Applied Radiation and Isotopes 67 (2009) 1254–1258

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Flow-rate measurements of a dual-phase pipe flow by cross-correlation technique of transmitted radiation signals

Sung-Hee Jung *, Jin-Seop Kim, Jong-Bum Kim, Taek-Yong Kwon

Korea Atomic Energy Research Institute, Republic of Korea

ARTICLE INFO

Keywords:
Industrial process diagnosis
Radioisotope
Gamma radiation
Cross correlation technique
Multi-phase flow rate measurement

ABSTRACT

The flow rate measurements of dual-phase pipe flow were conducted with a couple of sealed radioisotopes for the cross-correlation technology. The flow was produced in an acrylic tubing of which internal diameter is 8 cm and into which pressurized nitrogen gas was periodically injected. Under the given conditions where the distance between two sources is four times of the diameter, *N*/*S* ratio ranges from 0.12 to 0.15 and the data sampling time is 4 ms, the measured flow rates were estimated with the maximum relative error of 1.7%. From the subsequent experiments, it was proven that the closer the distance between the two sealed sources is, the higher the precision of measurement result is. It is anticipated that the industrial application of the technique for flow rate measurements in an in-service process can play an important role for monitoring multi-phase process media in petrochemical and refinery industries.

1. Introduction

Multiphase flows are commonly encountered in the petroleum industry, and yet their measurement nearly always presents difficulties to the process engineer. In the traditional method the multiphase flow is separated by physical characteristics and each phase is measured with the conventional instruments. The typical example is the oil production process where the oil–water–gas mixture is pumped out and then physically separated for measurement of oil and gas components with turbine meters and orifice plates. This method demands long period of time for separation as well as high cost. Although precise estimation of multi-phase flow regime directly leads to enormous economic benefit, there has been seldom a technique showing high precision for long-term operation.

Presently most frequently used systems for multi-phase flow measurement such as pressure differential method, turbine method, venturi method and others require shutting down of industrial processes for their installation. Ultrasonic system that can be applied to an operating process analyzes signals with the cross-correlation technique that is the same as the technique used in this paper (Schneider et al., 2003; Worch, 1998; Xu et al., 1998; Beck, 1981; Beck and Plaskowski, 1987). However, the precision of the ultrasonic system is vulnerable to the content ratio of vapor.

In spite of the considerable researches till recent years, there is no commercially available multi-phase flowmeter that can be used for in-service plants. Gamma attenuation method has been applied to measure gas/water fraction in a multiphase flow. The gamma radiation technique has an advantage over other component fraction methods like microwave attenuation and phase shift, pulsed neutron activation and nuclear magnetic resonance due to high penetration power, non-disturbance during its application, a wide range of void fraction for application and its relatively low cost for implementation (Thorn et al., 1997).

Previously Leszek Petryka has applied the gamma radiation method associated with cross-correlation technique to measure multi-phase flow (Petryka, 1998, 2001). He applied the technology to pilot plants and compared them with radiotracer velocity measurement results in order to show the practical availability of the technology as an industrial process diagnosis method. The studies in this paper focused on quantitative evaluation of the influence of radiation detection geometry and signal acquisition frequency to the measurement results. It is of importance to get fundamental information that makes great influence to the accuracy of measurement analysis and is required for the optimal installation of measurement equipments.

2. Material and method(s)

Dual-phase flow of air and water was realized with an experimental set-up made of acrylic resin of which dimension is 8 cm in diameter and 3.5 m long. Pressurized nitrogen gas was injected through a controlled solenoid valve (Fig. 1). The flow rate was monitored with a conventional turbine current meter

* Corresponding author.
E-mail address: shjung3@kaeri.re.kr (S.-H. Jung).

0969-8043/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apradiso.2009.02.057

Fig. 1. Experimental set-up for sealed gamma radioisotope application to the measurements of velocity in a multi-phase flow.

installed in a straight section of the pipeline. The reading value was compared with the results obtained from gamma radiation cross-correlation method. The turbine meter is followed by an in-line mixer that completely mixes gas and water. The real flow rate was estimated by measuring the water volume filled in a tank of 5 m^3 capacity for a given time duration.

The gamma radiation sources are 20 mCi and 17 mCi of ^{137}Cs(0.662 MeV, 0.326 $R\,h^{-1}\,m^2\,Ci^{-1}$) and the radiation intensity transmitting the pipe was measured with two scintillation detectors of 2×2 in NaI(Tl) (Eberline, SPA-3). The radiation detectors were mounted on metal brackets separately so that the distance between them could be adjusted. An additional Cs-137 source was installed at the downstream of the in-line mixer in order to measure void fraction of each experiment.

Cross-correlation technique for analyzing data requires high speed signal sampling rate that is in the order of ms. 32-bit counter/timer (NI PXI-6602, max frequency: 80 MHz) and MXI-4 Kit (NI PXI-PCI8331) were coupled to the radiation detectors for fast data acquisition. Data recording into a computer and processing the data with the cross-correlation method were performed with the software programmed with the LabVIEW of National Instrument.

Noise coming with experimental data was removed by low-pass filter following the Fourier transformation process. The result from the cross-correlation function was finally calibrated by applying void faction value obtained from the detection at the final stage of the pipe.

3. Results and discussion

3.1. The principle of the analysis

(1) Transit time measurement of multi-phase flow: The air bubbles in water phase passing the radiation detection area instantaneously increase radiation intensity. Numbers of bubbles create some sort of fluctuation in the measurement data and this plays the role of signal generation for measuring the transit time of the bubble between two detectors installed in a row.

The discrete Fourier transform defined as in Eq. (1) converts time domain signal into frequency domain data to be applied with the low-pass filter for removing noise from the experimental data (Avinash and Malcolm, 1999):

$$X_k = \sum_{n=0}^{N-1} x_n e^{-j(2\pi/N)nk} \tag{1}$$

The filtered data was input to the cross-correlation function that evaluates the similarity of two sets of data. The cross-correlation function for two signals of $x(t)$, $y(t)$ is defined as

$$R_{xy}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{T/2} x(t)y(t-\tau)\,dt \tag{2}$$

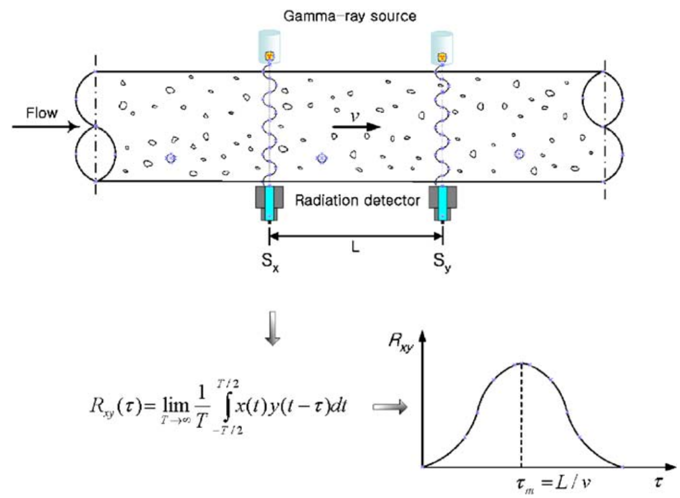

Fig. 2. The cross-correlation principle of component velocity measurement in a multi-phase flow.

The quantity of the cross-correlation between two signals can be estimated with the correlation coefficient(ρ_{xy}) shown in Eq. (3) where R_{xx} and R_{yy} represent the auto-correlations of $x(t)$ and $y(t)$, respectively, and τ is the time when the correlation coefficient reaches to the maximum value (Fred, 1994). In other words, two signals, $x(t)$ and $y(t)$, have the maximum similarity to each other when one of the signals shifted by τ of time. The cross-correlation technique has been used for processing a variety of measurement results for multi-phase flow (Beck and Plaskowski, 1987). The principle was schematically described in Fig. 2.

$$\rho_{xy}(\tau) = \frac{R_{xy}(\tau)}{\sqrt{R_{xx}(0)R_{yy}(0)}} \tag{3}$$

(2) Air fraction measurement: Radiation attenuation coefficient for mixture system can be described as Eq. (4) where μ_{mix} is the attenuation coefficient of a homogeneous mixture of two components, μ_g and μ_l are linear attenuation coefficients of the gas and the liquid, respectively. α_g and α_l are the corresponding volume fractions. The sum of α_g and α_l is unity in a pipe. The gas fraction is expressed as Eq. (5) where I_E is the beam intensity with an empty pipe and B_{mix}, B_l and B_g are the build-up factors of corresponding phase. Eq. (5) was derived on conditions that the build-up factors are almost the same due to the maintained detection geometry (Geir and Peter, 2004).

$$\mu_{mix} = \mu_g\alpha_g + \mu_l\alpha_l \tag{4}$$

$$\alpha_g = \frac{\mu_{mix}-\mu_l}{\mu_g-\mu_l} = \frac{\ln[I_{mix}/B_{mix}I_E] - \ln[I_l/B_lI_E]}{\ln[I_g/B_gI_E] - \ln[I_l/B_lI_l]} \approx \frac{\ln(I_{mix})-\ln(I_l)}{\ln(I_g)-\ln(I_l)} = \ln\left[\frac{I_{mix}/I_l}{I_g/I_l}\right] \tag{5}$$