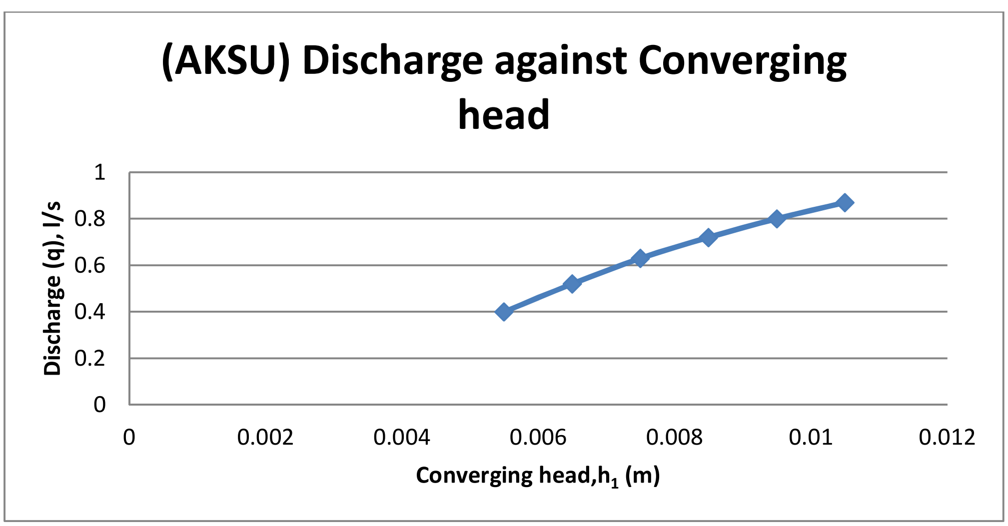


Figure 4.1: The relationship between Discharge and Converging Head (h_1)

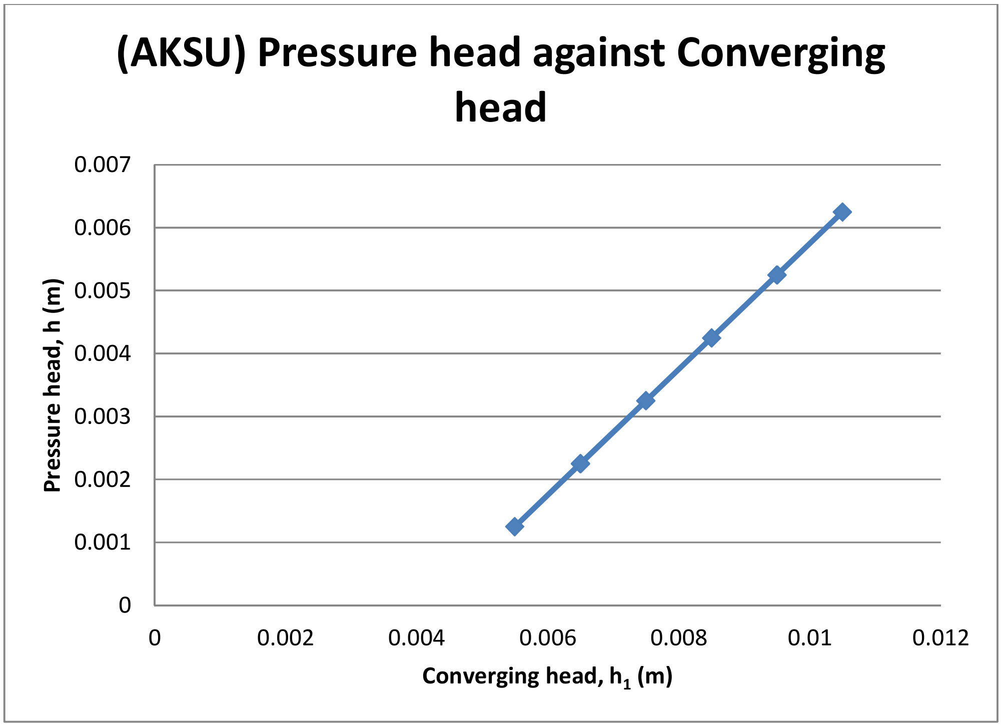


Figure 4.2: The relationship between the Pressure head and Converging head (h_1)

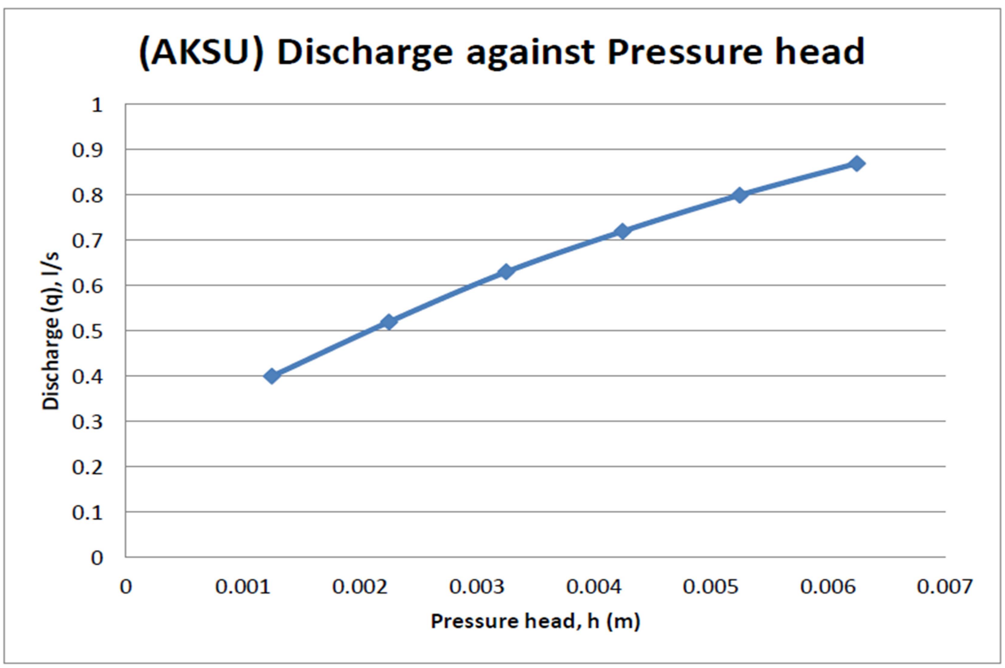


Figure 4.3: The relationship between the Discharge and the Pressure head.

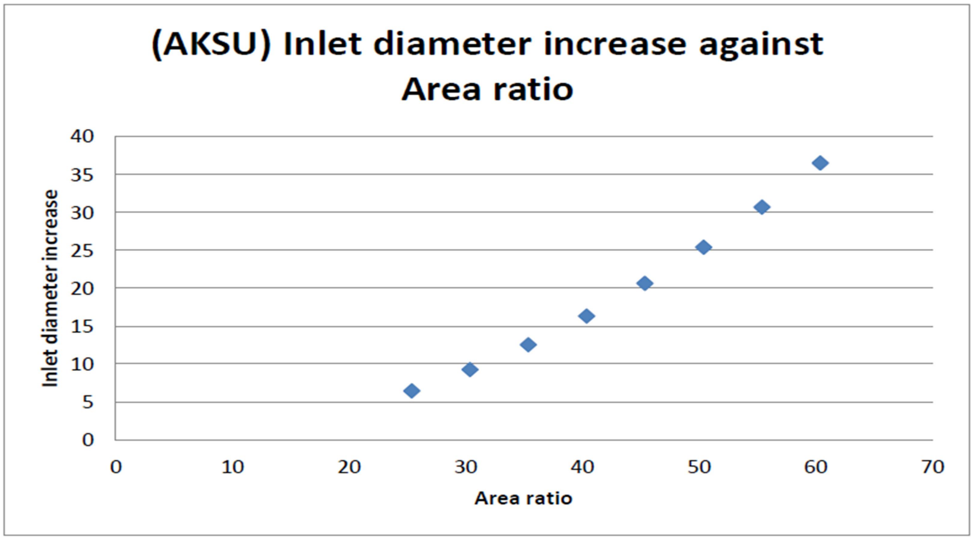


Figure 4.4: The relationship between Inlet diameter increase and the Area ratio

4.2 Computation Analysis of a Standard Khurmi Venturimeter

According to Ekong (2020), using the standard Khurmi (2006) experimental data 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 m and that at the throat is 4.25 m. Assuming the meter coefficient, C is 0.99, the computed result of the discharge through the Venturimeter is presented as follows:

h= $h_1 - h_2$ = 6.5 -4.25 = 2.25 m

where h = difference in pressure head
h_1 = pressure head in the large section
h_2 = pressure head at the throat

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

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

The discharge through the meter 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 converging head produces a corresponding increase in the pressure head, hence an increase in the discharge of the Venturimeter as presented in Table 4.2.

Table 4.2: Differences in heads by varying and the corresponding discharge

SN	h_1 (m)	h_2 (m)	$h = h_1 - h_2$ (m)	Discharge q (Litres/sec)
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

The resulting analysis is presented graphically as Figure 4.5 which indicates the variation between discharge and the converging head while Figure 4.6 shows the variation between pressure head and the converging head respectively. The variation between the discharge and the pressure head is presented as Figure 4.7 and the analysis is completed with the presentation of the variation of inlet diameter increase and the area ratio as Figure 4.8.

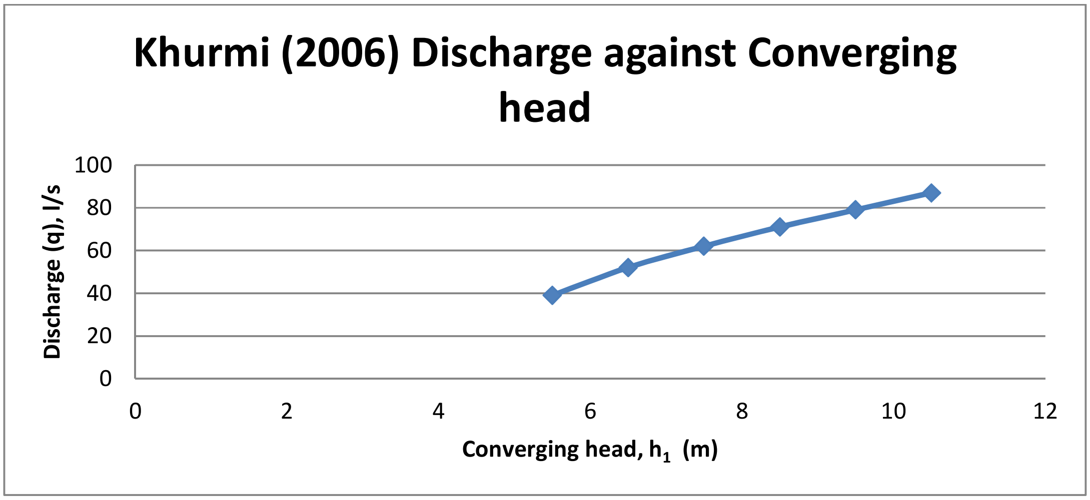


Figure 4.5: The relationship between Discharge and the Converging head (h_1)

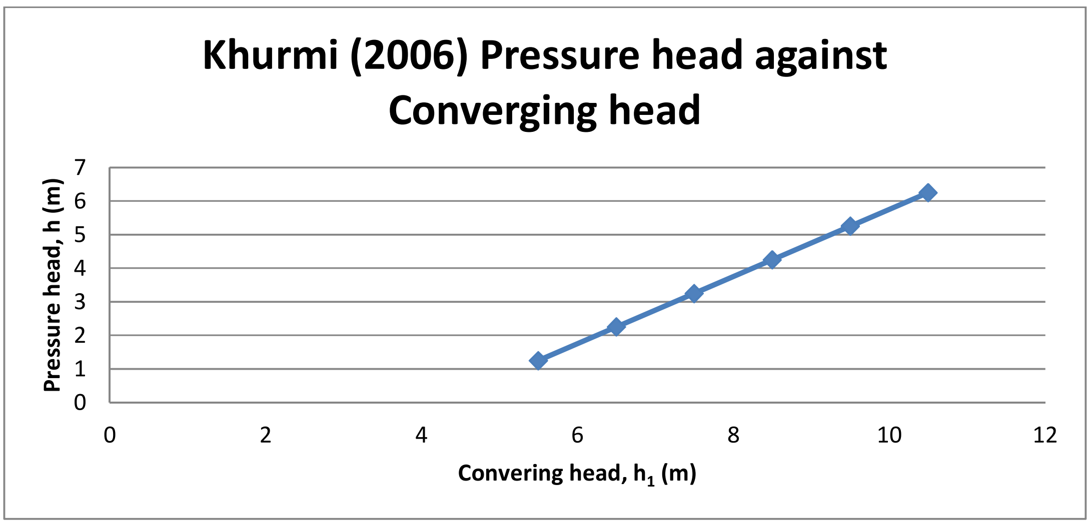


Figure 4.6: The relationship between the Pressure head and Converging head (h_1)

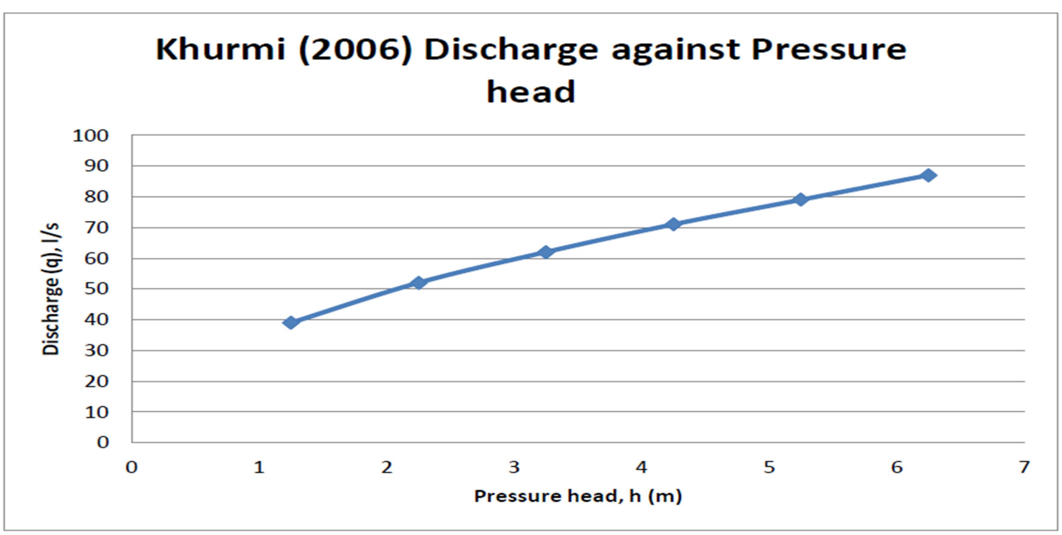


Figure 4.7: The relationship between Discharge and the Pressure head (h)

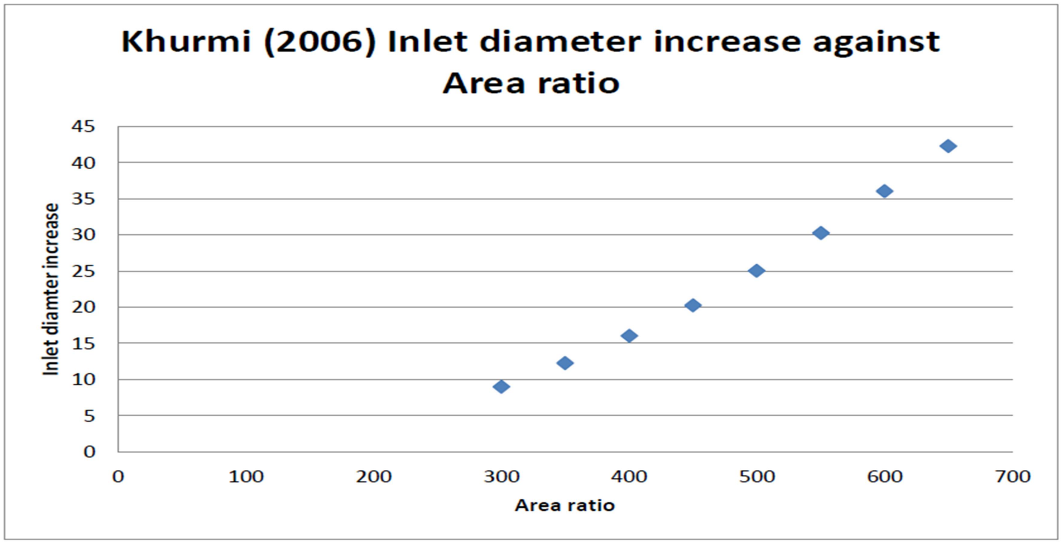


Figure 4.8: The relationship between Inlet diameter increase and Area ratio

4.3 DISCUSSION OF RESULTS

The results of the analyses of both the AKSU Venturimeter flow rig and the Khurmi (2006) show that as the converging head increases, the discharge through the Venturimeter increases. Accordingly, when the pressure head increases, there is a corresponding increase in the discharge of fluid, hence confirming the effectiveness of the Bernoulli's principles and Continuity equation in the analysis of flow discharge through Venturimeter.

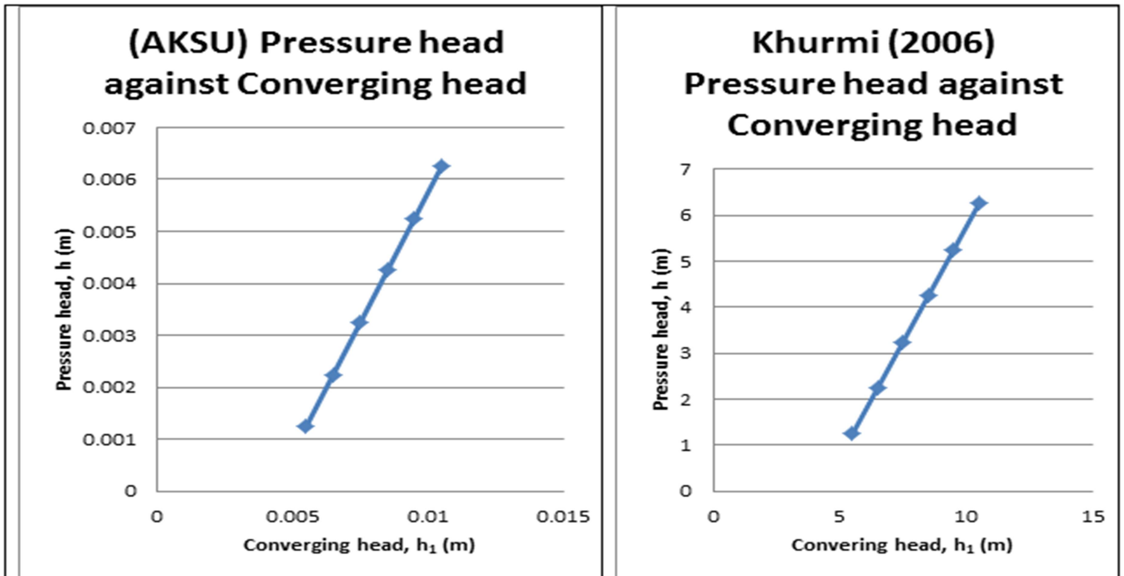
4.3.1 VALIDATION AND DISCUSSION OF RESULTS

The parametric analyses of the AKSU Venturimeter flow rig were validated against the standard Khurmi (2006) analyses, and they were in good agreement since the trends and profiles were the same. The parameters involve converging head, pressure head, inlet diameter, area ratio and the discharge. In each case, an increase in the converging head lead to an increase in the discharge from the Venturimeter in both results as shown in Table 4.3. The validated analyses presented in this paper are the validation of AKSU Venturimeter Flow Rig Pressure head and Converging head profile against Khurmi (2006) Venturimeter Pressure head and Converging head profile which is presented in Figure 4.9 while the validation of AKSU Venturimeter Flow Rig discharge analysis against Khurmi (2006) Venturimeter discharge analysis presented as Figure 4.10 and Figure 4.11 demonstrate the validation of AKSU Venturimeter Flow Rig Pressure head and Converging head profile against Khurmi (2006) Venturimeter Pressure head and Converging head profile. However, for the validation of discharge against pressure head, the reader is referred to Ekong (2020) for details.

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

SN	h_1(m)	AKSU Venturimeter rig discharge q (sec)	h_1 (m)	KHURMI discharge q (sec)
1	0.0055	0.40	5.5	39.00
2	0.0065	0.52	6.5	52.00
3	0.0075	0.63	7.5	62.00
4	0.0085	0.72	8.5	71.00
5	0.0095	0.80	9.5	79.00
6	0.0105	0.87	10.5	87.00

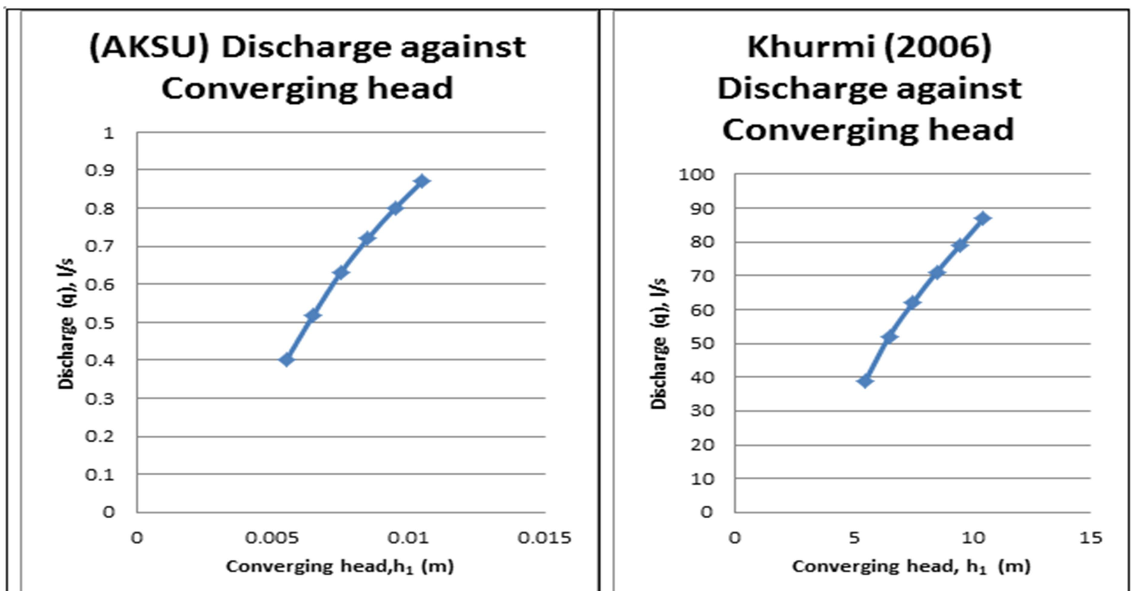
The relationship between the converging head and the pressure head is linear relationship as shown in Figure 4.9a and Figure 4.9b respectively while the characteristic curve of the relationship between the converging head and the discharge of both plots is parabolic as shown in Figure 4.10a and Figure 4.10b respectively. This indicated that the higher the converging head, the higher the flow discharge as presented in Figure 4.10; hence confirming the effectiveness of the Bernoulli's principles and Continuity equation in the analysis of flow discharge through Venturimeter. For completeness, the characteristic curve of the relationship between the Inlet diameter increase and Area ratio of both AKSU and Khurmi analyses are parabolic as shown in Figure 4.11a and Figure 4.11b respectively.



a)The relationship between AKSU Pressure head and Converging head profile

b) The relationship between Khurmi (2006) Pressure head and Converging head profile

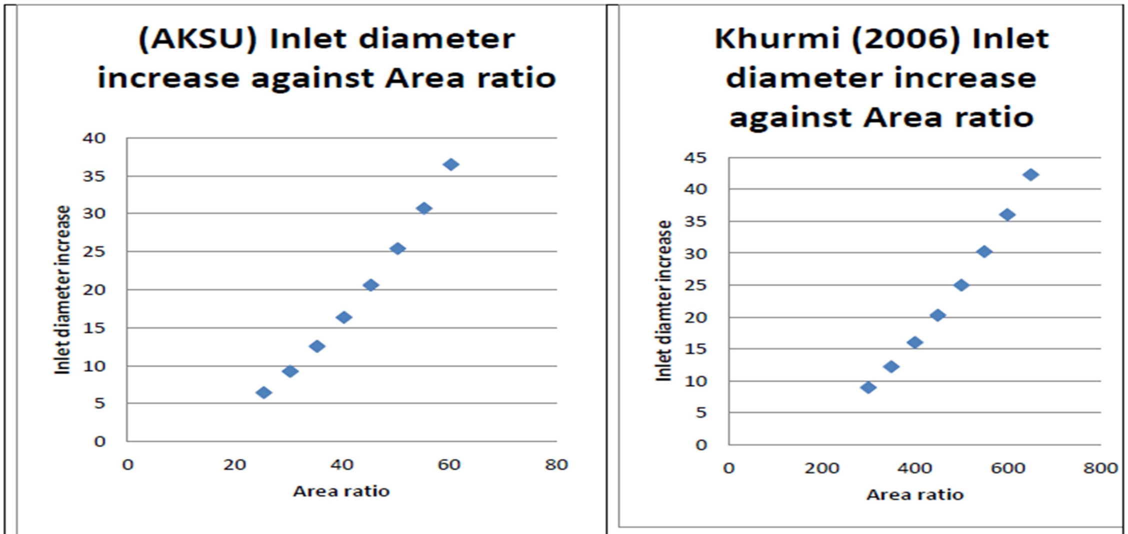
Figure 4.9: Validation of AKSU Venturimeter Flow Rig relationship between Pressure head and Converging head profile against Khurmi (2006) Venturimeter relationship between Pressure head and Converging head profile



a) AKSU Venturimeter Flow Rig discharge analysis profile

b) Khurmi (2006) Venturimeter discharge analysis profile

Figure 4.10: Validation of AKSU Venturimeter Flow Rig discharge analysis against Khurmi (2006) Venturimeter discharge analysis



a)The relationship between AKSU Inlet diameter increase and Area ratio

b)The relationship between Khurmi (2006) Inlet diameter increase and Area ratio

Figure 4.11: Validation of AKSU Venturimeter relationship between Inlet diameter increase and Area ratio profile against Khurmi (2006) Venturimeter relationship between Inlet diameter increase and Area ratio profile

V. CONCLUSION

The manufactured Venturimeter flow rig was analysed and the result of the analysis indicates that as the converging head increases, the discharge through the Venturimeter increases. The converging head increase leads to the pressure head increase and hence, the corresponding discharges increase through the Venturimeter. This analysis confirmed the expediency of the use of Bernoulli's principles and Continuity equation in the analysis of flow discharge through Venturimeter. This flow system is appreciated for practical demonstration of fluid measurement and control in fluid flow studies in Laboratories, research centres and practical application in real life situation. The result of this study can effectively be applied by personnel in the control and measurement of flow rates inside pipe in wastewater collection and treatment plants, agricultural, water, automotive, chemical, oil and gas industries. The overall parametric result shows that the results of the AKSU Venturimeter flow rig are in good agreement with the results of the standard Khurmi (2006) Venturimeter experiment. Evidence can be seen in the matching trends and profiles of both results.

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