



Online measuring density of oil products in annular regime of gas-liquid two phase flows



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ABSTRACT

Gamma-ray densitometry is widely implemented in oil industry because it is an online technique and also has a good precision. If there is single phase flow in oil pipelines, measuring the density is possible just by using one source and one detector. But if in addition to oil, there is gas in oil pipelines and in fact there is a two-phase flow, conventional gamma ray densitometry (one source and one detector) could not be used for determining the density of liquid phase. In this study, a novel method is proposed for online measuring density of liquid phase in annular regime of liquid-gas two-phase flows using dual modality densitometry technique and artificial neural network (ANN). An experimental setup was designed in order to provide the required input data for training and testing the network. Registered counts in both scattering and transmission detectors were used as the inputs of the ANN and density of liquid phase was used as the output of the ANN. Using the proposed methodology, density of liquid phase was predicted with error of less than 0.031 g/cm^{-3} in annular regime of gas-liquid two phase flows for void fractions in the range of 10–70 percentages.

1. Introduction

Measuring the density is of great importance in lots of industries such as mining [1], ceramic, cement, power plant, wood and steel industries [2]. In oil industry, measuring the density is usually used for monitoring the oil products and their interfaces which make it essential to utilize an online and non-destructive measurement method [3,4]. By comparing with the conventional methods, the gamma densitometer system is a reliable, accurate, online, continuous and non-intrusive method [5]. If there is single phase flow in oil pipelines, measuring the density is possible just by using one source and detector. But sometimes in addition to oil, there is gas in oil pipelines and in fact there is a two-phase flow. Comparing with the single-phase flow, there are a lot of difficulties for measuring direct and indirect parameters accurately in gas-liquid two-phase flow.

In recent years, some studies have been done on measuring the density of oil products when flow is single phase (just there is liquid in pipeline). Khorsandi and Fegghi simulated various geometries for density measurement of petroleum products based on the scattering and transmission principles using Monte Carlo N particle (MCNP) code [6].

They demonstrated that scattering modality is more sensitive relate to transmission-based technique, because attenuation slope in

transmission modality is higher. An experimental setup was used for benchmarking of the simulation results. A ^{137}Cs source (disc shape) with an activity of $50 \mu\text{Ci}$, a $7.62 \times 7.62 \text{ cm}$ NaI (TI) Scintillator detector and a polyethylene pipe with diameter of 10.16 cm and wall thickness of 0.2 cm were utilized in that experiment. Based on the obtained experimental results, they showed that in practical conditions, oil products such as gasoline and gasoil, can be recognized from each other with the accuracy of 0.1 g/cm^3 . Roshani et al. showed that adaptive neuro-fuzzy inference system (ANFIS) could be applied for estimation of fluid density inside the pipes which have different diameters [7]. The pipe diameter and the number of the registered photons in detector were used as the inputs of proposed ANFIS model and density of the fluid was also used as the output. They utilized simulated data which were obtained from MCNP4C Monte Carlo code for testing and training the ANFIS model. They could estimate the fluid density for pipes of different diameters with mean relative error (MRE %) of less than 2.64%. They also could predict the fluid density for pipes of various diameters using multi-layer perceptron (MLP) model in another work [8].

In the case of measuring parameters of gas-liquid two phase flows such as void fraction and flow regime using attenuation of gamma ray, lots of studies have been done. Roshani et al. proposed a methodology

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using dual modality densitometry technique and ANN model of MLP to first distinguish the type of flow regime and then estimate the void fraction in gas-liquid two-phase flows [9]. The input parameters of the proposed MLP model were the total count in the scattering detector, the photo peak and the number of registered counts under Compton edge in transmission detector which were obtained by simulation. By using this methodology, they could correctly recognize all the three flow regimes of annular, stratified and homogenous and predict the void fraction of each phase with error of less than 1.1%. Nazemi et al. proposed a gamma-ray transmission method to determine the void fraction and recognize the flow regime type of a two-phase flow utilizing ANN model of radial basis function (RBF) and two detectors which were optimized in terms of detector orientation [10]. The required data for testing and training the ANN were obtained from experimental data. RBF neural network was utilized to distinguish flow regimes (annular, stratified and bubbly) and estimate the void fraction percentage. All of the flow regimes were recognized correctly and the void fraction percentage was determined with mean relative error of less than 1.5%. More studies in this field can be found in Refs. [11–23].

As mentioned above, in all previously works less attention has been paid to the measuring the density of liquid phase in gas-liquid multiphase flows. Since in two phase flows either void fraction and or flow regime could be changed in addition to density of liquid phase, conventional gamma ray densitometry (one source and one detector) could not be used for measuring the density of liquid phase. In our previous work [14], we demonstrated that it is possible to measure the density of liquid phase in stratified regime (the most typical flow regime in horizontal pipes) of gas-liquid two-phase flows using a combination of dual modality densitometry technique and artificial neural network (ANN). In this work, a same technique as our previous work was applied to measure the density of liquid phase in annular regime which is one of the most typical flow regimes in vertical pipes. It should be noted that although the implemented technique (dual modality densitometry) is same in this work and our previous work [14], each flow regime type requires its specific experimental measurement setup and data analysis. The procedure is completely explained in the following sections.

2. Methodology

2.1. Experiment

In this research, density of liquid phase in annular regime of gas-liquid two phase flow was predicted. Therefore, the flow regime is constant and just void fraction could be changed in addition to density of liquid phase. Annular regime is one of the most typical flow regimes which occurs in vertical pipes in oil industry. As shown in Fig. 1, annular regime with various void fractions in range of 10–70% was modeled in static conditions. The range of 10–70% was selected because of experimental limitations, the reason is that by increasing the void fraction the liquid phase would get so thin and for void fractions more than 70% it was not possible for us to make the annular regime phantoms. It was not possible to make annular flow regimes more than 70%. Air was utilized constantly as the gas phase in all experiments, while liquid phase was changed in each void fraction. Water, lubricant oil, gasoil, kerosene and Gasoline with the densities of 0.980, 0.852,

0.826, 0.795 and 0.735 g/cm^{−3}, respectively, have been used as liquid phases in each void fraction. Totally 35 experiments were done in this study (7 different void fraction \times 5 different liquid phase).

A gamma ray emitter source ¹³⁷Cs with radioactivity of 7.4×10^{10} Bq (2 mCi) and gamma energy of 662 keV was used. The measurement time was chosen 600 s for each experiment. Some lead blocks were used for shielding of the source container. The source was also collimated (a cubic collimator with 6 mm width, 20 mm height and 100 mm length) in order to make a narrow beam passing through the center of the pipe. One 25.4 \times 25.4 mm NaI (TI) scintillation detector was positioned 500 mm far from the source registering transmitted photons. Another same detector was positioned 20 mm far from the pipe and in direction of 45° respect to the transmission detector for registering scattered photons. Also the distance between source and pipe was chosen 300 mm. The reason of selecting one transmission detector and one scattering detector in experimental setup is that the registered photons in them are sensitive to the void fraction and the density, respectively. The transmission detector was placed in front of the source (in the angle of 0°) in order to register the transmitted photons, but in the case of the scattering detector it is worth to mention that in contrast to our previous work [14] that we first obtained the best position (the position that the scattering detector has the most sensitivity relative to density changes) for the scattering detector, in this work the it was arbitrary placed in orientation of 45° respect to the transmission detector. Because the gas and liquid phases in annular regime have a cylindrical symmetry, consequently the scattering detector has a same sensitivity relative to density changes in all angles around the pipe and there is no difference to place it in which orientation. The configuration arrangement for the source, scintillation detectors, collimators and the main pipe are shown in Fig. 2.

In transmission detector, which was connected to a Multi-Channel Analyzers (MCA), only the transmitted photons (photo peaks) were registered, while in the scattering detector which was connected to a counter, total count of scattered photons were registered. The registered counts in both detectors versus void fraction and liquid phase density are shown in Fig. 3. As it can be seen from these figures, by increasing the void fraction and decreasing liquid phase density, registered counts in transmission detector would be increased, while it would be decreased in the scattering detector.

2.2. Artificial neural network

Artificial Neural Network (ANN) was inspired by the human brain. In fact, it is a mathematical model [24]. Multi-layer Perceptron (MLP) is one of the most used kind of ANNs [25]. The main characteristic of this technique is ability of learning using of accurate data. This model can estimate behaviors from a finite set of accurate data, which is called the “training set” of the MLP [21]. The schematic of the presented MLP model has been shown in Fig. 4, where the inputs are registered counts in transmission and scattering detectors and the output is liquid phase density.

Experimental results have been used as the data set required for training and testing the network. Number of samples for training and testing data were: 25 (70%) and 10 (30%), respectively. According to a presented algorithm, several different structures were examined in

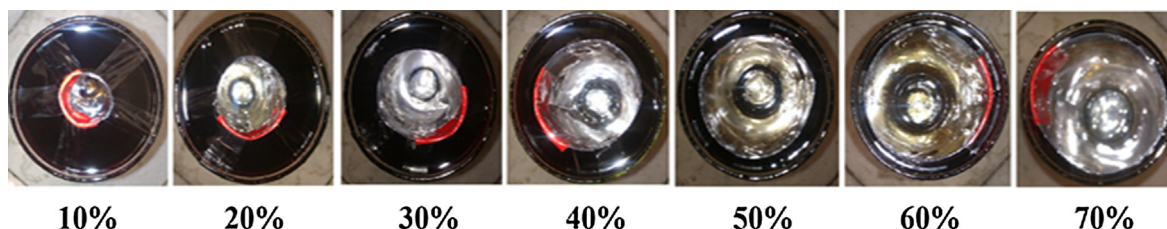


Fig. 1. Phantoms used to model various void fractions in the range of 10–70% for annular regime.

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