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Original Article

Precise Void Fraction Measurement in Two-phase Flows Independent of the Flow Regime Using Gamma-ray Attenuation

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ABSTRACT

Void fraction is an important parameter in the oil industry. This quantity is necessary for volume rate measurement in multiphase flows. In this study, the void fraction percentage was estimated precisely, independent of the flow regime in gas–liquid two-phase flows by using γ-ray attenuation and a multilayer perceptron neural network. In all previous studies that implemented a multibeam γ-ray attenuation technique to determine void fraction independent of the flow regime in two-phase flows, three or more detectors were used while in this study just two NaI detectors were used. Using fewer detectors is of advantage in industrial nuclear gauges because of reduced expense and improved simplicity. In this work, an artificial neural network is also implemented to predict the void fraction percentage independent of the flow regime. To do this, a multilayer perceptron neural network is used for developing the artificial neural network model in MATLAB. The required data for training and testing the network in three different regimes (annular, stratified, and bubbly) were obtained using an experimental setup. Using the technique developed in this work, void fraction percentages were predicted with mean relative error of <1.4%.

1. Introduction

Gas volume fraction (GVF), or simply void fraction, is an important parameter in describing gas–liquid two-phase flows, since it is required to predict values such as pressure drop, heat transfer, and the occurrence of critical two-phase flow. Quantitative knowledge of such effects is needed in the oil industry and to design industrial reactors. Several methods can be applied to measure GVF [1,2]. The methods commonly used are based on weight, electromagnetic signals, optical signals, or radiation

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attenuation. Radiation attenuation methods such as γ densitometry determine the GVF of two-phase systems nonintrusively. Among the techniques based on radiation attenuation (neutron, γ, and X-rays), γ densitometry has several advantages: it is less expensive than neutron densitometry and it offers—contrary to X-ray attenuation techniques—monoenergetic rays without intensity fluctuations [3]. Several attempts have been made to measure void fraction using γ-ray attenuation. Jiang et al designed a single-beam γ-densitometer operated in the count mode for small pipe sizes [4]. They measured the void fraction with error $< 7\%$. Åbro and Johansen studied the void fraction measurement of gas-liquid flow by means of multibeam γ-ray attenuation [5]. The system consists of an Am-241 source, two transmission detectors, and one scattered detector. The void fraction estimation was improved by the flow regime compensation. Åbro et al also investigated a method for determining the flow regime using γ-ray densitometry and multilayer perceptron (MLP) neural networks [6]. The MLP neural networks were trained on simulated γ-ray data and then used to identify the simulated flow regime. The results show that annular, stratified, and bubbly regimes were always correctly distinguished and the error of the void fraction is $<3\%$ for all the three regimes. Jing and Bai also studied flow regime identification in two phase flow in a vertical pipe using radial basis function neural networks based on dual modality densitometry [7]. In 2009, Salgado et al proposed a methodology based on neural networks to predict volume fractions [8]. They simulated a system comprised of three detectors (one of them for transmitted γ-rays and two of them for scattered) and a dual energy γ-ray source (Eu-152 with energy 121 keV and Ba- 133 with energy 356 keV) using the Monte Carlo N-particle code. In 2014, El Abd showed that the sensitivity of Compton–Compton scattering is more than transmission and traditional Compton scattering for determining the void fraction in the stratified regime of two-phase flows [3]. Also, it has been shown that artificial neural networks (ANNs) could be as a useful tool for prediction, classification, and optimization in engineering, especially in cases where many parameters could influence the operation of the system [9–16].

In all previous studies based on a multibeam γ-ray attenuation technique to determine void fraction independent of the flow regime in two-phase flows, three or more detectors were used. In this study, a methodology is proposed to determine void fraction independent of the flow regime in gas–liquid two phase-flows based on a multibeam γ-ray attenuation technique and using an ANN. Using fewer detectors is of advantage in industrial nuclear gauges because of reduced expenses and improved simplicity. ANNs could be useful and powerful tools for predicting and classifying the data. Experimental data obtained from an experimental setup in the laboratory were used as training and test data for the ANN to predict the void fraction independent of the flow regime.

2. Materials and methods

2.1. *Multibeam γ-ray technique*

An experimental setup was implemented to provide the required training and test data for the ANN to predict the void fraction independent of the flow regime in gas–liquid two-phase flows. All the experiments were done in static conditions. A Pyrex-glass pipe with an inner diameter of 9.5 cm, wall thickness of 0.25 cm, and density of 2.35 g/cm^3 was used as the main pipe. A cesium (Cs-137) source with an activity of 2 mCi was also used. A measurement time of 600 seconds was chosen because of the static nature of the experiment. A collimator with an opening of 36° was used to make a broad beam. Two 2.5-cm NaI detectors were located 25 cm from the source as transmission detectors. The first detector was located at an angle of 0° and the second at 13° with respect to the source. In both detectors, which were connected to two multichannel analyzers, only the transmitted photons under the full energy peak of emitted γ-of Cs-137 are registered (1 FWHM from centered channel). The experimental setup is shown in Fig. 1.

Gasoil and air were chosen as the liquid and gas phases, respectively. Void fractions of 10%, 20%, 30%, 40%, 50%, 60%, and 70% were tested for the annular, stratified, and bubbly regimes (totaling 21 experiments). For the annular regime, different void fractions could be calculated by using Eq. (1) [5]:

$$\alpha_a = \frac{\pi r^2}{\pi R^2} = \frac{r^2}{R^2} \tag{1}$$

where R is the radius of the pipe, r is the radius of the gas phase, which is located in the center of the pipe, and α_a is the void fraction in the annular regime. Since the radius of the pipe (R) is constant, different void fractions would be calculated just by changing the radius of the gas phase (r). The void fractions from 10% to 70% made in the laboratory in the annular regime are shown in Fig. 2 from the top side view.

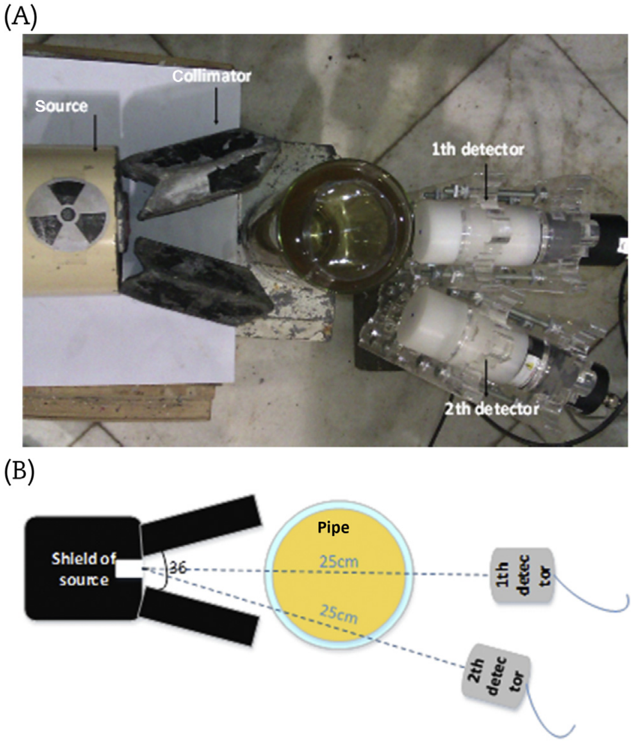

Fig. 1 – (A) Experimental setup. (B) Schematic view of experimental setup.