Flow Diagnostics

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1. Introduction

Multiphase flows operations are integral to various process applications for example in mining industry, Oil and Gas industry as well as metallurgical industry etc. In multiphase flow operations it is important to control various flow characteristics such as volume fraction of different phases, phase velocities along with several local and global flow parameters. The multiphase pipelines can handle fluids flowing in more than one phase and it is not uncommon to have pipelines handling more than two phases. Most commonly used multiphase pipelines handle solid-liquid and liquid-gas flows. Conventional single phase velocity measurement techniques do not work well for multiphase flow applications because of presence of secondary phase. For example use of Pitot tube in solid-liquid flows may result in clogging of pressure sensing holes.

Use of electrical / electronics based sensors systems may have numerous operational problems including electrode erosion. Mishra et al[1] developed an impact probe for measurement of solid liquid flow successfully over a wide range of flow conditions. However this probes calibration has been carried out over a limited range of operational velocities. In the present work extensive CFD based optimisation has been carried out to develop an optimised sensor shape for better operation. Although electrical / electronics sensors systems have been used extensively for oil and gas applications, the accuracy of such systems is still under continuous improvement. In the present investigation a CFD/FEA analysis has been carried out to establish accuracy levels of such systems.

2. Impact probe for solid-liquid flow measurement:

Liquid flow characteristics with a pipe a pipe are reasonably well understood. Presence of solid phase makes the flow field extremely complex and these flow characteristic vary widely with changing solid loading and mixture flow velocity. At higher mixture flow velocities the solid particles would be in suspension and the solid distribution would be fairly uniform and velocity profile would be axi-symmetric. At lower flow velocities the solid distribution will be non-uniform with higher solid concentration at the bottom of the pipe and low solid concetration at the top of the pipe. Furthermore mixture velocity profile will be non-axi-symmetric with low flow velocities at the bottom of the pipe. It is evident from the above discussion that solid concentration profiles and mixture velocity profiles are interdependent and hence both need to be measured simultaneously to resolve the flow field completely.

The presence of solid phase in the mixture eliminated use of active pressure probe systems for such application and keeping this in view a hybrid system was developed [1]. The system consisted of an iso-kinetic sampler to measure solid distribution and an impact probe with passive measure system for mixture velocity distribution. Figure 1 shows the isokinetic sampler that has been used [1] in the present investigation. The dimensions of this sampler has been finalised after extensive trial and error and it has further been shown [1] that this sampler allows the mixture to flow through it iso-kinetically. Figure 2 shows the solid concentration profile measured in a 100 mm pipeline at 20% efflux concentration of solid and at the two flow velocities of 1.67 m/s and 2.95 m/s for the flow of Zinc slurry.

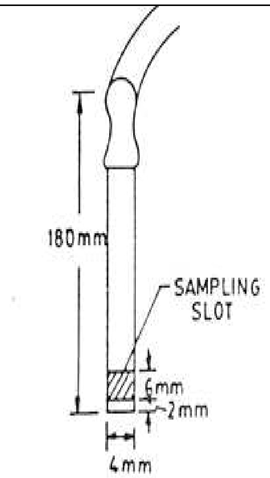

Figure 1: Isokinetic sampler for solid concentration measurement within a pipeline

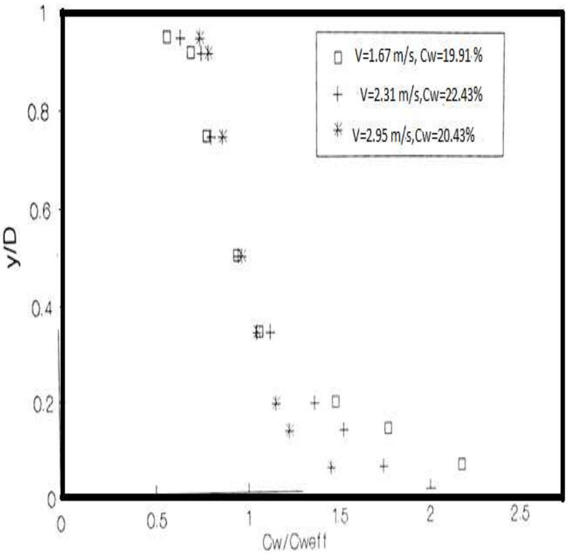

Figure 2: variation of solid distribution across a pipeline at an efflux concentration of nearly 20% at different flow velocities

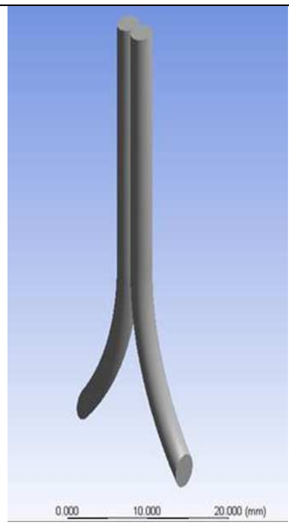

Figure 3: An impact probe for mixture velocity measurement within a pipeline

The flow clearly indicates that as the flow velocity increases the solid distribution pattern becomes more uniform. For the development of mixture velocity measurement the constraints that were kept in view included, a) Solid particles should not affect pressure sensors, b) The developed system should be accurate, efficient and effective and 3) It should be easy to make and easily maintainable.

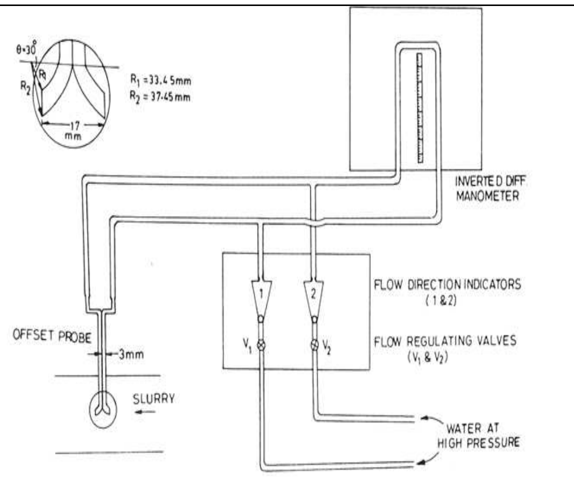

Figure 4: Schematic diagram of velocity measurement system

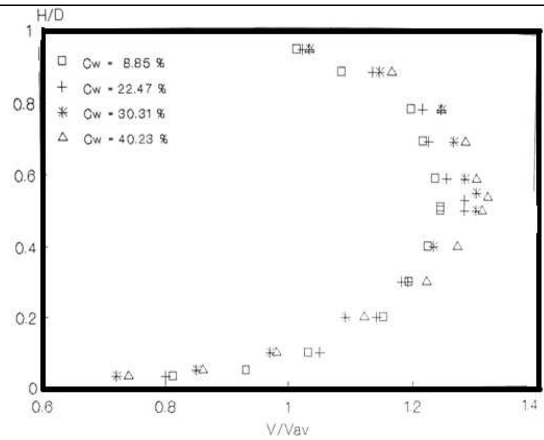

Figure 5 : Velocity distribution in a pipeline transporting solid at flow velocity of 2.31m/s at various solid concentrations.

Keeping the above in view a system as shown in figures 3 and 4 is developed. The system consists of supplying high pressure water through an impact probe as shown in figure 3 discharging into the slurry pipeline with same pressure acting on two ends. This pressure is then counteracted by the flowing fluid in the pipeline and the resulting difference in pressure is then measured to provide local mixture flow velocity. The system was calibrated for water flow by placing it against a pitot tube and the calibration coefficient was obtained to be 0.86. This calibration constant was then used to obtain mixture flow velocity for various flow conditions. Figure 5 shows the velocity profile obtained for the flow of solid-liquid mixtures. It can be seen that as the solid concentration increases the flow asymmetry keeps on increasing at low concentration after which it starts decreasing. To improve the response characteristics of the sensing probe further investigations have been carried out using computational fluid dynamics on obtaining best sensing dimensions of the impact probe's head. For this three configurations were selected. All the sensing areas had elliptical shape with different major and minor axes values. The three cases analysed have the vertical axis values 'a' as 4mm, 4mm, 2mm and horizontal axis values 'b' 3 mm, 5mm and 3mm respectively.

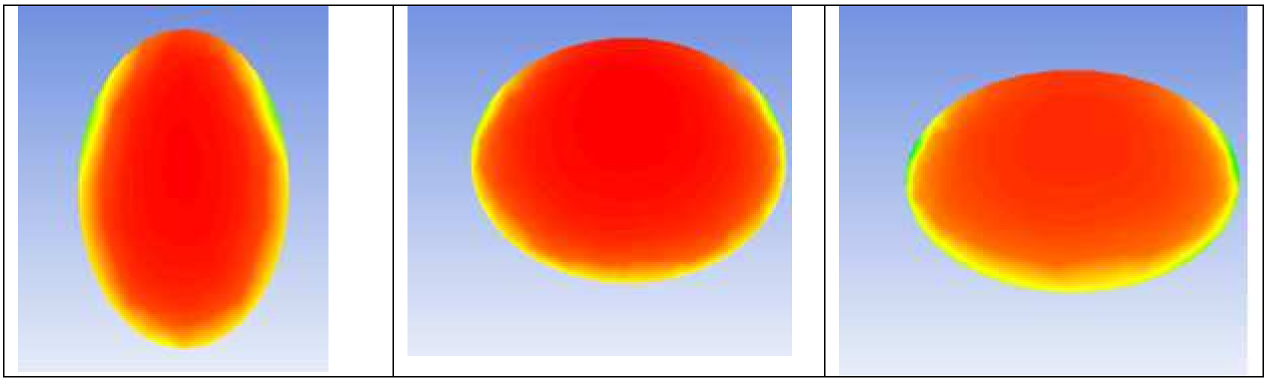

Figure 6: Optimisation of sensing tip, a) Pressure contour for b/a =0.75, pressured drop = 3095 Pa, b) pressure contour for b/a= 1.25, pressured drop=3494 Pa c) pressure contour for b/a= 1.5 pressured drop=3356 Pa

It can be seen form the figure 6 that the probe with sensing head dimensions with b/a=1.25 is the best shape for the velocity measurement as for the same velocity it gives the maximum pressured drop. Figures 6 (a) to (c) show the pressure contours on the sensors corresponding to different dimensions.

3. Four sensor probe for oil and gas measurement:

Mishra et al [2] introduced a novel measurement technique for measuring the local axial, radial and azimuthal velocity components of the gas in bubbly gas-liquid flows using a local four-sensor conductance. This technique included a mathematical model which was valid for bubbles that had a plane of symmetry normal to their direction of motion, including spherical and oblate spheroidal bubbles. The novel mathematical technique represented in three independent equations in terms of the bubbles' velocity magnitude v, the polar angle α of bubbles' velocity vector and the azimuthal angle β of the bubbles' velocity vector as shown in figure 7, which can be written in the form:

$$x_i \sin\alpha \sin\beta + y_i \sin\alpha \cos\beta + z_i \cos\alpha = \frac{v\delta t_{ii}}{2}$$

Where, x_i, y_i and z_i represent the coordinates of the i^{th} rear sensor (i = 1, 2, 3) in the probes' coordinate system of the four-sensor probe and the terms δt_{ii} (i = 1, 2, 3) are defined as:

$$\delta t_{ii} = \delta t_{ia} + \delta t_{ib} - \delta t_{ob}$$

With reference to figure 8, δt_{ia} is the time interval between the first contact of the bubble's surface with sensor 0, and the first contact of the bubble's surface with the i^{th} rear sensor; δt_{ib} is the time interval between the first contact of the bubble's surface with sensor 0, and the last contact of the bubble's surface with the i^{th} rear sensor; δt_{0b} is the time between the first and last contacts of the bubble's surface with sensor 0. By solving above equations simultaneously the following expressions for tan β and tan α are obtained.

$\tan\beta = \dfrac{\left(\frac{z_1}{\delta t_{11}}-\frac{z_2}{\delta t_{22}}\right)\left(\frac{y_1}{\delta t_{11}}-\frac{y_3}{\delta t_{33}}\right)-\left(\frac{z_1}{\delta t_{11}}-\frac{z_3}{\delta t_{33}}\right)\left(\frac{y_1}{\delta t_{11}}-\frac{y_2}{\delta t_{22}}\right)}{\left(\frac{z_1}{\delta t_{11}}-\frac{z_3}{\delta t_{33}}\right)\left(\frac{x_1}{\delta t_{11}}-\frac{x_2}{\delta t_{22}}\right)-\left(\frac{z_1}{\delta t_{11}}-\frac{z_2}{\delta t_{22}}\right)\left(\frac{x_1}{\delta t_{11}}-\frac{x_3}{\delta t_{33}}\right)}$	$\tan\alpha = \dfrac{\left(\frac{z_2}{\delta t_{22}}-\frac{z_1}{\delta t_{11}}\right)}{\left(\frac{x_1}{\delta t_{11}}-\frac{x_2}{\delta t_{22}}\right)\sin\beta+\left(\frac{y_1}{\delta t_{11}}-\frac{y_2}{\delta t_{22}}\right)\cos\beta}$

With known values of the angles, the velocity magnitude can now be easily calculated with initial equation.

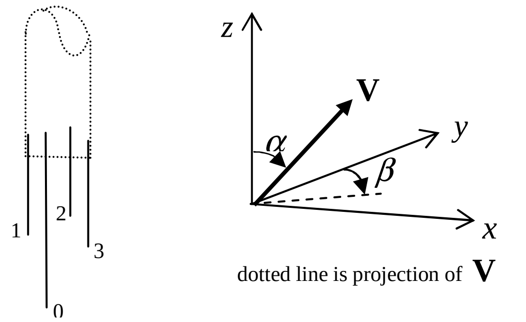

Figure 7. Probe coordinate system

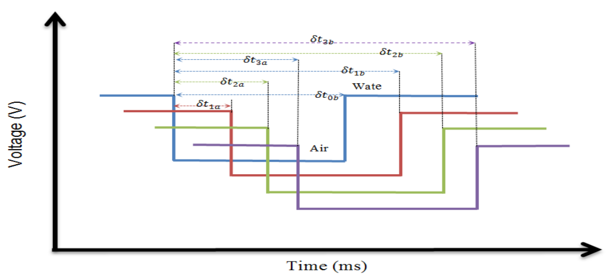

Figure 8. Ideal signals generated from the 4-sensor probe

The authors found that this technique was relatively insensitive to assumptions made regarding the exact times of contact of the sensors and the surface of the bubble. The authors also found that the presence of the four-sensor probe in the flow stream could cause the magnitude v of the bubble velocity vector to be reduced by about 20%. Since the intrusiveness and the finite size of the four-sensor probe and the difference between the assumed and real interfaces around the probe were inevitable, it is very important to reduce, evaluate, and correct the errors in the practical applications. In this work the main aim is to estimate and reduce the errors that may occur due to the relocations of the sensors tip, which is produced by the deflections of the probe body or the multi-sensors in multi-sensor conductivity probe because of flowing fluid. Furthermore, this research aims quantify these errors so that accurate estimates of volume fraction and flow velocities can be made. An integrated CFD-CFA simulation was attempted over a wide range of flow situations.

Three-dimensional computational domains of a vertical straight pipe of 80, 100 and 200mm internal diameter and 2000 mm length, have been created for simulations. Upward bubbly gas-liquid flows were modelled for low volume fractions of approximately 3.8% at three water superficial velocities of 0.76, 3 and 6m/s. Figures 9 and 10 depict the ability of the numerical simulation to reproduce the radial volume fraction and the gas velocity profile with good agreement to the experimental measurements. Numerical evaluations were carried out using a commercial finite element code, for effective depiction of the sensors' and probe body's displacement and to quantify the maximum displacement that each sensor would undergo.

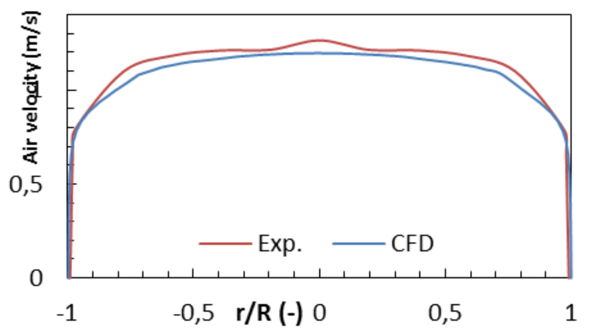

Figure9: Gas velocity comparison of CFD results with experimental data

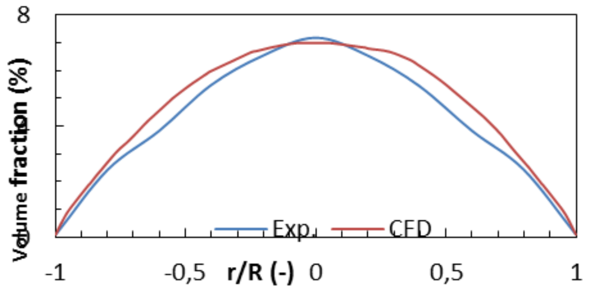

Figure 10: Volume fraction comparison of CFD results with experimental data

The static pressure has been predicted from the CFD simulations from two perpendicular planes at each sensor and the probe body dividing each surface into four 45˚ surfaces. Chrome stainless steel material has been selected to be the material for both the probe and the sensors.

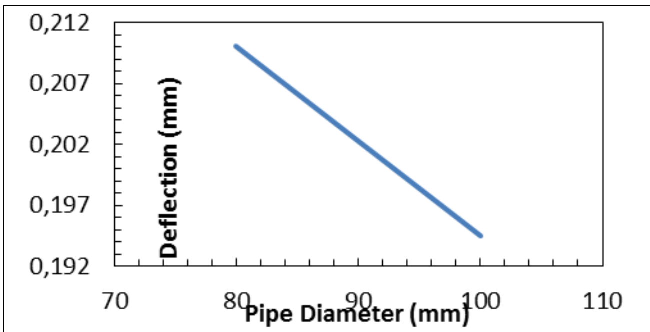

Figure 11. The effect of the change in pipe diameter on the sensor deflection

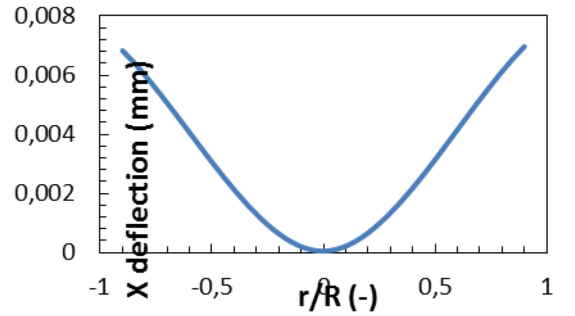

Figure 12. The effect of the change in radial location on the sensor deflection for low flow velocity

In this paper, three parameters have been taken into consideration namely, the effect of the pipe diameter, the effect of the probe radial distance and the effect of the mixture velocity on the sensor deflection. One of the important parameter that affects sensor deflection is the use of conductivity probe in different diameter pipes. From figure 11, it can be seen that by using conductivity probe in larger pipe diameters, with keeping the mixture velocity constant, the sensor deflection decreases.

The effect of the probe location within the pipe on the sensor and the probe body has been considered in this paper at three pipe locations of 10, 50 and 90% of each pipe diameter. From figure 12, it can be clearly observed that pipe walls have a significant effect on the sensor deflection in cases where the flow velocity is relatively low. Maximum deflection can be found when the probe is close to the pipe wall; whilst almost no deflection can be found at the pipe centreline. Figure 13 shows the probe deflection at high velocities. It can be seen that the deflection of probe depends on the length of exposure. Three mixture velocity values of 0.76, 1 and 6m/s have been considered in this study to quantify the effect of the mixture velocity variation on the sensor and probe deflections.

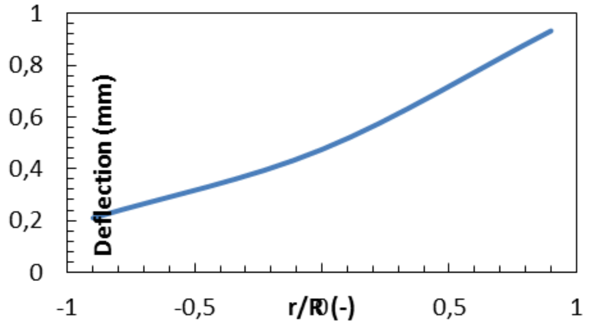

Figure 13. The effect of the change of probes radial location on the sensor deflection at high flow velocity

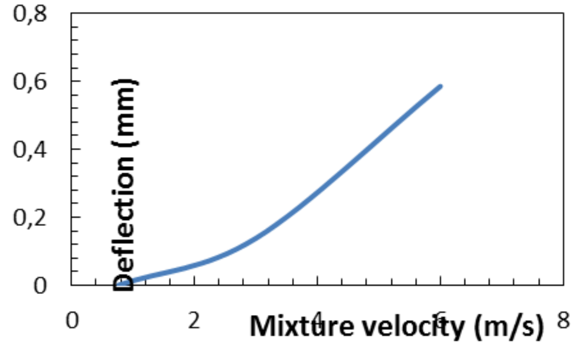

Figure 14. The effect of the change in the mixture velocity on the sensor deflection

Figure14 depicts the sensor deflection due to the increase in mixture velocity. It can be clearly observed that the increase in flow velocity increases the sensor deflection. This process occurs because of the increase in static pressure.

4. Conclusions

A combined analytical, numerical and experimental study has been attempted to measure the multiphase flow properties with increased accuracy and repeatability. For the solid-liquid flow it has been possible to develop a system that can measure the mixture flow velocity with reasonable accuracy. The CFD investigation has been able to suggest the best possible sensor shape for better results. For oil-gas pipelines it has been possible to demonstrate that in-accuracies in volume fraction and flow velocity measurement can be minimised by predicting sensor dislocation and including a correction for this in the measurement scheme.

References:

1. R. Mishra, S.N. Singh and V. Seshadri, Velocity measurement in solid–liquid flows using an impact probe, Flow Measurement and Instrumentation, Volume 8, Issues 3–4, Pages 157–165,1998.
2. R. Mishra, G.P. Lucas, and H. Kieckhoefer, A model for obtaining the velocity vectors of spherical droplets in multiphase flows from measurements using an orthogonal four-sensor probe, Measurement Science and Technology, Volume 13, Issue 9, p. 1488-1498. 2002.