Determination of void fraction in two phase liquid-gas flow using gamma absorption

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Abstract. Full description of a two-phase liquid-gas flow requires the designation of lot parameters. First one, which describes which part of the pipeline is fulfilled by the gas, is the void fraction. Moreover the share of gas in a flowing mixture determines the structure of the flow and also affects the velocity of the individual phases. In that case void fraction can be determined by use the gamma absorption method, as well as other flow parameters may be evaluated by the same equipment. In addition the article presents the calibration of radiometric set, which consists of gamma radiation source Am-241 and scintillation probe NaI(Tl), for determination of the void fraction, illustrated by exemplary results of the described method application to various structures of air-water flow in the horizontal pipeline.

1. Introduction
Such two-phase mixtures as a liquid-gas are an essential part of many industrial flows, e.g. in chemical, energy or agricultural industries. Due to the lack of a coherent theory of that compound flow in pipelines, which take into account issues related to the temperature of individual phases, their mixing or chemical reactions in the stream, the experimental studies are necessary.

The authors based on their long experience, proposed to analyze of gas-liquid flows by gamma-ray absorption. Currently commercially offered apparatus apply radioisotope sources (mainly based on the Cs-137) to measuring density of the mixture fulfilling the pipe. However, the previous study show that applying such nuclear equipment is possible to determine mean velocity of the gas phase, as well as, itsflow rate and the void fraction [1-10]. The instantaneous or average value of a void fraction $\alpha$ can be designated at a fixed measurement. In that method the void fraction determination is based on the proper calibration of the measuring system [5-8, 10].

This paper presents the calibration methodology of a radiometric set, which consists of gamma radiation source Am-241 and scintillation probe NaI(Tl).
2. The idea of the measurement and a laboratory stand

Figure 1 shows an idea of the twin gamma absorption set. That equipment allows measurement of both the velocity of the transported gas phase and determination of the void fraction instantaneous value $\alpha$ inside the pipeline.

According to that, the applied device comprises two collimators 1, wherein have been put two linear gamma radiation sources 2 of 100 mCi Am-241, emitting 59.5 keV photons. Properly collimated gamma rays 6, are weakened during passing through the pipeline 5, primarily due to absorption and scattering in the flowing compound. Thus, depending on the volume fraction of gas in the pipe, and each scintillation probe 4 allows record the time-varying radiation intensities $I_x(t)$ and $I_y(t)$. Received signals allow determining the flow velocity of gas phase and its participation in the mixture.

![Diagram of the gamma absorption set](image)

**Figure 1.** Diagram of the gamma absorption set: 1 - collimator of the radioactive source, 2 - linear radioactive source, Am-241, 3 - collimator of probe, 4 - probe with scintillation crystals of NaI(Tl), 5 - pipeline with the flowing mixture, 6 - collimated beam of gamma rays, $I_x(t)$ and $I_y(t)$ - the radiation intensity recorded by the first and second probe respectively.

Described below calibration and experiments were carried out in the Sedimentological Laboratory of the Faculty of Geology, Geophysics and Environmental Protection AGH University of Science and Technology in Krakow. Full description of the installation was presented in the articles [11, 12].

Essential elements of the laboratory stand are shown in Figure 2, where basic experimental equipment consists of a rotary pump 1, forcing the flow in the pipeline 3. The analyzed mixture passes through the measuring tube made of Plexiglas with the inner diameter of 30 mm. The air from the compressor 7 through the nozzle 6 is supplying the installation. The stable operation of the stand provides expansion tank and vent 2. The flow control is possible by setting the pump revolution and throttle valves. The additional measuring systems including ultrasonic flowmeter 5. Due to that the absorption set 4 and data acquisition stand 8, allow the measurement of velocity of the both phases and the void fraction in the pipeline.
3. Calibration of the gamma-absorption set

Activities related to the determination of the relationship between the intensity of the radiation emitted from two sources, Am-241, and void fraction $\alpha$, performed on a test system, by gradually filling the measuring section, to give at least eight set points with a different levels of water. The height of the liquid column was measured from a specially prepared, stable reference point, using calipers. Calibration was directly secured to the installation at the same geometry, as during the evaluation of different types of liquid-gas flow. This was important in the previous leveling of the pipeline, so that the same amount of water was above one, and the second detector.

Figure 3 illustrates the void fraction determination, which is defined as the ratio of the volume occupied by the gas $V_G$, the inner volume of the pipeline $V$:

$$\alpha = \frac{V_G}{V}. \quad (1)$$

Since the collimated beam of gamma photons, overexpose selected cross-section of the pipeline, the dependence (1) reduces to the equation:

$$\alpha = \frac{A_G}{A}, \quad (2)$$

where: $A_G$ - the surface area occupied by air, $A$ - inner cross-section of the pipe.
Figure 3. Geometrical quantities applied to determine the coefficient of the pipeline fulfilling: $h$ - measured water level in the pipeline, $R$ - inner radius of the pipeline, $\phi$ - central angle circular sector.

According to the geometrical relationship between values shown in Figure 3, let consider the following cases:

a) $h < R$:

$$\alpha = 1 - \frac{R^2 \cdot \arccos \left(1 - \frac{h}{R}\right) - (R - h) \cdot \sqrt{2 \cdot R \cdot h - h^2}}{\pi \cdot R^2},$$  \hspace{1cm} (3)

b) $h > R$:

$$\alpha = \frac{R^2 \cdot \arccos \left(\frac{h}{R} - 1\right) - (h - R) \cdot \sqrt{2 \cdot R \cdot h - h^2}}{\pi \cdot R^2}. \hspace{1cm} (4)$$

The collection of water levels in the pipe and recorded gamma radiation intensity gives the calibration as shown by Figure 4 and by the least squares line, fitting the following equation:

$$\ln(I) = 0.3203 \cdot \alpha + 3.6671. \hspace{1cm} (5)$$

The uncertainty of the slope coefficient is 0.0042 cpch (counts per channel), and the translation vector 0.0023 cpch, with a coefficient of determination, $r^2 = 0.999$. 

Figure 4. The relationship between the natural logarithm of the gamma radiation intensity $I$ (recorded by scintillation probe) and the fixed void fraction $\alpha$.

The presented above calibration should be made at the beginning and end of every series of measurements arranged at the same flow and environment conditions.

4. Exemplary results

For the same liquid, by changing revolution of the pump and gas rate, the most typical gas transportation forms were obtain. Table 1 shows the collected results.

Uncertainty of the void fraction evaluation was calculated from the law of the uncertainty propagation. It will be notice that the relative $\alpha$ accuracy does not exceed 4%.

Table 1. Results of experiments conducted for three characteristic flow structures. $v_L$, $v_G$ – mean velocities of water and air respectively, $u(\alpha)$ – uncertainty of the void fraction.

| Flow structure | $v_L$ (m/s) | $v_G$ (m/s) | $\alpha$ (-) | $u(\alpha)$ (-) |
|----------------|-------------|-------------|--------------|-----------------|
| plug           | 1.23        | 0.756       | 0.043        | 0.001           |
| bubble-plug    | 1.58        | 0.849       | 0.037        | 0.001           |
| bubble         | 2.01        | 1.018       | 0.027        | 0.001           |

Table 1 shows that, despite providing the same amount of air from the compressor, the average void fraction $\alpha$ throughout measurements lasting 8 minutes is function of the water flow rate. This is likely related with the flow resistance. Hence the greatest value of $\alpha$ is for plug flow, while the smallest one is for bubble flow.

5. Conclusions

Gamma ray absorption is a convenient tool to two-phase flow evaluation, as well as for the void fraction $\alpha$ determination [1-3, 5-8]. Although the measurement principle is not compound, but proper
determination of the calibration curve requires high precision, appropriate methodology of research and carefully selected geometry of measurement.

The sensitivity of this method depends on the energy of radioactive source or even their scattered radiation selection [6, 7, 13]. However, that selection is often restricted by the environment, pipeline material and components of the flowing mixture. If the lighter elements are included in the transported material, then the energy of gamma radiation should be reduced. Therefore, in the presented study we use isotope Am-241, which emitting 59.5 keV photons. Due to 100 mCi activity of each source, the uncertainty of \( u(\alpha) \) measurement does not exceed 4%.

The authors experienced that the compound experiments design may be facilitated by simulations based on the program code MCNP (Monte Carlo N-Particle) [6].

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7. References
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