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Void fraction measurement in modeled two-phase flow inside a vertical pipe by using polyethylene phantoms

Reza Faghihi, Mohammadreza Nematollahi, Ali Erfaninia, Mahtab Adineh*

Shiraz University, School of Mechanical Engineering, Mollasadra St, 71348-51154, Shiraz, Iran

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ABSTRACT

The main purpose of this study is experimental and numerical void fraction measurement in two-phase flow inside a vertical pipe by using gamma-ray. Three types of flow regimes including homogenous, stratified and annular were modeled in a vertical pipe by using polyethylene phantoms. These three flow regimes are basis regimes in two-phase flow and the other flow regimes are incorporated of these patterns. 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. Numerical modeling was done by using MCNP code to improve the accuracy and validation of experimental results. Finally, innovative correlations to predict the void fraction in two-phase flow in a vertical pipe was presented.

Introduction

Two-phase flow is often encountered in a lot of industrial applications, such as core and steam generators in nuclear reactors, boilers, petroleum transportation, electronic cooling and various types of chemical reactors [1].

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

The void fraction in two-phase flow systems is an important and noticeable parameter in designing and operation.

There are several methods to determine this parameter including intrusive and nonintrusive. In intrusive method the perturbation of local two phase flow field is unavoidable. In the nonintrusive method without perturbation of local flow field, measurement of void fraction is done by using ultrasonic technique, nuclear radiation attenuation, and absorption of X-ray [3].

A lot of experimental investigations of two-phase flow have been carried out, however, still not accepted by everyone in the development for the flow pattern classification [2]. Hsu et al. [4] utilized a hot wire anemometry technique for measuring void distribution for vertical flow and also used the signal output for flow pattern characterization.

Thiyagarajan et al. developed a nonintrusive measurement system using gamma rays form a ^{60}Co source to measure void fraction profile in a two phase flow of high density liquid metal

* *Corresponding author.*
E-mail address: nema@shirazu.ac.ir (M. Nematollahi).
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and nitrogen. Finally they compared the average void fraction from the profile data with the values predicted by empirical correlations [5].

Peter Stahl et al. studied the accuracy of the measurement of void fraction by single-beam gamma-densitometry for gas–liquid two-phase flow in pipes. Finally they presented a dimensionless relation, which gives their accuracy as a function of the pipe radius and the absorption coefficient of the liquid phase [6].

Eckhard Krepper and his coworkers in 2007 done experimental and numerical studies on the distribution of void fraction in the vertical rectangular void slugs. Void slugs in the flow pattern with gas velocity more than 0.02 m/s were considered. A high speed camera was used to observe the flow pattern. For calculation the voids velocities, void turbulence parameters and size distribution of voids were processed [7]. Myong Seop Kim and his coworkers in 2009 studied the application of gamma-ray gauge for measurement of the void fraction in liquid hydrogen moderator, HANARO, in cold neutron source (CNS). They found that measuring the void fraction for designing an operation of HANROCNS is very useful [8]. W.A.S. Kumara and his coworkers in 2010 developed the application of a single gamma-ray gauge for investigation water-oil in horizontal and little inclined tubes. The gamma-ray gauge was included radioactive isotope Am-241 with radiation energy 59.5 kev and [NaI(Ti)] detector and signal processing system. Void fraction and slip ratio were estimated and also uncertainty of gamma-ray gauge was discussed [9]. Yu Zhano et al. studied the void fraction of gas–liquid two-phase flow in vertical upward pipes using the gamma densitometer. Firstly, they identified the flow patterns of the two-phase flow by the high speed camera system and gamma densitometer system. Secondly, they measured the void fraction of the two-phase flow by the gamma densitometer, and the results were compared with the quick closing valve measurement. Thirdly, the variations of the flow patterns with the void fraction were discussed [2].

This study aims at measuring the void fraction in modeled two phase flow inside a vertical pipe based on the earlier study [10]. By putting polyethylene phantoms into the pipe, different two-phase flow regimes are modeled. By measuring the gamma-ray attenuation across the pipe, which is filled by polyethylene phantoms the void fraction are calculated via related formula. Finally numerical calculation of void fraction is made by using MCNP code to verify the experimental results. Based on the earlier modeling [10], in order to predict the void fraction in two-phase flow in a vertical pipe an innovative formula is also presented.

Table 1 – Modeled void fractions by using polyethylene phantoms in different two-phase flow regimes.

	Homogenous flow	Stratified flow	Annular flow
Void fraction	0	0	0
	0.2	0.2	0.2
	0.25	0.25	0.25
	–	0.4	0.4
	0.5	0.5	0.5
	0.56	0.56	0.56
	–	0.7	0.7
	100	100	100

Mathematical formulation and modeling

Mathematical formulation

Void fraction in a homogenous mixture of two-phase fluid which contains two kinds of fluids with different densities can be determined by measuring the mixture linear gamma ray attenuation coefficient μ_{mix}.

Generally, for a mixture with n components the linear gamma ray attenuation coefficient is:

$$\mu_{mix} = \sum_{i=1}^{n} \alpha_i \mu_i = \alpha_1 \mu_1 + \alpha_2 \mu_2 + \ldots + \alpha_n \mu_n \tag{1}$$

For a mixture including gas and liquid the linear attenuation coefficient is:

$$\mu_{mix} = \mu_g \alpha_g + \mu_l \alpha_l \tag{2}$$

where μ_g and μ_l are linear gamma ray attenuation coefficients. α_g and α_l are void fractions. Subscripts g and l refer to gas and liquid, respectively.

However, the equation (2) can be written as follow:

$$\mu_{mix} = \mu_g \alpha_g + \mu_l \alpha_l = \mu_g \alpha_g + \mu_l (1 - \alpha_g) = \mu_l + \alpha_g \left(\mu_g - \mu_l\right) \tag{3}$$

Meanwhile the pipe is filled only with liquid phase the intensity of attenuated transmitted gamma-beam through the pipe is I_l (i.e. $\alpha_l = 1$ *and* $\alpha_g = 0$), as well as that the pipe is filled only with gas phase the intensity of attenuated transmitted gamma-beam through the pipe is I_g (i.e. $\alpha_l = 0$ *and* $\alpha_g = 1$). By using equation $I = BI_0 e^{-\mu_{eff} x}$ where B is medium build-up factor:

$$I_l = B_l e^{-\mu_l d} \Rightarrow \mu_l = -\frac{1}{d} \ln\left[\frac{I_l}{B_l I_E}\right] \tag{4}$$

$$I_g = B_g e^{-\mu_g d} \Rightarrow \mu_g = -\frac{1}{d} \ln\left[\frac{I_g}{B_g I_E}\right] \tag{5}$$

Fig. 1 – Polyethylene phantoms which are used to model void fractions in homogenous flow.