Design & Development of Model for Flow Measurement by Venturimeter & Orifice meter

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Abstract— In this thesis, The Venturimeter & Orifice meter, typical obstruction type flow meters are widely used in industry for flow measurements. The application of these Flow meters are found in Aviation, Automotive, chemical, petro chemical industries, etc. Four parameters namely pressure drop and Velocity, discharge, nozzle angle of the Venturi will be analyzed using computational fluid dynamics. Differential pressure at minimum pressure loss is the most desirable condition for an ideal Flow Meter. This research covers the following aspects: To study the theory of the Orifice as well as venturimeter and calculate the data theoretically by using Bernoulli's equation, to analyze the experimental data. The study aims at comparing the results calculated by both, the computational and experimental methods. The location of vena-contracta was also estimated from CFD simulations. the CFD analyses to determine the pressure drop, turbulence intensity, mass flow rate, and velocity. Finite Element Analysis has been used to compute the permanent pressure loss and relative pressure loss for incompressible fluid for orifice plate. The value of Coefficient of Discharge depends on the type of flow, pressure tappings and contour of the obstruction. Software used are AUTO-CAD software and analysis done in ANSYS.

Keywords: Venturimeter, Orifice Plate, Coefficient of Discharge (Cd), Computational fluid dynamics (CFD)

I. INTRODUCTION

A. *Venturimeter:*

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.

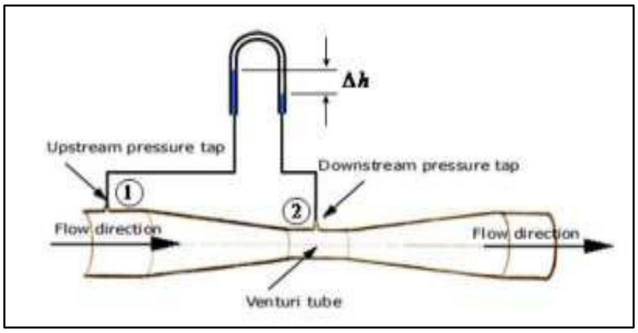

Fig. 1: Venturimeter

The Venturimeter is constructed as shown in Figure. 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.

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.

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 venturimeter 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.

B. *Orifice Plate:*

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. The orifice plate is very inexpensive for it is just a flat plate and a thin orifice plate. It is also very easy to install in the pipeline. It works on simple principle of using effects of velocity and pressure variation caused by reduction of the available area for flow.

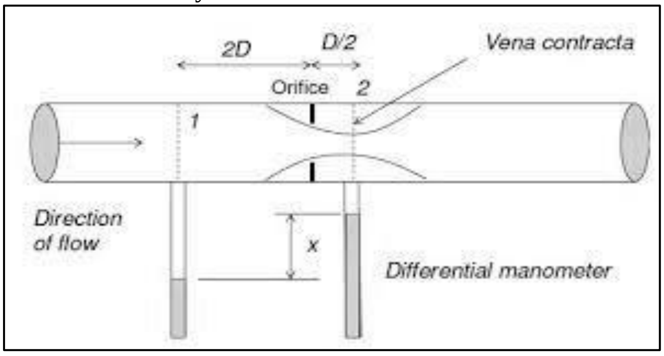

Fig. 2: Orifice meter

Orifices are widely used in flow metering because of their ruggedness, simple mechanical construction, and other known advantages. The study on effects of orifice to pipe diameter ratio are extensive. The effects of ratio on the mass transfer rate behind the orifice numerically studied by and. The characteristic length and velocity scales in different regions of orifice flows using PIV was studied by and found out that the position of the vena contracta shows a slight orifice to pipe diameter ratio dependence. CFD tools are also widely used in modelling and analyzing orifice meters [5-8]. The flow through conventional single-hole orifice meter and integrated CFD simulation with measurements to analyze oscillating air flow through an orifice in a circular pipe was studied using used Open FOAM-1.6 by Some studies have focused on obtaining the associated discharge coefficients and pressure drops. With the above distinct advantages of a flow meter of high industrial importance, it is necessary to understand the flow pattern of orifice meter to further improve its performance in terms of flow measurement with better accuracy. Therefore, in this paper, CFD simulations are carried out to predict the flow pattern and vena contracta in the orifice meter. The outcomes of the CFD simulations in terms of velocity profile and pressure profile. CFD would candidate as a valuable engineering tool for the design and use of these devices in all those situations, quite common in the oil and gas fields, where experiments may be too complex or time consuming.

II. LITERATURE REVIEW

A. *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. Using several simplifying assumptions, the analytical solution for a proposed model for the pressure drop is obtained. This solution can be used for estimating the flow conditions at which the contribution of the pressure drop due to the gas release is significant compared with 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.

B. *N. Tamhankar, A. Pandhare, A. Joglekar [2] 2014*

They analyzed the pressure variations across the Venturimeter using CFD analysis and validated results by experimentation. 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 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.

C. *Huang X., G. Li, M. [3] 2015*

They used CFD technique to analyze relationship 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.

D. *Malatesh Barki et al. [4] August 2014*

represents the effect of orifice holes arrangement or distribution in a plate on the performance of flow characteristics. The analysis is carried out for four diameter ratio. The pressure drop is minimum for multi holes orifice plate compare to single hole. It shows that the nine holes in circular arrangement have better performance compare with square arrangement.

E. *Abhishek Kala, Dr. S.K Mittal, Prof M. K. Choudhary [5] 2018*

In case of pipe conduits various flow meters are used for flow estimation; out of which venturimeter and orifice meter are most commonly used and conventional means. Pipes or conduit carrying sediment laden flow or slurry-water mixture is very common in most of the industries, sewage carrying system etc. Suitability of flow meters i.e. venturimeter and flow meter need to be analyzed for sediment laden flow. Due to the presence of slurry or sediments, coefficient of discharge of flow meter will vary. In the present paper, various works that have been carried out till now in the analysis of characteristics of venturimeter and orifice meter with sediment laden flow are described.

F. *Ramya B N, Prof. Yogesh Kumar K J, Dr. V Seshadri [6] 2016*

did the analysis on standard sharp edge orifice meter for different plate thicknesses (3 mm, 5 mm, 10 mm and 15 mm) in a pipe of 50 mm diameter and the effect of pipe diameter on coefficient of discharge has been studied. The value of coefficient of discharge depends on the type of flow, pressure tapping’s, contour of the obstruction and it is a function of Reynolds number.

III. PROBLEM STATEMENT:

– Design, develop and fabricate a Model to reduce the losses and to increase the coefficient of discharge in order to measure the correct flow rate of fluid flowing through the pipe.

- Differential pressure at minimum pressure loss is the most desirable condition for an ideal Flow Meter.
- To analyze parameters namely pressure drop and Velocity, discharge, nozzle angle of the Venturi using computational fluid dynamics.
- To determine the pressure drop, turbulence intensity, mass flow rate, and velocity.
- To determine the location of vena-contracta in Orifice meter.
- Suggest a feasible solution for the proposed problem. Design the Model accordingly.
- Do the simulation for the same and find the errors if any. Fabricate the Model according to the best analysis results.

IV. Experimentation:

Experiment Set-up: Experiments are conducted on model made by our Project Group in our laboratory shown in picture below

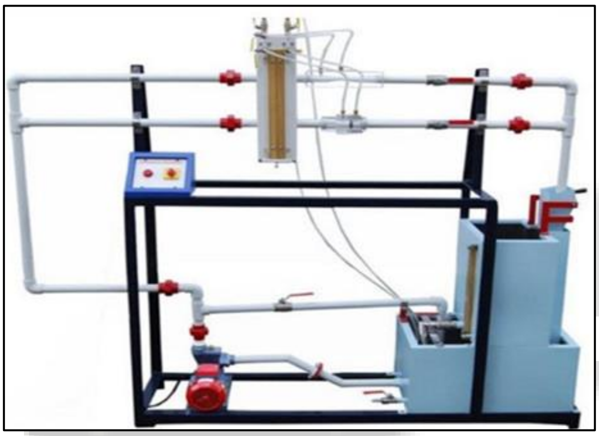

Fig. 3: Experimental setup

A. *Experimentation of Venturi Meter*

1) *Specification:*

- Supply pipe of Diameter 40 mm connected to inlet manifold.
- Venturimeter size inlet Diameter 40 mm and throat Diameter24 mm.
- Differential mercury manometer tapping's provided at inlet and throat of Venturimeter. Manometer size 50 cm height.
- Measuring tank size - 400 mm x 400mm x 600 mm height.

B. *Experimental Procedure:*

Check all the clamps for tightness.

- Open the gate valve and start the flow.
- Open the outlet valve of the Venturimeter and close the valve of orifice meter.
- First open air cocks then open the Venturimeter cocks, remove all the air bubbles and close the air cocks slowly and simultaneously so that mercury does not run away into water.
- Close the gate valve of measuring tank and measure the time for 10 cm rise of water in tank and also the manometer difference.

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

Table 1: OBSERVATION TABLE FOR VENTURIMETER

1) *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 m^3/sec
- Theoretical Discharge:

  Q_{th} = 0.0007554 m^3/sec

  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_{th}=A*B^2

  (2*9.81*dH)/ (1- B^4)

Sr no	Pressure drop (m of water)	Actual flow rate Q_a ($x10^{-4}$)	Theoretical flow rate Q_{th} ($x10^{-4}$)	Coefficient of Discharge
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

Table 2: Results by hand calculation

2) *RESULT AND DISCUSSION:*

No.	Cd (Experimental)	Cd (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

Table 3: Results comparison

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.

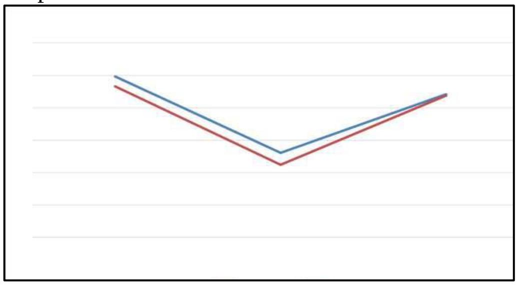

Fig. 4: Comparison of CFD and Experimental results

3) Signal-to-Noise Ratio

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

1) Smaller-The-Better: n = -10 Log10 [mean of sum of squares of measured data]
2) Larger-The-Better: n = -10 Log10 [mean of sum squares of reciprocal of measured data]
3) Nominal-The-Best: n = 10 Log10 (square of mean / variance)

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 4: Factors and levels for DOE

Sr No.	Convergent Cone Angle (θ1)	Divergent Cone Angle (θ2)	Beta Ratio (β)	Throat Length x10^{-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

Table 5: Test Table for CFD Simulation

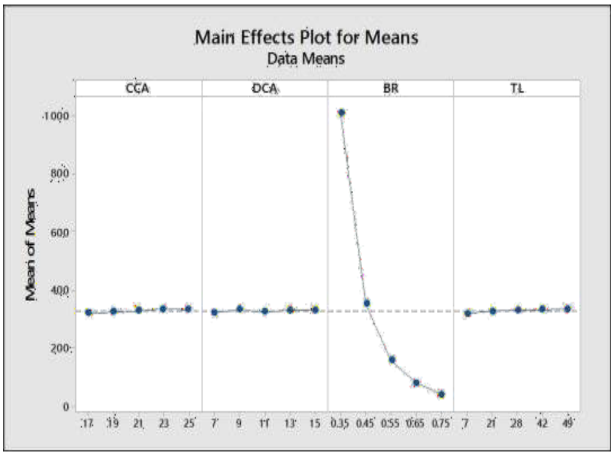

Fig. 5: Effects of Geometrical Parameters on Pressure Drop

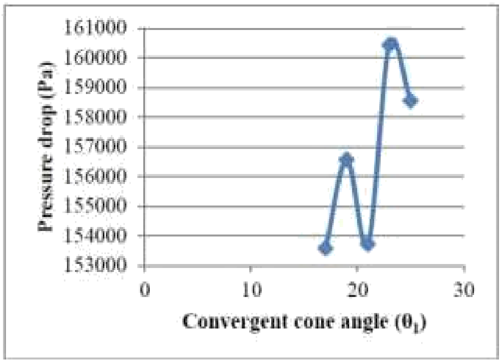

Fig. 6: Effect of convergent cone angl on pressure drop

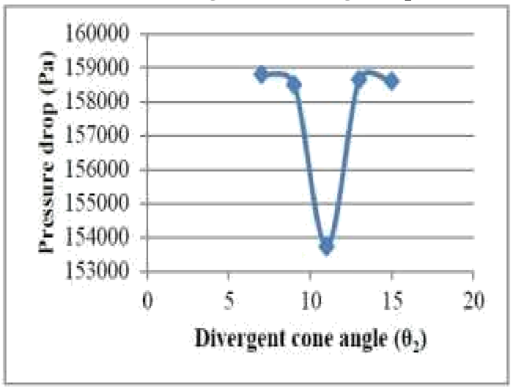

Fig. 7: Effect of divergent cone angle on pressure drop

C. Experimentation of Orifice Plate:

1) THEORETICAL ANALYSIS OF PRESSURE DROP IN ORIFICE METER

The calculation of fluid flow rate by reading the pressure loss across a pipe restriction is perhaps the most commonly used flow measurement technique in industrial applications. The pressure drops generated by a wide variety of geometrical restrictions have been well characterized over the years these primary or head flow elements come in a wide variety of configurations, each with specific application strengths and weaknesses. Variations on the theme of differential pressure (dp) flow measurement include the use of orifice meter. The theoretical analysis of orifice meter pressure drop can be found from following method:

$$Q = A_1 * A_2 * \frac{\sqrt{2gh}}{\sqrt{A_1^2 - A_2^2}}$$

$$\therefore A_1 * V = A_1 * A_2 * \frac{\sqrt{2g} * \sqrt{h}}{\sqrt{A_1^2 - A_2^2}}$$

$$\therefore \sqrt{h} = V * \sqrt{A_1^2 - A_2^2} / (A_2 * \sqrt{2g})$$

$$\therefore h = V^2 * \frac{A_1^2 - A_2^2}{A_2^2 * 2g}$$

$$\therefore \rho * g * h = \rho * g * V2 * \frac{A_1^2 - A_2^2}{A_2^2 * 2g}$$

$$\therefore \mathbf{P} = \boldsymbol{\rho} * V^2 * \frac{A_1^2 - A_2^2}{2 * A_2^2}$$

Theoretical Pressure Drop = $\boldsymbol{\rho} * V^2 * \frac{A_1^2 - A_2^2}{2 * A_2^2}$

$= 995.18 * 1.85^2 * \frac{0.00061544^2 - 0.00015386^{\,2}}{2 * 0.00015386^2}$

Theoretical Pressure Drop = 25430.10 Pa

S.N.	Velocity	Pressure Drop
1	1.85	25430.10
2	1.92	27624.53
3	1.87	26151.49
4	1.90	26882.96

Table 6: Theoretical calculation of Pressure Drop

2) *BOUNDARY CONDITIONS*

In all the simulations, velocity is set at the inlet of the orifice meter, pressure is set at the outlet and no-slip condition is set at the wall.

3) *PRACTICAL ANALYSIS*

This experiment was performed on this set up. The working medium was water. When we have performed this experiment the temperature of atmosphere was 30°C. At this temperature the density of water is 995.18 kg/m^3, thermal conductivity is 0.6194 Watt/m-K, specific heat is 4070.2 kJ/kg-K, readings were taken. As orifice disk is installed in the pipe, the experiment is designed to investigate the pressure drop for different velocities by measuring pressure in manometer in water column and the flow rate Q.

Technical specification of this set up is as follow.

- Orifice Diameter = 14mm
- Pipe Diameter = 28mm
- Orifice thickness = 2.5mm
- Orifice angle = 45^0
- Area of measuring tank = 0.4*0.4 m^2

MANOMETER READING			MEASURING TANK READING			
HIGH X_2	LOW X_1	$X = X_2 - X_1$	FINAL h_2	INITIAL h_1	$H = h_2 - h_1$	TIME
25.1	3.3	0.218	8.1	1	0.071	10

Table 7: Observation Table

As per the observation, the pressure drop δp for the orifice tube can be calculated by the following formula:

HEAD (H) = Δ × (13.6 – 1) = 0.218 × (13.6 – 1)

= 2.7468 METER OF WATER

PRESSUREDROP (δP) = ρ ∗ g ∗ h

= 995.18*9.81*2.7468

=26816.23 Pa

Practical Pressure Drop = 26816.23 Pa

Similarly if we calculate pressure drop for every reading we find following results:

Theoretical Pressure Drop	Practical Pressure Drop
25430.10	26816.23
27624.53	27677.30
26151.49	26201.18
26882.96	27677.30

We found following results:

- Average pressure difference between theoretical & Practical Pressure drop is 2.2%
- This experiment is authenticated in ANSYS & FEA done for authentication.

4) *FE ANALYSIS OF PRESSURE DROP*

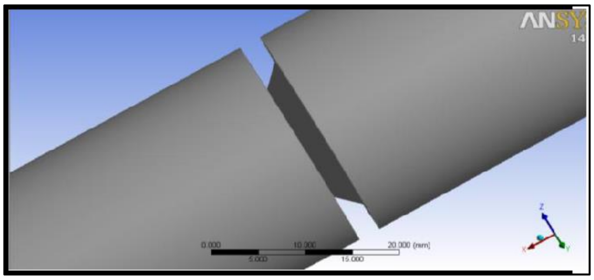

Fig. 8: 3-D model of orifice plate

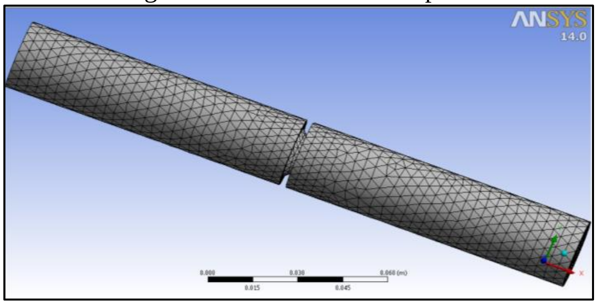

Fig. 9: Meshing of the model

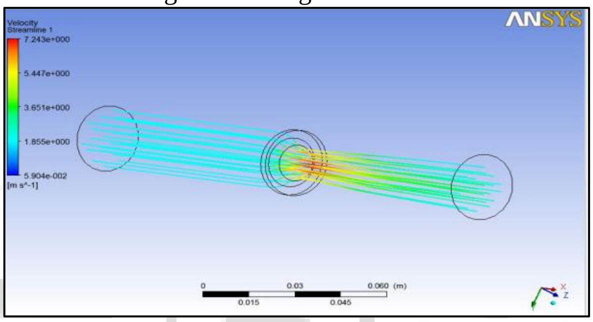

Fig. 10: Velocity profile

From velocity analysis it is clear that V = 1.85 m/s

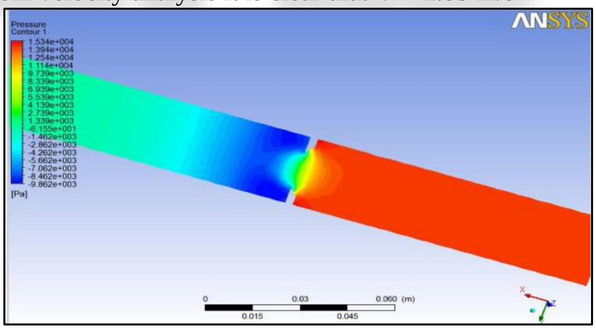

Fig. 11: Velocity profile

From Pressure drop contour it is observed that on position the manometer is fitted from which we take the readings of pressure drop.

- It is clear from the Pressure drop contour that pressure drop = 15339.2 – (- 9862.04) = 25201.24 Pa
- Difference between FEA Pressure drop & Practical Pressure drop is 0.9%
- The comparison chart of FEA Pressure drop & Practical Pressure drop is also shown.

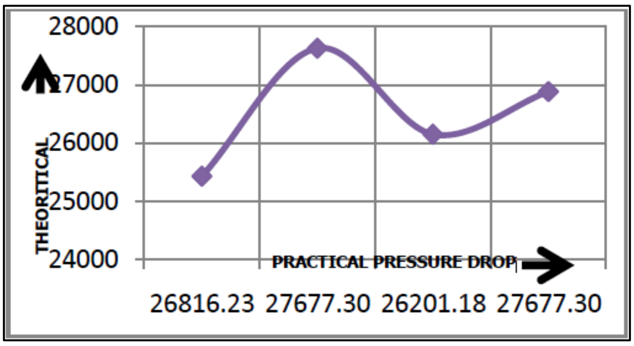

Fig. 12: Theoretical vs. Practical Pressure drop

– Future Scope

- In Venturimeter analysis working fluid for this experimental setup is water, for further analysis working fluid can be changed as per the applications such as oil, sediment, etc.
- For different shapes of venturimeter the analysis can be performed and different results can be plotted.
- Analysis can be done for two phase mixture, i.e. for steam and water mixture, air and water mixture.
- It will be a complete guidance for solving fluidity problems under any flow movements.
- CFD has a great science and has a great future, Fighters, bombers, cargo aircrafts, Helicopters, Air breathing engines,
- Through this CFD analysis we can make sure that this analysis is very useful in design of venturimeter for different applications.
- Orifice meter is widely used in industries these days to measure the flow rate of fluid flowing through the pipe as it is an easy and cheaper method of measuring the flow rate.
- The only problem with the orifice meter industries are facing is while measuring the flow rate of fluid through a pipe of shorter length; the fluid is creating turbulence due to sudden decrease in the cross section area. So the solution we are proposing here in this project will definitely solve this problem and if this concept worked mass scale production of the same can be done in the future.

V. Conclusion:

A. VENTURIMETER:

- 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.

B. ORIFICE METER:

- Average Difference between theoretical & Practical Pressure drop is 2.2%
- Difference between FEA Pressure drop & Practical Pressure drop is 0.9%
- We have found good agreement among the three results theoretical Practical & FE analysis. So, we can change the pressure drop by changing velocity, shape of orifice and angle and find out optimum design of orifice.

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