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A radiation-based hydrocarbon two-phase flow meter for estimating of phase fraction independent of liquid phase density in stratified regime

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ABSTRACT

The fluid properties strongly affect the performance of radiation-based multiphase flow meter. By changing the fluid properties (especially density), recalibration is necessary. In this study, a method was presented to eliminate the dependency of multiphase flow meter on liquid phase density in stratified two phase horizontal flows. At the first step the position of the scattering detector was optimized in order to achieve highest sensitivity. Several experiments in optimized position were done. Counts under the full energy peak of transmission detector and total counts of scattering detector were applied to the Radial Basis Function neural network and the void fraction percentage was considered as the neural network output. Using this method, the void fraction was predicted independent of the liquid phase density change in stratified regime of gas–liquid two-phase flows with mean relative error percentage less than 1.2%.

1. Introduction

The radiation-based multiphase flow meter (MPFM) is relatively new technology in Oil industry. MPFMs are used to measure the phase fractions of oil, gas and water in the flow from an oil well. The conventional methods used to measure the phase fraction in the flow for each well at wide intervals that could span over several months. The radiation-based MPFMs provide such information instantly, easing monitoring problems and enabling quick access to data, which allows rapid decisions to be made on well performance. The wealth of data accumulated by radiation-based MPFM can be fed into reservoir simulation codes to enhance their accuracy and reliability [1].

In recent years, many researchers and engineers have implemented gamma ray attenuation in order to measure volume fraction and identify the flow regime in multiphase flows. Tjugum et al. used a multibeam gamma-ray densitometry to identify flow regimes in hydrocarbon multiphase oil, water and gas pipe flows [2]. They demonstrated that a fan beam geometry with one radiation source and several collimated detectors is sufficient to provide information on the liquid–gas distribution of the pipe flow. Using ^{241}Am source with the activity of 500 mCi and 9 CdZnTe semiconductor detectors, they identified several flow regimes in gas–liquid flows in a pipe with a diameter of 2 in. Jing et al. investigated the dual modality densitometry method using artificial neural networks (ANNs) in order to determinate the gas and water volume fraction in a three-phase flow [3]. 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 [4]. In 2014, Roshani et al. 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 [5]. By using ANN, they predicted the volume fraction of oil, water and gas phases with Mean Absolute error (MAE%) of less than 1%. Roshani et al. also proposed a method based on dual modality densitometry using ANN to first identify the flow regime and then predict the void fraction in gas–liquid two-phase flows [6]. They used the total count in the scattering detector, the full energy peak and photon counts of Compton edge in transmission detector as the three inputs of the ANN. By applying this method, they correctly distinguished all the three regimes of stratified, homogenous and annular and estimated the void fraction of each phase in the range of 5–95% with error of less than 1.1%. Also it has been shown that artificial neural networks could be as a useful tool for predicting, classification and optimization for industrial nuclear gauges especially in cases that lots of parameters could influence the operation of the system [7–14].

Calibration of radiation-based multiphase flow meter (MPFM)

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depends strongly on the fluid properties [15]. By changing the fluid properties such as density, recalibration is required. Performance of radiation-based MPFMs will be improved by eliminating any dependency on the fluid properties. In all previous studies, the void fraction has been measured with a constant density liquid phase and little attention has been paid to the changes of the density of the liquid phase. Since attenuation of gamma-ray depends on both amount and density of the matter, fluctuations of the density of the liquid phase can cause significant errors in determination of the void fraction. For example, fluctuations of temperature and pressure which occur typically in pipe-lines of Oil industry, could cause changes of the liquid density and consequently measuring the void faction would deal with significant errors.

In this work, an approach is proposed based on dual modality densitometry using ANN to solve the problem of measuring the void fraction in stratified regime of hydrocarbon gas–liquid two-phase flows in situations that the liquid phase density is changeable. At the first step, sensitivity response of the scattering detector relative to the density changes of liquid phase in different positions around the pipe, was investigated by using Monte Carlo N Particle (MCNP) code. As much as the sensitivity is more, the ANN could predict the void fraction independent of density changes of the liquid phase with less error and consequently the measuring precision of the system would be improved. After obtaining the most sensitive position relative to density changes for the detectors by simulation, an experimental setup according to the simulated geometry was designed in order to provide the experimental required data for ANN. By applying this methodology, the void fraction was predicted independent of the liquid phase density in stratified regime of gas–liquid two-phase flows with root mean square error of less than 1.4.

2. Proposed methodology

2.1. Monte Carlo simulation

As the first step in this study, a Monte Carlo simulation model is used to obtain the best positions for the detectors in dual modality densitometry configuration. 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. In this work, a dual modality densitometry setup based on the existing devices in our laboratory has been simulated. As shown in Fig. 1, the position of 1-in. NaI transmission detector was kept fixed in the angle of 0° and position of 1-in. NaI scattering detector was changed from 15° to 135° respect to center of the pipe with steps of 15°.

The void fractions in the range of 10–70% for stratified regime of gas–liquid two-phase flows were simulated. Distance between both the detectors and pipe was chosen 5 cm. The ^{137}Cs source was placed 10 cm far from the pipe. Also the source was collimated in order to make a narrow beam passing through the center of the pipe. Air with density of 0.001 g/cm^3 was used as the gas phase in the pipe. For making a wide range of density for liquid phase in laboratory (from 0.735 g/cm^3 to 0.980 g/cm^3), gasoline, kerosene, gasoil, lubricant oil, and water with the densities of 0.735, 0.795, 0.826, 0.852, and 0.980 (g/cm^3), respectively, have been used as the liquid phases. Same as the experiments, in simulations these liquid phases were used, too. Since the predominant interaction mechanism for high energy photons in low atomic number materials is Compton scattering and the photoelectric interaction could be negligible, therefore, the interaction probability depends just on the density of the liquid phase regardless of its composition. Also, because the effective atomic numbers of used liquids are close to each other, it could be assumed that all of the 5 liquid phases regardless of their compositions, are considered as one liquid phase with various densities.

Registered counts in both transmission and scattering detectors were calculated per one source particle in the MCNP-X code using Pulse Height Tally F8. A special tally card with the Gaussian Energy Broadening (GEB) option is also included in the model in order to take into account the Gaussian energy broadening and obtain a better and more realistic simulation of the whole spectrum in detectors. 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 different energies in the laboratory. The tallied energy is broadened by sampling from the Gaussian function shown in Eq. (1) [16]:

$$f(E) = Ce^{-\left(\frac{(E-E_0)}{A}\right)^2} \quad (1)$$

Where, E is the broadened energy, E_0 is the un-broadened energy of the tally, C is the normalization constant and also A is related to the FWHM by Eq. (2):

$$A = \frac{\text{FWHM}}{2\sqrt{\ln(2)}} \quad (2)$$

The desired FWHM which is specified by the user-provided

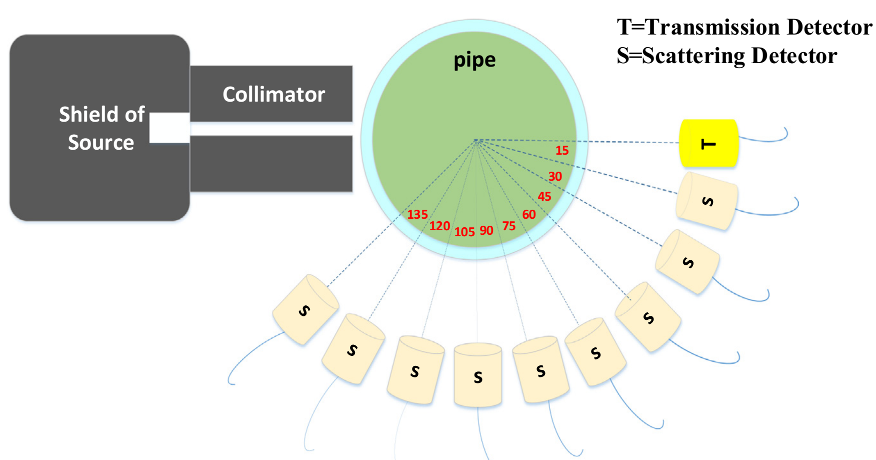

Fig. 1. A top view of positioning of the scattering detector in different angles used in simulated geometry in order to obtain the most sensitive position relative to density changes.