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Radioisotope method of compound flow analysis

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Abstract. The paper presents gamma radiation application to analysis of a multicomponent or multiphase flow. Such information as a selected component content in the mixture transported through pipe is crucial in many industrial or laboratory installations. Properly selected sealed radioactive source and collimators, deliver the photon beam, penetrating cross section of the flow. Detectors mounted at opposite to the source side of the pipe, allow recording of digital signals representing composition of the stream. In the present development of electronics, detectors and computer software, a significant progress in know-how of this field may be observed. The paper describes application of this method to optimization and control of hydrotransport of solid particles and propose monitoring facilitating prevent of a pipe clogging or dangerous oscillations.

1 Introduction

A pipe transport of compound flow is a convenient and environmentally safe way to transport bulk materials. Unfortunately, as the prevalence of application it is also increasing the number of reported cases of costly failures involving the clogging or damage of pipelines. Detailed analysis often showed that the cause could be a transitory instability of flow [1]. In order to reduce number of such cases, the Authors propose an application of nuclear techniques for diagnostics and continuous observation or effective control of the flow. Moreover it would be stressed that so far seen limited application of nuclear methods result not only from the hazard of radiation, but also of their difficulty discussed in detail e.g. by Arvoh et al. [2].

In nuclear measurements increasing accuracy requires the use of excessive activity isotopes that emit high-energy photons in the full spherical angle, and outcomes the use of heavy lead collimators protecting staff and forming a beam penetrating the pipeline. Moreover, although the recorded signals are discrete, but are sensitive to ambient and the electrical network noise, as well as require stable electronics and strict fulfill to complex measurement procedures [3].

Article shows an example of the use of absorption and scattering of gamma radiation to observe the density and concentration of the solid phase, simultaneously with its velocity during hydraulic pipeline transport.

2 Absorption method

Photons emitted by radioactive isotopes are differentially absorbed and scattered by the individual elements located between the source and the detector. If the components of the mixture transported through the pipeline will be distinguish by gamma radiation, and the measurement geometry, as well as the pipeline environment will be fixed, the only variations in the intensity of recorded pulses $I(t)$ are caused by changes in the composition of the analyzed mixture and the statistical nature of radiation [2].

It is worth noting that while determine the composition and density of the transported compound requires an annoying the calibration procedure, but monitor or control the flow in pipelines may use only the digital signals after relatively simple processing [4].

Additional advantage of that method may be achieved due the Cross Correlation Analysis application. This route allows both the solid phase velocity estimation and the density measurement improvement [5].

3 Measuring set

Long lasting investigation of multiphase flows facilitated the Authors to construct the measurement equipment consisting of two radioactive sources and two detectors shown in figure 1. In this set, such isotopes as ^{241}Am, ^{137}Cs, or ^{60}Co may be used, depending on the pipe material and diameter.

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The data acquisition equipment based on scintillation detectors and the dedicated 8-channel counter connected to a PC by an USB port. Due to that voltage pulses I_x and I_y provided by probes may be counted within the sampling time $\Delta t = 1$ ms for hydrotransport and 100 µs for pneumatic flows. Duration of the data recording in this system is only limited by a PC memory, and may be observe on a monitor or process by a software alowing analysis of the flow composition and velocity [6].

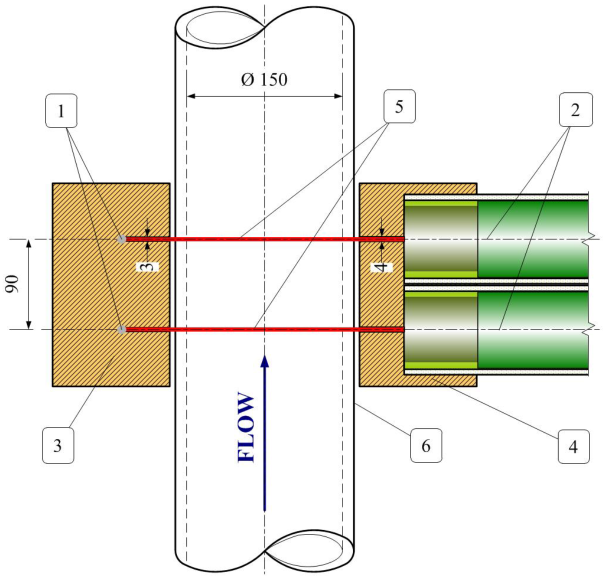

Figure 1. The measuring set (all dimensions are in mm): 1 – ^{241}Am source, 2 – scintillation probe with 2” NaI(Tl) crystal, 3 – collimator of sources, 4 – collimator of detectors, 5 – γ-ray beam, 6 –pipeline

4 Laboratory test

The proposed methods were tested at the hydraulic laboratory of Wroclaw University of Environmental and Life Sciences [3]. In the used investigations ceramic models were applied to study manganese nodules transportation. The experimental pipe loop shown in figure 2 was equipped by pressure gauges, ultrasonic and electromagnetic flow meters as well as a special weighing scale with sampling tank to measure the flow rate of the investigated mixture.

In addition, the installation gives an opportunity to control flow rate of centrifugal pump with variable speed drive and a grain feeder yield by auger revolution. Thanks to this, the system gave opportunity to observe the transport of grains in the vertical pipeline when water velocity changed from 2 up to 4 m s^{-1} and vary concentrations of solid particles to simulate the flow conditions during the expected undersea transportation [6].

The phases separator located in upper part of the installation allows convenient recirculation of water and solid particles in the individual loops equipped in the measuring and control facilities.

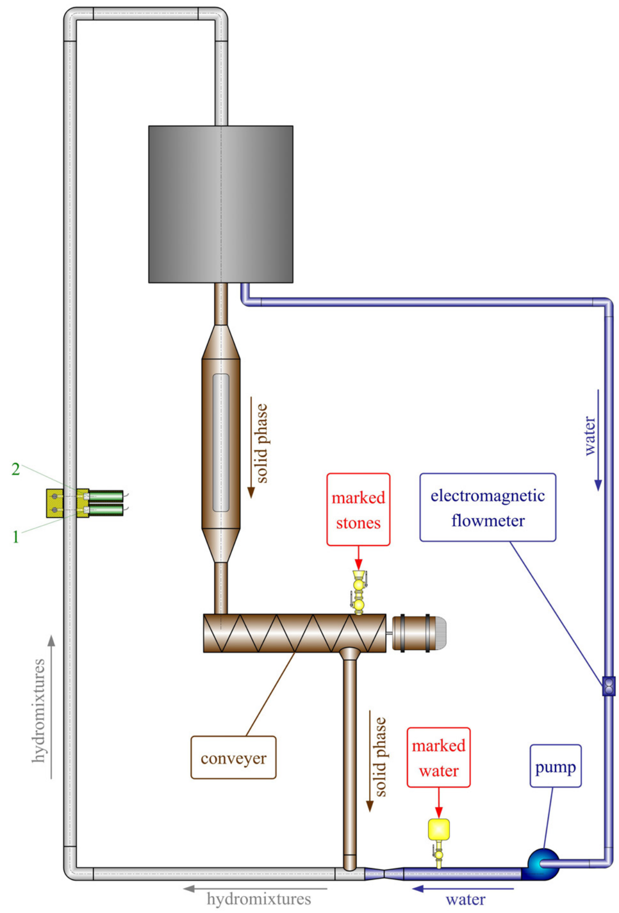

Figure 2. The experimental pipe loop

5 Exemplary results

An arbitrary selected part of the experiment Wrs70 explicitly illustrates a nonstationary flow typical for industrial and environmental conditions, as shown in figure 3 and following. The count rates intensities provided by probes 1 and 2 shown in figure 2, allow determination of the intensity of photons I^* which pass through the investigated pipe flow:

$$I^* = I - I_B , \quad (1)$$

where I total pulses rate intensity at a probe output, cpms; I_B background rate intensity, cpms.
For convenience all those intensities were recorded in counts per millisecond (cpms).

During presented measurements:

$$I_B = const , \quad (2)$$

and received data in sections x and y are presented in figure 3.

In this plot it is easy to find differences in the probes efficiency resulting in higher $I_x^*(t)$ intensity then $I_y^*(t)$ and small dissimilarities caused by electonic equipment noize becouse the distance between probes was equal only 90 mm and should observe almost the same flow.

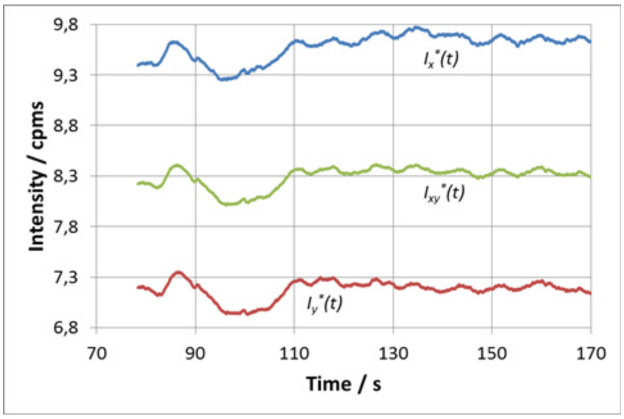

Figure 3. Applied signals in the experiment Wrs70

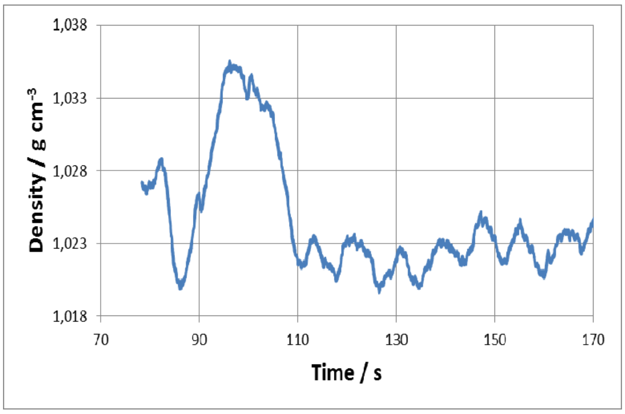

Figure 4. Mixture density estimated in the experiment Wrs70

In this example it was possible to recognize the advantage of replacing record from a single probe by the both signals correlation $I_{xy}^*(t)$.

Consequently that signal is more adequate for describe the content of the flow and may be used for its monitoring and control. Moreover in connection with the calibration, one may obtain the density or solid phase concentration plot [2, 7].

In the described experiment, calibration was made with the same solid partiles and fragment of the original pipe bring to the Laboratory of Sedimentology, Faculty of Geology, Geophysics and Environmental Protection, AGH – University of Science, Krakow.

In result the density of the flow ρ_m was calculated from:

$$I^* = I_0^* \exp(-\mu_m \rho_m D)\,, \tag{3}$$

where I^* γ radiation intensity after transfer through the pipe with investigated solid-liquid mixture, cpms; I_0^* γ-ray intensity after transfer through the empty pipe, cpms; μ_m the mass attenuation coefficient, cm^2 g^{-1}; ρ_m density, g cm^{-3}; D internal diameter of the pipe, cm.
The obtained mixture density distribution is presented in figure 4.

Consequently the volumetric concentration of solid phase in the vicinity of the measuring set was calculated by:

$$C_V = \frac{V_S}{V_M} = \frac{V_S}{V_L + V_S}\,, \tag{4}$$

where V_S volume of solid phase, m^3, V_M volume of the mixture, m^3, V_L volume of liquid phase, m^3.

The obtained volumetric concentration distribution in the observed cross-section is shown in figure 5.

The signals delivered by detectors, after the background I_B deducting, represented photons passed through two cross sections x and y of $L = 90$ mm distance. That allows determination of the transit time delay τ_0 used for transportation of the solid phase through the investigated part of the pipe.

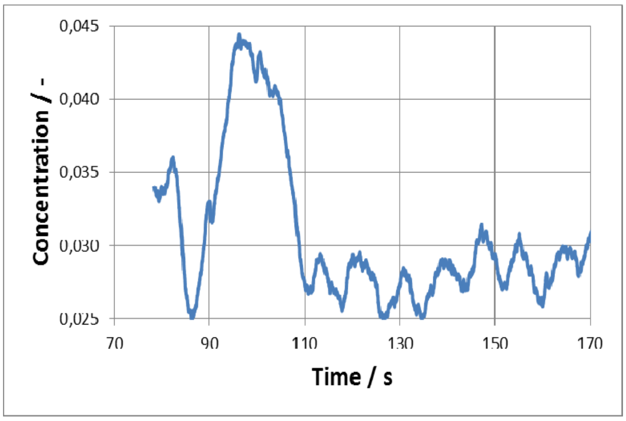

Figure 5. Volumetric concentration estimated in the experiment Wrs70

Then the average velocity of solid particles flow υ_S may be calculated from:

$$\upsilon_S = L / \tau_0\,. \tag{5}$$

Averaged transit time delay τ_0 was determined by the maximum of the cross – correlation distribution $R_{xy}(\tau)$ of the I_x* and I_y* signals:

$$R_{xy}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_0^T I_x^*(t) I_y^*(t+\tau)dt\,, \tag{6}$$

where T approximation time, s; τ time delay, s [8-10].

In the experiment Wrs70 the approximation time $T = 10$ s was sufficient to estimation the average velocity of solid particles distribution $v(t)$ shown in figure 6.
In this way the hydrotransport of solid phase was monitored [6].

6 Conclusions

The completed test confirms possibility of simultaneous observation of solid phase concentration and velocity during transportation in pipe by liquid. Moreover the constructed device may be mounted at any part of the installation and may establish contactless watch even of

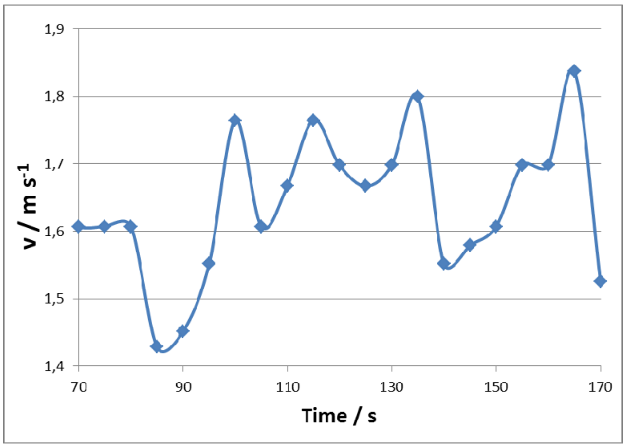

Figure 6. Velocity of solid phase estimated in the experiment Wrs70

nonstationary flows, providing digital signals convenient for the process monitoring or control. In consequences higher pipes exploitation reliability may be achieved and reduction of the safe margins providing to the lower energy consumption may be possible.

Additional advantage of the proposal is a huge applicability from occasional diagnostics of the installation, up to its continuous control and optimization.

Acknowledgements

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