“Analysis of venture-meter using Computational Fluid Dynamics (CFD) for performance improvement’’

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ABSTRACT

The conceptualization of this project is inspired by the experiments conducted for the calibration of Venturimeter and the loss of water head at the downstream of pipe flow in various hydraulic power plants. The Venturimeter, a typical obstruction type flow meters are widely used in industry for flow measurements. A significant amount of pressure loss occurs in pipelines due to the obstructions present in these types of flow meters. Permanent pressure loss depends on the shape of obstruction, the diameter ratio and also on properties of the fluid. But a differential pressure at minimum pressure loss is the most desirable condition for an ideal Flow Meter. In the present work, Computational Fluid Dynamics (CFD) has been used to compute the permanent pressure loss and relative pressure loss for 3D incompressible fluid for various designs of a classical Venturimeter. Further different parameters are defined to be varied to study effect of each in combination to minimize pressure drop in future work.

Key Words: -*Venturimeter, Cd , Pressure drop, Flow rate meter*

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1. INTRODUCTION:

A Venturimeter is a measuring or also considered as a meter device that is usually used to measure the flow of a fluid in the pipe. A Venturimeter may also be used to increase the velocity of any type fluid in a pipe at any particular point. It basically works on the principle of Bernoulli's Theorem. The pressure in a fluid moving through a small cross section drops suddenly leading to an increase in velocity of the flow. The fluid of the characteristics of high pressure and low velocity gets converted to the low pressure and high velocity at a particular point and again reaches to high pressure and low velocity. The point where the characteristics become low pressure and high velocity is the place where the Venturi flow meter is used.

The Venturimeter is constructed as shown in Figure 1. It has a constriction within itself. The pressure difference between the upstream and the downstream flow, Δh, can be found as a function of the flow rate. Applying Bernoulli’s equation to points 1 and 2 of the Venturimeter and relating the pressure difference to the flow rate yields.

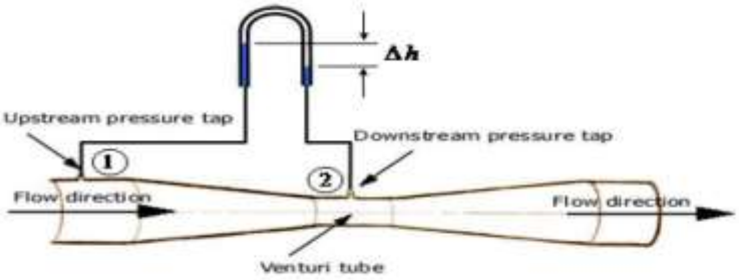

Fig.1 Venturimeter

1.1Principal of Venturimeter :-

The basic principle on which venture meter work is that by reducing the cross section area of the flow passage.

The pressure difference is created and the measurement of the pressure difference enables the estimation of the discharge/flow through the pipe.

1.2 Working:

A venturi meter of known coefficient is installed in the pipeline and the pressure taps are connected to a pressuring device.

Air pockets, if any, are removed from connecting tubing after starting the flow of fluid through the pipeline in which is installed for flow measurement.

An increasing in the flow velocity at the throat results in a decrease in the pressure at the throat.

Due to this a pressure difference is developed between the inlet section and throat section which is measured by pressure gauge after the steady state is attained.

This pressure difference is than related to the flow rate by a mathematical flow equation for the meter.

In the venturi meter, fluid is accelerated in the convergent cone from the inlet section to the throat section and in the divergent cone, it is retarded from the throat section to the end section of venturi meter.

In order to avoid the possibility of flow separation and consequent energy loss, the divergent cone of a venturi meter is made long with a gradual divergence.

Since the separation of flow may occur in the divergent cone of a venture meter, this portion is not used for measuring the flow rate.

Since the gradual reduction in the area of flow, where is no vena contract and the flow area is minimum at the throat so that the coefficient of contraction is unity.

LITERATURE REVIEW:

T. Elperin, A. Fominykh, M. Klochko.[1] 2016 evaluated performance of a Venturimeter in gas–liquid flow in the presence of dissolved gases for pressure drop. A model of release of the gas dissolved in the liquid phase during two-phase flow through a Venturi tube is proposed. Usingseveral simplifying assumptions, the analytical solution

for a proposed model for the pressure drop is obtained. This solution canbe used for estimating the flow conditions at which the contribution of the pressure drop due to the gas release is significant comparedwith that due to the flow acceleration. The dimensionless parameters appearing in the solution can be used for interpretation of the experimental data on gases flashing during flows through differential pressure devices and other flow constrictions.

N. Tamhankar, A. Pandhare, A. Joglekar [2] 2014 analyzed the pressure variations across the Venturimeter using CFD analysis and validated results by experimentation. The authors have made an attempt to study and prepare a computational model of a venturimeter, which can be used as an efficient and easy means for calibration of the instrument instead of costly experimental methods. The research covers the following aspects: to study the theory of the venturimeter and calculate the data theoretically by using Bernoulli's equation, to analyses the experimental data and to plot graphs for it. The focus here is to analyse the pressure variations across the venture section by means of Ansys Fluent 13.0, a commercial CFD code, which explores the use of computational methods to compute the flow parameters in the tube. The study aims at comparing the results calculated by both, the computational and experimental methods. An effort is made to check the validity of Bernoulli's equation when applied to the steady flow of water in a tapered duct and to calibrate the venturi as a flow meter by calculating the coefficient of discharge

Huang X., G. Li, M. [3] 2015 used CFD technique to analyzerelationship among the throat length, throat diameter, slot diameter and suction capacity of venturi injector. The results revealed that with keeping the inlet pressure and the slot position constant, the suction capacity of venturi injector increases with the decrease of throat diameter and throat length and the increase of slot diameter.

M. S. Karthik, V. Seshadri [4] 2015. They have predicted discharge coefficient for different Reynolds numbers using STAR CCM + CFD program. Literature shows lack of information for optimum dimensions of Venturimeter for minimum pressure drop.The focus of the study was directed towards very small Reynolds numbers commonly associated with pipeline transportation of viscous fluids. However high Reynolds number were also considered. The Computational Fluid Dynamics (CFD) program STAR CCM + was used to perform the research. Heavy oil and water were used separately as the two flowing fluids to obtain a wide range of Reynolds Numbers with high precision. Multiple models were used with varying characteristics, such as pipe , size and meter geometry , to obtain a better understanding of theCd vs. Re relationship.

P. Hari Vijay, V. Subrahmanyam. [5] 2015, compared four different models of Venturimeter to analyze the velocity, pressure, turbulence and mass flow rate using CFD method. This paper describe an analytical approach for comparison of four different models to describe the velocity, pressure, turbulence and mass flow rate taken place in the venturimeter and graph are plotted. Venturimeter are most commonly used for flow meters for measuring volumetric or mass flow rate and velocity of fluid flowing through the venturimeter. Hence are also know as variable head meters. Variable head meters work on the principle that a variation of the flow rate through a constriction with a constant cross-sectional area causes a pressure drop suffered by the fluid as it flows through the constriction. The pressure drop is related to the flow rate, and hence variations of the pressure drop can be used to measure variations in the flow rate. Fluent software was used to plot the characteristics of the flow of fluid through the flow meter and gambit software was used to design the 2D model. Two phase computational fluid dynamic calculation, using K-Epsilon model were employed. The numerical results were validated against experimental data from the literature and were found to be in good agreement. The pressure recovery is better in the venturi meter. They concluded that The flow through venturi meter was numerically simulated with water by steady flow in k-epsilon scheme. The major observations made related to the pressure, turbulence, velocity contours and mass flow rate in the process of flow. The accuracy of results is with in 5%. The velocity and pressure distribusions are discribedbrifly and graphs are plotted.

S. Bharani, R Mishra, S N Singh [6] 2014, evaluated performance characteristics of an eccentric Venturimeter with elongated throat for flow measurement of solid-liquid mixture and it was found that discharge coefficient is slightly higher for slurry flow compared to pure water flow. The performance characteristics of an eccentric venturimeter with elongated throat for 68 mm NB pipeline having an area ratio of 0.327 for the measurement of flow rates in solid-liquid flow, have been investigated. The modified geometry of the venturimeter is expected to suppress the erosion rate caused by the motion of solid particles. Copper tailings obtained from a processing plant have been used with water to prepare the solid-liquid mixture. Experiments performed over a wide range of flow velocities and solid concentrations show that the value of discharge coefficient of the eccentric venturimeter with elongated throat is slightly higher for slurry flow as compared to the value obtained for clear water flow. It is also seen that the average value of discharge coefficient obtained at different solid concentrations increases marginally with increase in solid concentration. The redistribution of solids at the throat of the venturimeter has also been investigated at different solid concentration.

3. EXPERIMENTATION:

3.1 Experiment Set – up:

Experiments are conducted at set up already available at laboratory shown in picture below.

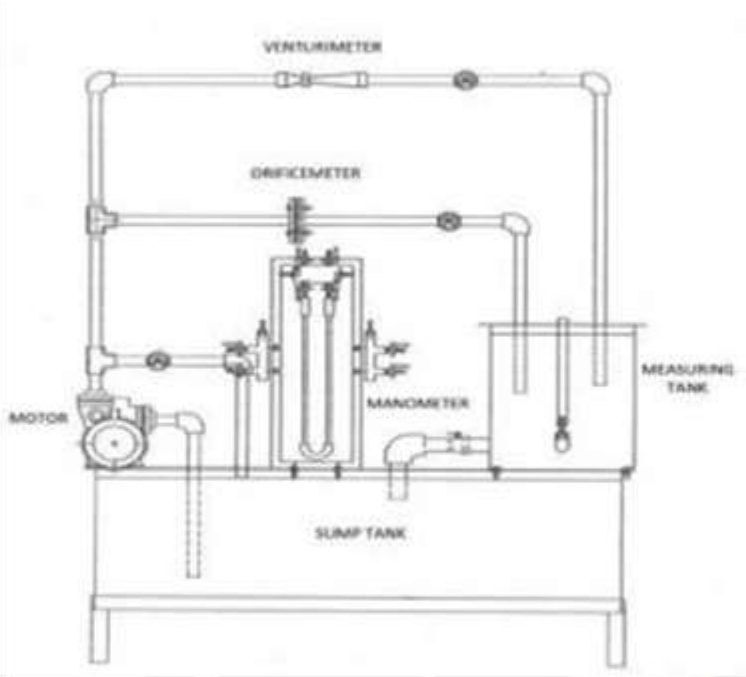

Fig. 2 Experimental setup

3.2 Specification:

(1) Supply pipe of Diameter 40 mm connected to inlet manifold

(2) Venturimeter size inlet Diameter40 mm and throat Diameter24 mm

(3) Differential mercury manometer tapping's provided at inlet and throat of Venturimeter. Manometer size 50 cm height.

(4) Measuring tank size - 400 mm x 400mm x 600 mm height.

3.3 Experimental Procedure:

(1)Check all the clamps for tightness

(2) Open the gate valve and start the flow.

(3) Open the outlet valve of the Venturimeter and close the valve of orifice meter.

(4) First open air cocks then open the Venturimeter cocks, remove all the airbubbles andclose the air cocks slowly and simultaneously so that mercury does not run away intowater.

(5)Close the gate valve of measuring tank and measure the time for 10 cm rise of water in tank and also the manometer difference.

Table 1: OBSERVATION TABLE FOR VENTURIMETER:

Sr.No	H1(cm of Hg)	H2(cm of Hg)	Time for 10 cm rise of water discharge t (Sec.)
1	6.3	14.3	21.18
2	9.2	11.2	57.40
3	8	12.2	29.22

3.4 Calculation:

- Area of venturi throat, a = 1.32 x 10 $^{-4}$ m^{2}
- Area of convergent cone, A = 0.001256 m^{2}
- Area of measuring tank = 0.16 m^{2}
- Actual discharge :

$Q_{act} = 0.016$

$= 0.016_{21.18}$

$Q_{act} = 0.0007554 m^{3}/sec$

- Theoretical Discharge :

  Let 'H' be the water head across manometer in, m.

  H = Manometer difference (Sp. gravity of Mercury - Sp. gravity of water) Or H = Manometer difference x (13.6 -1)

  H= 0.08 x 12.6 m of water

  H= 1.008 m of water

  D= 40 mm

  Beta ratio (B) = 0.6

  $Q_{theoretical} = A*B^{2}$ $(2*9.81*dH)/(1-B^{4})$

Table 2: Results by hand calculation

Sr No.	Pressure drop(m of water)	Actual flow rate Q_a (x10^{-4})	Theoretical flow rate Q_{the}(x10^{-4})	Coefficient of discharge Cd
1	1.008	7.55	8.42	0.8966
2	0.252	2.78	4.21	0.6603
3	0.53	5.47	6.50	0.8415

4. RESULT AND DISCUSSION:

Table 3: Results comparison

No.	C_d(Experimental)	C_d(CFX Result)	% error
1	0.8966	0.8658	3.45
2	0.6603	0.6235	5.57
3	0.8415	0.8376	4.028
		Average % error	**4.35**

This error is due to constrain assumed at starting of report that are inner tube wall assumed to be no slip wall.

The above created model is validated so now it can be used for further modification and results can be compared and optimum parameters can be selected.

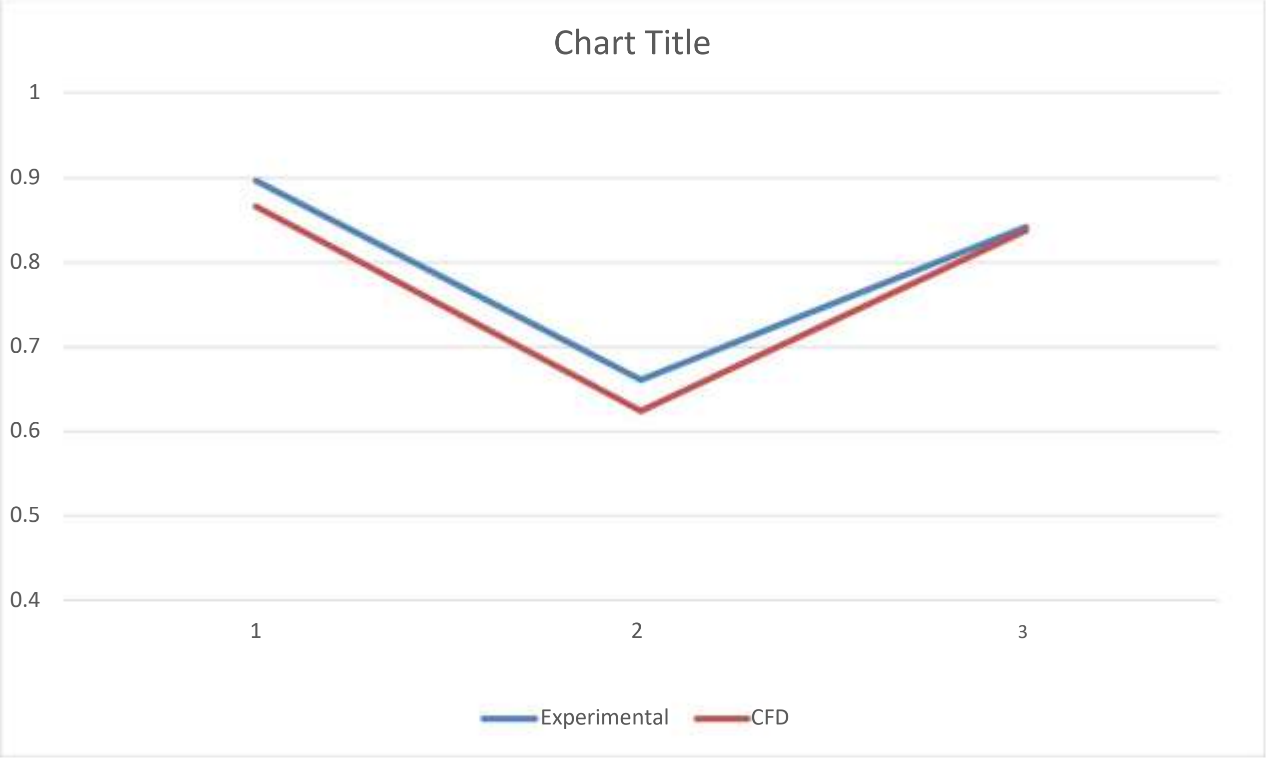

Fig.3 Comparison of CFD and Experimental results

Signal-to-Noise Ratio

There are 3 Signal-to-Noise ratios of common interest for optimization

(I) Smaller-The-Better: n = -10 Log10 [mean of sum of squares of measured data]

(II) Larger-The-Better: n = -10 Log10 [mean of sum squares of reciprocal of measured data]

(III) Nominal-The-Best: n = 10 Log10(square of mean / variance)

Table 4: Factors and levels for DOE

Factors	Parameters	Levels				
		L1	L2	L3	L4	L5
A	Convergent cone angle (θ1)	17	19	21	23	25
B	Divergent cone angle (θ2)	7	9	11	13	15
C	Beta ratio (β)	0.35	0.45	0.55	0.65	0.75
D	Throat length (l)(mm)	7	21	28	42	49

Table 5: Test Table for CFD Simulation

Sr. No	Convergent cone angle (θ1)	Divergent cone angle (θ2)	Beta ratio (β)	Throat length X 10^{-3} (l)(mm)	Pressure Drop (ΔP, kPa)
1	17	7	0.35	7	982.135
2	17	9	0.45	21	352.411
3	17	11	0.55	28	154.313
4	17	13	0.65	42	75.969
5	17	15	0.75	49	41.038
6	19	7	0.45	28	356.929
7	19	9	0.55	42	155.524
8	19	11	0.65	49	76.836
9	19	13	0.75	7	41.682
10	19	15	0.35	21	995.473
11	21	7	0.55	49	157.985
12	21	9	0.65	7	79.139
13	21	11	0.75	21	41.904
14	21	13	0.35	28	1007.681
15	21	15	0.45	42	362.216
16	23	7	0.65	21	79.833
17	23	9	0.75	28	42.358
18	23	11	0.35	42	1025.858
19	23	13	0.45	49	367.018
20	23	15	0.55	7	164.203

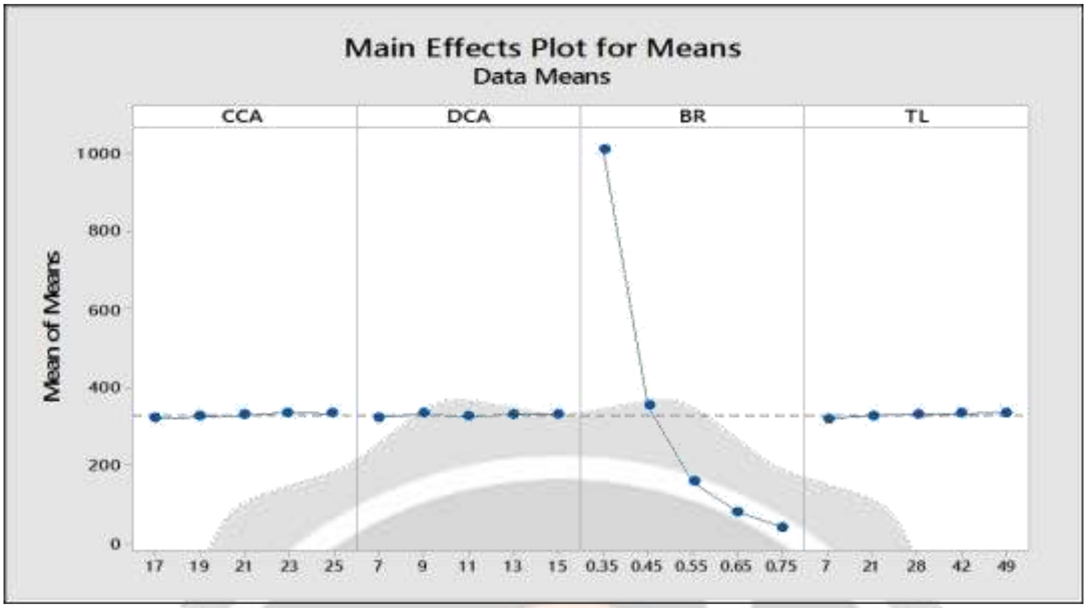

Figure 4. Effects of Geometrical Parameters on Pressure Drop.

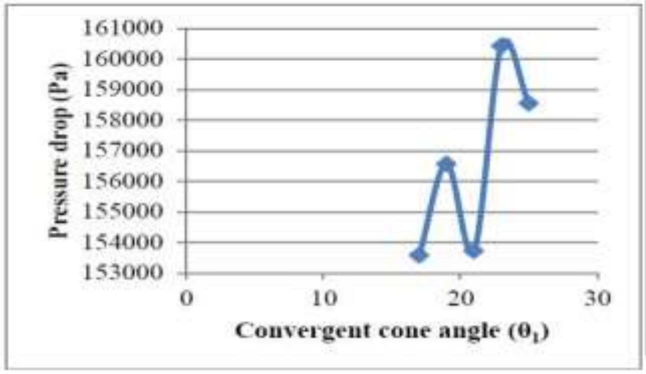

Figure 5: Effect of convergent cone angle on pressure drop

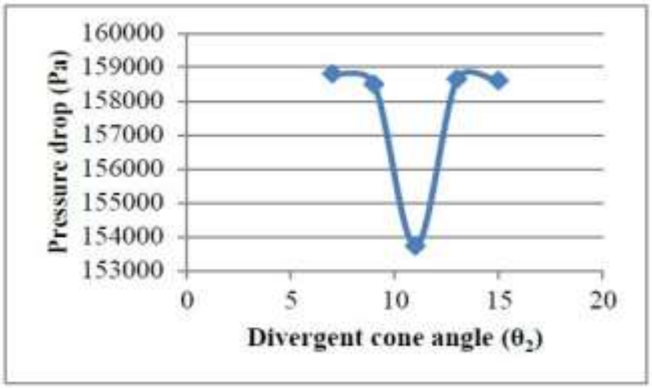

Figure 6: Effect of divergent cone angle on pressure drop

5. CONCLUSIONS:

- By increasing convergent cone angle, pressure drop fluctuates.
- Minimum pressure drop occurs at divergent angle of 11º.
- Pressure drop decreases with increase in diameter ratio (β).
- Maximum pressure drop occurs at throat length of 0.042mm. Analysis of variance suggests that the beta ratio is the most significant parameter for pressure drop having influence of 99.99%.
- The combination of optimum levels of geometrical parameter is Convergent Angle=17º, Divergent Angle=7º, Beta Ratio=0.75, Throat Length=0.007 mm and the value of pressure drop at those parameters is 41.038 KPa.

6. ACKNOWLEDGEMENT:

"Optimism Is The Faith That Leads To Achievement. Nothing Can Be Done Without Hope and Confidence - Helen Keller "On the very outset of this report, I would like to extend my sincere and heartfelt obligation towards all the personages who have helped me in this endeavor. Without their active guidance, help, corporation and encouragement, I would not have made head way in the project.

First and foremost, I would like to express my sincere gratitude to my project guide, **Assistant professor Rahul M Desai .**It has been a great pleasure for me to get an opportunity to work under him and complete the present work successfully.

We wish to extend my sincere thanks to **Prof. Sanket T Gandhi**, Head of our Department, for approving our project work with great interest.
We would also like to thank **Dr.Paras Kothari**, Principal of our institution for giving me moral guidance. We wish to express my heartiest regards to my parents for their guidance and moral support.

We are also like to thanks to all Mechanical Engineering Department of Our College. Because more guidance about our project, and also helpful for support.

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