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ACOUSTICS DETERMINATION OF VOID FRACTION IN TWO-PHASE FLOW IN HORIZONTAL PIPELINES BY EXPERIMENTAL METHOD

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Abstract. *In multiphases flows the phases can flow arranged in different spatial configurations in the pipe called flow patterns. This type of flow is found in the oil, chemical and nuclear industries. For example in the production and transport of oil and gas, the identification of the flow patterns are essential for questions wich are related to the economic return of the field, such as, measuring the volumetric flow, determining the pressure drop along the flow lines, production management and supervision. In offshore production, these factors are very important. This paper presents a new method for measuring the void fraction in horizontal pipelines, taking the air as gas in water-air two-phase flow. Through acoustic analysis of the frequency response of the pipe, the method gets the parameters to changes in runoff regime, in an experimental arrangement constructed on a small scale. The main advantages are the characteristic non-intrusive and easy to implement. The paper is composed of a qualitative experimental evaluation and transducers (microphone) are used to analyse variations in the response accompanying variations in void and flow pattern changes. Changes are imposed and controlled by a two-phase flow experimental simulation rig, including a measurement cell constituted of an external casing to isolate the measurement from the environmental background noise fitted with acoustic pressure transducers radially arranged, and a monitored excitation mechanism by impact. The signals captured by the microphones are processed and analyzed by checking their frequency contents changes according to the amount of air in the mixture.*

Keywords: *experimental method, two-phase flow, determination of void fraction, horizontal pipelines.*

1. INTRODUCTION

The multiphase flows are present in the oil, chemical and nuclear industries. In this type of flow, the phases can be arranged in different configurations inside the pipeline, called flow patterns. In the production and transportation of oil and gas, the identifying the flow patterns are essential to the economic return from the field, as in the measurement of volumetric flow, determining the pressure drop along the flow lines, production management and supervision. These factors are critical in terms of offshore production, because large distances and high costs are involved. In the petroleum industry, the problems associated with multiphase flow have been studied a long time. In these systems, can be found multiphase flows with varying behaviors, depending on flow parameters such as speed and volume fractions.

2. OBJECTIVE

The conventional meters are expensive, heavy and large, that confronted with the criteria in offshore oil production. Moreover, they present a lag between the time that occurs the biphasic mixture and the instant that the phases are measured. Modern techniques can make the measurement in real time, but are commercially unviable and in some cases intrusive. The aim of this study is to present a new method to measure the void fraction, in this case having air as gas, in water-air two-phase flow in horizontal pipelines, in real-time and non-intrusive way.

3. THE BIPHASIC FLOW

The flow of oil, water, gas and sediments, are called as multiphase flow, but in the modeling, are considered as a two-phase flow, where one phase is gaseous and the other liquid and the sediments, solid phase, are unvalued. In oil production, the multiphase flow is found in the column of production and production pipelines. It can occur in patches vertical, inclined or horizontal, and his investigation of essential importance in industrial processes, demanding reliable solutions for design and maintenance. In offshore production, the gas and the liquid phases are transported over long distances before to being separated. Therefore, besides the dimensioning of production pipelines based on pressure

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drop, it is important that we can determine the composition of fluid in the pipeline, in various flow conditions, to allow the proper design of the system separating process plant of the platform.

3.1 The gas volume fraction

The gas volume fraction (Hg) is definied is defined as the ratio of the volume of a segment of pipe occupied by the gas and the total volume of pipe segment (Eq. (1)).

$$H_g = \frac{V_{gas}}{V_{pipe}} \tag{1}$$

The volume fraction of the gas is a fraction ranging from 0 (liquid flow only) to 1 (gas flow only).
The rest of the pipe segment is occupied by the liquid, called the volume fraction of the liquid (HL) is shown in Eq. (2).

$$H_L = 1 - H_g \tag{2}$$

3.2 The no-slip gas volume fraction

The no-slip gas volume fraction (λ_g) is defined as the ratio of the volume of gas in a pipe segment, divided by the volume of the pipe segment that exist, if the gas and the liquid to flowing at the same speed (no-slip).
The calculation can be done using known flow rates of gas and liquid as shown in Eq. (3).

$$\lambda_g = \frac{q_g}{(q_g + q_L)} \tag{3}$$

where: q_L is the liquid flow rate and q_g is the gas flow, respectively.
The no-slip gas volume fraction (λ_L) is defined by Eq. (4).

$$\lambda_L = 1 - \lambda_g = \frac{q_L}{(q_g + q_L)} \tag{4}$$

3.3 The velocity

Many correlations for two-phase flow is based on a variable called superficial velocity. The superficial velocity of a fluid phase is defined as the speed in which this phase would be subject to flow if the total cross section of the tube.

3.3.1 The superficial velocity of the gas

The superficial velocity of the gas velocity is calculated by Eq. (5).

$$v_{sg} = \frac{q_g}{A} \tag{5}$$

where: A is the cross section of the tube.
The real velocity of the gas is calculated by Eq. (6).

$$v_g = \frac{q_g}{A \cdot H_g} \tag{6}$$

3.3.2 The superficial velocity of the liquid

The superficial velocity of the liquid is calculated by Eq.(7).

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$$v_{SL} = \frac{q_L}{A} \tag{7}$$

The real velocity of the liquid is calculated by Eq. (8).

$$v_L = \frac{q_L}{A \cdot H_L} \tag{8}$$

3.3.3 The superficial velocity of the biphasic mixture

The superficial velocity of the biphasic mixture is the sum the superficial velocity of the phases as shown in Eq. (9).

$$v_m = v_L + v_g \tag{9}$$

3.4 The non-slip velocity

The non-slip velocity is definied as the difference between the actual speeds of the gas and liquid phases and is shown by Eq. (10).

$$v_s = v_g - v_L = \frac{v_{sg}}{H_g} - \frac{v_{sL}}{H_L} \tag{10}$$

The no-slip volume fraction is calculated by Eq. (11).

$$\lambda_g = \frac{v_{sg}}{v_m} \tag{11}$$

3.5 Determination of the properties of the liquid mixture

When the liquid mixture containing oil and water a way to measure the effect of these phases is using the proportionality factor defined by Eq. (12). Where the index "o" refers to oil, the index "a" refers to water and, the index "l" to the liquid mixture.

$$prop_l = prop_o\left(\frac{q_o}{q_o + q_a}\right) + prop_a(1 - f_o) \tag{12}$$

3.6 The acoustics and the vibration mode cylinders

When a container is filled with liquid, its natural frequency modifies. This is a property of the system and independent of the magnitude of the active force.The Equation (13) presents the equation of vibrations in beams with free ends and without effect of load, where m is the total mass of the pipe plus the components of the biphasic mixture water and air, per unit of the length, and v is the cross displacement of the uniform pipe with product of the EI stiffness.

$$EI\frac{\partial^4 v}{\partial x^4} + m\frac{\partial^2 v}{\partial t^2} = 0 \tag{13}$$

The natural frequency is presented in the Eq. (14), where ρ is the density of the pipe plus water, without the air.

$$f = \beta^2\sqrt{\frac{EI}{\rho A}} \tag{14}$$

Where the density is shown in the Eq. (15).

$$\rho = \frac{\rho_{pipe}.A_{pipe} + \rho_{water}.A_{water}}{A} \tag{15}$$

where A_{water} is the cross-sectional area occupied by water, A_{pipe} is the cross-sectional area of the pipe.

This is a two-phase flow water-air, the A_{water} will depend directly on the amount of air present H_g, or void fraction. It can then be replaced by a more general expression where the area occupied by water, is the volume fraction multiplied by inner area of the pipe, is shown in Eq. (16).

$$A_{water} = A_{pipe}.H_L = A_{pipe}(1 - H_g) \tag{16}$$

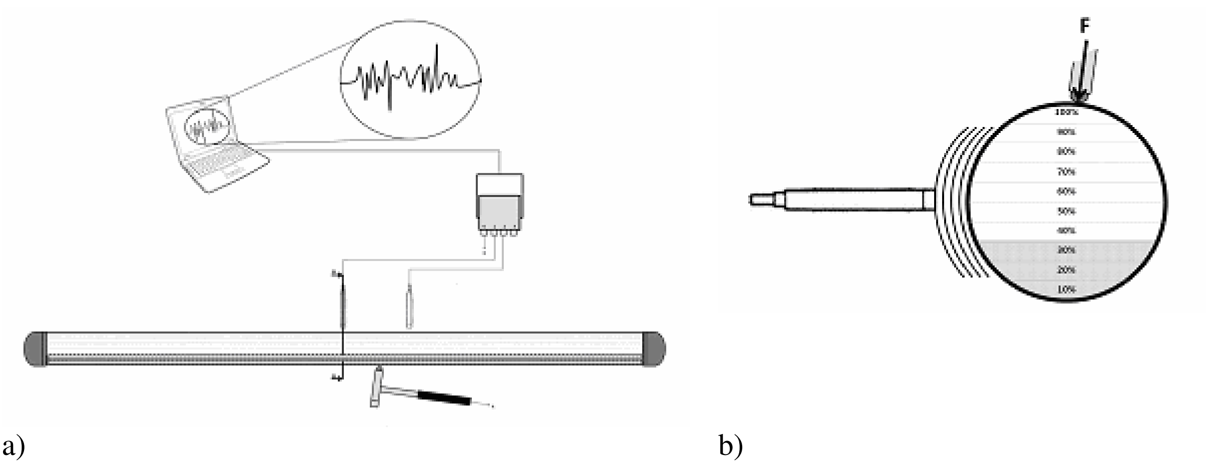
It can be concluded that the natural frequency of the cylinder has indirect relations with the void fraction. From the acoustic occur vibrations capable of generating pressure fluctuations, with power enough to be perceived by a transducer element type microphone. The vibrations involving a global analysis dependent on boundary conditions, are not well received acoustically. Therefore, the vibrating modes expected to obtain the desired response, will be provided by a mechanism of the different nature, which is analogous to the speaker.

4. EXPERIMENTAL MODELING

The goal is the measurement of void fraction, through the acoustic response of the system of the extrusive manner and in real time, a bench experiment was built with the function of inserting a flow of air in water, obtaining the desired biphasic mixture. The control of the amount entering each stage will create the flow pattern. Indirectly, this control will impose a certain volume of air and a certain volume of water, for a given volume of the test, has the volume fraction of the phases involved. Thus, it can obtain quantities of air in the system which ranges from 0% to 100%. The natural frequency of the system is directly related to the variation of void fraction. The greater the amount of water in the system, the larger the mass to be moved. Therefore, the period to maintain the same amplitude of vibration would be higher, corresponding to a lowest natural frequency. Can be taken as the first criterion to be analyzed, the variation of the natural frequencies of the system as a response variation of void fraction submitted, but in a local method being captured by microphones through pulsating modes of vibration.

4.1 The flow patterns and calibration

Given the criteria that may form and possibly implement the method it is necessary the creation of the patterns, if possible stationary, to adjust a reference to the experimental results found. The data will be obtained under similar conditions that will be submitted in the test experimental to ensure the reliability of the results. The apparatus for determining the patterns consists of a tube with free ends, suspended by nylon threads and closed at their ends. It will be filled with water from 0% to 100% by volume, an increase of 10% to 10%. Therefore, have a total of 11 patterns available to be measured. The Figs (1a) and (1b) show schematically the apparatus.



a) b)

Figure 1. a) The scheme for determining patterns. b) The cut of the pipe test for better visualization of the phenomenon

The procedure is to fill the tube to 100% water, emptying into a beaker, with scale of 2000 ml and a resolution of 20 ml, and dividing the mass of the liquid (subtracted mass of water to mass of the beaker) per 10, equivalent to the

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number of the total increments measured on a precision balance. The LabVIEW® was used to reading the data. In the Tab. (1) are presented the sensors and actuators used and in the Tab (2) the parameters of the measurement signals.

Table 1. Description of sensors and actuators used.

Sensor	Model	Sensibility
Impact hammer	086C03 - PCB	-5 / + 5 Volts
Microphone 01	MPA416 - BSWA	46.8 mV/Pa
Microphone 02	MPA416 - BSWA	45.7 mV/Pa

Table 2. Analysis parameters and measuring signals.

Sample rate	Numbers of samples	Resolution in frequency	Acquisition time	Number of measuring cycles
25.6 kHz	8192	3.125 Hz	300 ms	1

For a portion of the spectrum generated , the result obtained is shown in the Fig. (2). In the Fig. (3) shows in more detail, for a single frequency band, these changes.

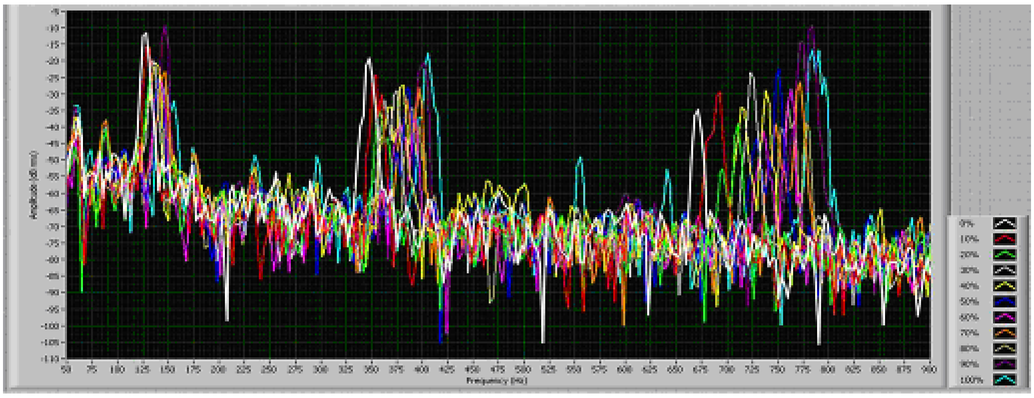

Figure 2. The power spectral range containing the 11 measurements for each void fraction

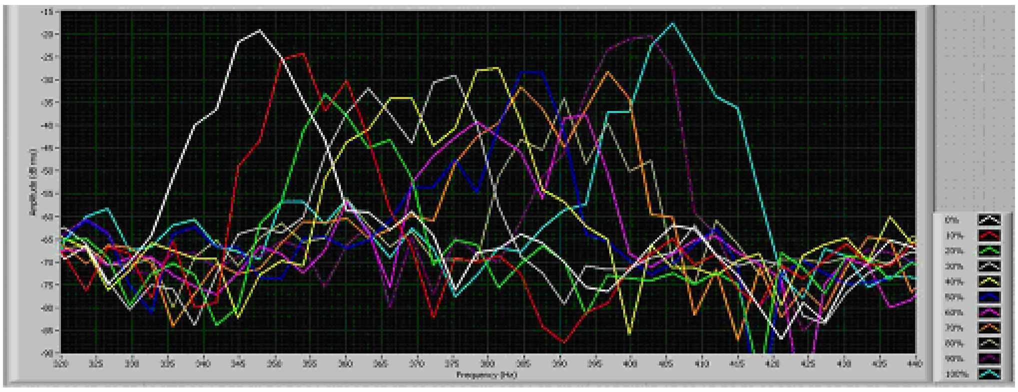

Figure 3. The variation in only one frequency band

From these observations of behavior, can be obtained the pattern, with the generation curves calibrated. In total, seven tracks were found: (1) 125-150 Hz, (2) 340-410 Hz, (3) 650-800 Hz, (4) 1070-1300 Hz, (5) 1580-1920 Hz, (6) 2150-2630 Hz and, (7) 3650-4350 Hz. In the Fig. (4) is shown one of the curves generated with their respective standard error.

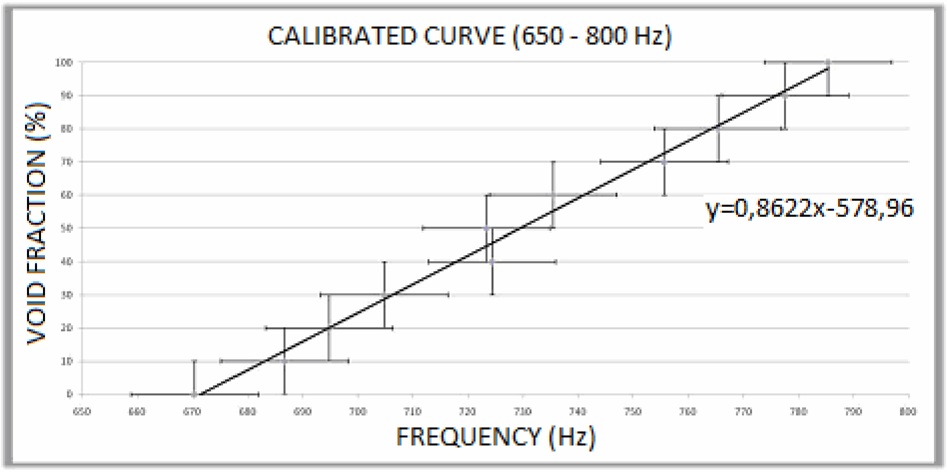

Figure 4. Curve calibrated to the range of 650 to 800 Hz, with a standard error and equation of a line

With the patterns for each measurement channel, can continue the technique that is used in the tests with experimental bench. The technique used in the measurement consists of collecting and treating cycle to cycle, where each cycle sweeps the acquisition time set to its resolution of 250 ms, and the interval between each cycle is given by frequency of the impact, in this case 4 Hz. The logic used to process data, consists in routines of the data loading in the time domain, changes in the power spectrum, reading the peaks of the bands of the curves to the pattern calibrated, calibration of possible peaks diverted by resolution of acquisition frequency, comparison of curves calibrated with peaks in each frequency band, average between the values of the void fraction found in the comparison for each frequency band, average between the microphones (channels) used and finally, the presentation of a unique result of the void fraction, for that measurement on the front panel. The technique is to excite the pipe with an impact identified by the acquisition software, are realized multiple cycles spaced in time. Thus can be obtained the necessary parameters for the understanding of the flow studied.

4.2 The experimental bench

The bench is shown schematically in the Fig. (5).

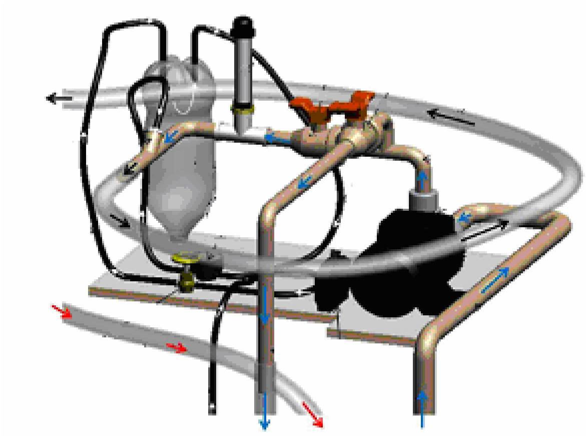

Figure 5. The experimental bench of two-phase flow

The measuring cell is mounted in the test section on the steel pipe. The use of a cell in cylindrical shape and closed, beyond the isolation function, is able to mount on any pipe same size diametrical. The instrumentation embedded in the cell consists of two microphones arranged radially, a mechanism of excitation and electronic responsible for its implementation. The microphones used have a frequency range of 20 to 20,000 Hz. The excitation mechanism exerts an impact on the pipeline, so that the noise can be picked up by the microphone. The Figure 6 shows in a generalized way the assembly, in detail the location and positioning of the measuring cell.

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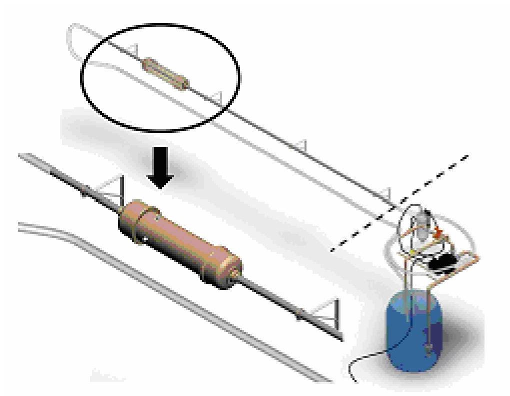

Figure 6. The generalized view of the assembly

4.3 The processing equipment and analysis

To process and analyze the data obtained from the experiment, were used: battery power excitation mechanism, signal generator for the excitation mechanism, acquisition module of the four channels model NI 9233, support USB NI 9162, notebook and LabVIEW software.

5. RESULTS

Firstly, a power spectrum of two microphones placed in the measuring cell and a third microphone, identical to the other two, however outside the cell, measured at the same time. The fact proves the effect of isolating the casing 20dB to 40dB in the frequency range used, being shown in the Fig. (7).

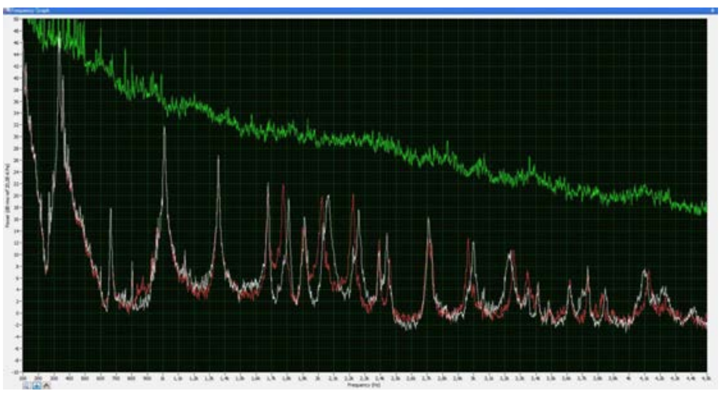

Figure 7. The difference of the isolation signal. The spectra in white and red are the inside microphones for measuring cell and the green is for the microphone outside the cell

As initial parameter of verification, the extreme situations of the exposure of the results will be tested, as measured of evaluating the calibration performed. This situation is to carry out the test at 0% and 100% void fraction, with the test tube filled with flowing water, and and the test tube filled with only air flow, respectively. In the Fig. (8) and (9) presents the results of simulations of two phase flow.

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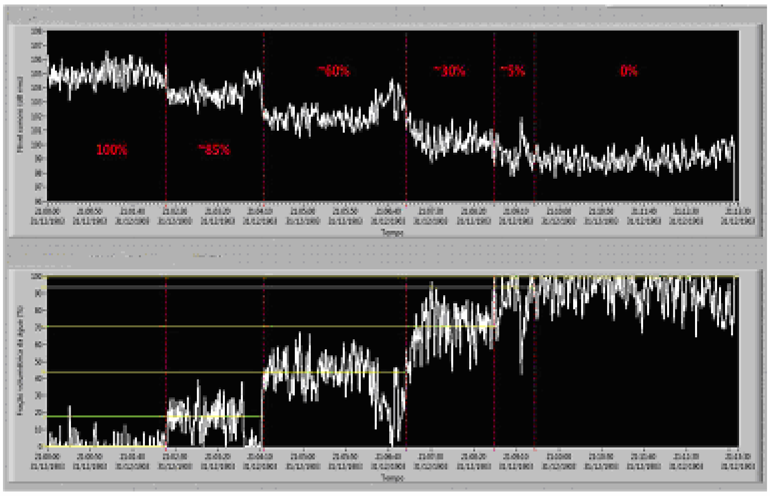

Figure 8. The curve of the sound level and the evolution of the flow verification method

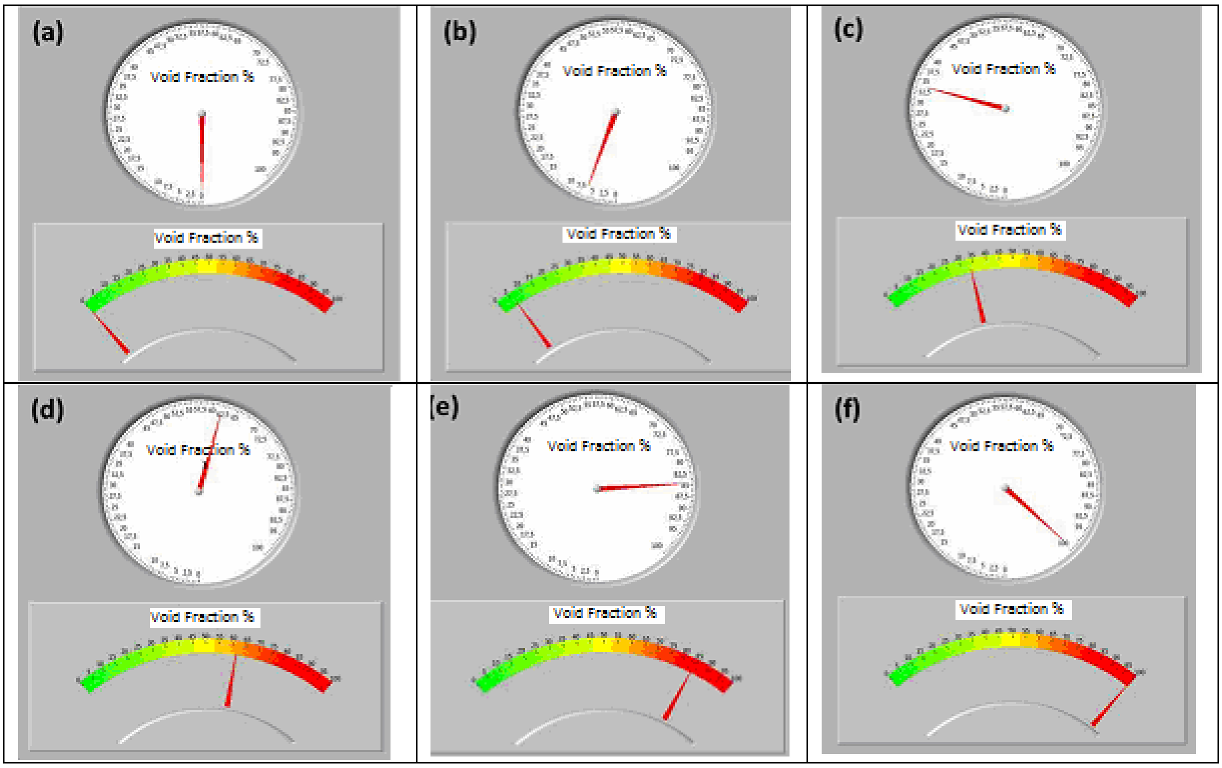

Figure 9. The front panel indicators of the program with the pointer showing the results in real time.
(a) 0%, (b) 5%, (c) 30%, (d) 60%, (e) 85%, (f) 100%

6. CONCLUSION

As the study aimed to, one new method to determine of the void fraction in the biphasic flow of type liquid-gas based on the analysis of the acoustic response of the pipe, was presented and verified experimentally. Through a goal established, was realized experimental verification of a new method for measuring of the void fraction in two-phase flow, not found in the literature. Based on other research, although verified by global vibration of the pipe, appeared relevant hypotheses, about the acoustic response instead of performed by vibration. The calibration curves were generated under a controlled standard, and prepared a logic for the measurement apparatus constructed. The calibrated curves are presented very definite in the criteria developed, besides having a good relation between the spacing of the peaks, the so far as it increases the frequency range used. This suggests there can be some relation dimensionless may become a common standard for whatever sizing pipe used. The construction of the apparatus was effective at all stages, ensuring stability in its use. However, it was found difficult to control the experimental parameters of the flow. In the

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absence of flow meters, both the air and the water, could not have control the speed of the phases. Due to the innovation of the experiment, it was decided a priori to perform indirect measurements, through pressure transducers and manometer. Therefore, it becomes important the acquisition of flowmeters for future study, finding the void fraction in real time and allowing, by a graphical method, evaluate the regime in which the flow is located. The method establishes the principle the real-time measurement, unobtrusive and low-cost, identifying the void fraction in two-phase flow in industrial pipes. There is still that improve this method, including the possibility of measuring the velocity of the gaseous phase at the same time and with the same cell. Can be conclude that providing a multiple microphones along the pipe, with the same function, it is possible to determine the displacement of the gas phase per period between two consecutive measurements. Can be complement this study, by varying the dimensions of the pipe and the fluid properties, to obtain the dimensionless parameters important to unify the method.

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