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Intelligent densitometry of petroleum products in stratified regime of two phase flows using gamma ray and neural network

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ABSTRACT

Radiation based instruments in the petroleum industry are usually utilized to measure the volume fraction and flow regime type of multiphase flows in stable conditions. But in unstable conditions (when the temperature and pressure could change in pipelines), in addition to mentioned parameters, online measuring the density of liquid phase is of great importance. In this work, a combination of dual modality densitometry technique and artificial neural network (ANN) was used in order to predict the density of liquid phase in the stratified regime of gas-liquid two phase flows. In the first step, a Monte Carlo simulation model was used to obtain the optimum position for the scattering detector in dual modality densitometry configuration. At the next step, an experimental setup was designed based on obtained optimum positions for detectors from simulation to generate the required data for training and testing the ANN. Applying this novel method, density of liquid phase was predicted with the mean relative error (MRE) of less than 0.1243% in the stratified regime of gas-liquid two phase flows for void fractions in the range of 10–70%.

1. Introduction

Gamma radiation based instruments are typically implemented in single phase and multiphase flows in the petroleum industry. In the case of single phase flows, some studies have been done in recent years. Khorsandi and Feghhi [1] used Monte Carlo N Particle (MCNP) code for simulation of different configurations of density measurement tools based on the transmission and scattering principles. A laboratory setup was implemented for benchmarking of the simulation results. They used a disc source of ^{137}Cs with the activity of 50 μCi, a 3-in. NaI (Tl) Scintillator detector and a 4-in. (in diameter) polyethylene pipe with the wall thickness of 0.2 cm for experiment. Their experimental results showed that petroleum products such as gasoil, gasoline and kerosene can be distinguished from each other with the accuracy of 0.1 g/cm^3 in practical conditions. Khorsandi et al. [2] designed a gamma ray densitometer with the help of ANN that was capable of measuring the fluid density inside a pipe independent of it's diameter (in fact the pipe's diameter could be variable). They used MCNP code to register transmitted photons from a polyethylene pipe with various diameters that was filled with different fluids. The simulated results were used for training the ANN model of multilayer perceptron (MLP). Trained ANN model predicted the density inside the pipe independent of it's diameter with a MRE of less than 0.5%. Roshani et al. [3] also used same methodology for predicting the density independent of pipe's diameter with this difference that they utilized adaptive neuro-fuzzy inference system (ANFIS) instead of ANN. They could predict the density with the MRE of less than 2.64%.

In the case of multi phase flows, a large number of studies have been done in recent years using gamma radiation based instruments. Roshani et al. [4] used a dual energy source consists of ^{241}Am (59.5 KeV) and ^{137}Cs (662 KeV) with just one transmission NaI detector to predict volume fraction in oil-water-gas three-phase flows. By using ANN, they predicted the volume fraction of oil, water and gas phases with the mean absolute error (MAE) of less than 1%. Nazemi et al. [5] presented a gamma-ray transmission technique 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. They utilized ANN to classify flow regimes (annular, stratified and bubbly) and predict the value of void fraction. All the flow regime types were determined correctly and void fraction was predicted with the MRE of less than 1.5%. Roshani et al. [6] investigated a simple detection system comprised of one ^{60}Co source and just one NaI detector in order to identify flow regime and measure void fraction in gas-liquid two phase flows. For this purpose, 3 main flow regimes of two-phase flows including stratified, homogenous and annular with void fractions in the range of 5–95% were simulated by MCNP code. At the first step, 3 features

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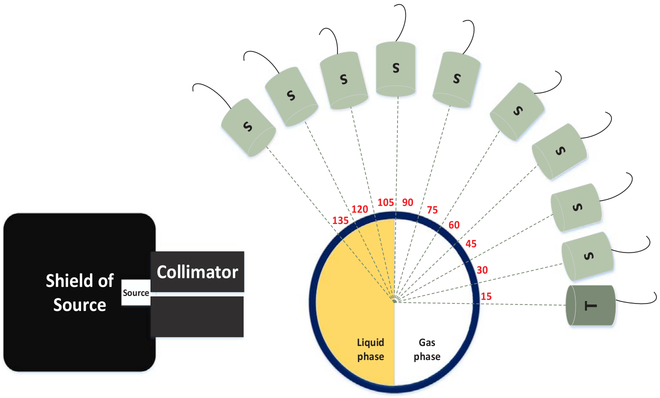

Fig. 1. Various simulated positions of the scattering detector in order to obtain the most sensitive position relative to density changes.

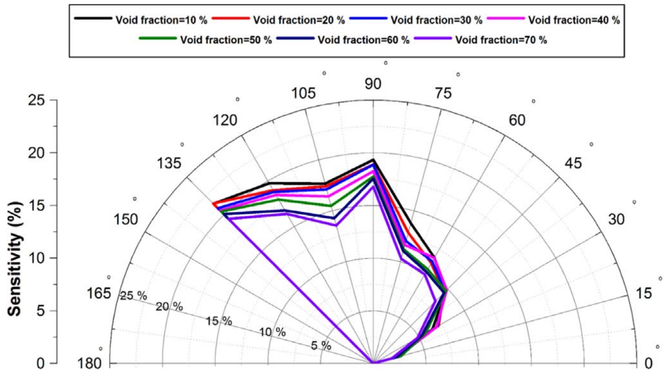

Fig. 2. Sensitivity of the scattering detector in different positions relative to the density changes of the liquid phase for void fractions of 10%, 20%, 30%, 40%, 50%, 60% and 70%.

(count under full energy peaks of 1.173 and 1.333 MeV, and count under Compton continuum) were extracted from registered gamma spectrum. These 3 extracted features were used as the inputs of ANNs. A primary network was trained for identifying the flow regimes, but after testing many different structures, it was found that just two regimes of stratified and annular could be completely identified from each other. After identifying the mentioned two flow regimes by the first ANN, two specific ANNs were also implemented for predicting the void fraction. Using the proposed method, void fraction was predicted with a the MRE of less than 0.42%. More investigations about this field can be found in references [7–44].

As mentioned above in single phase and multi phase flows, the density of fluid and the volume fraction have typically been measured using gamma ray attenuation, respectively. But sometimes in multi phase flows, online measuring the density of liquid phase is required that is the main purpose of the present study. In this work we used a combination of dual modality densitometry technique and ANN in order to predict density of liquid phase in stratified regime of gas-liquid two phase flows. At the first step, we used a Monte Carlo simulation model to obtain the optimum position for the scattering detector in dual modality densitometry configuration. At the next step, an experimental setup was designed based on obtained optimum positions for detectors from simulation to generate the required data for training and testing the ANN. A comprehensive description of this procedure is explained in the following.

2. Materials and method

2.1. Simulation

Purpose of this paper is predicting the density of liquid phase in the stratified regime of a gas-liquid two phase flow. Since the flow regime is constant and just the density of liquid phase and void fraction can be changed, therefore at least two features should be extracted from the flow. To this aim, we used dual modality densitometry technique which is comprised of one detector for registering the transmitted photons and one detector for registering the scattered photons. In this technique, transmission detector is usually positioned in front of the source (angle of 0°) while scattering detector can be positioned in different angles. By changing position of the scattering detector, sensitivity of that relate to the density of liquid phase can be changed, too. Therefore, at the first step in this paper, we used a Monte Carlo simulation model to obtain the optimum position for the scattering detector in dual modality densitometry configuration. The desired position is where the sensitivity of detector relate to the density changes of liquid phase is the most. The Monte Carlo model used in this work is based on the MCNP code, version X, that is a general purpose code for calculating the time dependent and continuous energy neutrons, photons and electron transports in three dimensional geometries [45]. The dual modality densitometry configuration was simulated based on the existing devices in our laboratory (one ^{137}Cs source, two 25.4 × 25.4 mm NaI scintillator detectors and a Pyrex-glass pipe with the inner radius of 47.5 mm and wall thickness of 0.25 mm). In all simulations, position of the transmission detector was kept fixed in the angle of 0° and position of the scattering detector was changed from 15° to 135° respect to the center of the pipe with steps of 15°. This procedure is shown in Fig. 1.

Registered counts in the transmission and scattering detectors were calculated per one source particle in the MCNPX code using pulse height tally F8. In order to better fit the full energy peak shape of gamma-ray energy spectrum, the Gaussian energy broadening (GEB) option was utilized (FTn card in the input file of the code). The technique consists of using a “FT8 GEB” card in the input file of MCNP code and calculating the full width at half maximum (FWHM) of the full energy peak of gamma ray with various energies in the laboratory. GEB parameters (a, b and c) were calculated for a 25.4 × 25.4 mm NaI scintillator detector in our previous study [6]. In that work, parameters of “a”, “b” and “c” were obtained 0.0109 MeV, 0.0696 MeV$^{1/2}$ and 0.0226 MeV^{-1}, respectively. These parameters were utilized with the GEB command in the input file of MCNP code to take account the energy resolution of a 25.4 × 25.4 mm NaI detector in the simulations.

Sensitivity response of the scattering detector in different positions relative to the density changes of the liquid phase from the lowest density (0.735 g/cm^3) to the highest density (0.980 g/cm^3) of liquid phase for void fractions in the range of 10–70% was calculated according to Eq. (1):

Fig. 3. Phantoms used to model various void fractions in the range of 10–70% for stratified regime.