

Volume Fraction Measurement in Crude Oil-Water Two-Phase Mixture using a Neutron Beam

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Abstract

A neutron beam has been used to measure the volume fraction of crude oil in water of non-flow two-phase mixture experimentally. ²⁴¹Am-Be neutron source were used with an activity of 3.7x10⁴ MBq. The volume fraction was simulated by using small plastic tubes filled with oil and immersed in non-flow water tube. The results show that it is feasible to measure the volume fraction of crude oil in a crude oil-water mixture.



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Introduction

The subject of two-phase flow is important in many industrial fields; such as oil and gas pipeline, process pipeline, column flotation of minerals, fluidized bed combustion, heat exchangers and certain type of nuclear reactor.

The nuclear attenuation is one of important methods that has been used for measurement of void/volume fraction and are considered non-intrusive as they do, not cause perturbation at the local structure of the two-phase flow and a relative easiness of calibration.

The method is essentially based on allowing a beam of radiation (beta, gamma, neutron and X-ray) to traverse the cross-section of the pipe where it is detected. The using of neutron beam technique for the volume fraction measurement offers the following advantage: relatively good accuracy and the neutrally charged neutrons easily penetrate thick walled steel pipe.

The radiation attenuation technique has been used by various investigators for determining the volume fraction in two-phase flow such as Foglia

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et al. (1961) used β -particles to measure the void distribution and slip ratio in heated channels. Perkins *et al.* (1961) used monoenergetic β -particles to measure the void fraction in a two-phase channel. Schrock (1969) used γ -rays for the measurement of void fraction. Slug flow was identified in this study. Harms and Forrest (1971) and Harms and Lavatta (1974) observed a "dynamic-bias" in the estimation of the average hold-up. It was attributed to the time variation of hold-up during the time interval of radiation transmission measurement. Heywood and Richardson (1978) used γ -ray absorption to measure

the liquid hold-up in a pipe of circular cross-section. Banerjee *et al.* (1979) made a simulation of a neutron scattering method of measuring void fraction in two-phase flow. Perez-Griffo *et al.* (1982) used pulsed neutron activation method to measure the rate of two-phase flow in large pipe. Kniodic *et al.* (1983) used γ -ray scattering techniques for phase distribution measurements. Kendoush (1992) found that the uncertainty in void fraction measurement was the least when using beta particles, neutrons and gamma rays consecutively, while x-ray exhibited a behavior between gamma and beta.

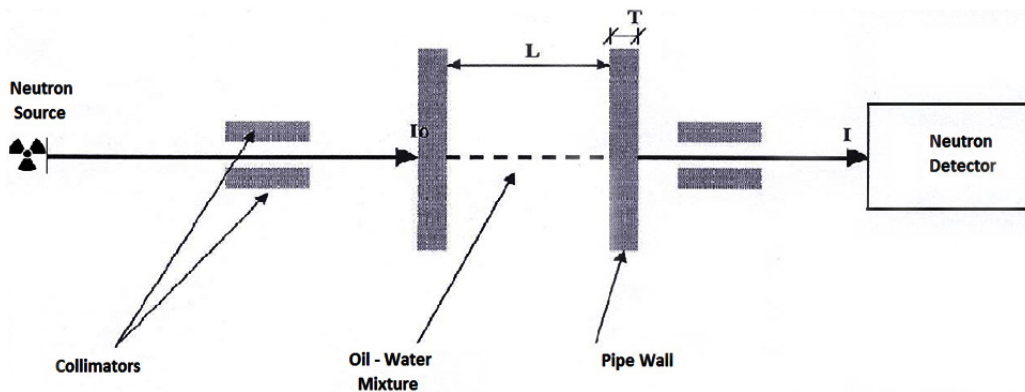


Fig. 1: Geometrical Arrangement of Volume Fraction Measuring Equipment.

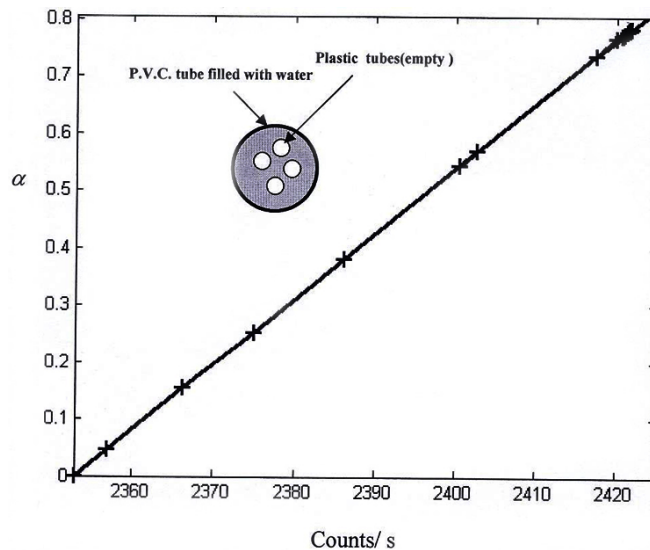


Fig. 2: Void Fraction Measurement Versus Neutron Counted Per Second for Two-Phase Air-Water Mixture.

Other investigators used a non-radiative technique to measure the volume fraction such as Wamsteker *et al.* (1964) who used the capacitance method for transient void fraction measurement and presented a comparison with γ - ray attenuation technique. Cimorelli *et al.* (1966) used the impedance gauge (capacitance) to measure the void fraction. Gregory *et al.* (1973) used capacitance sensors with different electrode configurations to measure the void

fraction. Abulwafa and Kendall (1979) showed that the relation between the capacitance and the void fraction is linear and independent of the flow pattern and relative permittivity of the media. Geraetes and Borst (1987) developed the capacitance sensor for measuring time average void fraction in two-phase pipe flow. Kendoush and Sarkis (1996) proved experimentally the auto-transformer method as a new method used for measuring void fraction of two-

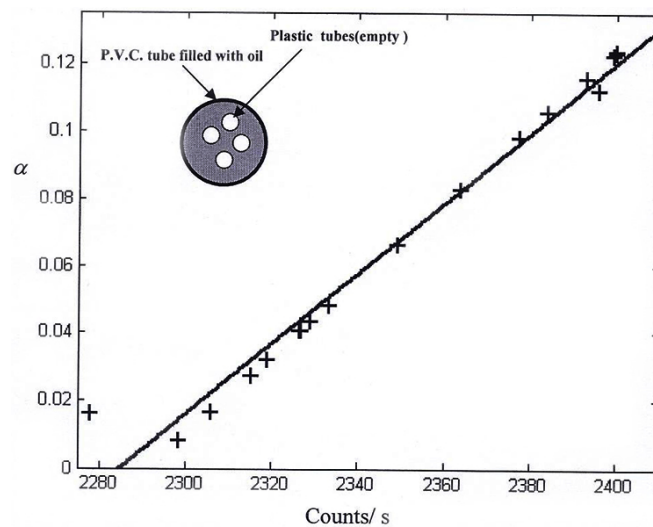


Fig. 3: Volume Fraction Measurement Versus Neutron Counted per Second for Two-Phase Air-Oil Mixture.

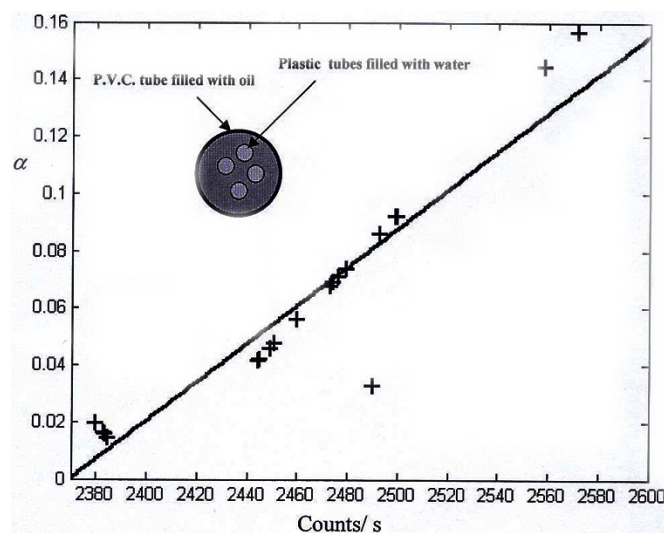


Fig. 4: Volume Fraction Measurement Versus Neutron Counted Per Second for Two-Phase Oil-Water Mixture.

phase medium inside the tube. In the present work a non-intrusive method using a neutron beam was used to measure the volume fraction of non- flow oil-water, water-oil, water-air and oil-air mixtures.

Experimental Measurements and Procedure

A PVC tube of 4.5 cm inside diameter and 0.6 cm thickness was used as a container of oil-water mixture. The tube was filled with tap water. Small diameter (0.375 cm), plastic tubes (straw tubes used for drinking beverages) filled with crude oil were used for volume fraction simulation by inserting them into the PVC tube . Detector readings were taken with empty plastic tubes immersed in the water filled PVC tube. This was done for every time a certain number of plastic tubes were used to get the actual value of volume fraction from mock-up arrangement. This method ensures that the thickness of the small plastic tubes was canceled. The crude oil was brought from Doura Petroleum Refinery near Baghdad.

The experimental arrangement for measuring the volume fraction (Fig.1) consists of an 241Am- 9Be neutron source of 3.7x104 MBq activity and a 3He proportional counter of 2.54 cm outside diameter, 25.4 cm active length and 10 bar gas pressure. The sensitivity of this counter was 45 count/s per neutrons/cm2 s.

The volume fraction measurements based on allowing a collimated beams of nuclear radiation (neutron beams) to traverse the cross section of the pipe. The neutron source is positioned diametrically on the opposite side of the detector. The attenuation of the beam of radiation (neutron) when passing through oil-water mixture medium of bath length (L) is given by:

$$I = I_o \exp- [2\Sigma_w T + \Sigma_r L] \tag{1}$$

where:

I= Intensity of radiation beam incident on the detector (cm⁻². s⁻¹)

I_o= Intensity of radiation beam emitted from the neutron source (cm⁻². s⁻¹)

Σ_w= Macroscopic cross-section of the material of the tube wall (cm⁻¹)

Σ_r= Macroscopic cross-section of the oil – water mixture (cm⁻¹)

T= Thickness of the tube wall (cm)

L= Inner tube diameter (cm)

The total macroscopic cross-section of neutron interaction with oil – water mixture is:

$$\Sigma_r = \alpha \Sigma_{oil} + (1 - \alpha) \Sigma_f \tag{2}$$

Where:

α= volume fraction

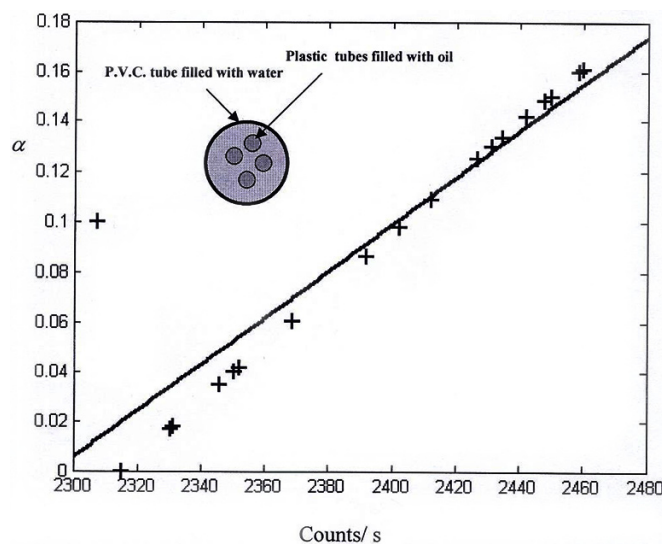


Fig. 5: Volume Fraction Measurement Versus Neutron Counted per Second for Two-Phase Water Oil Mixture.

Σ_{oil} = macroscopic cross-section of neutron with oil (cm^{-1})

Σ_f = macroscopic cross-section of neutron with water (cm^{-1})

Using the above relation and considering the two extreme cases of $\alpha = 0$ (pipe full of water) and $\alpha = 1$ (pipe full of oil) we get:

$$\alpha = \frac{h\left(\frac{I}{I_f}\right)}{h\left(\frac{I_g}{I_f}\right)} \dots\dots(3)$$

where:

I_g = intensity of neutron radiation passing through a pipe full of oil,

I_f = intensity of neutron radiation passing through a pipe full of liquid (water).

Results and Discussion

The neutron attenuation technique for measuring void volume fraction is more accurate than other nuclear or non-nuclear techniques except β - rays as was demonstrated by Kendoush (1992). This technique is based on the intensity of radiation passing through the two-phase mixture. The attenuation of the neutron beam is done by absorption or scattering from the nuclei of the two-phase mixture. The degree of attenuation depends on the nature of the mixture.

Different two-phase mixtures were tested in the present experiments namely air-water, air-oil, water-oil and oil-water. The volume fraction of the particular phase is simulated by using small plastic tubes filled with that phase and immersed in the large tube filled with the continuous phase. The actual volume fraction in these cases calculated from the total volume occupied by the small immersed tubes.

Figure 2 shows the relationship between the volume fraction of air in water and the neutron count rate. A linear relationship was found and a high void fraction was recorded but it is not exceeding 0.7 due to geometrical limitations, as this value is approximately equal to the maximum packing of spheres. Figure 3 shows the relationship between the air volume ratio in oil and the neutron count rate. A linear relationship was seen and a low void fraction was recorded. Figure 4 denotes the relation between the water volume ratio in oil and the neutron count rate. A linear relationship was demonstrated and the water volume ratio recorded is limited to that recorded in Fig.3.

Figure 5 shows the relationship between the volume fraction of oil in water. The behavior is not different from other figures and the volume fraction recorded is similar to those found in Figs. 3 and 4.

Figure 6 shows a typical percentage error versus the volume fraction. At very low volume fraction the

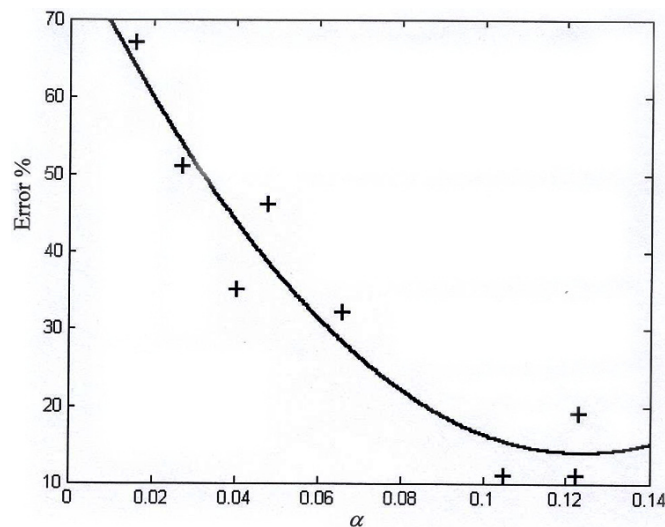


Fig. 6: Typical Percentage Error Versus Volume Fraction of Two phase Mixture

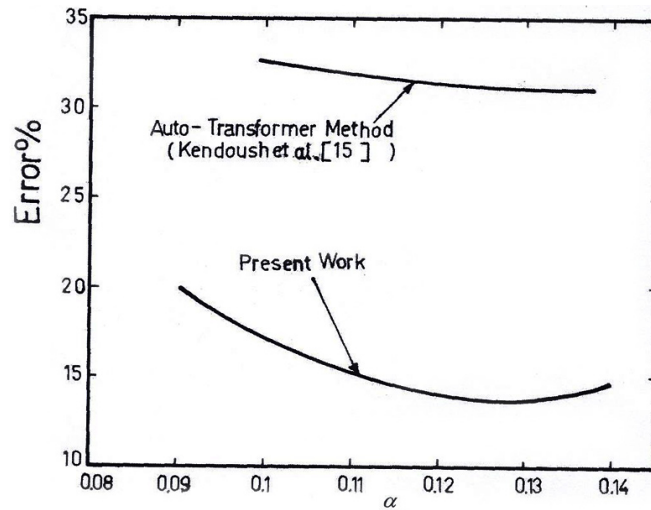


Fig. 7: A Comparison Between the Percent Experimental Percentage Error and Percentage Error of Auto-Transformer Technique given by Kendoush *et al.*(2005)

percentage error seems to have a high value but it becomes acceptable at a value near to the value of 0.1. The percentage error is obtained as follows

$$\%error = \frac{\text{Actual value of } \alpha \text{ from geometry} - \text{Measured value of } \alpha}{\text{Actual value of } \alpha} \%$$

Figure 7 shows a comparison between the present percentage error and that given by Kendoush *et al.* (2005) using auto-transformer technique. At low values of volume fraction the present technique is more accurate than the auto-transformer one.

Concluding remarks

The following conclusions are drawn from the present study:

1. The neutron attenuation technique is useful for measuring the volume fraction of oil in water especially at low volume ratios.
2. Using this technique for measuring volume fraction of air in air-water mixture leads to higher percentage errors.

3. The present technique is more suitable for steel walled test section or pipelines because of the ability of neutrons to pass through.

Nomenclature

- I neutron intensity after passing the two-phase mixture
- I₀ initial neutron intensity
- L inner tube diameter
- T thickness of the tube wall

Greek Letters

- Σ macroscopic cross-section
- α void/ volume fraction

Subscript

- f fluid (liquid)
- g gas or little liquid phase in mixture
- w wall
- T total
- Oil oil

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