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INSTALLATION OF ELECTRICAL PROBES FOR MEASURING THE VOLUMETRIC CONCENTRATION IN TWO PHASE PIPING FLOWS

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Abstract. *Electrical probes are a robust, simple and low cost solution to measure different parameters of the two-phase flows, mainly the volumetric concentration. In this work, aspects related to the installation of electrical probes were discussed, concerning the intrinsic complex fluid dynamics of two-phase flows and the sensing principle of such instruments. Different types of singularities can be present in industrial pipelines, as valves, elbows, tees, expansions, reductions disturbing the flow, and this situation can cause variations of the volumetric concentration along pipeline that is, therefore, a relative quantity of the flow,. Additionally, from the literature, it was discussed about the concept of fully-developed condition and the suitable local for installation of probes. Finally, the concept of "sensing volume" of an electrical probe was introduced, which was related to their sensing principle based on the interaction of electrical/electromagnetic soft fields with the components of flow distributed into this sensing volume. The main contributions of this work also highlights that the distance from singularities, the sensing characteristics of the probe and the monitoring goals are important aspects for installation of electrical probes for measuring the volumetric concentration in two-phase piping flows.*

Keywords: *Two-phase flow, Electrical Probe, Volumetric Concentration, Installation.*

1. INTRODUCTION

Pipelines are widely used in chemical, power, food and oil industries for transportation of flowing materials as liquids, gases, slurries or solid particulates (Silva Telles, 2001). Two immiscible materials flowing together in the same pipeline compose the two-phase flows, which are a complex occurrence acting directly on the efficiency of many industrial processes, mainly due to the occurrence of the so-called flow regimes or patterns, related to the spatial arrangement of the components along the pipeline (Chisholm, 1983).

The efficiency of industrial transportation processes depends on the monitoring and control of such two-phase flows. To make this feasible, many researcher around the world are involved on the development of dedicated actuators, instruments and control strategies (Félix and dos Reis, 2014). Such dedicated instruments can be based on different principles in search of the best method for measuring each different quantities of two-phase flows: microwave, magnetic resonance, ultrasound, magnetic and electric fields (electric probes), X-rays, gamma rays, among others (Powell, 2008). Among them, electrical probes have advantages since they are a robust, simple to operate, and low time response solution. In addition, they does not require license or special care as gamma or X-rays based sensors.

The volumetric fraction or concentration, in an arbitrary finite volume into a segment of the pipeline, is defined as the ratio of the volume occupied by one of the flow components by the total volume (Wallis, 1969). The volumetric concentration is the most important quantity for monitoring and control of two-phase flow (Ghajar and Tang, 2012), and it can be measured with electrical probes based, more specifically, on different operating principles: the impedance ones are based on the impedance (Z)(Opekar *et al*., 2013), the capacitive on the capacitance (C) (Falcone, 2009, dos Reis and Goldstein Jr, 2005), the resistive or conductive ones are based on the electric conductance (G) or resistance (R), and the electromagnetic or inductive on the inductance (L) (Wei and Soleimani, 2012). There are also those based on the Electrodynamic phenomena, call of electric charges or electrodynamic probes being used with gas-solid two-phase flows (Rahmat and Kamaruddin, 2009).

As shown in Fig. 1, electrical probes consist, essentially, of two parts: a sensing section connected to the process with sensors that "sense" the flow differently depending on their operating principle, as shown in the upper side of the figure, and an electronic transducer at bottom side that converts the electric signal from the sensors to some intermediate variable, which can also be converted to digital and treated by some computational algorithm to get some requested flow parameter. In order to become electrical probes suitable for industrial environments, the electronic transducer can be installed directly into the sensing section body.

The sensing section of an electric probe is composed of: (1) a pipe section of electrically non-conductive material; (2) a system of electrodes or coils called of sensor, which are, commonly, composed of two electrodes or coils being one of them for excitation and the other for sensing the electric or magnetic field crossing the flow, except the electrodynamic sensor that has only the sensing electrode, since the sensed electrical field is from the bulk of electrical charges on the solid particles, which are generated by friction into the gas-solid flow itself. The sensor can be mounted internally or externally to the pipe, being this last arrangement the most common for non-intrusive probes, since it is simpler and also avoids the effects from incrustations and corrosion on its performance; (3) the process connection system are important for connection to the pipeline of the sensing section, which must be removable for maintenance or calibration; (4) a sealing system allows the assembly of the metallic and non-metallic parts, avoiding leakage or contamination of the fluids, and it must be designed and selected according to the temperature, pressure and chemical properties of each flow component; (5) cables and connectors that perform the sensor-transducer transmission of signals; and the electromagnetic shield (6), being it important in order to prevent disturb the measurements due to transitory couplings with the external environment generated by internal electric or magnetic fields, or also external electromagnetic fields to disturb the sensor. It must be made of metal sheet and connected to ground potential as a Faraday's cage.

In Fig. 1, the pipe section is regarded to be of electrically non-conductive material (1) due to two facts: (i) such materials allow electric field to cross them and does not sink it to ground potential around the sensing volume, which is requested for probes based on electric fields; (ii) due the low magnetic permeability of non-metallic typical flow components, such materials does not cause concentration of magnetic field lines into the pipe's wall. Both are important for increasing the sensitivity of electrical probes based on electric or magnetic fields.

Another important aspect in Fig. 1 is the internal "sensing volume" into the sensing section. In this work, it is defined as region, into the pipe, which contain the whole mass of fluid that affects the response of the electrical probe. Depending on the characteristics of the probe, installation, fluids and flow itself, such volume can extend from only the region between the electrodes or coils to several tens of diameters upstream and downstream due to the presence of axial electrical couplings with the pipeline itself or with the external environment.

Evidently, all elements shown in Fig. 1 must be taken into account when designing an electric probe, including the selection of the most suitable sensing principle and the sensor format, which should be based on the monitoring goals, the pattern or flow regime, and on the electrical properties of each component.

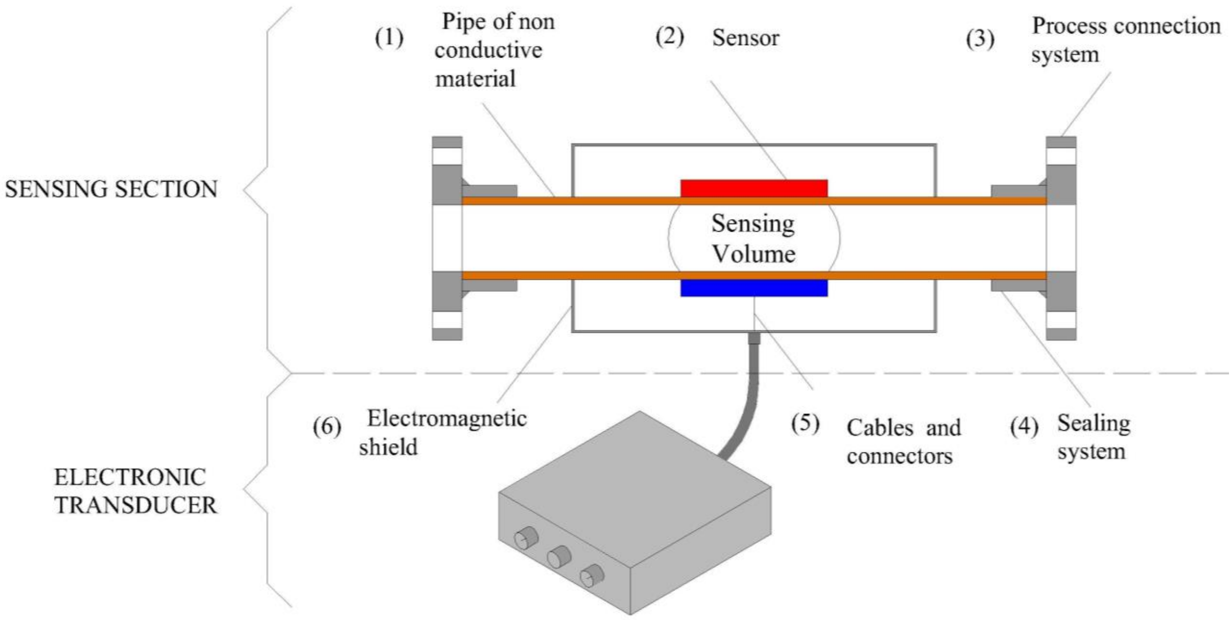

Figure 1. Installation diagram of an electric probe in industrial environments

The installation of a sensing section of an electrical probe for operation in industrial environment, in general, requests to cut off a section of the pipeline, being the most of them are made of carbon steel (Silva Telles, 2001) and it must be done in a location that comply with some requirements. One of them is related to the fluid dynamics, i.e., a condition of suitable flow that depends on the presence of singularities such as elbows, tees, reducers, expansion and valves (Yadav *et al*, 2014), both upstream or even downstream from the sensing section of a probe. The other one is related to the fact of the response of these probes be affected by the spatial distribution of the components itself (Andreussi, 1993, Ahmed, 2006, dos Reis and Cunha, 2013) within the sensing volume.

Regarding the previous information, in this paper we proposed to contribute to the general understanding of the installation aspects of electrical probes, intending to extend their application in industrial environments.

2. THE VOLUMETRIC CONCENTRATION AS A RELATIVE QUANTITY OF THE TWO-PHASE FLOW

Along the pipeline, the choice for the suitable site for installation of an electrical probe depends, firstly, on the analysis of the flow condition. The volumetric concentration of the component 2, in [m^3/m^3], can be determined using two quick-closing valves (QCV) as shown in Fig. 2. This system, at a time instant *t*, can isolate the flow volume given by *A.L* at the axial center coordinate z_o along a pipeline of cross section *A*. The component 2 should separate from 1 by gravity and its volume, V_2, can be measured at the same pressure *P* and temperature *T* in the flow (Wallis, 1969, p. 12).

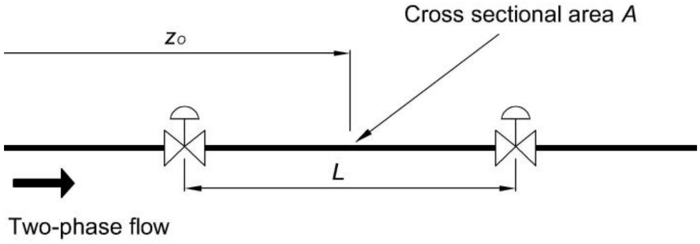

Figure 2. Measurement system of the volumetric concentration by using QCV.

In this case, the instantaneous volume concentration at time *t* of component 2 into *L* and at the axial position z_o along the pipeline is determined by Eq. (1).

$$\langle\alpha_2\rangle(z_o,t) = \frac{V_2}{A.L} \quad (1)$$

On a one-dimensional approach, Eq. (2) represents the total instantaneous mass flow of a two-phase flow in the cross section *A* located in the pipe on axial coordinate *z*, which is equal to the sum of the instantaneous mass flow of components 1 and 2 given by Eqs. (3) and (4) below.

$$W(z,t) = W_1(z,t) + W_2(z,t) \quad (2)$$

$$W_1(z,t) = \int_{A_1(z,t)} \rho_1(r,\theta,z,t).v_{1z}(rx,\theta y,z,t)dA_1 \quad (3)$$

$$W_2(z,t) = \int_{A_2(z,t)} \rho_2(rx,\theta y,z,t).v_{2z}(rx,\theta\, y,z,t)dA_2 \quad (4)$$

where r and θ are the cylindrical coordinates in the $A = A_1(z,t) + A_2(z,t)$, $v_{1z}(r,\theta,z,t)$, $v_{2z}(r,\theta,z,t)$ are the instantaneous and local axial velocity of each component and $\rho_1(r,\theta,z,t)$ e $\rho_2(r,\theta,z,t)$ are the instantaneous local densities.

Assuming the specific mass of 1 and 2 as constant in *A*, i.e, $\rho_1 = \rho_1(z,t)$ e $\rho_2 = \rho_2(z,t)$ and taking the average velocities for each component $\langle v_{1z}\rangle(z,t)$ and $\langle v_{2z}\rangle(z,t)$ into $A_1(z,t)$ and $A_2(z,t)$, respectively, the Eqs. (3) e (4) can be rewritten as the following equations.

$$W_1(z,t) = \rho_1(z,t).A_1(z,t).\langle v_{1z}\rangle(z,t) \quad (5)$$

$$W_2(z,t) = \rho_2(z,t).A_2(z,t).\langle v_{2z}\rangle(z,t) \quad (6)$$

Dividing Eq. (5) by (6), taking $A_1(z,t) = A - A_2(z,t)$ and isolating $A_2(z,t)$:

$$A_2(z,t) = \frac{A}{1+\frac{W_1(z,t)}{W_2(z,t)}\cdot\frac{\rho_2(z,t)}{\rho_1(z,t)}\cdot\frac{\langle v_{2z}\rangle(z,t)}{\langle v_{1z}\rangle(z,t)}} \quad (7)$$

The instantaneous volumetric concentration of component 2 in the same section of length *L*, showed in Fig. 2, can be obtained by integration of A_2 along *z* as in Eq. (8), where $\alpha_2(z,t) = A_2(z,t)/A$ is the ratio of the area occupied by component 2 in *A* at the axial coordinate *z* and at time instant *t* by the area of cross-sectional of the pipe, which can be interpreted as the concentration of 2 in *A* in [m^2/m^2]:

$$\langle\alpha_2\rangle(z_o,t) = \frac{1}{A.L}\int_{z_o-L/2}^{z_o+L/2} A_2(z,t)\,dz = \frac{1}{L}\int_{z_o-L/2}^{z_o+L/2} \frac{1}{1+\frac{W_1(z,t)}{W_2(z,t)}\cdot\frac{\rho_2(z,t)}{\rho_1(z,t)}\cdot\frac{\langle v_{2z}\rangle(z,t)}{\langle v_{1z}\rangle(z,t)}}dz = \frac{1}{L}\int_L \alpha_2(z,t)dz \quad (8)$$

One should observe that Eq. (9) is always intrinsically valid under the last assumption. However, $\langle\alpha_2\rangle(z_o,t)$ determined from Eq. (8) can, hypothetically, be different from that of Eq. (1) if both components are compressible along the volume of length L, since the fluid dynamics effects are absented when using a QCV system. In this case, $\langle\alpha_2\rangle(z_o,t) + \langle\alpha_2\rangle(z_o,t) \neq 1$ in $A.L$.

$$\alpha_1(z,t) + \alpha_2(z,t) = 1 \text{ in } A \qquad (9)$$

Equation (8) also indicates that the volume concentration $\langle\alpha_2\rangle(z,t)$ is equal to the spatial average of $\alpha_2(z,t)$ in L. Therefore, this point the performance of the sensor also as a low-pass filter of $\alpha_2(z,t)$. According Ma and Yan (2000) who studied electrodynamic sensors of ring format, the pass band width of this filter, B, is inversely proportional to the length L and proportional to the effective velocity of the gas-solid flow. However, this statement should not be valid when measuring of the volumetric concentration. However, in a general case, the statement of the pass band width B be inversely proportional to the axial length L should be still valid, however, the dependence of such to other geometric characteristics of the sensor and of the whole measurement system is still an opened subject for research.

Along the pipeline, the balance among values of the variables in Eqs. (5) and (6) can cause variations of the volumetric concentration of component 2 (or 1). In Eq. (10), being ξ a local generic variable, $\bar{\xi}$ is the temporal average in a time period $T = t_1 - t_o$ sufficiently large to become its value constant and independent of the initial instant t_o, and ξ' instantaneous temporal variation, therefore: $\xi = \bar{\xi} + \xi'$. The existence of a finite T is reasonable if the hypothesis of steady state flow with $\overline{W_1}$ and $\overline{W_2}$ constant and independent of the t and z is assumed. Under this condition, the temporal averages of other flow variables will be dependend of z only.

$$\overline{\langle\alpha_2\rangle(z_o,t)} + \langle\alpha_2\rangle(z_o,t)' = \frac{1}{L}\int_{z_o-L/2}^{z_o+L/2} \frac{1}{1+\left(\frac{\overline{W_1}+W_1(z,t)'}{\overline{W_2}+W_2(z,t)'}\right)\cdot\left(\frac{\overline{\rho_2}(z)+\rho_2(z,t)'}{\overline{\rho_1}(z)+\rho_1(z,t)'}\right)\cdot\left(\frac{\overline{\langle v_{2z}\rangle}(z)+\langle v_{2z}\rangle(z,t)'}{\overline{\langle v_{1z}\rangle}(z)+\langle v_{1z}\rangle(z,t)'}\right)}\,dz \qquad (10)$$

Equation (10) indicates that as $\overline{\langle\alpha_2\rangle(z_o,t)}$ as $\langle\alpha_2\rangle(z_o,t)'$ can vary along z due to the fluid dynamics of flow associated fluctuations of mass flow of each component, effects associated with the compressibility, thermal expansions and contractions, mass transfer between the components or even due to changes in the velocity profiles of each one. Therefore, the volumetric concentration is a relative quantity of the two-phase flow, and this fact must be taken into account when choosing the suitable location for installation of a probe for measuring such quantity.

Singularities as valves, elbows, contractions, expansions, tees or even straight sections are commonly present in industrial pipelines. They can affect the fluid dynamics of the two-phase flow in different intensities and ways (Kourakos *et al*., 2009, Roul and Dash, 2012, Yadav *et al*., 2014). Consequently, all they can cause variations of the volumetric concentration along the pipeline.

Figure 3 shows a lateral view of a pipeline with different types of singularities. In point 1, one can find some fluid dynamic condition of the inlet system flow. In point 2, changes in the flow due to the presence of the valve should be observed. After that, the flow reaches the point 3 after two elbows, and the point 4 after a contraction of the cross sectional area of the pipe. In this point 4, all changes in the flow are a result of the combination associated to all upstream singularities, all straight section including changes in orientation with respect to gravity, and the distance of each singularity from point 4 because the viscous effects act into the flow diminish the influence of each one along the pipeline. Between sections 4 and 5, there is a tee whose lateral branch would be open, dividing the flow, or closed. In either situation, dos Reis and Goldstein Jr. (2013) showed that changes on the fluid dynamics of the passing two-phase flow are present.

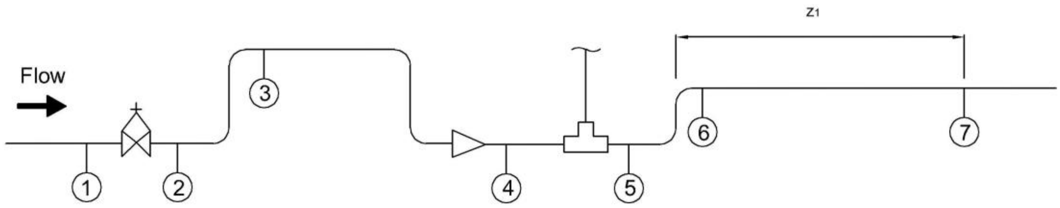

Figure 3. Schematic of a pipe containing singularities.

The situation described in the previous paragraph leads to the following question: if the volumetric concentration is a relative quantity and its value can vary along the pipe, even when $\overline{W_1}$ e $\overline{W_2}$ are constant, how can we choose the most suitable location for installation of a probe for measurement of such quantity? The answer of this question must consider that most of the information about the two-phase flows, including about the so-called patterns or regime flow (Crowe, 2005), and about the performance of electrical probes in such flows, are available in the literature on steady state and fully-developed flow condition (Bertanini, 2010), in which all temporal average of the volumetric concentration, and of other quantities of the flow, are constant in Eq. (10). Consequently, this condition is assumed as reference for performing the volumetric concentration measurements. However, it occurs only in point 7 shown in Fig. 3, after a straight section of the pipeline at z_1 downstream from the elbow near to point 6. However, such condition should be difficult to be observed in industrial environments and, in addition, there isn't still conclusive studies in literature for determination of z_1. One should observe that it is a complex subject, since z_1 will depend on the mass flow and properties of each component, the diameter and roughness of the pipe, the flow condition at point 6 of Fig. 3 from the combined action of the upstream singularities and straight section as discussed previously, and even of other parameters.

Table 1 shows data from literature on electrical probes of different operating principles discussed in item 1. All the experiments were reported by the authors as performed in laboratory environment.

Table 1. Characteristics of sensing sections of electrical probes according to literature.

Type	**Citation**	**Working fluids**	**Flow orientation**	**Tested flow regimes**	**Diameter *D* (mm)**	**Sensor type**	**Upstream Singularities**	**Dist. from upstream singularity z_1/D (-)**
Impedance	Klug and Mayinger (1993)	Gas-oil and gas-water	Horizontal	Stratified	54.0	Concave	Ball valve	185
	Rocha and Moreira (2008)	Air-water	Vertical	Bubbly, slug, and turbulent churn	52.3	Concave	Air bubbles generator	21
	Ko *et al.* (2012)	Air-water	Horizontal	Stratified	40.0	Concave	Mixer of water and air	115
	Rosa *et al.* (2012)	Air-water	Vertical	Bubbly, slug and annular	26.0	Ring	Mixer of water and air	247
Capacitive	Ahmed (2006)	Oil-water	Horizontal	Annular, slug, and stratified	12.7	Concave, ring	Mixer of water and air	>144
	dos Reis and Goldstein Jr. (2010)	Air-water	Horizontal	Stratified, wavy and slug	34.0	Concave	Mixer of water and air	150
	Strazza *et al.* (2011)	Oil-water	Horizontal	Annular	21	Concave	Mixer of water and oil	238
	An *et al.* (2014)	Oil-water	Horizontal	Slug flow, stratified smooth and way	20.0	Concave	Contraction	116
Resistive	Fossa (2003)	Air-water	Horizontal	Plug and Slug	40.0	Ring	Mixer of water and air	255
	Kima *et al.* (2009)	Air-water	Vertical	Slug	25.4	Ring	Bubble generator	45
	Cantelli *et al.* (2011)	Air-water	Vertical	Bubble ,cap, slug, plug, churn and annular	240.0	Ring	Mixer of water and air	80
	Fan and Yan (2014)	Air-water	Horizontal	Slug	50.0	Ring	Elbow	160
Inductive	Cha *et al.* (2003)	Sodium-nitrogen	Vertical	Bubbly and slug	25.0	Coil	Bubble generator	60
	Wylie *et al.* (2005)	Gas-oil-water	Horizontal	Stratified and dispersed and annular	104.0	Coil	Elbow	>290
	Sawai *et al.* (2010)	Magnetic solid-liquid	Inclined at 30º	Moving bed, pseudo homogenous	36.0	Coil	Elbow	28

In this table, one can observe that the major of these studies were realized with air and water as flowing fluids in horizontal orientation. The flow regimes changes the two-phase gas-liquid flow map from stratified smooth to bubbly, and from slug to annular flow, being slug flow the most common among them. The higher values up to 150 of z_1/D were reported by authors that studied the slug and the annular flow regime. Diameter of pipe about 40 mm is the common, however, diameter as lower as 20 and as higher as 240 mm were reported. Concave and ring format sensors were the most used, and mixers and bubble generators are the most common upstream singularity.

Evidently, such data are not conclusive for choosing the correct z_1/D for installation of a electrical probe in industrial enviromnent.

3. THE INFLUENCE OF DISTRIBUTION OF FLOWING COMPONENTS ON THE PERFORMANCE OF ELECTRICAL PROBES

The distribution of flowing components affects the performance of electrical probes. Rocha e Simões Moreira (2008) report the effect of the distribution of phases on the performance of an impedance probe, changing the position of a plastic PTFE cylinder along a test section. Dos Reis and Goldstein Jr. (2014) studied such phenomenon on a static bench with air and deionized water and different configurations of electrodes (double ring, concave and double helix) of capacitive sensors. Andreussi *et al*. (1993), by simulations and experiments, stated this for conductive probes, which was confirmed by Kima *et al*. (2009). Inductive or electromagnetic probes are also influenced by it as reported by Sawai (2010). In other words, even keeping the same volumetric concentration, the response of an electrical probe will vary for different arrangements of the components into the sensing volume, and it can represent a strong disadvantage of electrical probes.

Such phenomenon occurs due to the electric or magnetic soft fields easily spread through space, making complex arrangements that depend on different parameters and conditions, including the spatial arrangements of the nearby metallic and non-metallic components (Hayt Jr and Buck, 2006) in the sensing section, and the pipeline and the surrounding environment itself.

Consequently, one must take it into account when installing an electrical probe, since the performance of the electrical probe will depend of the flow patterns or regime, being decisive the correct choice of the sensing operation principle allied to the format of the sensor, and the suitable calibration method of the probe.

If all types of probes are affected to the distribution of the components into the sensing volume of length L_s from the calibration condition with a specific distribution of the components into the sensing volume and when the calibration curve $\langle\alpha_2\rangle_{meas} = f(\Gamma)$ is obtained, where $\langle\alpha_2\rangle_{meas}$ is the volumetric concentration of 2 measured by the probe at time instant t and at the axial center position z_o of the sensing section under operation, and Γ is the probe's electrical quantity (Z, C, R or L as discussed in item 1), the response deviation function $\psi(z,t)$ along the whole pipeline from z = 0 to z = z_∞, excluding factors related to the electronic transducer, can be introduced within Eq. (11) similar to Eq. (8), where the unit of $\psi(z,t)$ is dimensionless while of $\langle\alpha_2\rangle(z_o,t)_{meas}$ is [m^3/m^3].

$$\langle\alpha_2\rangle(z_o,t)_{meas} = \frac{1}{L_s}\int_0^{z_\infty} \psi(z,t).\alpha_2(z,t)dz \tag{11}$$

For a fixed spatial arrangement of the flow components at t, the sensing volume length $L_s = z_{dwn} - z_{up}$, where z_{dwn} is the downstream limit of L and z_{dwn} is the upstream limit of the sensing volume. Ideally, $\psi(z,t) = 1$ when $z \in [z_{up},\ z_{dwn}]$, and $\psi(z,t) = 0$ when $z \notin [z_{up},\ z_{dwn}]$. However, in practice when $z \to z_{up}$ or $z \to z_{dwn}$ the response deviation function $\psi(z,t) \to 0$ reaching the sensing volume limits, and $\psi(z,t) \neq 1$ in $[z_{up},\ z_{dwn}]$. One can observe that not necessarily $z_{dwn} - z_o = z_o - z_{up}$ or, in other words, the sensing volume is not necessarily symmetrical in relation to the axial center position z_o of the sensing section.

By rearranging Eq. (8), one can obtain Eq. (12) below.

$$\alpha_2(z,t) = \frac{d[\langle\alpha_2\rangle(z_o,t)]}{dz/L}\ in\ L \tag{12}$$

Therefore, by rearranging Eq. (11) and taking the calibration curve $\langle\alpha_2\rangle_{meas} = f(\Gamma)$, one obtain Eq. (13) below for the response deviation function $\psi(z,t)$.

$$\psi(z,t) = \frac{L_s}{\alpha_2(z,t)}\frac{d[f(\Gamma(z_o,t))]}{dz/L_s}\ in\ [z_{up}, z_{dwn}] \tag{13}$$

4. CONCLUSIONS

In this study, aspects on selection of the correct location for installation of an electrical probe for measuring volumetric concentration where discussed, in order to extend their application in industrial environments.

The main conclusions are: (i) there is a "sensing volume" of an electrical probe, which was defined as region into the pipe which contain the whole mass of fluid that affects the response of the electrical probe, which is dependent of several characteristics of the probe, fluids and flow, and toward the pipeline and the external environment itself due to possibility electrical couplings; (ii) the volumetric concentration is a relative quantity of the two-phase flow, and it depends on the fluid dynamics that causes mass flow or velocity profile variations of each component, and on the effects associated with compressibility, thermal expansion and contraction, mass transfer between them, therefore, it can considered by the engineer regarding the monitoring goals; (iii) an electrical sensor acts as a low-pass filter for signals related to ratio of the area occupied by component 2 in a cross sectional area into the sensing volume, and as lower will be the cut off frequency as higher the axial length of the sensing volume; (iv) the main data available in the literature are reported with the flow under steady state and fully-developed conditions and, therefore, it is the reference condition for measurement of the volumetric concentration and other quantities flow, however, such condition should not be so easily obtained in industrial environments; (v) there is not conclusive information available for determination of the upstream length of a straight section of a pipeline that allows archive? the fully-developed flow condition, for choosing a suitable location for installation of the probe, being it still an opened subject for research investments; (vi) based on literature, all types of electrical probes among the different operating principles are affected by the spatial distribution of the components into the sensing volume, and the response deviation function was defined for quantifying of such phenomenon and determining the axial limits of the sensing volume, therefore, when choosing and installing an electrical probe, one must take it into account, regarding the flow patterns or regimes, the sensing operation principle allied to the format of the sensor, and the calibration method of the probe.

5. ACKNOWLEDGEMENTS

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