Measurement of Void Fraction for Two-Phase Flow by Using Self-Inductance Technique

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Abstract

Winding with low resistance wire is consternated around the test section like that of auto-transformer winding. This winding is used experimentally to measure the void fraction when the two-phase flow in such tube. This technique is based upon the fact that the two-phase mixture behave as transporter if the magnetic field, so any change in the permeability of the two-phase mixture causes any change in the void fraction value.

Keywords: void fraction, volume fraction, self-inductance, multi-phase flow, fluid flow measurement.

1. Introduction

The subject of two-phase is important in many industrial fields, such as oil and gas pipelines, process pipelines, heat exchangers, boilers and certain type of nuclear reactor.

The void fraction of two-phase, gas-liquid flow is defined as the ratio of the volume of gas to the total volume of gas-liquid mixture in a finite length of the pipeline. The ratio is useful for the determination the average density, pressure drop, of the flowing two-phase [Ramesh, 2003-Myer, 2006].

Nuclear radiation attenuation methods have been used for the measurement of void fraction [Kendoush, 1992] and are considered nonintrusive because do not cause perturbation of the local structure of the two-phase flow. The method is essentially based on allowing a beam of radiation (beta, gamma, neutron or X-rays) to traverse the cross-section of the pipe where it is detected.

Multiphase flow is the simultaneous flow of two or more phases in direct contact in a given system. It is important in many areas of chemical and process engineering and in the petroleum industry, e.g. in production wells and in subsea pipelines. The behavior of the flow will depend on the properties of the constituents, the flows and the geometry of the system. There are four combinations of two-phase flows namely: gas-gas, gas-liquid, gas-solid, liquid-liquid, solid-solid and solid-liquid. Liquid-liquid flows, the subject of the present project are extremely important particularly in two-phase flow applications in horizontal pipes, for instance in the oil industry. In the oil industry, the dispersion of oil-in-water or vice versa usually appears in the oil well, to produce a fully oil in the well from offshore to onshore is one of the major problem for examples to investigate the physical of the pipe and the physical properties of the liquid that can affect the flow structure and production [Hussain et al., 2008].

Also there are many methods are considered nonintrusive and used for measurement of void fraction, such as, capacitance [Kendoush, 1995].

Emulsion stability is one of the most important factors governing the shelf life of foods, pharmaceuticals, cosmetics, etc. Principally, emulsions are dispersed, multiphase systems consisting of at least two insoluble liquids [Kostoglou, 2010].

The ultimate aim of this work is to prove experimentally the possibility of measuring void fraction of two-phase media by using winding of electrical wires around the test section.

2. Theory

Figure 1 shows the auto-transformer type of wire winding around the glass tubular test section. The basic principle of the auto-transformer is that [Hirst,1956], when the primary (input) coil is connected to an alternative current supply, an alternating magnetic flux is set up inside the core (test section) for each turn of the coil. This flux induces an electromotive force (emf) of self-inductance in the secondary (output) coil.

If a two-phase medium is occupying the test section. The emf will indicate a particular value for the void fraction α. The presence of gas-liquid or gas solid two-phase medium in the test section (which is the core of the magnetic field) produces a net change in the magnetic flux across the medium. This change induces the measured emf of self-inductance in the secondary (output) coil.

To discuss the effects of self-induction we must define the property of a coil which gives rise to them. This property is called the self-inductance of the coil, and is defined as follows:

Self-inductance = [emf induced in coil by a changing current] / [rate of change of current through coil]

Self-inductance is denoted by symbol L; we may therefore write its definition as [Nelkon1979- Kraus, 1984]:-

$$L = \frac{E}{dI/dt}$$

$$E = L\frac{dI}{dt} \qquad (1)$$

Eq.(1) is the simplest form in which to remember the definition.

Since the induced emf $E = d\Phi/dt = LdI/dt$, numerically, it follows by integration from a limit of zero that:-

$$\Phi = LI$$

Thus $L = \Phi/I$. Hence the self-inductance may be defined as the *flux linkage* per unit current. When Φ is in weber and I in ampere, then L is in Henry. When a long coil of N turns and length ℓ carries a current I, the flux density B inside the coil with an air core is given by $B = \mu_{\circ} NI/\ell$, where $\mu_{\circ}$ is the permeability of air, $4\pi \times 10^{-7}\, H\, m^{-1}$. With an iron core of *relative permeability* μ_r, the flux density is given by $B = \mu_r \mu_{\circ} N_1 I/l$. In this case:-

Flux linkage $\Phi = N_2\, AB = \dfrac{\mu_r \mu_{\circ} N_1 N_2\, AI}{\ell}$

$$\therefore L = \frac{\Phi}{I} = \frac{\mu_r \mu_\circ N_1 N_2 A}{\ell} \qquad (2)$$

This formula may be used to find the approximate value of the inductance of a coil. The self-inductance of a coil can also be expressed as:-

$$L = K_1 \mu_r \qquad (3)$$

Where K_1 is equal to

$$K_1 = N_1 N_2 \mu_\circ A / \ell \qquad (4)$$

But

$$(V_1)_m = K_2 L \qquad (5)$$

Substituting **Eq. (3)** into **Eq. (5)**, we get

$$(V_1)_m = K_3 \mu_r \qquad (6)$$

Where

$$K_3 = K_1 K_2 \qquad (7)$$

Eq.(6) shows that any change in the permeability of the medium due to the different void fraction produces a change in the measured emf.

It can be deduced from the above argument that the self-inductance depends among other parameters on the following constants number of input & output coil turns, cross-sectional area A, coil length ℓ, and the optimum input signal characteristics (i.e. frequency & voltage). Therefore, we have analytically related the self-inductance directly to the maximum output emf **eq. (3)**.

By eliminating the effects of all the above mentioned parameters and the effects of cables on the measured void fraction, relative inductance L* can be obtained as

$$L^* = \frac{(V(\alpha))_m - (V(\alpha = 1))_m}{(V(\alpha = 0))_m - (V(\alpha = 1))_m} \qquad (8)$$

$V(\alpha)_m$: the voltage on the output coil at any void fraction.

$V(\alpha=0)_m$: the voltage on the output coil when the void fraction equal zero.

$V(\alpha=1)_m$: the voltage on the output coil when the tube is empty.

All of the experimental results of the void fraction measurements were presented by using **eq.(8)** as seen in **table 2,3** and **figures 3,4**.

3. Apparatus Characteristic

Table (1) gives the specification of the connecting wires, coil and the optimum number of input and output coil turns. It was found that when the axial length ℓ of the input coil turns was made less than or equal to the test section outer diameter D (that is $\ell / D \leq 1$)

4. Experimental Procedure:

When the axial length ℓ as seen in **figure 1** the input coil turns less or equal to the test section outer diameter D, which is, $\ell / D \leq 1$, this mean that the input signal phase shift are minimized to give narrow operating frequency range with reduced sensitivity (see **figure 2**).

The sensitivity $(\Delta(V_1)_m / \Delta\alpha)$ is defined as the difference in the values of the output emf for filled $(\alpha = 0)$ and empty $(\alpha = 1)$ test sections, we calculate the void fraction for the case of the water-air and wood-water as a medium by filled the water and inserting known geometrical size of wooden shape into the test section alone as seen in **figure 1**.

5. Amplification Circuit Design:

We designed the amplification circuit to amplify the low output signal produced from the function generator this signal is very low to ensure the magnetic flux generation at output coil turns, therefore after this amplification, the signal inserts the coil turns at test section.

We use the transistor and different resistances in this design as shown **figure 1**, to obtain amplification circuit between (1MHz - 3MHz) and frequency 1.8 MHz rather than 0.6 volt. We supplied 15 volt from the power supply into amplification circuit but the second side for the circuit connected to the oscilloscope to record voltage and the signal frequency. The best frequency is 1.8MHz, its give high sensitivity, such as show in **figure 2**.

6. Results and Discussion:

The **figure 3** shows the result which is simulated to air and water, a semi linear behavior was obtained for actual void fraction measurement.

Figure 4 shows another relative inductance L* as a function of the actual void fraction which are using by water and wooden shape, a linear behavior was obtained for the void fraction measurement.

The auto-transformer technique for void fraction measurement is novel, easy, simple and nonintrusive.

The highest sensitivity in void fraction measurement was achieved when the frequency was 1.8 MHz and the voltage was 15 volt.

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Table (1): Characteristics of wires, coils and devices

Diameter of the test tube	Inner diameter test tube is 26 mm outer diameter test tube is 29 mm thickness of tube glass is 1.5 mm
Turns number of coil	turns number of input coil is 50 turns number of output coil is 100
Wires resistance	Input coil resistance is R_2=1.1 Ω output coil resistance is R_3=2.2 Ω diameter of copper coil wire is 0.3 mm
Oscilloscope	Type 422, 2 channel
Function Generator	Hp(100 Hz – 3 MHz)
Electronic amplification circuit	It was fabricate by hand
Power supply	DC current (0-25)volt

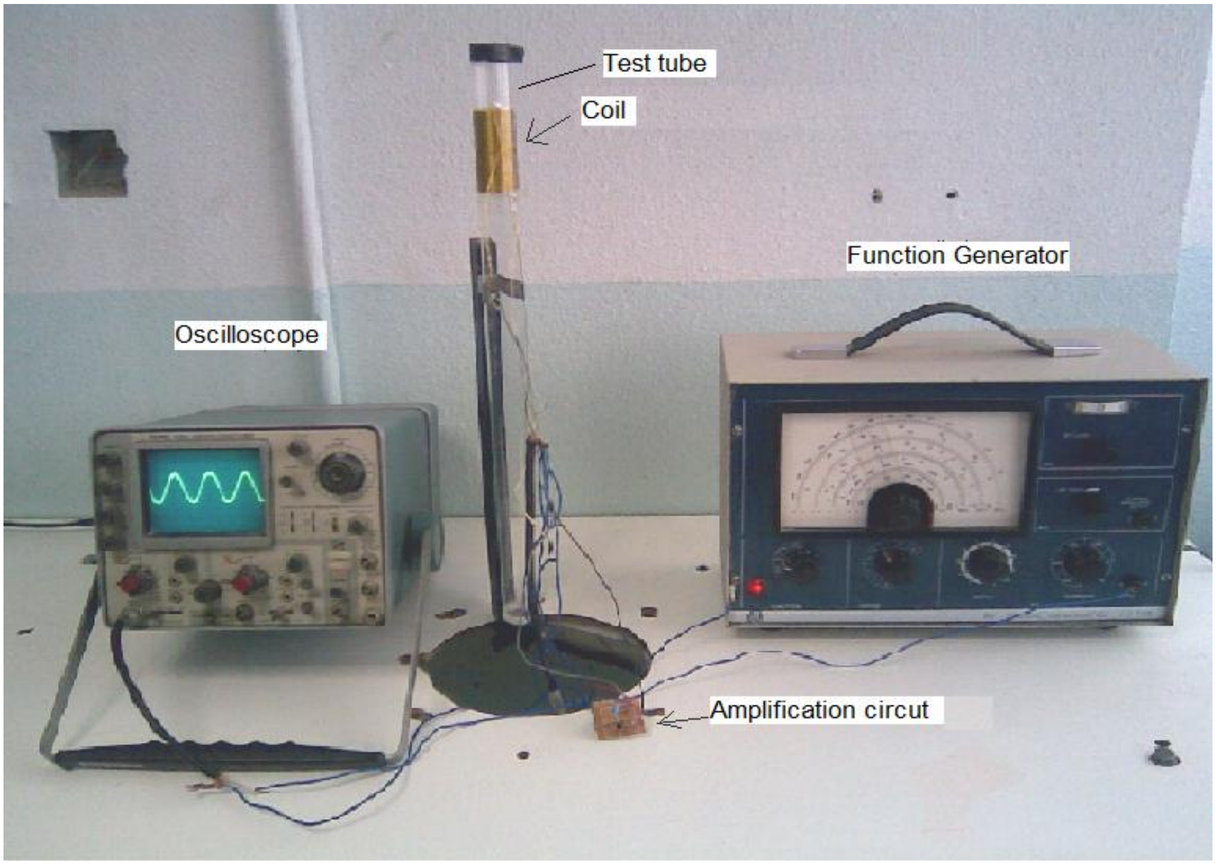
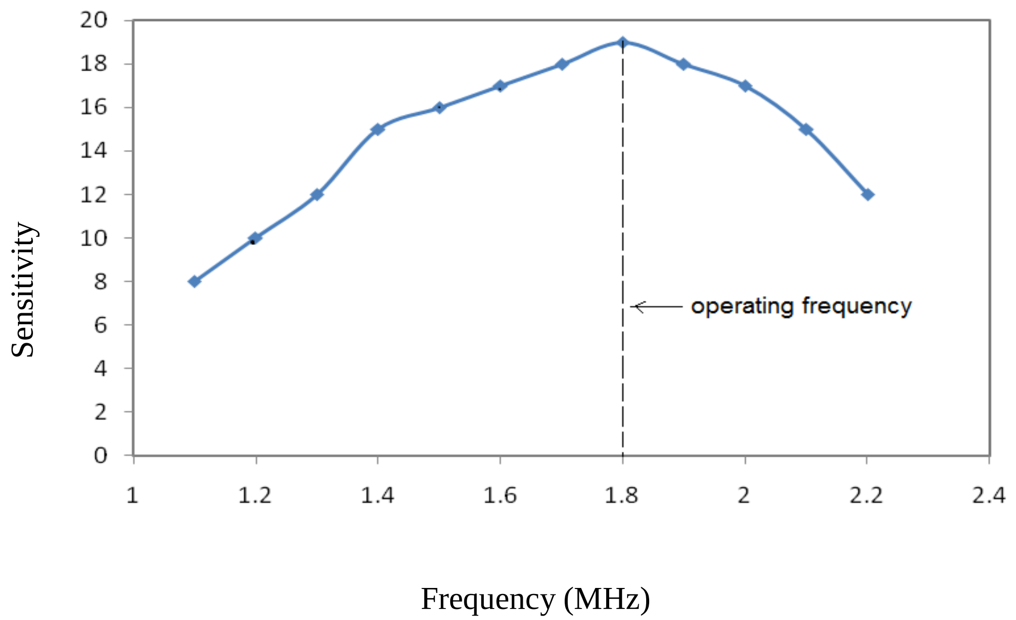


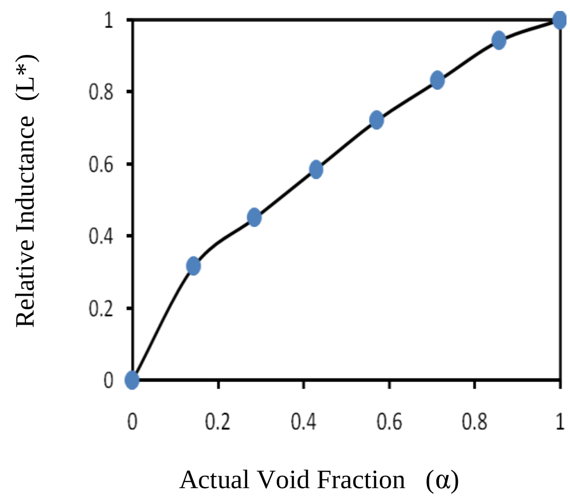
Figure (1): The experimental arrangement of the auto-transformer used for void fraction



Figure(2): Experimental determination of maximum sensitivity of the auto-transformer

Relative Inductance (L*)	Output Voltage (V)	Actual Void Fraction (α)
0.0000	42	0.0000
0.3157	36	0.1428
0.4505	35.5	0.2857
0.5850	35	0.4285
0.7212	34.5	0.5714
0.8321	32	0.7142
0.9417	27	0.8571
1.0000	23	1.0000

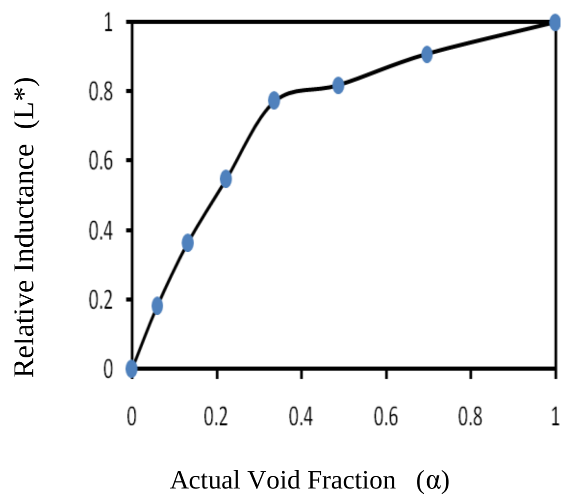
Table(2): The relative inductance values for air and water



Figure(3): Calibration curve for void fraction using air and water

Relative Inductance (L*)	Output Voltage (V)	Actual Void Fraction (α)
0.0000	42	0.0000
0.180	41	0.059
0.363	40	0.132
0.546	39	0.222
0.7727	38	0.336
0.819	37.5	0.488
0.908	37	0.696
1.0000	36.5	1.000

Table(3): The relative inductance values for wood and water



Figure(4): Calibration curve for void fraction using wood and water