International Journal of Engineering Research
Volume No.4, Issue No.5, pp : 240-243

ISSN:2319-6890)(online),2347-5013(print)
01 May 2015

Characteristics of Flow Meters with Sediment Laden Flow – A Review

Abhishek Kala, Dr. S.K Mittal, Prof M.K.Choudhary
Department of Civil Engineering, MANIT Bhopal
abhishekkalacivil@rediffmail.com

Abstract: ***Measurement of flow is an important aspect in the field of hydraulic engineering, both in case of open channel as well as pipe or conduits. 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.

Keywords: Venturimeter, Orifice meter, Sediment laden flow, Coefficient of discharge

1. INTRODUCTION

1.1 Flow measurement simply means quantification of the moving fluid, which may be either liquid, gas or a mixture of liquid solid or liquid gas. Measurement of flow plays a vital role in various field of civil engineering mainly in irrigation engineering and hydraulic engineering. While transporting fluid over a distance through pipe, it is essential to measure the flow inside for accurate distribution for its proper use among the users. Various techniques have been used till now for flow measurement in conduits.

A flow meter is a device used to measure the flow rate or quantity of a gas or liquid flowing inside a pipe. Most commonly used flow meters are orifices, venturimeter, nozzles, rotameters, pitot tubes etc. All flow meters can be broadly classified into following categories;

- Differential Pressure Flow meters
- Velocity Flow meters
- Positive Displacement Flow meters
- Mass Flow meters
- Open Channel Flow meter

In differential pressure flow meters, flow is measured by measuring the pressure drop in the flow. They are mainly based on Bernoulli's principle, which states that rise (fall) in pressure in a flowing fluid must always be accompanied by a decrease (increase) in the speed, and vice versa. Mathematically Bernoulli's equation can be represented as "$P/\gamma + V^2/2g + Z =$ Constant"; where P/Υ is pressure head, $V^2/2g$ is velocity head and Z is datum head. The most commonly used differential pressure flow meters are orifice meter, venturimeter, flow nozzles and rotameters.

1.3 Venturimeter - A venturimeter mainly consist of a short pipe which has two conical parts joined by a short uniform cross section in between known as "Throat". The two conical portions have the same diameter but one having larger length and smaller cone angle and other having the opposite as shown. The conical parts are called as Convergent and Divergent part. The venturimeter is always used in such a way that the upstream flow takes place through short conical portion and the downstream through the larger one. If h is the piezometric head difference between inlet and throat of diameter d_1 and d_2 respectively, the discharge through the venturimeter is give as following.

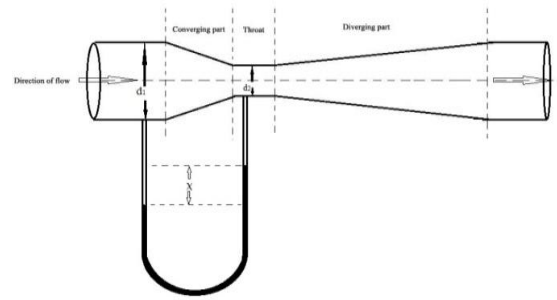

Fig 1 – Plan View of Venturimeter

$\mathbf{Q = (C_d \times A_1\ A_2 / \sqrt{A_1^2 - A_2^2}) \times \sqrt{2gh}}$, where C_d is known as discharge coefficient which is the ratio of actual discharge and theoretical discharge. Value of C_d depends upon the Reylond's number. For venturimeter C_d generally lies in between 0.95 to 0.98.

1.4 Orifice Meter – An orifice meter is one of the oldest and cheaper flow measuring device for pipes which is just a thin circular edge with a sharp edged concentric hole in it as shown below. The area of orifice is much smaller than the area of pipe. Diameter of orifice is generally 0.4 to 0.8 times of the pipe diameter. So the flow approaching the orifice gets accelerated and flow area is decreased by forming a vena contracta within some distance of pipe diameter. Theoretical analysis of flow through orifice meter is based on continuity equation and energy equation.

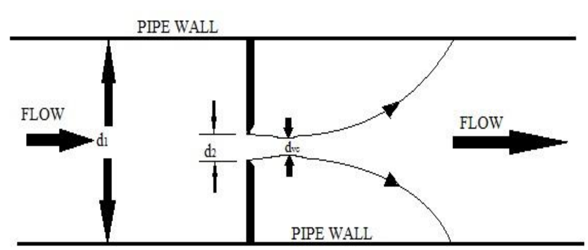

Fig 2 – Plan View of Orifice meter

 ISSN:2319-6890)(online),2347-5013(print)
01 May 2015

The basic equation for calculating discharge by using orifice meter is given by

$\mathbf{Q = (C_d \times A_1\ A_2 / \sqrt{A_1^2 - A_2^2}) \times \sqrt{2gh}}$, where C_d is known as discharge coefficient which is the ratio of actual discharge and theoretical discharge. Value of C_d for orifice meter is much less than venturimeter. Mainly two types of orifice meter such as eccentric and segmental is used for sediment laden liquid flow or liquid carrying foreign matter. For accurate measurement of discharge, proper calibration of orifice meter is required.

1.5 Sediment Laden flow or Flow of Slurries –

In most of the practical cases, mainly in industries it is required to carry mixture of liquid solid, liquid gas or liquid carrying different concentration of sediments over a long distance. Sediment laden flows generally create several problems because diluteness of solids in the liquid violets the continuums approach in the liquid - liquid flow analysis of conduits. Also the performance of pumps is affected by sediment laden flow. In these cases, for proper measurement of discharge, venturimeter or orifice meter has to be used with sudden modification. Till now a number of works has been carried out to study the behavior of different flow meters under sediment laden flow. Since orifice meter and venturimeter are most commonly used instruments, they need special attention. Variation of coefficient of discharge and other parameters with different types of sediment concentration has been analyzed by various experimental studies.

2. LITERATURE REVIEW

This part of the paper represents some of the past research works that has been carried out in this field for better understanding of the behaviour of orifice meter and venturimeter with sediment laden flow. Various experimental works including the methods, assumptions, working procedure and test results are described in this section.

Brook (1962) [3] was probably the first investigator to analyze the effect of solid liquid mixture in venturi and other meters. He carried out experiment in a non-standard type of venturi meter with a wide throat. He used the mixture of water and crushed Bakelite or water and basalt chippings. Results obtained from this were compared with a 90^0 bend s flow meter. A vertical counter flow meter was also been described which measures both concentration and velocity of the solid liquid mixture.

Graf (1967) [5] carried out an experiment on venturi meter to modify it for two phase flow. He used sand water mixture for the experiment by putting the venturimeter in horizontal position. He analyzed the data by plotting pressure drop against flow rate and a modified loss was correlated with sediment concentration. A theoretical model was developed to describe the results.

Robinson et al (1970) [12] carried out experiment to investigate the application of the venturimeter in the flow with solid concentration. Two different venturi meters of diameter 3inch and 4inch were tested for observing pressure drop an energy loss. Solids used were sand mixture of size d_{50} of 0.45mm, .80mm, 1.17mm and 1.70mm. Pressure drop was correlated with mixture discharge and velocity at the throat of venturimeter. An average value of discharge coefficient was determined for each condition and compared with clear water. The relative energy loss due to solid concentration was related with solid concentration and nomograms were prepared. He put forward some generalized expressions as below.

$A_m = C_m Q_m^2$ where Q_m is the flow rate and a_m is the pressure drop of mixture. The solid concentration (C) was related to relative energy loss of solids by the equation, $(b-b_0)/b_0 = kC^n$, where k and n were determined from experiment. The above two equations have to be solved simultaneously to determine the unknowns Q_m and C. For faster calculation, they had given certain nomograms.

Shook and Masliyah (1971) [14] analyzed the various factors affecting the flow of slurries through venturimeter both theoretically and experimentally. Discharge coefficients were found to be greater than unity in absence of wall friction coefficients. Experiments were carried out to analyze the theoretical result and to examine the combined effects of wall friction coefficients and finite slip velocity phenomenon. Experimental result agreed to theoretical values at extreme case and for venturimeter also it was found that wall friction increased with increase in particle size and density.

Herringe (1977) [8] studied the behavior of pressure difference devices for measuring slurry concentration and flow rates. He used variety of medium sized sand particles with size varying from 150 to 740 μm, ilmenite slurry with a median particle size of 170μm and a few tests on 17μm sand slurry. Solids concentration was determined by pressure measurements in vertically upwards and downwards sections of the flow, and flow rates measured by a venturi meter located alternately in horizontal, vertically upwards and vertically downwards flows. He analyzed venturi performance in terms of discharge coefficient and concentration values were compared with those obtained from weight tank samples. It was found that for fine slurries only water calibrations or calibrations from Standards were required while for coarser slurries, discharge coefficient was dependent upon solid concentration and Reylond’s number. These values were found to be smaller than the clear water values. He concluded that combination of a vertical loop section of flow (for concentration or specific weight measurements) and a venturi meter (for flow rates) provides a simple and accurate means of measuring slurry flows.

Hasan et al (1982) [7] carried out an experimental study to analyze the effectiveness of venturimeter as a flow measuring device for slurries. A two inch black iron pipe line containing lignite concentration varying from (0-40) % and flow velocity ranged from (2.4 to 6) ft/sec was used. The pressure drop was measured across three venturi of throat diameter 0.75,1 and 1.5inch. They concluded that for measurement of slurries density must be used in the flow equation of venturimeter. For slurry flow, the Reynolds Number was defined in terms of pipe diameter, slurry velocity (assuming homogeneous flow), and slurry density and carrier medium (water) viscosity as given below.

$(N_{RE})_m = (D_p V_m \rho_m) / \mu_W$.

Reynolds Number, slurry concentration, or throat diameter was the same for single-phase fluids and slurries. Data at lower Reynolds Number was difficult to take since critical velocity was soon reached causing the slurry to settle. For greater accuracy, the venturimeter should be calibrated, because the coefficient of discharge was found to be a weak function of Reylond's number and found to be increased with increase in solid concentration.

Values of discharge coefficients obtained at various flow rates and concentrations for the three meters were plotted using above equation. From those plots, the discharge coefficient at high Reynolds Number (>60,000) for all slurry concentrations and venturies was about the same as that for single phase flow. Thus, at high Reynolds Number, the discharge coefficient was independent of Reynolds Number, slurry concentration, or throat diameter and is the same for single-phase fluids and slurries. Data at lower Reynolds Number is difficult to take since critical velocity is soon reached causing the slurry to begin to settle

Shook (1982) [13] carried out experiment on stratified slurries flowing through horizontal venturi meters. It was found that for stratified slurries, the discharge coefficient was higher than that of homogeneous fluids. This effect was found to be increased by increasing slurry concentration and decreased by increasing the velocity of flow. The analysis of the flow was carried out by applying two layer model of Wilson which includes mass and momentum balance of both layers. This analysis was qualitatively useful but due to lack of knowledge about the lifting force of fluid, it couldn't give quantitative prediction.

Kapoor et al (1986) [10] carried out an experimental study of orifice meter in sediment laden flows. The experiment was conducted by using concentric circular orifice meter having four different diameter ratios. Sediments used were uniform sized fine sand and coal. All runs were conducted either in homogenous or heterogeneous flow regime. In the first phase, experiments were conducted with clear water at different Reylond's number. In the second phase, experiment was carried with sediment laden flow by varying its concentration from 0.5% to 7% by volume. The results obtained were analyzed graphically and it was found that discharge coefficient of orifice meter for sediment laden flow was less than that for clear water.

Tiwari (1992) [15] conducted an experiment for segmental orifice plates, which area ratio was varying from 0.143 to 0.625. The experiment was done first with clear water and then solid-water mixture at different concentrations. His results showed that the value of C_d increases with increase in Reynolds number and after certain value of Re, the coefficient of discharge depends on area ratio only. The limiting value of C_d increases with increases with increase in area ratio. Also, the limiting value of C_d decreases with increase in concentration of solids. He derived the equation as, $C_d = 0.525 + 0.35(a/A)^{1.1} - 0.04(C_w)^{0.7}$, where C_w is the percentage concentration of solids by weight.

Gahlot et al (1994) [4] investigated the characteristics of a conventional venturimeter and an eccentric 90^0 sector orifice plate used for measuring flow rate in a pipe carrying slurry. The venturimeter used in the experiment had nominal pipe bore of 100mm and diameter ratio 0.6. The pressure taps of the venturimeter were provided with special separation chambers to avoid clogging due to solid particles. Five different orifice plates were used with area ratio varying from 0.2 to 0.6. For preparation of slurry, coal sample from a steel plant ad tailing materials from a zinc processing plant were mixed with clear water by varying concentration from 0 to 57% by weight. The discharge coefficient for orifice plat and venturimeter were calculated for different flow condition and represented graphically. They analyzed variation of discharge coefficient (C_d) of venturimeter with average velocity of flow and specific gravity of mixture and variation of C_d of orifice plate with area ratio and solid concentrations. They concluded that C_d of venturimeter was not so much affected by solid concentration, except for high concentration slurries. For orifice plate, C_d value was found to be increase with increase in area ratio but decreased with increase in solid concentration.

Azzopardi et al (1998) [1] derived a quasi one dimensional model for gas or solid flows in venturimeter. They proposed that the pressure drop in the throat of venturi and recovery of pressure across the diffuser were the two unknowns to be solved. The model developed allowed acceleration and deceleration of gas and solid particles and also the change in thickness of boundary layer. The model was validated with previously published experimental data and found to be well agreed.

Bharani et al (1999) [2] carried out an experimental study of a modified venturimeter which was expected to suppress the erosion rate which was caused by the movement of solid particles in solid-liquid mixture flow in venturimeter. To analyze the performance characteristics of an eccentric venturimeter with elongated throat for solid-liquid flows. A conventional venturimeter having 68mm ND and a diameter ratio of 0.54 was modified at the throat to get an elliptical shape. The resulting area ratio was 0.327 and equivalent diameter ratio was 0.572. Solid material obtained from copper processing was used with water. For different solid concentration and flow condition, discharge coefficient was calculated. It was concluded that discharge coefficient of modified venturimeter was little less than conventional venturimeter. Discharge coefficient was found to be increased up to solid concentration of 15% and thereafter remains constant. The flow pattern inside the modified one was found to be heterogeneous at moderate flow velocities and efflux concentration.

Miller et al (2009) [11] carried out an experimental study to analyze the effect of emulsion mixture flow through venturimeter. They had derived the following equation to calculate the coefficient of discharge for Reylond's number 400 to 24000.

C_d = B+A* log (R_e). The error involved in the equation was nearly 2% to 4% for R_e>= 2000 while the uncertainty rose to 6% for R_e between 400 and 2000.

Hollingshead et al (2011) [9] analyzed the discharge coefficient performance of venturi, standard orifice meter, V cone and wedge flow meters at low Reylond's number under both laminar and turbulent flow condition. They found out the solutions to the steady Reylond's average Navier stokes equation by using CFD (Computational fluid dynamics) to relate Reylond's number and discharge coefficient. The theoretical results were validated with experimentally obtained data. They concluded that at low Reylond's number, coefficient of discharge decrease rapidly by decreasing the Reylond's number for venturi, V cone and wedge flow meter. But for orifice meter, discharge coefficient was found to be increased with decrease in Reylond's number till a maximum value was reached. He presented the result in graphical form between Reylond's number and discharge coefficients on semi log graph. He concluded that for moderate to high Reylond's number all the flow meters generally show sane discharge coefficient. But at low Reylond's number, certain modification is required in flow measurement. For possible discharge coefficient of nearly 0.2 for all flow meters, to reduce error in flow measurement an iterative process should be followed.

3. CONCLUSIONS

Estimation of flow or discharge in pipe lines is very important for its design and to charge accurate value for the amount of fluid flowing. In practical fields like industries, oil carrying pipe lines, sewage or effluent discharge from factories; water flows along with some sediments or slurries in pipe lines. Venturimeter and orifice meter are most commonly used flow metering devices in pipe flow from very old days due to simplicity in uses and accuracy. Applicability of these flow meters for measuring sediment laden flow or slurry flow has been investigated by various researchers till now as described in the above section. A number of experimental and also analytical studies have been carried out in this field. Still there is a scope to analyze the variation of discharge characteristics of venturimeter of different sizes with sediment laden flow.

References

i. *Azzopardi, B.J., Teixeira S.F.C.F., Pulford, C.I., "A QUASI-ONE-DIMENSIONAL MODEL FOR GAS OR SOLIDS FLOW IN VENTURI" Powder Technology 102:281–288, 1998.*

ii. *Bharani, S., Mishra, R., Singh, S.N., and Seshadri, V., "PERFORMANCE CHARACTERISTICS OF AN ECCENTRIC VENTURIMETER WITH ELONGATED THROAT FOR MEASUREMENT OF SOLID-LIQUID FLOWS" , Indian Journal of Engineering & Materials Sciences Vol. 6,June 1999, 119-124.*

iii. *Brook, N., "FLOW MEASUREMENT OF SOLID-LIQUID MIXTURES USING VENTURI AND OTHER METERS" Proceedings of the Institution of Mechanical Engineers June 1962 176: 127-140.*

iv. *Gahlot, V.K., Sharma, K.K., Seshadri, V., "CHARACTERISTICS OF VENTURIMETER AND SECTOR ORIFICE PLATES IN THE FLOW OF SOLID-LIQUID MIXTURES", 4th Triennial International Symposium of Fluid Control, Measurement and Visualization, Toulouse, France, 1994.*

v. *Graf, W.H., "A MODIFIED VENTURIMETER FOR MEASURING TWO-PHASE FLOW" or "PARTICLE DYNAMICS AND THE VENTURIMETER", Journal of Hydraulic Research 01/1967; 5(3):161-187.*

vi. *Jain, A.K. (2012) "Fluid Mechanics including Hydraulic Machines", Khanna Publisher, Eleventh Edition.*

vii. *Hasan, R., Baria, D.N., Chowdhury, N.M., "LIGNITE-WATER SLURRY FLOW MEASUREMENT USING A VENTURIMETER", The proceedings of the 1981 symposium on instrumentation and control for fossil-energy processes 1981, 458-464.*

viii. *Herringe, R.A., "SLURRY FLOW METERING BY PRESSURE DIFFERENTIAL DEVICES", International Journal of Multiphase Flow 03/1977; 3(3):285-298.*

ix. *Hollingshed,C.L., Johnson, M.C., Barfuss, S.L., Spall, R.E., "DISCHARGE COFFICIENT PERFORMANCE OF VENTURI, STANDARD CONCENTRIC ORIFICE PLATE, V-CONE AND WEDGE FLOW METERS AT LOW REYNOLDS NUMBERS", Journal of Petroleum Science and Engineering 78(2011) 559-566.*

x. *Kapoor, B.S., Grade, R.J., Ranga Raju, K.G., "DISCHARGE CHARACTERISTICS OF ORIFICE METERS IN SEDIMENT-LADEN FLOWS", The Canadian Journal of Chemical Engineering 03/2009; 64(1):36 - 41.*

xi. *Miller, G., Pinguet, B., Theuveny, B., Mosknes, P., 2009. The influence of liquid viscosity on multiphase flow meters, TUV NEL, Glasgow, United Kingdom.*

xii. *Robinson, M., Yucel, O., Graf, W.H., "MODIFIED VENTURIMETER; A MEASURING DEVICE FOR SOLID-LIQUID MIXTURES" Fritz Laboratory Reports.*

xiii. *Shook, C.A., "FLOW OF STRATIFIED SLURRIES THROUGH HORIZONTAL VENTURI METER", The Canadian Journal Of Chemical Engineering, Volume 60, June 1982, 0008-4034/82/03-0342.*

xiv. *Shook,C.A., Malshiya, J.H., "FLOW OF A SLURRY THROUGH A VENTURI METER", The Canadian Journoul Of Chemical Engineering, Volume 52, Issue 2, pages 228–233, April1974.*

xv. *Tiwari, H.L., "CHARACTERISTICS OF FLOW THROUGH SEGMENTAL ORIFICE PLATES FOR SEDIMENT LADEN WATER", M.Tech Thesis, Department of Civil Engineering, MANIT, Bhopal, 1992*