A SCHEMATIC STUDY ON VARYING THE FLOW RATE OF A VENTURIMETER USING CFD APPROACH

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Abstract:
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 known 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. . In this work, two parameters: pressure drop and velocity discharge nozzle were analyzed using Computational Fluid Dynamics (CFD). The results obtained were then analyzed for accurate determination of the Venturi tube's discharge coefficient, Cd. It was found that there is less than 1% difference between the average values of the discharge coefficient obtained from the numerical analysis and experimental results.

1.0 Introduction:

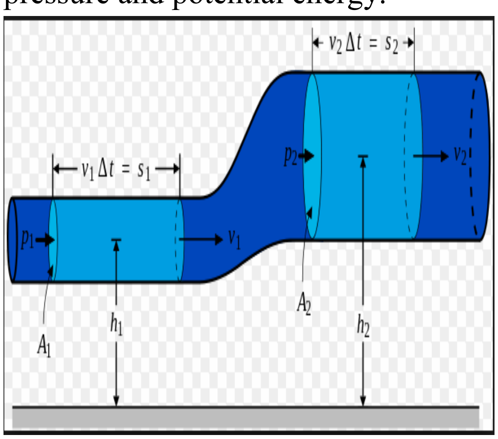
The venturi meter is an obstruction meter named in honor of Giovanni Venturi (1746–1822), an Italian physicist who first tested conical expansions and contractions. The original, or classical, venturi was invented by a U.S. engineer, Clemens Herschel, in 1898. It consisted of a 21° conical contraction, a straight throat of diameter d and length d, then a 7 to 15° conical expansion. The discharge coefficient is near unity, and the non-recoverable loss is very small. The modern venturi nozzle consists of an ISA 1932 nozzle entrance and a conical expansion of halfangle no greater than 15°. It is intended to be operated in a narrow Reynolds-number range of 1.5 × 105 to 2 × 106 Venturi meters consist of a short length of pipe shaped like a vena contract, or the portion with the least crosssectional area, which fits into a normal pipe-line. The obstruction caused to the flow of liquid at the throat of the venturi produces a local pressure drop in the region that is proportional to the rate of discharge. This phenomenon, using Bernoulli's equation, is used to calculate the rate of flow of the fluid flowing through the pipe. Nowadays, it is necessary to perform the calibration tests of the flow meters in order to find out the accuracy of the instrument. These can be done by calculating the discharge coefficient of the venture. Although experimental procedures offer a good result, they are often time consuming. Hence a more sophisticated method of testing the flow meter is through numerical methods. Due to a variety of commercial CFD codes being available in the market, it is possible to obtainmore accurate results which take less time. These results can then be compared with the initial experimental results to calibrate the instruments.

Venturi effect:

The Venturi effect is a jet effect; as with a funnel the velocity of the fluid increases as the cross sectional area decreases, with the static pressure correspondingly decreasing. According to the laws governing fluid dynamics, a fluid's velocity must increase as it passes through a constriction to satisfy the principle of continuity, while its pressure must decrease to satisfy the principle of conservation of mechanical energy. Thus any gain in kinetic energy a fluid may accrue due to its increased velocity through a constriction is negated by a drop in pressure.

Bernoulli's Principle:

The Venturi effect is a special case of Bernoulli's principle, in the case of fluid or air flow through a tube or pipe with a constriction in it. Bernoulli's principle can be derived from the principle of conservation of energy. This states that, in a steady flow, the sum of all forms of mechanical energy in a fluid along a streamline is the same at all points on that streamline. This requires that the sum of kinetic energy and potential energy remain constant. Thus an increase in the speed of the fluid occurs proportionately with an increase in both its dynamic pressure and kinetic energy, and a decrease in its static pressure and potential energy.



If the fluid is flowing out of a reservoir, the sum of all forms of energy is the same on all streamlines because in a reservoir the energy per unit volume (the sum of pressure and gravitational potential ρ g h) is the same everywhere.Bernoulli's principle can also be derived directly from Newton's 2nd law. 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.

Pressure+ kinematic energy/volume = constant

Main parts of Veturimeter:

The main parts of a venturimeter are:

A short converging part: It is that portion of the venturi where the fluid gets converges.

Throat: It is the portion that lies in between the converging and diverging part of the venturi. The cross section of the throat is much less than the cross section of the converging and diverging parts. As the fluid enters in the throat, its velocity increases and pressure decreases.

Diverging part: It is the portion of the venturimeter (venturi) where the fluid gets diverges.

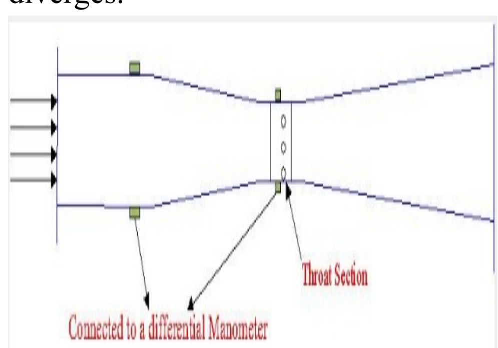


Figure: venturimeter

Construction of Venturi meter:

The following are the main parts and areas of venture meter:

- The entry of the venture is cylindrical in shape to match the size of the pipe through which fluid flows. This enables the venture to be fitted to the pipe.
- After the entry, there is a converging conical section with an included angle of 19' to 23'.
- Following the converging section, there is a cylindrical section with minimum area called as the throat.
- After the throat, there is a diverging conical section with an included angle of 5' to 15'. 5. Openings are provided at the entry and throat (at sections 1 and 2 in the diagram) of the venture meter for attaching a differential pressure sensor (u-tube manometer, differential pressure gauge, etc) as shown in diagram.

Limitations:

• They are large in size and hence where space is limited, they cannot be used.

• Expensive initial cost and installation maintenance.

• Require long laying length. That is, the veturimeter has ti be proceeded by a straight pipe which is free from fittings and misalignments to avoid turbulence in flow, for satisfactory operation. Therefore, straightening vanes are a must.

•Cannot be used in pipes below 7.5cm diameter.

2.0 Literature review:

P. HariVijay , V. Subrahmanyam (2014)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

Sapra, M.K., Bajaj, M., Kundu, S.N., Sharma,(2011). 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 soft ware 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. To conclude, this examination results indicate that FLUENT can be used with high degree of accuracy to visualize the various contours of velocity, pressure and turbulence can be understand clearly, the relationship between the mass flow rate and pressure drop for each flow meter is done and pressure recovery is better in the venturimeter

A Tukimin1, M Zuber2 and K A Ahmad(2016) Venturi tube plays a very important role in different fields of engineering. It has a number of industrial applications in which its design is an essential factor. Venturi tube used in gas measurement applications provides an accurate critical gas flow measurement. There is a need to design Venturi tube with an effective analytical tool or software. In this work, two parameters: pressure drop and velocity discharge nozzle were analyzed using Computational Fluid Dynamics In the investigation, the flow through Venturi tube was analysed with SKE turbulence model. The results from the numerical simulation had been used to obtain the Cd values for each of the tests. The analysis also indicated that pressure has more computational impact compared to velocity, and by understanding the correlation between pressure gradient and pressure, the convergent cone of the Venturi can be designed to operate within the velocity limit at Venturi throat.

Singh, Rajesh Kumar, Singh, S.N., Seshadri V. (2010). Flow meter or orifice meter are widely used in industry for flow measurement. A pressure loss takes place in the pipe line due to the restriction present in it. An amount of pressure loss occurs due to the thickness, shape and diameter of the plate. In the present paper, fluent software was used to plot the characteristics of the flow and gambit software was used to design the 2D model. Two phase computational fluid dynamics calculations, using k-Epsilon model were employed. The design of a flow meter with a provision to track vena contract using CFD technique has been explained. As per the application, selection of flow meters can be done and the behaviors of the flow pattern are plotted for four different models

3.0 Methodology:

The Venturi model is drawn using ANSYS Design Modeller. The model consists of the internal section of the Venturi tube. For analysis, 2D symmetry has been used for the numerical simulation. Pressure based solver and SIMPLE pressure-velocity coupling have been used as these are applicable for wide range of flow regimes and applicable for this analysis. It also requires less memory (storage) and allows flexibility in the solution procedure.

Experimental setup:

The high-pressure wet-gas test facility at NEL is based around an 200 mm nominal bore flow loop. A schematic diagram of the nominal facility arrangement for wet-gas tests is provided in Figure 1. Although nominally 200 mm diameter, the test section can accommodate line sizes ranging from 100 mm to 300 mm. The gas used for testing is oxygen-free nitrogen, supplied in 230 bar gauge cylinder banks. The facility typically operates at a nominal temperature of 20°Cover a nominal pressure range of 10 to 63 bar gauge, which corresponds to a gas density range of 12.76 to 74.54 kg/m3 ,the gas is driven around the flow loop by a 200 kW fully-encapsulated gas blower. In wet gas operation, the gas is drawn from the gas-liquid separator outlet by the blower and is then cooled using a chilled water supply flowing through shell and tube heat exchanger. The gas then passes through the reference gas flow meter and into the test line. The gas flow rate is controlled by varying the speed of the blower while the liquid flow rate is controlled by using two variable flow control valves located downstream of the liquid pumps. The maximum achievable dry gas volumetric flow rate is dependent on the size and type of reference or test flow meter installed.

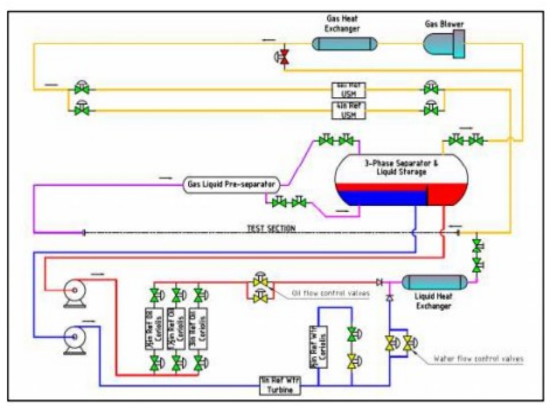


Figure: Flow velocity direction

Turbulence model: For the analysis, SKE turbulence model has been selected for the numerical simulation. The SKE model solves for two variables: turbulent kinetic energy, k and rate of dissipation of kinetic energy, epsilon. The wall functions are used in this model. The SKE model is selected because of its good convergence rate and relatively low memory requirements

Near wall: meshing As the differential pressure is measured from the pressure taps at the wall of the Venturi tube, near wall numerical simulation is important. Inflation has been used for the near wall meshing. Based on y+ equals to 1, the first layer thickness for the inflation setup is calculated for each of the test cases. The selected first layer thickness is 0.0011 mm as this is the smallest calculated first layer thickness from the test cases.

Convergence analysis: The numbers of elements ranges from 100,000 to 1,350,000 are used in the numerical analysis. The convergence for both cases has shown a decrease in residuals by two orders of magnitude for epsilon and continuity which indicates good qualitative convergence. The number of elements of 650,000 has been selected for the economics of computation

Design of flowmeters:

Efficient handling, utilization and disposal of fluids in engineering processes require knowledge of quantities of fluids flowing. Indirectly, this information can be obtained by stoichiometric calculations. However, precise and accurate measurements of flow quantities become essential to efficient operation. Most of the flow measuring devices for engineering purposes can be designed by using mechanical energy balance for the device.

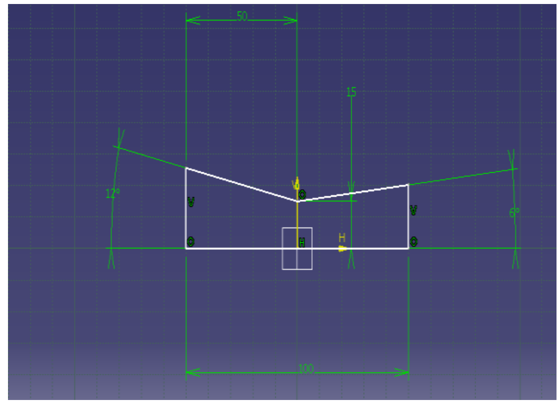


Figure: Flow meter geometric view

Operation of venturi meter:

The fluid whose flow rate is to be measured enters the entry section of the venturi meter with a pressure P1.As the fluid from the entry section of venturi meter flows into the converging section, its pressure keeps on reducing and attains a minimum value P2 when it enters the throat. That is, in the throat, the fluid pressure P2 will be minimum the differential pressure sensor attached between the entry and throat section of the venturi meter records the pressure difference(P1-P2) which becomes an indication of the flow rate of the fluid through the pipe when calibrated the diverging section has been provided to enable the fluid to regain its pressure and hence its kinetic energy. Lesser the angle of the diverging section, greater is the recovery.

Results and discussion:

Pressure contours are to plot pressure distribution across the Venturi tube. Flow direction for all the plots in Figure is from left to right. The results clearly show the effect of mass flow rate of gas on the pressure gradient as obtained for various test cases. The pressure values at the upstream of the Venturi and at the center point of the throat cylinder are recorded to determine the differential pressure across the Venturi tube, which are then used in the flow calculation

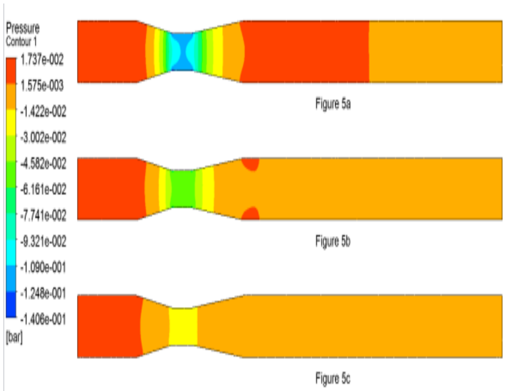


Figure: Pressure contours for all three tests

Velocity contour charts:

It is clear from that the velocity is at maximum at the throat of the Venturi. The velocity also decreases according to the decrease in flow rates. Flow direction for all plots in is from left to right. Velocity values recorded from the contours below are used to calculate the volumetric flow rates.

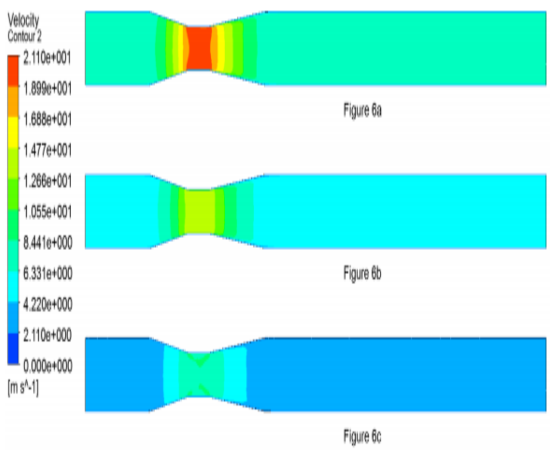


Fig: Velocity contours for all three tests

The pressure, temperature, density and expansibility are almost constant, it is interesting to note that decrease in flow rates resulting in the increase of calculated Cd values. It may suggest that, with additional test points at much lower flow rates may bring the Cd value closer to the result obtained by experimentalthough mass flow rate is directly proportional to Cd, the increase in mass flow rate does not register any increase in Cd. This indicates that the Dp1 has a significant effect on the Cd calculation.

Table: Mass flowrate versus discharge coefficient

pressure	Mass Flow Rate(kg/hr)	Discharge Coefficient c_d
60.37	86,030	0.97551
60.36	62,057	0.98850
60.30	36,855	0.98902

Analysis on pressure gradient increment against the mass flow rate increment indicates that for every 1% increase in mass flow rate, it will register 2.5 times percentage increase in pressure gradient. The analysis also indicates that for every 1% increase in mass flow rate, it will register 1% increase in velocity gradient

Table: Pressure and velocity gradients

pressure	Mass Flow Rate (kg/hr)	Pressure Gradient	Velocity Gradient
60.37	86,030	-0.26	56.51
60.36	62,057	-0.13	40.77
60.30	36,855	-0.5	24.23

Increase in pressure will exponentially increase the pressure gradient. This means for every bar increase in pressure, pressure gradient will exponentially become steeper and this in return will increase flow velocity at the Venturi throat. By understanding the correlation between pressure gradient and pressure, the convergent cone of the Venturi can be designed to operate within the velocity limit at Venturi throat. In Table 6, the recorded PPL follows similar trend as compared to the Dp1. The PPL obtained is approximately 11% of Dp1 for each of the tests for 7.5° divergent angle

Conclusion:

In the investigation, the flow through Venturi tube was analyzed with SKE turbulence model. The results from the numerical simulation had been used to obtain the Cd values for each of the tests. TheCd values obtained from simulation for test 1, test 2 and test 3 were 0.97551, 0.98850 and 0.98902, respectively, which averaged to 0.984347. Test 1 resulted in the lowest Cd value whereas Test 3 provided the maximum Cd value. The error between the experimental and numerical results of 0.937% indicates the SKE turbulence model agreed with the experimental data. The analysis also indicated that pressure has more computational impact compared to velocity, and by understanding the correlation between pressure gradient and pressure, the convergent cone of the Venturi can be designed to operate within the velocity limit at Venturi throat.To conclude, this examination results indicate that FLUENT can be used with high degree of accuracy to visualize the various contours of velocity, pressure and turbulence can be understand clearly, the relationship between the mass flow rate and pressure drop for each flow meter is done and pressure recovery is better in the venturimeter.

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