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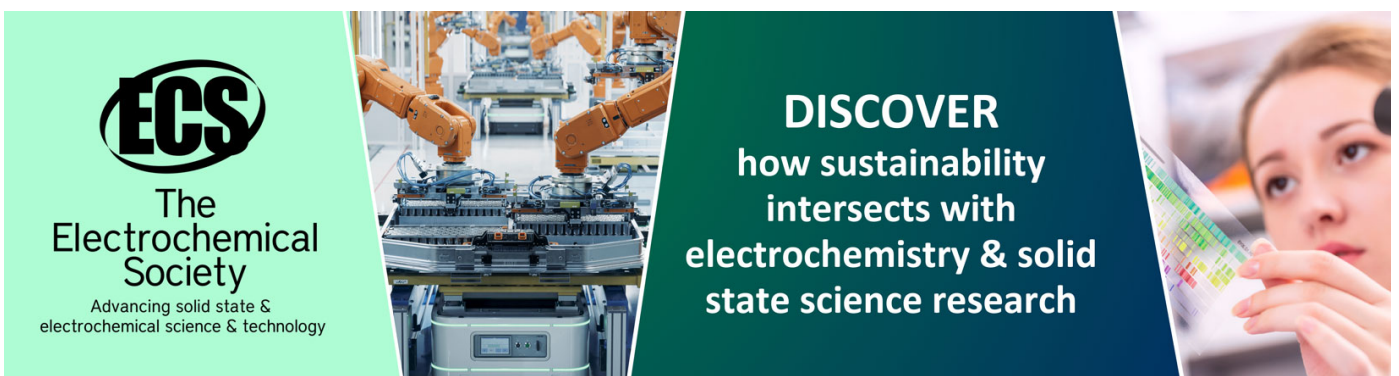
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# Determination of cross-sectional void fraction in a two-phase water flow through a PVC pipe

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**Abstract.** Gamma ray transmission method for void fraction measurement studies is in rare use in Nigeria, especially in industries and research. The study used this method to determine the cross-sectional void fraction of two-phase water flow through a Polyvinyl chloride (PVC) pipe channel. The gamma-ray counts transmitted through the water pipe were recorded and used to calculate the void fraction using a semi-empirical approach. Void ratio values varying from 0.171 – 0.036 were obtained for water flow rates ranging between 0.5gal/min - 4.0gal/min at estimated constant air flow rate. Conclusively, the experimental results compared well with Chisholm theoretical model predictions of void ratio applicable to horizontal flow. The use of two or more theoretical model predictions is recommended for further comparative study with experimental process. Also, more use of gamma ray transmission method should be encouraged.

**Keywords:** void fraction; two-phase air-water flow; single-energy gamma densitometer; horizontal flow

## 1. Introduction

The knowledge of void fraction is of key significance in two-phase flows, especially in fluid transportation from one point to another. Void fraction in gas-liquid two-phase flow is defined as the fraction of the flow-channel volume that is occupied by the gas phase. It is also defined as the fraction of the cross-sectional area of the channel that is occupied by the gas phase [1,2]. Matter can be in transitional states with more than one single phase flow (e.g. water in liquid and vapour states in heat exchangers) that is known as two-phase single component flow. Gas-liquid two-phase flows are commonly encountered in the petroleum and process industries as well as in boilers and steam generators in nuclear engineering [1, 2, 3, 4], particularly in neutronic thermal hydraulic calculations and heat transport rate predictions [5]. In a flow channel, void fraction varies according to the flow pattern and it can be measured directly or indirectly. The present study focused on the indirect method that is based on the ability of the two-phase mixture to absorb or transmit radiation from a point source, while serving as an interface between the later and the detector. Cross-sectional void fraction



is one of the most important parameters used to characterize gas-liquid two-phase flows [6]. The semi-empirical formula for cross-sectional void fraction is given as:

$$\alpha = \frac{A_g}{A_g + A_l} \quad (1)$$

where  $A_g$  is the cross-sectional area of the gas phase,  $A_l$  is the cross-sectional area of liquid phase and  $A_g + A_l$  is the total cross-section of the pipe.

Several studies have been done on void fraction in a two-phase water flow using several experimental methods of direct measurement of void fraction which include the quick-closing valves and the optical probe [7, 8]. [6] used indirect method to measure void fraction in steam-water two-phase flow. The study of [6], made use of gamma ray attenuation under high pressure and high temperature evaporating conditions. The gamma-ray transmission method does not alter the physical properties of the fluid nor does it intrude in the flow pattern as compared with other methods; such as the impedance method in which the accuracy of the measured void fraction is affected by the fluid temperature and the flow pattern [6]. The drawback of gamma-ray transmission method is that, it involves the use of radiation, which will require the need to have a radiation source (approved isotope source), thus it is rarely used for void fraction study. Besides that, it has high accuracy compared to other methods. Only a few studies have been done using this method, In Nigeria, industrial and research application of gamma ray for void fraction measurement is seldomly done. Little to none article was found on the use of gamma ray transmission for void fraction study in Nigeria, hence the adoption of [6] method for the present study. The present study aimed at measuring void fraction of fluids at different flow rates, through a PVC pipe. The knowledge of the cross-sectional void fraction in a two-phase flow through a PVC pipe will aid proper control/management of flow velocity and the density of the two-phase mixture. Ordinary water was used as fluid at ambient temperature and pressure for the study. Flow rates were varied and measured. Gamma-ray counts were used to compute the void fraction as outlined in the methods sections. The results obtained have been compared with the existing standard model.

## 2. Experimental Method

### 2.1. Experimental design and procedure

A polyvinyl chloride (PVC) pipe loop was constructed using 1.27cm diameter pipes together with valves, a 20l water-filled container, a 0.5hp INTERDAB water pump and a rotameter. The loop was mounted on a 7.62 cm × 7.62 cm calibrated cylindrical NaI (TI) detector gamma-ray spectrometer facility at the Centre of Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife, Nigeria [9]. A Cs-137 source was used for the study. The source has a single photo-peak energy of 661.5 keV which was collimated to pass through the centre of the pipe to the detector. A picture of the experimental setup (a) and a schematic illustration of the gamma densitometer (b) are shown in Fig. 1.

The experimental set-up consists of two collimators, one below the source and one above the detector in order to obtain a narrow beam of photons. The transparent rotameter which is mounted next to the section exposed to the gamma-ray is operated in a vertical position and allows the flowing water to be seen through it. The loop does not give room for air inlet except for the air in contact with the water surface in the reservoir which is propelled into the circuit by the pump and air bubbles are easily seen through the transparent flow meter hence allowing a water-air two-phase flow system to be created. In a bid to account for the background gamma counts, empty runs of the spectrometer with neither the source nor the pipe were first taken. Thereafter, another set of runs was taken with the empty pipe in place but with no water running through it. The gamma source was then mounted at the

test section while the pipe was totally filled with water and runs were taken. Water was then pumped through the loop for a few minutes until a stable flow could be observed on the rotameter. Four runs were taken for each of the flow rates considered. The control valve was used to vary the flow of the water and the flow rates of 1.0g/min, 1.5g/min, 2.0g/min, 2.5g/min, 3.0g/min, 3.5g/min, and 4.0g/min were considered. Each run lasted 180s and the corresponding gamma-ray counts were stored. The water flow rates,  $\dot{m}$ , were converted to water velocity,  $u_L$  from gallon per minute to meter per second using the following expression:

$$u_L = \frac{\dot{m}}{\rho_L \times A}, \quad (2)$$

where  $\rho_L$  is the water density and has a value of  $998.5 \text{ kg/m}^3$  and  $A$  is the cross-sectional area of the pipe in  $\text{m}^2$ .

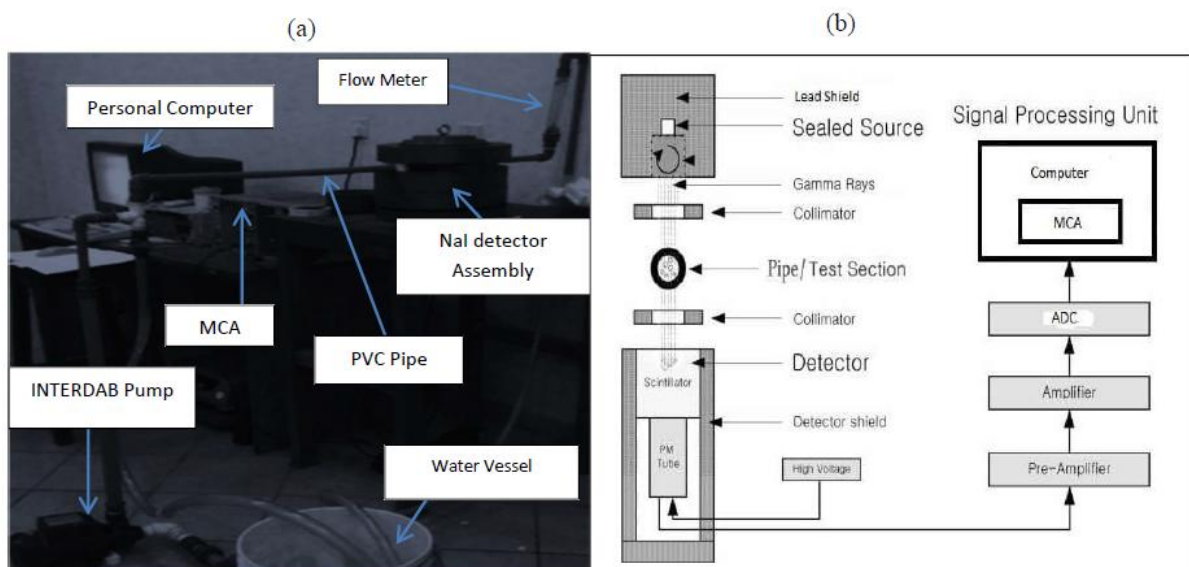


Figure 1: Picture of the experimental setup (a) and the schematic diagram of a simplified single-energy gamma densitometer (b)

## 2.2 Calculation of void fraction

For the calculation of the void fraction, the gas-liquid two-phase flow equation was used [10]:

$$\alpha_{exp} = \frac{\left(\frac{I_{GL}}{I_L}\right)}{\left(\frac{I_G}{I_L}\right)}, \quad (3)$$

where  $I_G$ ,  $I_L$  and  $I_{GL}$  are the counts for unit void, zero void and the void to be determined, respectively.

For the theoretical model to which the experimentally evaluated void fractions were compared the knowledge of the gas velocity is required. Although the experimental setup does not have any air inlets, air was pumped through the PVC pile loop alongside the water from the water surface since the water vessel was open to air. Since the air bubbles were circulated by the moving water, the air velocity is therefore a fraction of the water velocity. The water velocity fractions considered for the air are 5%, 15%, 30%, 40% and 50%.

## 3. Results and discussion

The gamma densitometer is operated in counts mode, the spectra are uniform and unaltered despite slight changes in counts from run to run. The experimental void fraction was computed from the measured count rates for different water velocities varying from 0.5 gpm to 4 gpm. Figure 2 shows the

experimentally derived void fraction and exponential fit. The exponential fit is plotted alongside the Chisholm ( $\alpha_{Ch}$ ) theoretical model in which the air velocity is varied as a fraction of the water velocity by 5%, 25%, 30%, 40% and 50%, as shown in Figure 3.

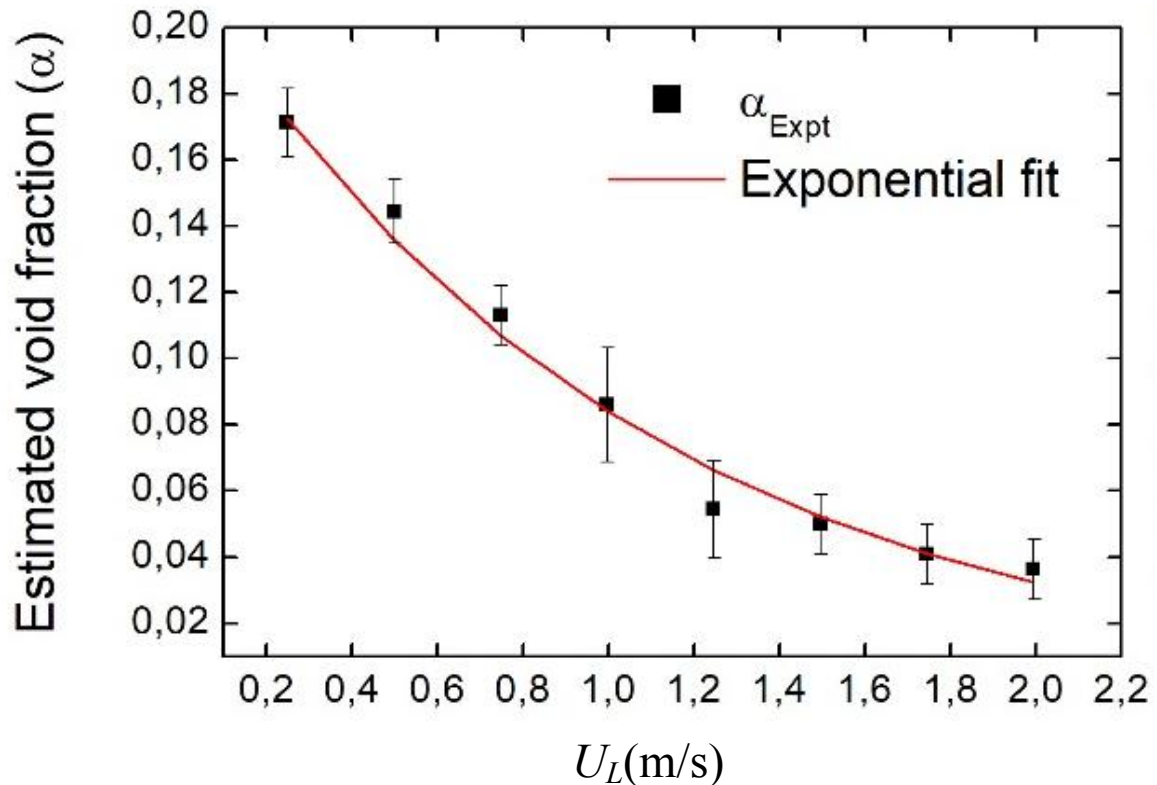


Figure 2: The experimental void fraction together with the exponential fit

As expected, the void ratio values reduced with increasing water velocity with errors margins ranging from between 6% to 27%. The experimental  $\alpha_{exp}$  was successfully fitted with an exponential decay function as:

$$\alpha_{exp} = 0.219e^{-0.959U_L} \quad (4)$$

While the fractions of 5% and 25% of  $U_L$  were found to be much lower than the experimental  $\alpha_{exp}$ , the fractions of 50% of  $U_L$  were found to be significantly higher. The best agreement between theory and experiment was achieved when the air velocity was taken to be 40% of the water velocity although a good agreement was also found for the fraction 30% of  $U_L$  for low values of  $\alpha_{exp}$  corresponding to water velocity of 1.2 – 2.0 m/s, for the theoretical model. Although the mathematical expression of the void fraction by the theoretical model is all hyperbolic functions which can well be compared with the exponential function obtained, as shown in Figure 2. In principle, hyperbolic functions are obtained as a sum of exponential functions when appropriate coefficients are applied. In order to better appreciate the model, the experimental results,  $\alpha_{exp}$  was plotted against the theoretical void fraction at 40% of  $U_L$  as shown in Figure 3 and it was observed that the model give, within the limits of experimental error, a fairly good representation of the void fraction up to  $\alpha_{exp} = 0.15$ . However, there is a noticeable disagreement between theory and experiment as the void fraction

values increase which corresponds to lower water velocity. At the lowest water velocity for example, the Chisholm models deviate by 59%.

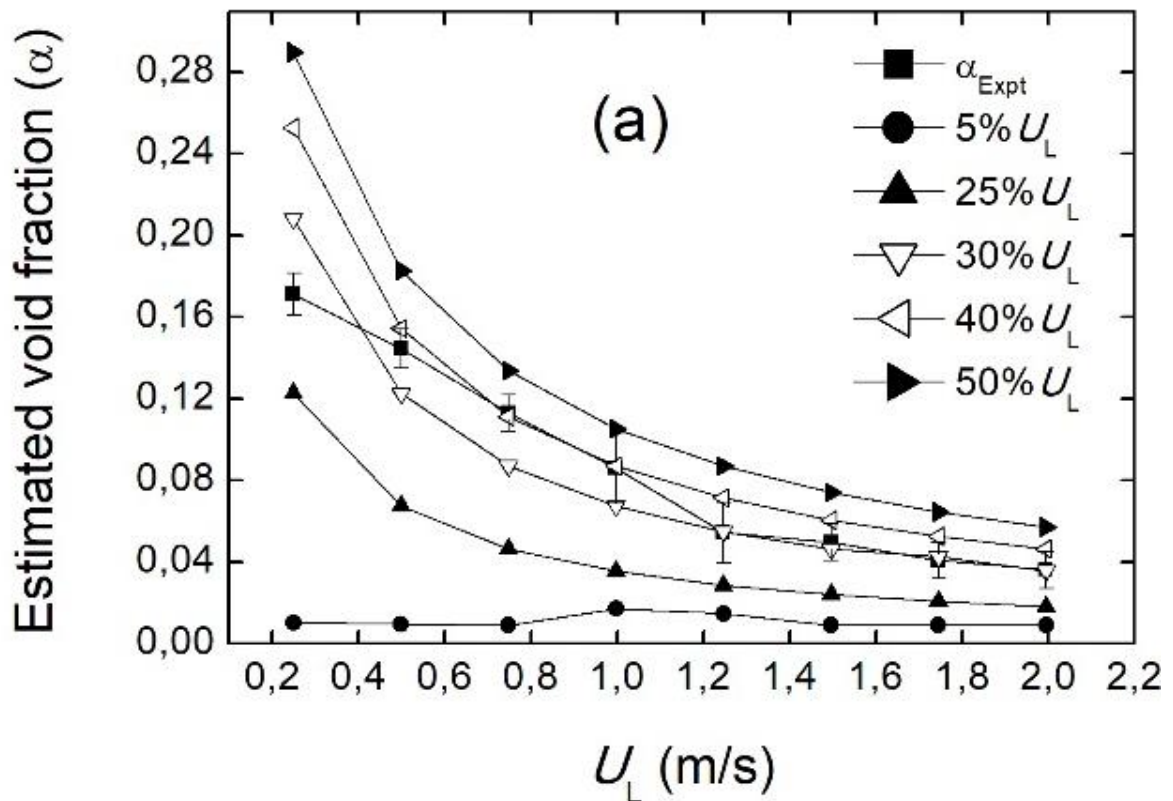


Figure 3: The experimental void fraction together with the parameterization of the Chisholm theoretical model with  $U_G = 5\%$ ,  $25\%$ ,  $30\%$ ,  $40\%$  and  $50\%$  of  $U_L$

#### 4. Conclusion

A single-energy gamma densitometer for monitoring the flow properties of liquid gas two-phase fluids using a Cs-137 gamma-ray source was studied using 1.27cm inner-diameter PVC pipe, a NaI (Tl) detector and an INTERDAP MKP type water pump. Water flow rate was varied from 0.5g/min to 4.0g/min and the obtained void fractions were compared with the parameterization of the Chisholm model, assuming constant air velocity. It was observed that the theoretical model agrees well with the experimental result when the air velocity is taken to be 40% of the water velocity of a horizontal bubbly type flow. The use of two or more theoretical model predictions is recommended for further comparative study with experimental process.

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## References

- [1] Poulikkas, A., 2003. Effects of two-phase liquid-gas flow on the performance of nuclear reactor cooling pumps. *Progress in Nuclear Engineering* 42, 3 – 10.
- [2] Julia, J.E., Hibiki, T., 2011. Flow regime transition criteria for two-phase flow in a vertical annulus. *International Journal of Heat and Fluid Flow* 32, 993 – 1004.
- [3] Usikalu M. R., Maleka P. P., Ndlovu N. B., Zongo S., Achuka J. A., and Abodunrin T. J. (2019). Radiation dose assessment of soil from Ijero Ekiti, Nigeria (2019) Radiation dose assessment of soil from Ijero Ekiti, Nigeria, *Cogent Engineering*, 6:1, 1586271. <https://doi.org/10.1080/23311916.2019.1586271>
- [4] Adagunodo T.A., George A.I., Ojoawo I.A., Ojesanmi K., and Ravisankar R. (2018). Radioactivity and radiological hazards from a kaolin mining field in Ifonyintedo, Nigeria. *MethodsX*, 5: 362–374. doi: 10.1016/j.mex.2018.04.009.
- [5] Cioncolini, A. Thome, J.R. 2012.Void fraction prediction in annular two-phase flow. *International Journal of Multiphase Flow*, 43, 72 - 84.
- [6] Zhao, Y., Bi, Q., Yuan, Y., Lv, H., 2016. Void fraction measurement in steam-water two-phase flow using the gamma ray attenuation under high pressure and high temperature evaporating conditions. *Flow Measurement and Instrumentation*, 49, 18 – 30.
- [7] Delhaye, J.M., 1986. Recent advances in two-phase flow instrumentation. *Proceedings of the Eighth International Conference on Heat Transfer*, San Francisco, Vol.1, Washington, D.C., Hemisphere Publishing Corp.
- [8] Roitberg, E., Shemer, L., Barnea, D., 2007. Measurements of cross-sectional instantaneous phase distribution in gas-liquid pipe flow. *Experimental Thermal and Fluid Science* 31, 867 – 875.
- [9] Gbenu, S.T., Oladejo, O.F., Olukotun, S.F., Fasasi, M.K., Balogun, F.A., 2016. Assessment of radiological hazard of quarry products from southwest Nigeria. *Journal of Radiation Research and Applied Sciences* 9, 20 – 25.
- [10] Park, H.-S., Chung, C.-H., 2007. Design and application of a single-beam gamma densitometer for void fraction measurement in a small diameter stainless steel pipe in a critical flow condition. *Nuclear Engineering and Technology* 4, 349 – 358.