

# Application of Electromagnetic Induction Technique to Measure the Void Fraction in Oil/Gas Two Phase Flow

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**Abstract.** In this work, electromagnetic induction technique of measuring void fraction in liquid/gas fuel flow was utilized. In order to improve the electric properties of liquid fuel, an iron oxide  $\text{Fe}_3\text{O}_4$  nanoparticles at 3% was blended to enhance the liquid fuel magnetization. Experiments have been conducted for a wide range of liquid and gas superficial velocities. From the experimental results, it was realized that there is an existing linear relationship between the void fraction and the measured electromotive force, when induction coils were connected in series for excitation coils, regardless of increase or decrease CNG bubbles distribution in liquid fuel flow. Therefore, it was revealed that the utilized method yielded quite reasonable account for measuring the void fraction, showing good agreement with the other available measurement techniques in the two-phase flow, and also with the published literature of the bubbly flow pattern. From the results of the present investigation, it has been proven that the electromagnetic induction is a feasible technique for the actual measurement of void fraction in a Diesel/CNG fuel flow.

## 1. Introduction

The inference of bubbles and void fraction measurement is one of vast interest in two phase flow research and many technical applications, such as processes of petroleum, chemical, energy and other industries [1]. It is the main physical magnitude for determining almost other important parameters, such as the two phase flow properties (density and viscosity), for analysing the relative average velocity for two phases, and is of fundamental importance in two phase models for predicting flow pattern transitions, pressure drop and heat transfer [2]. Void fraction has been studied for many years on different types of two phase flows (but horizontal two phase flow orientation has received less attention compared to vertical flow), on different sized pipes, and several geometric definitions are used for characterizing the void fraction for two phase flows in channels and over tube bundles: cross-section, volumetric, local, and chordal [3]. Many measuring methods have been proposed: quick closing valve method, electrical method, ray absorption method, ultrasound method, image processing techniques, and



magnetic resonance method,...etc. [4-7], these techniques can be divided into intrusive and non-intrusive techniques according to whether flow fields are disturbed or not by the measuring equipment. Although many methods used to measurement this parameter, but it still one of difficulties of parameter detection in liquid-gas two phase flow [8]. One of the new methods used to measure void fraction in the bubbly flow supported the possibility of benefiting from the magnetization characteristic of liquid with gas bubbles under the magnetic field, uses the electromagnetic induction (EMI) [1, 9, 10]. The electrical conductivity of liquid in two phase flow is relatively higher than gas phase, which can be exploited with contactless methods based on electromagnetic induction [10]. Initially, the utilization of electromagnetic induction technique (EMI) to measure a void fraction in the liquid-gas fuel horizontal pipe has not been studied, due to the low electrical properties of liquid fuel and gas thereby creating a low magnetic field flux in the line. Lately, the nanotechnology technique was used to enhance characteristics of liquid fuel, reduce ignition delay time and emissions [11-14]. More so, nanotechnology helped improve the electrical properties of liquid fuel, and has opened the way for the application of EMI technique in liquid-gas fuel flows. From here, the EMI method is not considered a monopoly in the use of liquid metal but can be used in oil-gas flow [15, 16]. The chief purpose of this work is to establish the possibility of applying the electromagnetic induction (EMI) method of measuring a void fraction in a gas and oil flows such as diesel-CNG bubbly flow. The current article investigates from the diesel electric properties by its enhancement with iron oxide  $\text{Fe}_3\text{O}_4$  nanoparticles. In addition, the use of electromagnetic induction system in measuring a void fraction of bubbly fuel flow is also studied. Table 1 shows the physical and chemical property of the diesel, diesel/CNG and Nano-additive diesel/CNG liquid in varying concentration.

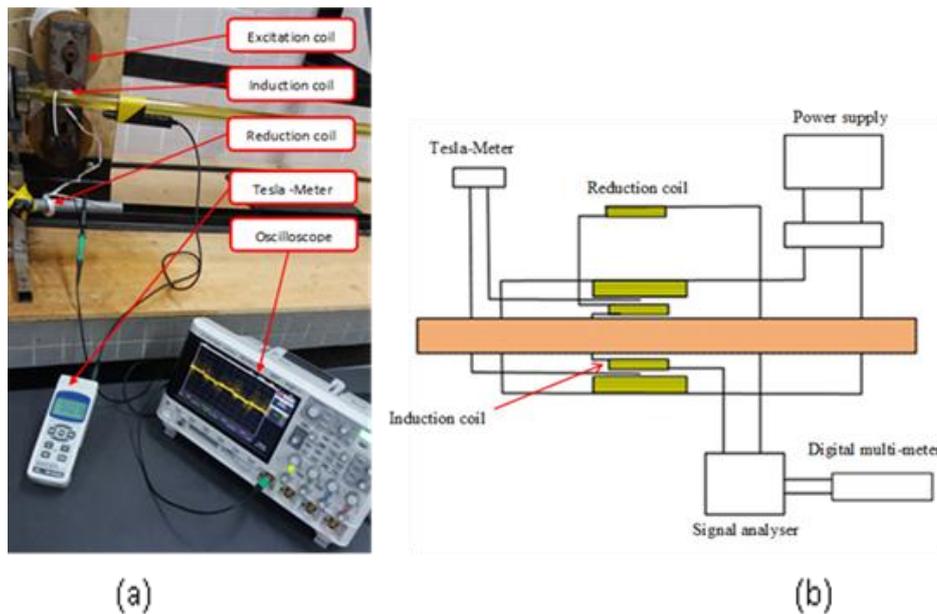
**Table 1.** A Diesel fuel, CNG, and Diesel/ $\text{Fe}_3\text{O}_4$  nanoparticles properties.

Parameter	Diesel	Diesel & 3% $\text{Fe}_3\text{O}_4$	CNG
Density ( $\text{kg/m}^3$ )	840	856	0.72
Kinematic Viscosity (cSt)	2.97	3.09	$4.3 \times 10^{-5}$
LCV (Mj/kg)	43.8	43.8	45.8
Octane Number	50	50	125
Carbon (% , w/w)	86.83	86.83	73.3
Hydrogen (% , w/w)	12.72	12.72	23.9
Oxygen (% , w/w)	1.19	1.19	0.4
Sulphur (% , w/w)	0.25	0.25	ppm < 5
Electrical conductivity (S/m)	$0.25 \times 10^{-9}$	$23.4 \times 10^{-6}$	-
Relative permittivity	2.0	2.2	-

## 2. Experimental Implementation

Figure 1 (a) shows the schematic diagram of the experimental facility for the two-phase flow in a horizontal pipe. The facility test portion is made from transparent polycarbonate. The pipe dimension is 1.2 m long and has an inner diameter ( $D_i$ ) of 0.02 m. The CNG bubbles generator had an induction system that produce a liquid and gas mixture inside the test section at the inlet of the pipe. The diesel supply line and the compressed CNG line are directly linked to the bubble generator. The diesel is supplied by a fuel pump which has a flow rate and supply pressure measured by a flow meter and a pressure gauge respectively. The diesel flows through the bypass valve and is filtered by the fuel pump (90 watts, 5 l/min, and 1.5 m), then go into the flow meter, then, pumped along with the pressure gauge. After that, it goes into the side hole of the bubble generator and where it is combined with the CNG to produce the two-phase flow. Then, the Compressed Natural Gas CNG goes into the mixer situated at the first edge of the bubble generator. The CNG pressure is controlled using a pressure regulator while the flow rate is measured by a gas flow meter before it enters the bubble generator. A one way valve is used to control the CNG flow rate precisely. A thin pipe of 0.15 mm (inner diameter) was passed through the centre of the cross-sectional area of the pipe inside the bubble generator. The diesel flow meter was calibrated prior to its use. The electromagnet charger (excitation coils) is supplied by a DC power as described in Figure 1 (b), and is made up of two coils having 250 wraps of copper wire that was covered

with enamel having a diameter of 2.1 mm and a U-type yoke. The yoke was made of steel; with the cross-sectional area for both poles was 22 mm, perpendicular to the direction of the flow (x-axis) and 60 mm that was parallel to the direction of flow (z-axis) to embrace the test pipe in order to reduce eddy current losses in the core. A pair of Tesla meter sensors was fixed between the yoke poles, and a test pipe was used to measure the magnetic intensity signing. The value of the magnetic field between the excitation coils had a variable magnetic field flux from 0 to 2000 Gauss. In capturing the induction voltage value from induction coils and the magnetic field intensity from excitation coils, the signal analyser (Oscilloscope) and AC/DC Magnetic Meter (Tesla-Meter: Model, MG-3003SD) were used to capture these values, as shown in Figure 1(a).



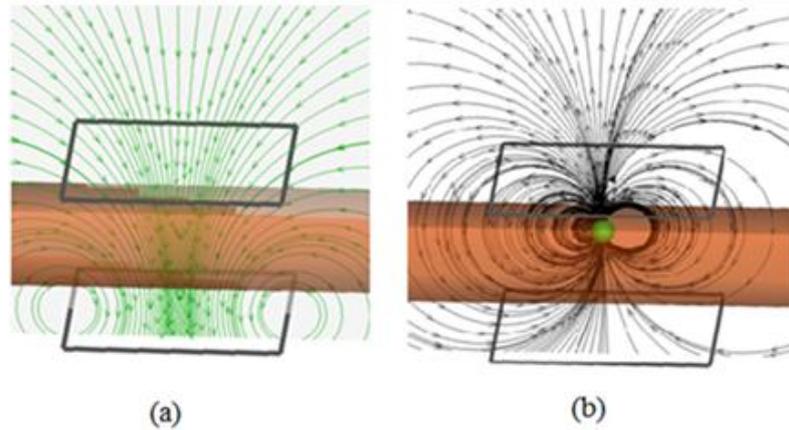
**Figure 1.** Components of an electromagnetic induction system.

### 3. Principle of EMI Measurement

The permeability of in a magnetic liquid differs from that of the gases because of the void fraction in the bubbly flow or Ferro-fluid dynamics [10, 17, 18]. When the magnetic field is excited, the coils generate eddy currents which serves as an insulating obstacle in the bubble created in the Ferro-fluid. The Ferro-fluid can detect the slight changes in the current distribution outside the fluid flow by measuring the amount of relative increase of the electromotive force between induction coils. It is assumed that there is no magnetisable material except for the magnetic fluid in the space affected by the magnetic field and no tangential components to the plane defined by either one of the induction coils in the space between the induction coils [18]. Thus, from the Gauss' low, the magnetic flux density becomes unique in the space between induction coils as well as in the test plug. In addition, in the induction coil, the induction current is small, (in the order of  $10^{-9}$  amp) and the magnetic fluid is nonconductive, thus the mutual effect of magnetic field intensity by the excitation coils and induction coils is minimal.

Figure 2 shows a schematic sketch of the EMI system, (a) the field lines of the magnetic field generated by the excitation coil, while (b) field deformation due to the presence of a bubble at the magnetic field. The induced voltages in both induction coils appeared on a signal analyser; they have same amplitude but opposite signs so they cancel each other out. The challenge of this method is the reliable detection of these small variations which requires a sensitive measurement system. On the other hand, the deformation of the field lines results in a non-symmetrical magnetic field distribution in signal analyser which generates a net voltage signal at the terminals. If the bubble reaches the excitation field the induced voltage becomes zero again, because the secondary magnetic field is symmetric with respect of

the signal analyser. When the bubbles move up further, again a voltage signal in the induction coil is generated, but now with an opposite sign [10]. The motion of bubbles in the horizontal pipe from the injection nozzle moved through the magnetic field thereby affecting the induction signal. Then, the difference in induction voltage values and magnetic field intensity traveling through diesel fuel recorded.



**Figure 2.** Principle of electromagnetic induction measurement.

### 3.1. Measurement of Void Fraction

The diesel with 3%  $\text{Fe}_3\text{O}_4$  nanoparticles fluid was electrically enhanced by improving the electromagnetic conductivity. The physical properties of diesel fuel and CNG are shown in Table 1. The magnetic intensity  $B$  is given by the following formula [9]:

$$B = \mu_o (H + M) \quad (1)$$

Where  $\mu_o$  is the permeability (H/m),  $H$  is the magnetic field (A/m) and  $M$  is the magnetization (A/m). While, the magnetic intensity  $B_f$  passed through the magnetic fluid can be written by the following formula (this is based on a space distribution of CNG bubbles and a distribution of magnetization of a magnetic fluid is equivalent):

$$B_f = \mu_o (H + (1 - \alpha)M_f) \quad (2)$$

Where  $M_f$  is the magnetization of magnetic fluid (A/m) and  $\alpha$  is the void fraction. Thus, the CNG bubble behaves like a magnetized substance. The CNG bubble has demagnetization against the magnetization of magnetic fluid so that the value of magnetization in the CNG bubble can be expressed by using a demagnetization factor:

$$\Delta B = B_{\alpha-\alpha} - B_{\alpha-0} \quad (3)$$

With the assumption that the change in CNG bubble shape is ineffective, the detected magnetic intensity is simply written as follows:

$$\Delta B = \mu_o (1 - \alpha)M_f \quad (4)$$

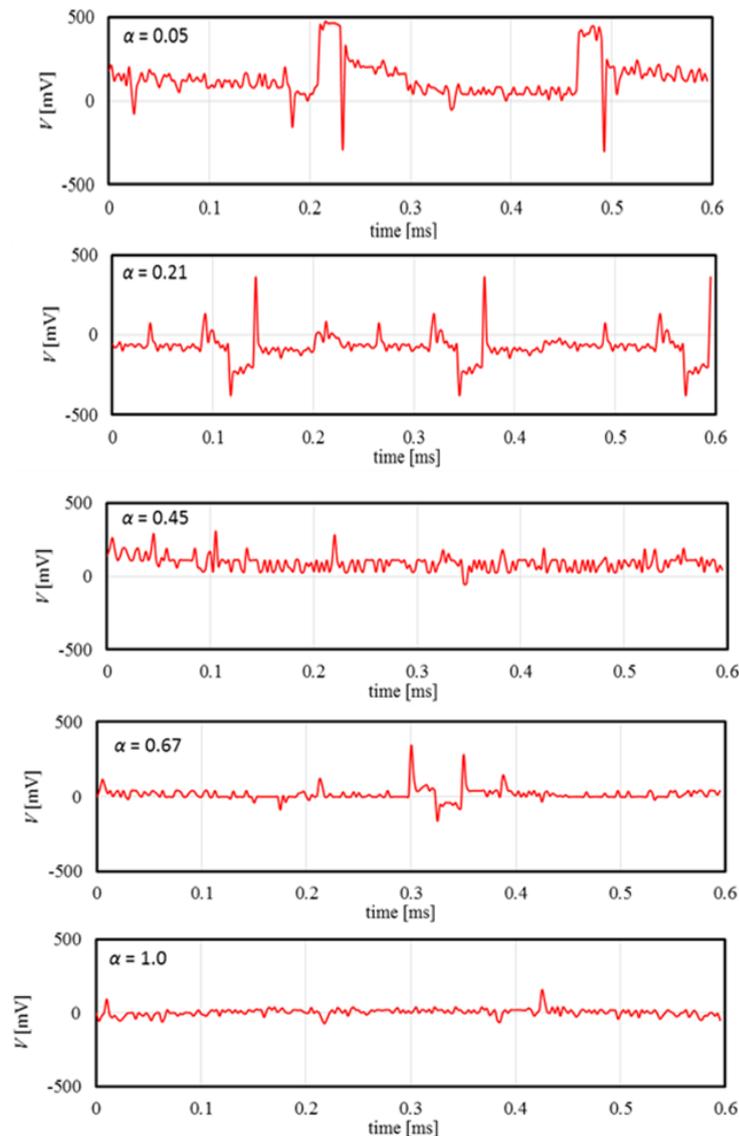
The differential value between the induced electromotive force in void fraction of 1.0 and the objective induced electromotive force was termed “detected voltage”, as expressed:

$$\Delta V = RMS_{\alpha=\alpha} - RMS_{\alpha=1.0} \quad (5)$$

Where RMS represents the root mean square value of voltage.

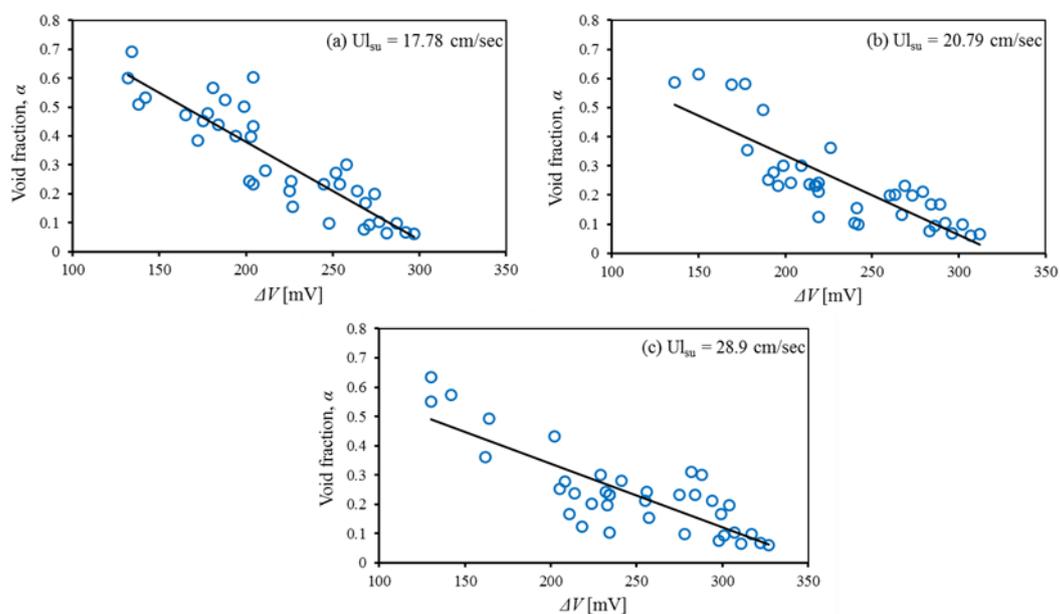
#### 4. Results and Dissuasion

Based on the measurement principle as described previously, the experiments were conducted at various conditions of two phase flow. The data obtained in these experiments depend on the master calibration line for actual flow experiments. Therefore, the void fraction measured by means of this electromagnetic induction method was compared with the void fraction data obtained by [9, 10]. In order to investigate how the measurement signal depends on higher gas flow rates. The first test carried out for measurement of detected voltage ( $V_{\alpha=1}$ ) for gas flow where without liquid flow. Then, successive tests were carried out to find ( $V_{\alpha=a}$ ) for several conditions of a liquid superficial velocity 17.78, 20.79, and 28.9 cm/sec and for a wide range of a gas superficial velocity (5.5 to 63.4 cm/sec), as shown in Figure 3. From the figure it can be seen that the detected voltage for  $\alpha = 1.0$  is 86 mV, while this voltage increase for liquid-gas flow with decreasing the gas superficial velocity until to 422 mV at  $\alpha = 0.05$ . To ensure the accuracy of the recorded reading of the detected voltage, the tests were repeated three times to detect and confirm the average value. More so, using a flat induction coil allows for a robust automatic detection of bubbles without any calibration, since the zero crossing of the induced voltage provides an exact time when the bubble is in the middle of this coil.



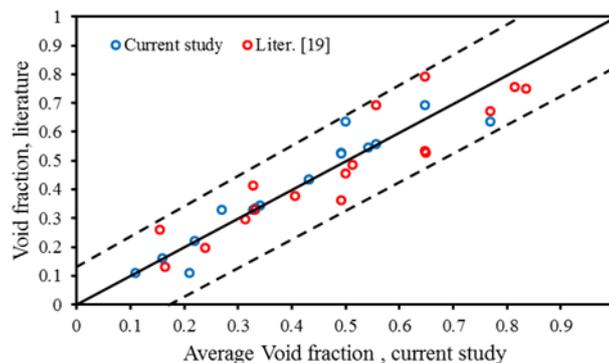
**Figure 3.** Induced voltage for void fraction analysis.

In Figure 4, the results obtained from the two phase flow experiments are displayed for the initial conditions of the liquid phase represented by the liquid superficial velocity 17.78, 20.79, and 28.9 cm/sec, respectively. In each diagram of (a), (b), and (c), the void fraction average was measured by recording the difference of magnetic field intensity ( $B_{\alpha=\alpha} - B_{\alpha=0}$ ) indicated by data points, corresponding to the data obtained by the induction method, the trend line was plotted for each case. The low value of a liquid superficial velocity (17.78 cm/sec) tends to obtain higher void fraction value due to the intermittent flow mode of two-phase, because the flow mode tends to become the slug flow. From the Figure 4, increasing liquid superficial velocity from 17.78 cm/sec to 20.79 and 28.9 cm/sec decreases the trend line slope of void fraction value at 11.4 and 21.7 %, respectively. The obtained result are in line with the result obtained by Shuchi et al. [9]. It is concluded that the electromagnetic induction method is feasible for measuring the void fraction average in an actual two-phase flow of magnetic fluid.



**Figure 4.** Void fraction versus  $\Delta V$  in two-phase flow experiments.

The validation of results, the experiments were conducted at various conditions of two phase flow. The data obtained has been compared with the published literature for bubbly flow at same liquid and gas superficial velocity, as shown in Figure 5. The comparison of results for the time-averaged void fraction. Very good agreements between the user sensor and the results for Min et al. [19] were confirmed. For all flow-rate conditions, the maximum deviation between two sides was 8.3%. However, it was observed that the void fractions resulted from this technique were generally under compared.



**Figure 5.** Comparison in results for average void fraction.**5. Conclusion**

In this study, the electromagnetic conduction technique was adopted to determine void fraction in Diesel-CNG bubbly flow after enhancing Diesel by Fe<sub>3</sub>O<sub>4</sub> nano particles, to improved electrical properties of a liquid fuel. This technique was applied to a horizontal pipe with a 20 mm inner diameter and a 1.2 m length. For several flow rate conditions covering stratified- and intermittent-flow regimes in bubbly flow. The chief purpose is to establish the possibility of applying the electromagnetic induction (EMI) method of measuring a void fraction in a gas and oil flows such as diesel-CNG bubbly flow. The experimental results was yielded quite reasonable account for measuring the void fraction, showing good agreement with the mechanical measured data in the two-phase flow, and with the published literature of the bubbly flow pattern.

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### **Acknowledgments**

The authors are obliged to the Universiti Teknologi PETRONAS for providing the centre for automotive research and energy management (CAREM).