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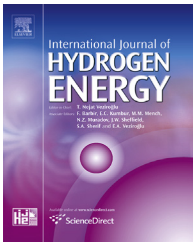

Optimization of a method for identifying the flow regime and measuring void fraction in a broad beam gamma-ray attenuation technique

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ABSTRACT

A gamma-ray transmission technique is present to measure the void fraction and identify the flow regime of a two-phase flow using two detectors which were optimized in terms of detector orientation. Using Monte-Carlo simulation, experimental results were utilized for training an artificial neural network. Radial Basis Function was used to classify flow regimes (annular, stratified and bubbly) and predict the value of void fraction. All of the training and testing data sets were determined correctly and the mean relative error percentage of predicted void fraction was less than 1.5%. Although the method was applied to a certain pipe size in a static flow configuration, it provides a framework for application to other configurations.

Introduction

Nowadays, identifying the flow regimes and precise predicting the void fraction through a multi-phase flow measurement is an important problem in petroleum, chemical, nuclear and mechanical engineering. In this regard, there are many different methods that gamma ray attenuation technique is one of the most precise techniques. The wealth of data accumulated by radiation-based MPFM can be fed into reservoir simulation codes to enhance their accuracy and reliability [1].

There are a lot of difficulties for modeling and measuring direct and indirect parameters accurately in the two-phase flow in comparison with the single phase flow [2–5].

Abro et al. examined the performance of single-beam and multi-beam gamma-ray densitometry for volume fraction measurement of gas–liquid two phase flows [6]. The results show that usage of the multi-beam gamma-ray measurement principles is more accurate than single-beam when four detector responses are combined. Abro and co-workers also

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proposed a multi-beam gamma-ray densitometry method using artificial neural network (ANN) to determinate void fraction and identify the flow regime in small diameter pipes [7]. Jing et al. investigated the dual modality densitometry method using artificial neural networks (ANNs) in order to determine the gas and water volume fractions in a three-phase flow [8]. Jing and Bai, also studied the flow regime identification in two phase flow in vertical pipe using Radial Basis Function (RBF) neural networks based on dual modality densitometry [9]. Faghihi et al. modeled three basis two-phase flow regimes including homogenous, stratified and annular in a vertical pipe by using polyethylene phantoms [10]. For all three modeled flow regimes all transmitted and scattered gamma rays in all directions were measured by setting a gamma ray source and detector around the pipe. Finally, they presented innovative correlations to predict the void fraction in two-phase flow in a vertical pipe. In 2014, El Abd showed that usage of Compton–Compton scattering is more precise than transmission and traditional Compton scattering for determining the void fraction in stratified regime of two phase flows [11]. In recent years, it has been shown that artificial neural networks could be as a useful tool for predicting, classification and optimization in nuclear engineering problems especially in cases which lots of parameters could influence the operation of the system. These wide applications were shown in many recent volume fraction measurement studies [12–20]. In all previous studies that multi-beam gamma ray attenuation technique has been implemented to identify the flow regime and measure void fraction in multiphase flows, three or more detectors have been used. In this study, a system consists of only two NaI detectors and one Cs-137 source, is introduced to identify the flow regime and determine void fraction in gas–liquid two phase flows precisely based on fan beam gamma ray attenuation technique and using artificial neural network (ANN). A Pyrex-glass pipe with inner diameter of 95 mm, wall thickness of 2.5 mm and density of 2350 kg/m^3 was used as the main pipe. The considered regimes in this study were annular, stratified and bubbly in 20°C and 1 bar pressure. In addition to precise prediction of volume fractions, usage of fewer detectors is significant advantage in industrial gamma-ray gauges because of reducing economical expenses and also simplicity of working with these systems. In our previous study, a method based on dual modality densitometry was presented to first identify the flow regime and then predict the void fraction in two-phase flows [21]. All the three regimes were correctly distinguished and void fraction was predicted in the range of 0.05–0.95. The required data had been achieved using simulation but in this study, the required data was achieved using experiment. Furthermore, one transmission detector and one scattering detector (dual modality densitometry) were replaced by two transmission detectors. This new configuring is very helpful in operational condition because of stronger signal of transmission detector relative to scattering detector. The flow has high velocity in pipe and the sufficient count in detectors must be achieved in minimum time, therefore the scattering detector in previous work was replaced with the second transmission detector in this work (registered count rate in transmission detector in this setup is more than a scattering detector).

In this study optimal detector positions were obtained using Monte-Carlo simulations, for three flow regimes and for void fractions in the range of 0.1–0.7. Experimental were conducted to train and test data for ANN to identify the flow regime and predict the value of the void fraction.

Determination of optimal detector orientations

The Monte Carlo N-Particle (MCNP) code [22], version X, was used in this study to obtain optimal position of the two transmission detectors used in a broad beam gamma ray attenuation method.

The defined geometry in the simulations is based on the experimental setup in the laboratory. A Pyrex-glass pipe with inner diameter of 95 mm and thickness of 2.5 mm was used as the main pipe. Gasoil with density of 835 kg/m^3 (chemical formula of $C_{12}H_{23}$) and air were used as the liquid and gas phases, respectively. Simulations were conducted for the three flow regimes of annular, stratified and bubbly in the void fraction range of 0.1–0.7 in steps of 0.1.

The bubbly regime was simulated an arrangement of 80 cubic plastic straws (same long as the pipe) distributed regularly over the pipe's cross section. For making each 0.1 void fraction, two straws which are covered by the measurement volume between the first detector and source were filled regularly with air, while 6 other straws over the total pipe cross section were filled randomly. A cross sectional view of the simulated void fractions in the range of 0.1–0.7 has been shown in Fig. 1. The white and blue (in the web version) cells correspond to gas phase and liquid phase, respectively. This method was used to model bubbly regime, because making the ideal bubbly regime with different void fractions in static conditions was so difficult.

We used ^{137}Cs which emits photons with energy of 662 keV, as the radioactive source. A photon with this energy has considerable penetration into matter and is appropriate for industrial applications. Also, a shield which is made of lead with thickness of 50 mm was used around the source. In all simulations, a broad beam geometry with the angle of 36° and two 25.4 mm NaI detectors which are located 250 mm far from the source, have been used. The distances were chosen arbitrary and optimization was done for this configuration. It is clear if distances are changed, the optimal positions which are obtained in this study would change too. Since just transmitted photons (photo peak) were registered in detectors, there was no need to collimate the detectors. The STOP card was used to terminate calculations when a desired tally precision was reached. In all simulations, a maximum 0.01 relative error was set using the STOP card; therefore, all of the Monte-Carlo results meet this standard of precision. The geometry of simulation is shown in Fig. 2.

One of the detectors was kept fixed at an angle of 0° with respect to the pipe's diameter, and the second detectors' orientation was changed from an angle of 7° to an angle of 18° by 1° steps. The angle 7° is the minimum possible angle in which the transmitted detectors do not interfere with each other. While, the angle 18° is the maximum possible angle that the gamma rays would transmit through the pipe and arrive to the 2nd detector. In each position of the detectors, various