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Efficiency of Locally Fabricated Venturi Meter Marched with ISO Standard

Akpan Paul Pualinus (MSc)[1], Uneke Louis Agwu (M.Eng)[2], Uebari Luton Sunday (B.Eng)[3]
[1,2]*Department of Civil Engineering, Rivers State Polytechnic, Bori-Ogoni, Rivers State, Nigeria, West Africa*
[3]*Department of Mechanical Engineering, Rivers State Polytechnic, Bori-Ogoni, Rivers State, Nigeria, West Africa*

***Abstract*-There is a dirt of laboratory equipment for learning in tertiary institutions across the Africa and the third world. Most apparatuses available in our laboratories are malfunctioning, not calibrated, dilapidated and outdated. Effort at fabricating one of this equipment namely Venturi meter, using ninety percent locally sourced material was made. Comparative study of the fabricated meter was made against International Standard Organization (ISO) standard factory –made Venturi. The fabricated meter compared very closely with standard as can be seen in the tables of results and graphs. The cost of importation, installation and availability manual for training is thus highly reduced.**

***Keyword*-- Cross sectional area, Differential pressure, Discharge, Fabrication, PVC material, Reynolds number, Tapping, Vena contracta, Venturi meter.**

I. INTRODUCTION

Inadequate Laboratory equipment in our tertiary institution is major challenges that demand urgent attention. There is lack of fundamental knowledge in hydraulics among students for lack of experimental hydraulic equipment such as Venturi meters. The need for attempts at manufacturing some of these apparatus is thus high. In this paper an attempt is made at producing an adoptive model venturi meter that meets international standard using ninety percent locally sourced material. Its efficiency was marched against an ISO standard venturi meter.

The research also considered the analysis, design and construction of the apparatus based on standards, precisions and quality control and assurance. The results of the experiment conducted on the apparatus are precisely accurate compared to ISO model. The apparatus is portable and can be used to conduct practicals on the hydraulic bench. This demonstrates the efficacy of the apparatus compared to other that are configured to operate on their own system, resulting to high cost of production, cumbersomeness and unreliability.

Our thoughts are very significant because they will help solve the problem of inefficient laboratory apparatus. Also they will enhance creative technological innovations and entrepreneurship development. It will also optimise cost since local materials that are readily available in virtually all our shops can be explored.

Since it is produced locally there is no need to invite expatriate from the developed world to train local technicians and technologist on operation and maintenance of the apparatus. Time and cost will be minimised as such training can be executed with little or no cost.

The Venturi tube is a device used for measuring the rate of flow along a pipe. A fluid moving through it accelerates in the direction of the tapering contraction with an increase in the velocity in the throat. This is accompanied by a fall in pressure, the magnitude of which depends on the rate of flow. The flow rate may therefore be inferred from the difference in pressure as measured by piezometers placed upstream at the throat. The effect that the meter has on the pressure change is termed as the Venturi effect.

II. LETERATURE REVIEW

[1] briefly discussed the principle of Venture meter. It started with Giovanni B., the first in record times to discuss the use of orifices for the measurement of fluids. Clemons Herschel in 1886 developed the modern Venturi meter modelled from the work of Venturi, an Italian Physicist, who in 1797 planted and cultivated the idea. [2] vented that the venturi flow rate is the mass or volume flow through an orifice meter per unit of time. The report discussed much on the discharge coefficient and Reynolds number of a venture meter.

A. Venturi Meter

The report of [3] described the features, details, operation and principles of a Venturi meter. Plate 1 in appendix shows the Venturi meter with the variable position of vena contracta. Venturi meter uses the same principle of continuity equation and Bernoulli principle to calculate the volumetric flow rate.

The account of [4] showed how the discharge can be derived.

Invoking bernolli's equation

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

The continuity equation is given by

$$U_1A_1=U_2A_2=U_nA_n=Q \qquad (2)$$

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Substituting equation 1 for U_1 equation (2) results in

$$\frac{U_1}{2g}\left[\frac{A_2}{A_1}\right]+h_1=\frac{U_2^2}{2g}+h_2 \qquad (3)$$

Where U_1, U_2, U_n, h_1, h_2, h_n, A_1, A_2, An represent initial velocity, final velocity, average velocity, pressure head at the inlet pipe(initial pressure head), pressure head at the throat (final pressure head) ,average pressure head, area of the inlet pipe(initial area of pipe), area of the Venturi throat (final area of pipe) and average area respectively.

Hence,

$$U_2=\sqrt{\frac{2g(h_1-h_2)}{1-\left(\frac{A_1}{A_2}\right)^2}}.) \qquad (4)$$

Thus, the Ideal discharge rate Q is

$$Q=A_2\sqrt{\frac{2g(h_1-h_2)}{1-\left(\frac{A_1}{A_2}\right)^2}}. \qquad (5)$$

And the Actual discharge is given by

$$Q=A_2.C\sqrt{\frac{2g(h_1-h_2)}{1-\left(\frac{A_1}{A_2}\right)^2}} \qquad (6)$$

Where Q = discharge, C_d = discharge coefficient, h_A = head at upstream section, h_D = head at throat section, A_1 and A_2 = pipe cross-sectional area at upstream section, and A_D = pipe cross-sectional area at throat section. The discharge coefficient (C_d), otherwise known as the coefficient of the Venturi meter, typically has a value between 0.92 and 0.99. The actual value is dependent on a given Venturi meter, and even then it may change with flow rate.

The velocity head $\frac{U_1}{2g}$ at the throat can be conveniently used to express a dimensionless way of expressing the distribution of Piezeometric head along the length of the venture meter.

B. Frictional Losses in a Venture Meter

In view of [5], the frictional losses depend on the type of the flow (laminar or turbulent) and pipe elements (valves, elbows, tees, etc.). A common approach to characterization of frictional losses is to use the Fanning friction factor f defined as the friction force per unit surface area divided by the kinetic energy per unit volume $\left[\frac{\ell v^2}{2}\right]$

The frictional loss in a circular pipe can be calculated using the relation

$$W_{loss}=4f\left[\frac{\Delta L v^2}{2D}\right] \qquad (7)$$

Where ΔL, is the equivalent pipe length, D is the inside pipe diameter, v is the average velocity of fluid over the pipe cross-section, and f is the fanning frictional factor. The frictional flow for a laminar flow can be solved using Navier-Strokes equations analytically to obtain the frictional factor expressed as

$$f=\frac{16}{\mathrm{Re}} \qquad (8)$$

Where, Re = Dvρ/μ is the Reynolds number (ρ and μ are the fluid density and viscosity, respectively). For a turbulent flow the friction losses are given by empirical relationships, such as the Colebrook equation or the Moody diagram. These relationships involve new parameter ε corresponding to the roughness of the pipe. The roughness depends on multiple factors, including the material from which the pipe is made and degree of corrosion. The flow network in our lab consists of pipes made from plastic and galvanized steel. In addition to the pipes, the fluid flow network contains various fittings, including valves, tees, and elbows. The friction losses due to the fittings are described using the loss factor *Kf*,

$$W_{loss}=Kf\left[\frac{v}{2}\right] \qquad (9)$$

[6] describes how the venture meter tubes were used to calibrate it in water. The Venturi tubes were calibrated in water in the UKAS-accredited National Standard facility for water flow measurement. [2] discussed on the discharge coefficient of a Venturi meter. [7] discussed the relationship between coefficient of discharge and Reynolds's number. Figure 3 show how the coefficient of discharge varies with Reynolds number. [8] and [9] discussed on the geometry and specifications of Venturi meter. Venturi meter with cast iron entrance cones are typically used in 10 to 80 cm diameter pipes. Venturi meter with machined convergences are typically used in pipes having diameter less than 25 cm while Venturi meter with a welded sheet metal convergence are used for larger pipes, typically up to 1.2 m diameter [8]. Table 1 below and graph in figure 3 was derived from data provided in [9].

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Table 1:
Cast Iron, Machined and Welded Sheet metal convergent as per ISO(1991)

CAST OR ROUGH IRON CONVERGENT		MACHINED CONVERGENT		WELDED SHEET METAL OR IRON CONVERGENT	
R_{ED}	C	R_{ED}	C	R_{ED}	C
$4x10^4$	0.957	$5x10^4$	0.970	$4x10^4$	0.960
$6x10^4$	0.966	$1x10^5$	0.977	$6x10^4$	0.970
$1x10^5$	0.976	$2x10^5$	0.992	$1x10^5$	0.980
$1.5x10^5$	0.982	$3x10^5$	0.998	$1.5x10^5$	0.990
$2x10^5$ to $1x10^6$	0.995	$2x10^5$ to $1x10^6$	0.995	$2x10^5$ to $2x10^6$	0.985

[10] discussed on the Coefficient of discharge and the measuring principles of a venture meter. (plate 1) gives details. Bernoulli's equation on energy conservation stipulates that the change in pressure in a pipe flow is the product of half the density of the fluid and the difference in the square of the final and initial velocity.

Invoking Bernoulli's equation

$$\rho_1 = \frac{1}{2}\rho_1 u_1^2 = \rho_2 = \frac{1}{2}\rho_2 u_2^2 = p_o \quad (10)$$

Where ,

p_0 is the total pressure in medium and p = p_0 where u=0

The sum of static and dynamic pressure is the same everywhere in pipe.

$$\Delta p = p_1 - p_2 = \frac{\rho}{2}\left(u_2^2 - u_1^2\right) \quad (11)$$

Where,

$\frac{\rho}{2} u^2$ is the dynamic pressure of the flow

Invoking continuity equation

$$q_m = A.\rho.u \quad (12)$$

But,

$$u_1^2 = \frac{4^2 q_m^2}{D_1^4 \pi^2 p^2} \text{ and } u_2^2 = \frac{4^2 q_m^2}{D_2^4 \pi^2 p^2} \quad (13)$$

Replacing the speed terms through geometric measures and inserting it in the above equation.

$$\Delta p = \frac{\rho}{2} \times \frac{4^2 q_m^2}{\pi^2 p^2}\left(\frac{1}{D_2^4} - \frac{1}{D_1^4}\right) \quad (14)$$

$$\Delta p\, D_2^4 = \frac{\rho}{2} \times \frac{4^2 q_m^2}{\pi^2 p^2}\left(\frac{D_2^4}{D_2^4} - \frac{D_1^4}{D_1^4}\right) \quad (15)$$

$$2.\Delta p\, \rho \pi^2 D_2^4 = 4^2 q_m^2 \left(1 - \frac{D_2^4}{D_1^4}\right) \quad (16)$$

Calculating for the discharge q_m

$$q_m = \frac{1}{\left(1 - \frac{D_2^4}{D_1^4}\right)} \frac{\pi^2}{4^2} D_2^4 .2\Delta p.\rho \quad (17)$$

Exchange unknown D_2 with the known and introduce a discharge coefficient C relating the unknown diameter D_2 to the known orifice diameter d. It is important to introduce an expansion coefficient ε for compressible media like gas, steam.

$$\beta = \frac{d}{D} \quad (18)$$

Hence,

$$q_m = \frac{C}{\left(\sqrt{1-\beta^4}\right)}.E.\frac{\pi}{4} d^2 . \sqrt{2\Delta p.\rho_1} \quad (19)$$

To compute the discharge q_m, measure the Δp from the tapings and then use the value obtained with all other constant to substitute in the above derived discharge equation

C. Differential Pressure in a Venturi

In the account of [11], the differential pressure (DP) devices work on a principle based upon the Law of Conservation of Energy, where a restriction in the fluid path causes an acceleration in the fluid velocity and hence an increase in kinetic energy. The gain in kinetic energy is at the expense of pressure energy and this is manifested as a drop in fluid pressure across the narrowest part of the restriction. The drop in pressure and the flow rate are linked by the following (albeit simplified) relationship:

$$Q = k\sqrt{h} \quad (20)$$

Where Q= fluid flow rate, k = a constant for that d_p device, h = the pressure difference across the restriction

The differential pressure generated for a given class of device depends on the bore of the restriction. Many calculation standards exist but in all cases the differential pressure produced by the restriction is larger than would normally be expected. Pressure taps can be positioned at a variety of different locations [12] and [13].

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III. Materials

The materials used for the construction include 38.1mm PVC Pipe, 25mm PVC Pipe, 38.1mm Gate valve, 38.1mm Union, 38.1mm to 25mm Reducer, 38.1mm Elbow, 8mm Nuts, 8mm Drill bit and drilling machine, 10mm transparent perspex glass plate, 3mm colored Perspex plate, 8mm bolt and nuts , 8mm screws, 8mm clip, 3psi pressure gauge, Petot tube for tapping, 38.1mm flange with bolt and nut, Orifice plate, PVC gum, Aluminum paint and spraying machine

A. Specifications

The speculations for the fabricated apparatus using local materials includes; Nett dimensions: 720 mm x 650 mm x 300 mm, Packed dimensions and weight: 0.14 m^3 and 15 kg. Maximum flow rate: Nominally 27 $L.min^{-1}$, Venturi tube material: PVC, Inside diameter of Venturi inlet: 26 mm, Inside diameter of Venturi throat: 16 mm, Inside diameter of Venturi outlet: 26 mm, Pressure tappings: 11, Manometer scale: Millimetres, Manometer tube range: 0 to 400 mm, Accessories (included): Hydraulic bench, stop watch, Measuring cylinder, pipe stand and clips

B. Essential Base Unit

The essential base unit used to perform the experiment include Gravimetric Hydraulic Bench (H1) or Volumetric Hydraulic Bench (H1D)

C. Essential Services

Essential services required to perform the experiment using the fabricated venturi meter include Power supply to the hydraulic bench and Water supply from the Hydraulic Bench (H1 or H1D),

D. Operating Conditions

The operating environment, storage temperature range, operating temperature range and relative humidity range are the laboratory environment,–25°C to +55°C (when packed for transport), +5°C to +40°C and 80% at temperatures < 31°C decreasing linearly to 50% at 40°C respectively.

E. Description

The Venturi Meter is fabricated to be used in all tertiary institutions. Experiment is expected to be performed on Gravimetric or Volumetric Hydraulic Bench (H1 or H1D). The apparatus measures discharge through a venturi meter and the results can be tabulated to produce graphs that can be used to determine the venturi meter coefficient of discharge.

The composition of the fabricated apparatus includes a horizontal PVC Venturi tube, a gate valve that permits water to enter the venturi meter through the pipe, a downstream flow-control valve that helps to regulate the rate of flow in the venturi meter, preventing turbulence upstream. A screw hole is provided to hold the pitot tube vertically. The pitot tube measures the head of water used to calculate the discharge. An adjustable foot is provided at the base with a spirit level which is used to maintain horizontal position. The PVC material used for fabricating the equipment provides corrosion – resistance finishes.

To perform experiments, flow rate through the Venturi meter is measured as well as the heads at the upstream cross sectional area and that at the throat. Pressure distribution along the metre length is also measured. The procedure is repeated at reduced flow rate increments and taking similar readings each time. Ideal pressure distribution is compared to measured pressure distribution and coefficient of discharge for the meter is calculated.

F Experiments

The experiment is performed on the Venturi meter to directly measure the static head distribution along a Venturi tube, Compare the experimental results with theoretical predictions and effectively calculated the meter coefficient of discharge at various flow rates.

IV. Methods

The method in this research involves using local materials to construct a Venturi meter that can measure flow in pipe accurately. The apparatus was be fabricated and calibrated as per [14].

Plate II-VI show case the model of the Venturi that was fabricated based on design standard. Details of how to perform practical on the apparatus is explained lucidly in http://en.wikipedia.org/wiki/Venturi_effect , www.tecquipment.com and Instruction manual from Fluid Mechanics Laboratory.

V. Experimental Procedure

Relative data for the meter is found behind the apparatus. The data include the cross-sectional areas and distances to each point in the Venturi meter. The procedure for performing the experiment is as follows

i. Turn the pump on and adjust the flow rate to a constant level using the valve on the tub. To adjust the flow rate for the rest of the lab, use the valve located on the Venturi meter. This will avoid introducing air into the system.

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ii. Set the discharge as high as possible (water in all piezometers must be readable on each of their scales) making sure there are no air bubbles in the piezometer tubes.
iii. When the water level had risen to a convenient height, the bench valve was also closed gradually so that as both valves are finally shut off, the meter was left containing static water at moderate pressure.
iv. The adjustable screws were operated to give identical reading for all of the tubes across the whole width of the manometer board. To establish the meter coefficient measurements of a set of differential heads (h_1-h_2) and flow rate Q were made.
v. The first reading was taken with the maximum possible value when (h_2– h_1) i.e. with h1closeto the top of the scale and h2 near to the bottom. This was obtained by gradually opening both the bench valve and the control valve in turn.-
vi. Successive opening of either valve increased both the flow and the difference between $h_1$and h_2. The rate of flow was found by timing the collection of a known amount of water in the weighing tank, in the mean time valves $h_1$and $h_2$was read from the manometer. Similarly, readings were then taken over a series of reducing values of h_1– h_2 roughly equally spread over the available range from 250mm to zero. About ten readings sufficed

VI. CALCULATIONS

Calculations are performed in accordance with [15], unless otherwise requested. Other calculation standards available include ASME, API, R W Miller, L W Spink.

Pressure loss is typically between 40 and 95% of the generated differential pressure, dependent on the throat ratio (d/D).

The following parameters were used to calculate the coefficient of discharge and discharge presented in the results. d_1=31.25mm, d_2=25mm, A_1= 767.1 and A_2= 490.873mm^2. Substituting them into equation 18 the various discharges for the nine experiments performed for the ISO standard Venturi meter were 1.9417, 2.9851, 3.6873, 4.5065, 4.8804, 5.4201, 6.4267, 7.3855, and 8.6580 respectively. Also, the various discharges for the nine experiments performed for the fabricated apparatus are 1.9436, 3.0211, 3.6982, 4.5147, 4.7259, 5.5402, 6.4392, 7.9428. and 8.8889 respectively. See table 2 and 3 for detail.

The theoretical discharge and coefficient of discharge can be calculated from equation 21 and 22. Tabulated results are presented graphical in figure 4 and 5

$$Q(Theoritical) \equiv \left[(a1*a2*Cd) \Big/ \sqrt{\left((a1^2)-(a2^2)\right)} m^3/\sec \right] \quad (21)$$

$$Cd \equiv \left[Q(Theoritical)*\sqrt{\left((a1^2)-(a2^2)\right)} m^3/\sec \Big/ (a1*a2) \right] \quad (22)$$

VII. RESULT

The following result were obtained from experiment performed using an imported Venturi meter in the laboratory. The results of the imported Venturi meter used as our control were used to compare that of the fabricated Venturi meter. This will evidently prove or show-case the efficacy of the fabricated apparatus.

Table II:
Results for the ISO Standard Venturi Meter

h_1 (mm)	h_2 (mm)	H_2O VOLUME COLLECTED (m^3/s)	TIME (s)	h_1 - h_2 (mm)	$(h_1 – h_2)^{1/2}$ (mm)	Q (m^3/s) (x10^{-4})
240	225	0.01	51.50	15	3.8730	1.9417
255	205	0.01	33.50	50	7.0711	2.9851
265	185	0.01	27.12	80	8.9443	3.6873
273	165	0.01	22.19	108	10.3923	4.5065
275	145	0.01	20.49	130	11.4017	4.8804
279	125	0.01	18.45	154	12.4097	5.4201
280	105	0.01	15.56	175	13.2288	6.4267
282	85	0.01	13.54	197	14.0357	7.3855
285	65	0.01	11.55	220	14.8324	8.6580

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Table III:
Results for the Fabricated Venturi Meter

h_1 (mm)	h_2 (mm)	H_2O VOLUME COLLECTED (m^3/s)	TIME (s)	$h_1 - h_2$ (mm)	$(h_1 - h_2)^{1/2}$ (mm)	Q (m^3/s) ($x10^{-4}$)
240	225	0.01	51.45	17	4.1230	1.9436
255	205	0.01	33.10	50	7.0711	3.0211
265	185	0.01	27.04	81	9.0000	3.6982
273	165	0.01	22.15	118	10.8628	4.5147
275	145	0.01	21.16	130	11.4017	4.7259
279	125	0.01	18.05	153	12.3693	5.5402
280	105	0.01	15.53	175	13.2288	6.4392
282	85	0.01	12.59	197	14.0357	7.9428
285	65	0.01	11.25	215	14.6628	8.8889

VIII. DISCUSSION

The result in table II showed that as the head in the first tapping positioned on the main pipe with a higher diameter (h_1) increases there is a corresponding decrease in the taping positioned on the vena contracta having smaller diameter (h_2). It is observed also that there is decease in the head from h_1=240 to h_2 =225 from the first to the last experiment performed for the fabricated and control venturi meter. This result account for the anticipated head loss at the vena contracta caused by the sharp bend or reduction in diameter of the pipe. The differential head and discharge in the result for the fabricated apparatus in table II showed a simultaneous increase from the 3.8730mm to 14.8324mm and 1.9417 x 10^{-4} m^3/s to 8.6580 x 10^{-4} m^3/s respectively while table 3 showed a simultaneous increase from the 4.1230mm to 14.6628mm and 1.9436 x 10^{-4} m^3/s to 8.8889 x 10^{-4} m^3/s respectively.

From the graph in figure V, there is a steady increase in $(h_1\text{-}h_2)^{1/2}$ with respect to the discharge for the ISO standard and the fabricated Venturi meter. It is observed that there is a sudden decrease in the rise at 130mm for $(h_1\text{-}h_2)^{1/2}$ value of the fabricated apparatus while the control apparatus sustains its steady increase. The graph also showed that $(h_1\text{-}h_2)^{1/2}$ is directly proportional to the discharge of the liquid.

The graph in figure IV showed that an increase in discharge (Q) results in corresponding increase in the differential head.

Discharge rises steadily with respect to the differential head. It is observed that when the discharge exceeded 5.5402 m^3/s , there is a sharp rise in flow rate before the liquid assumes it steady flow rate. It can also be said here that discharge (Q) is directly proportional to the differential head ($h_1 - h_2$).

IX. CONCLUSION

The operation of the fabricated apparatus should be done with some carefulness to ensure that that there is no air bubbles in pitot tube. Observations should be taken after the flow becomes tranquil. The head of the supply tank should be sufficiently high and the head in the volumetric tank should be kept constant as discharge, head and time will vary.

The experiments conducted on both apparatuses were successful as a rise in differential head of the two tapings caused the flow rate of the liquid in the tubes to increase and this proves the Venturi effect. Since the two apparatuses gave approximately same results (Table II and III and Figure IV and V). The Venturi meter constructed based on standard can be duplicated and adopted for use in all tertiary institutions.

X. RECOMMENDATION

1. The fabricated apparatus should also be duplicated and adopted for use in all tertiary institutions across the world.

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2. Fabrication of this apparatus will enhance entrepreneurship, project creativity and innovation to the next level.

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APPENDICES

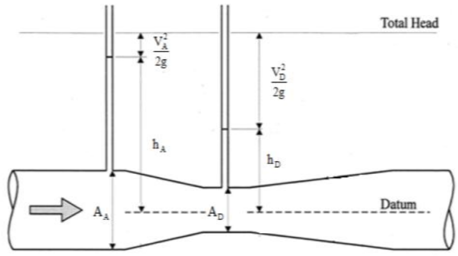

Plate I:
Venturi meter's ideal condition

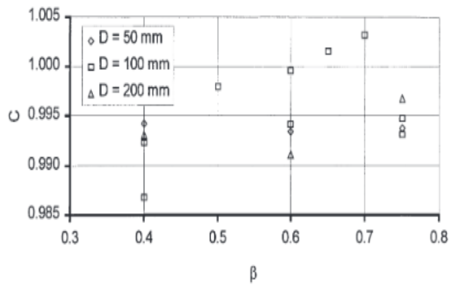

Figure I: Mean Discharge Coeffeicent in Water Standard Convergent Angle

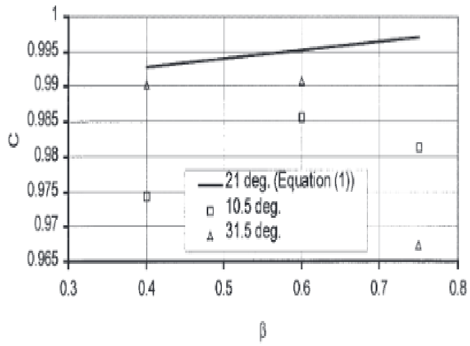

Figure II: Mean Discharge Coeffeicent in Water Non-standard Convergent Angle

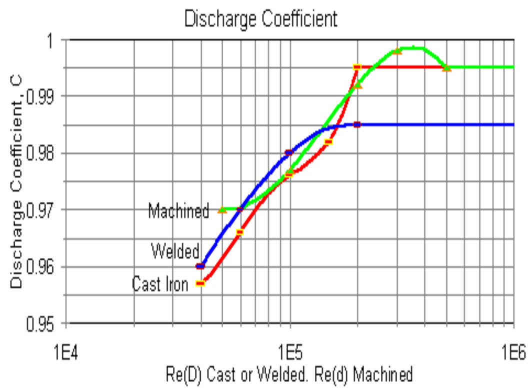

Figure III: Graph of Discharge Coefficient (C) against Reynolds number

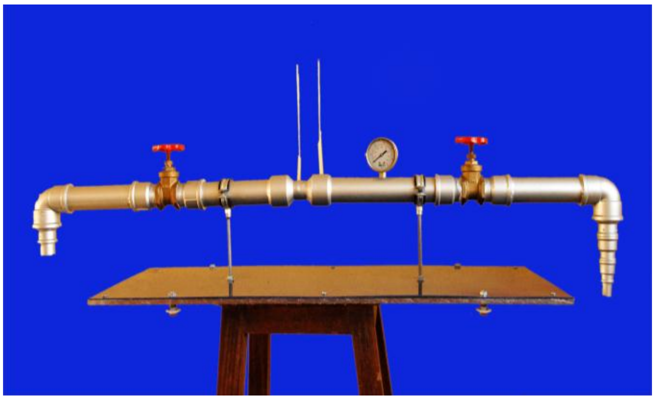

Plate II:
Front view of fabricated Venturi meter

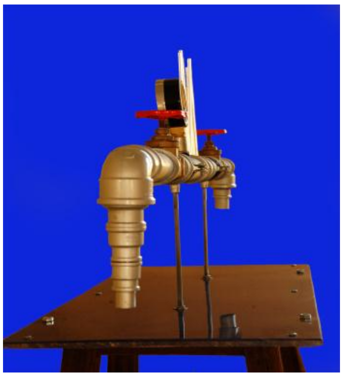

Plate IV:
3D view of fabricated Venturi meter .

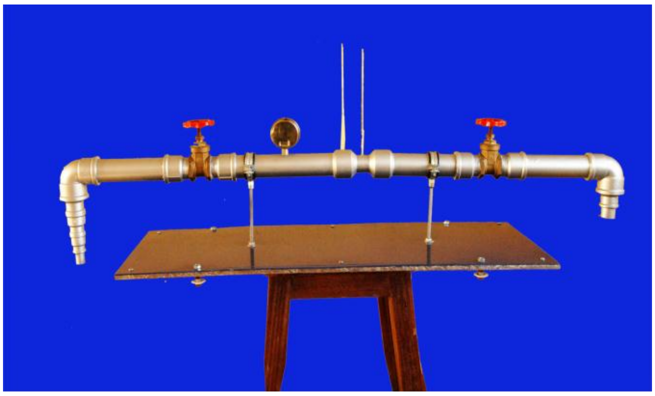

Plate III:
Rear View of Fabricated Venturi Meter

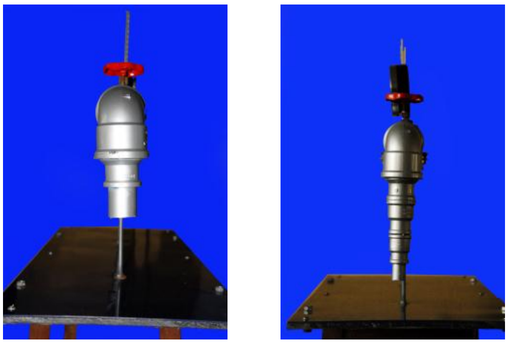

Plate V:
Side view of fabricated orifice meter

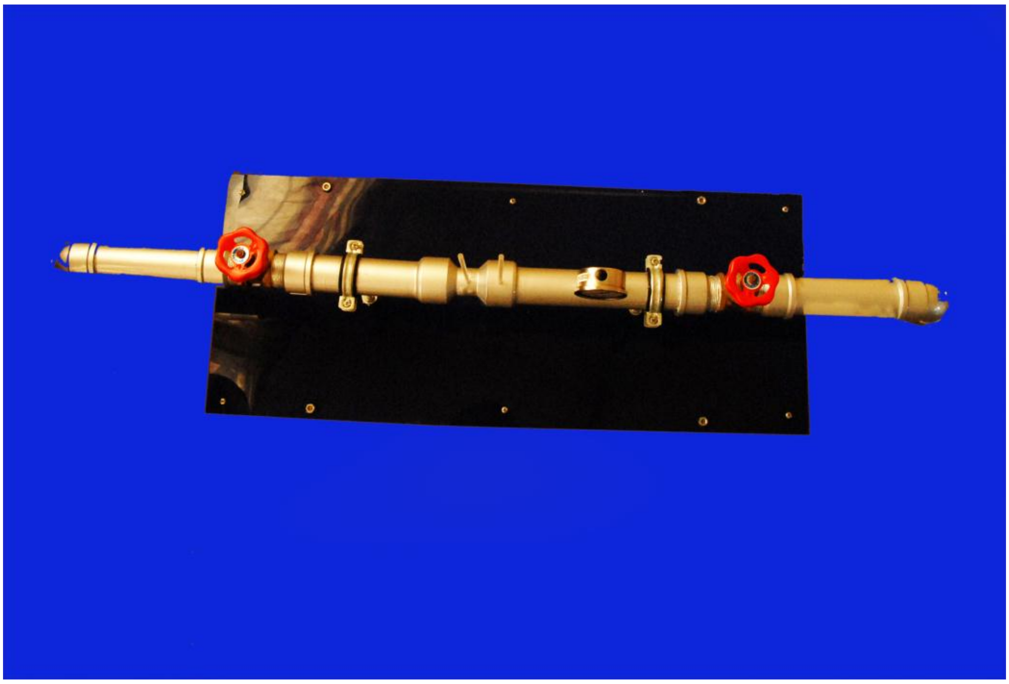

Plate VI
Top view of fabricated orifice meter

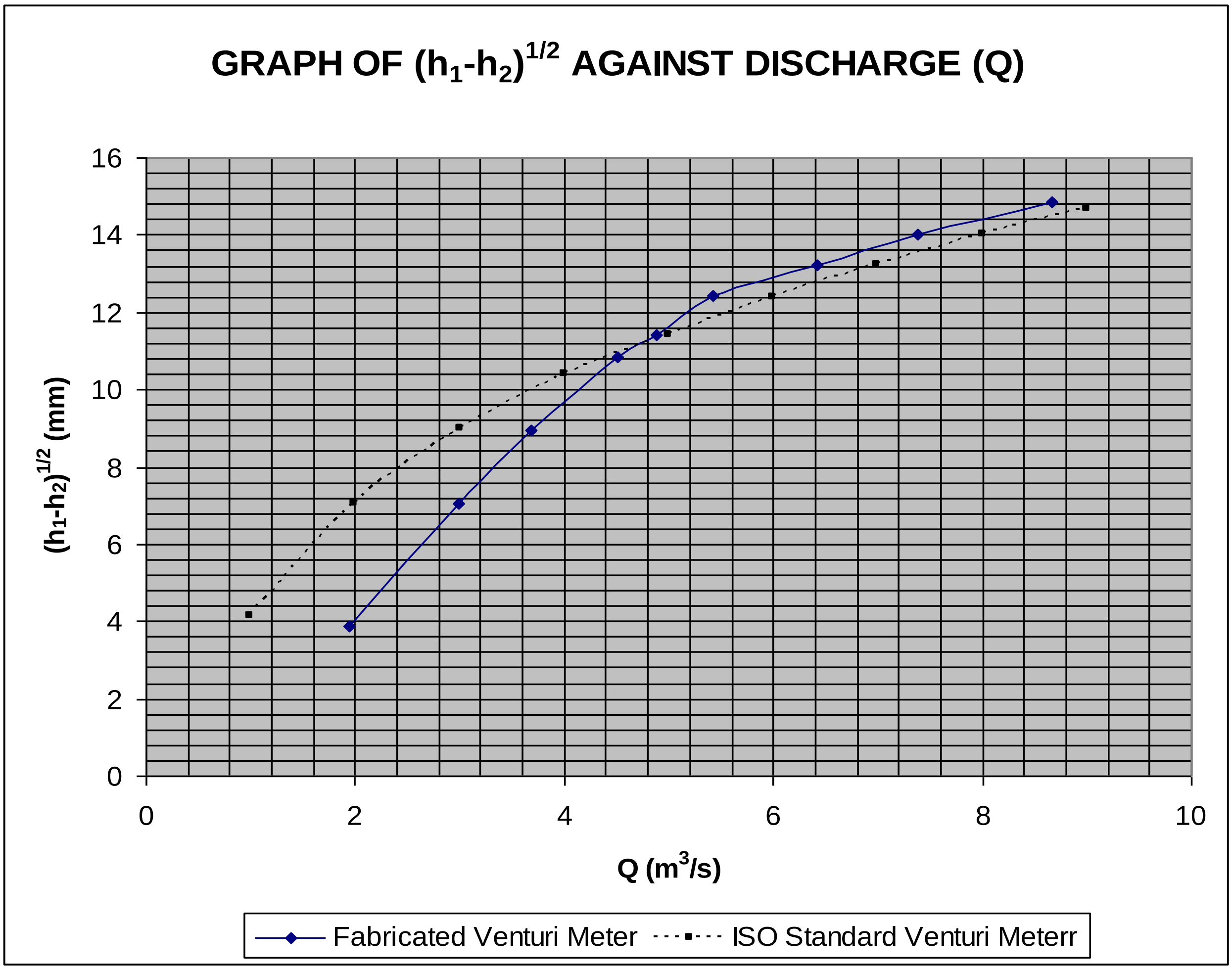

Figure IV: Graph of Differential Head $(h_1\text{-}h_2)^{1/2}$ against Discharge (Q) m^3/s

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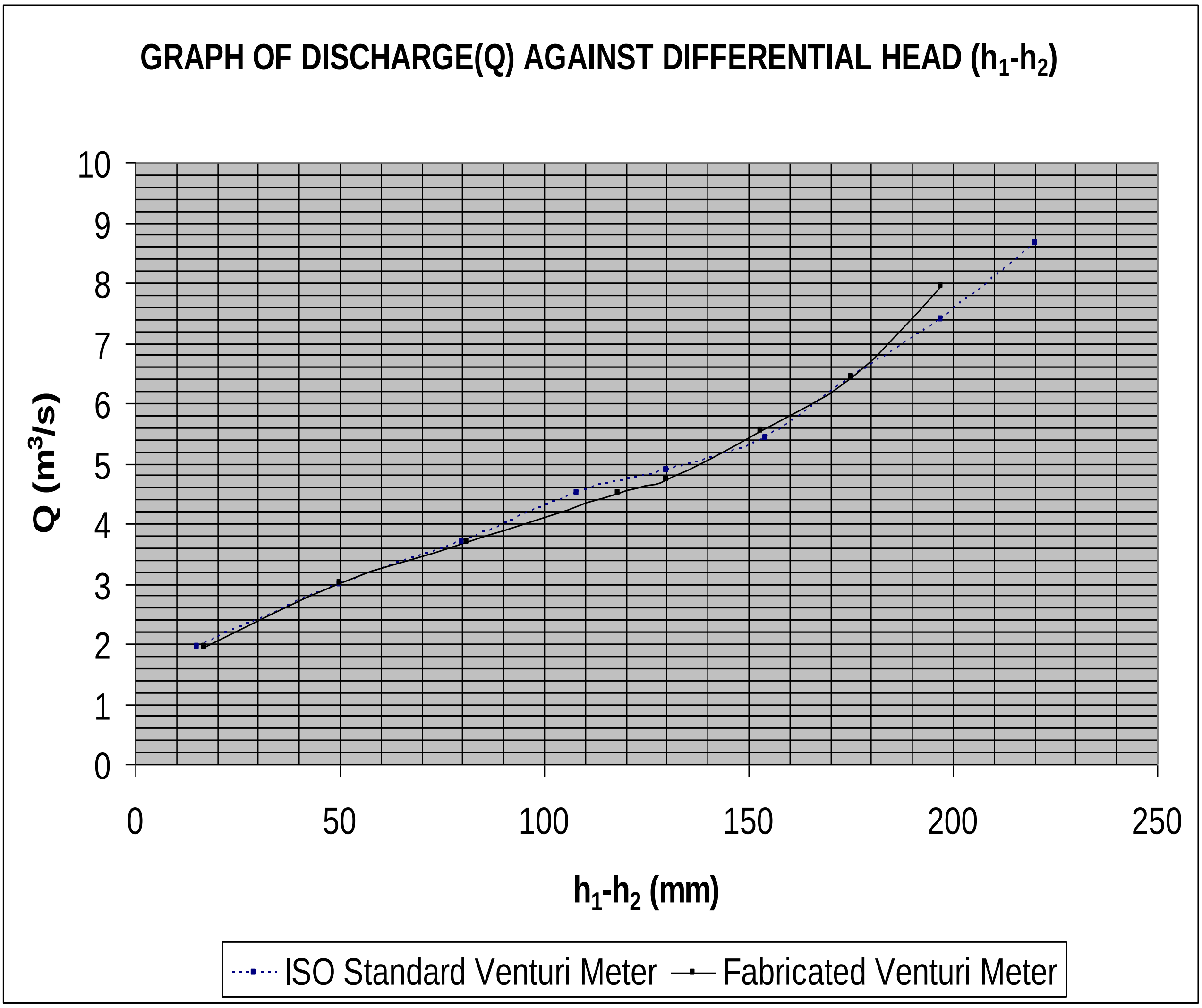

Figure V: Graph of Discharge (Q) m^3/s against Differential Head (h_1-h_2)mm