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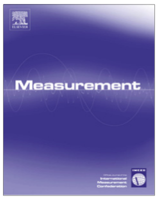

Flow regime identification and void fraction prediction in two-phase flows based on gamma ray attenuation

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ABSTRACT

Flow regime information can be used to improve measurement accuracy on gas volume fractions and as complementary information for other types of flow instrumentation in order to enhance their accuracy. In this study a method based on dual modality densitometry using artificial neural network (ANN) was presented to first identify the flow regime and then predict the void fraction in two-phase flows. The full energy peak (transmission count), photon counts of Compton edge in transmission detector and total count in the scattering detector, were chosen as the three inputs of the ANN. The stratified, homogenous and annular regimes with various void fractions were simulated by the Monte Carlo N-Particle (MCNP) code, version X, in order to obtain adequate data set used for training and testing the ANN. To validate the simulated results, several experiments were carried out in the annular regime of two-phase flow. Experimental results were in good agreement with the simulated data. The maximum difference between experimental and simulated results for the transmission, Compton edge and scattered counts, is 3.4%, 3.8% and 3.6%, respectively. By applying this method, all the three regimes were correctly distinguished and void fraction was predicted in the range of 5–95% with error of less than 1.1%.

1. Introduction

Volume fraction measurement of multiphase flows is of vital importance in oil and gas industries operating onshore, offshore and subsea. Liquids and gases are the main components of oil and gas reservoirs and these components are transported through pipelines. Whether continuing drilling is economical or not, quantitative estimates of the individual components are necessary. Also with sufficient information about the volume fraction of each component, the separating process can be optimized. There is the need to identify the type of flow regime in the transportation process and also volume fractions of the individual components. This is due to the fact that the flow regime directly affects the efficiency of the separating process whilst the volume fractions of the individual components provide indication as to whether the drilling process should be continued or stopped. The cost of production in the oil industry is relatively high and thus an efficient drilling and separating process greatly determines the profit margins [1]. Among the many available techniques in multiphase flow metering, those based on radiation techniques appear to be attractive in many application, because they are non-invasive and in general, quite reliable [2]. Some studies have been done on measuring the volume fraction and determining the flow regime in multiphase flows by means of gamma-ray attenuation techniques. Abro et al. [3] 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. Their system

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consists of an ^{241}Am source with energy of 59.5 keV and three detectors located at 180°, 154° and 140° respect to the source. Detector responses were simulated by using EGS4 software package for void fractions covering the range from 0% to 100% and the simulations were performed with homogeneous, stratified and annular flow regimes. All three regimes were distinguished correctly and void fraction was measured with error of less than 3% independent of the flow regime. Jing and Bai [4], used gamma ray scattering energy spectrum detected by one scattering detector as the input of RBF neural networks to distinguish the gas–liquid two-phase flow regime of vertical pipes. ^{241}Am was chosen as the low energy source and all simulations were done with Monte Carlo software Geant4. The results showed that annular and homogenous regimes could be completely distinguished and most of the slug flows were recognized by the neural network. Salgado et al. [5] proposed a new methodology for flow regimes identification and volume fraction predictions in water-oil-gas multiphase systems. Their methodology was based on gamma-ray pulse height distributions (PHDs) pattern recognition by means of the artificial neural networks. The PHDs were directly used by the ANNs without any parameterization of the measured signal. The system comprised four ANNs. The first, identified the flow regime and the other three ANNs were specialized for volume fraction predictions for each specific regime. The MCNP-X code was used to provide training, test and validation data for the ANNs. The proposed ANNs could correctly identify all three different flow regimes with satisfactory prediction of the volume fraction in water–oil–gas multiphase system. Jing et al. [6] also implemented the dual modality densitometry method using ANNs to determinate volume fraction in water–oil–gas three-phase flows. The results showed that the network could predict gas volume fraction fit real gas fraction well, but water volume fraction had some deviations.

In the present study, a method proposed to identify flow regime and measure the void fraction in two-phase flows based on dual modality densitometry using ANN.

Many researchers have used the different types of ANNs in gamma densitometry [3–13] in order to classification, clustering and prediction. Cong et al. [14] reviewed applications of ANNs in flow and heat transfer problems in nuclear engineering.

First, only the transmission and scattering counts were used as the inputs of the ANN in order to distinguish the three flow regimes from each other. These two inputs were insufficient for the ANN to distinguish correctly all the three regimes. So, the Compton edge count in transmission detector was used as the third input for the ANN. By using these three inputs, all the flow regimes were distinguished with 100% precision. After distinguishing the flow regimes, the other three developed ANNs, could predict void fraction for each specific regime with high precision.

2. Experimental setup

To validate the simulation data, several experiments were carried out for annular regime of two phase flows. All the experiments were done in static conditions. Separator pipes made of PVC films with various radii, were used to separate liquid and gas phases from each other and model the annular regime in static conditions. Because of the thin thickness of separator pipes, they were not considered in the simulations. Also a Pyrex-glass pipe with inner diameter of 9.5 cm and wall thickness of 0.25 cm was used as the main pipe. A 2 mCi Cs-137 (662 keV) source and a measurement time of 600 s were chosen because of the static nature of the experiment. For dynamic situations, less measurement time is required. The source was collimated in order to make a narrow beam (a cubic collimator with 0.6 cm width, 2 cm height and 10 cm length). One NaI detector with dimensions of 1 × 1 inch was located 50 cm far from the source as transmission detector. Another 1 × 1 inch NaI detector which serves as the scattering detector, was placed 2 cm far from the pipe and in direction of 45° respect to the transmission detector [6]. Also the distance between source and pipe was chosen 30 cm. In the transmission detector connected to a Multi-Channel Analyzer (MCA), transmitted photons and Compton edge counts are registered and in the scattering detector connected to a counter, scattered photons are registered. The experimental setup and the three inputs of the ANN are shown in Fig. 1. Gasoil and air were chosen as the liquid and gas phases, respectively. Void fractions of 0%, 20%, 30%, 40%, 50%, 60% and 70% were tested.

3. Simulation

A Monte Carlo simulation model of the dual modality densitometry measurement setup has been developed and is used in this study to predict what one can expect to measure with known void fractions and flow regimes. An important advantage for the simulation model is the exact defined reference of flow parameters for both the volume fractions and the flow pattern. The Monte Carlo model used in this work is based on the Monte Carlo N-Particle (MCNP) code, version X, which is used for neutron, photon, electron, or coupled neutron/photon/electron transport [15]. The entire dual modality densitometry setup is reconstructed in the MCNP simulator. Also gasoil with chemical formula $C_{12}H_{23}$ with density of 0.826 g/cm^3 was chosen as the liquid phase same as the liquid used in experiment. Registered counts in both transmission and scattering detectors are calculated per one source particle in the MCNP-X code using Pulse Height Tally F8. At the first step, simulated data for the annular regime were benchmarked toward experimental measurements. For the sake of simplicity in evaluation of the data, it is better to normalize both simulated and experimental results to unit [16]. As shown in Fig. 2, the maximum difference between experimental and simulated data for transmission count, Compton edge count and scattering count, is 3.4%, 3.8% and 3.6%, respectively. Results show that simulated data are in good agreement with the experimental results. The most part of observed deviations could be somewhat related to making the annular regime phantoms in the experiments. The dimensions of phantoms are not exactly same as the simulated geometry.