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The non-stationary two-phase flow evaluation by radioisotopes*

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Abstract Two-phase flows, especially those commonly applied during hydraulic exploitation of minerals, are often characterized by the presence of serious variations of density. The adequate control of such a system produces high discrepancy of the mixture velocity. These flows cannot be examined by traditional impulse injection of a tracer. A solution to these difficulties is proposed based on the application of sealed sources and measuring methods calibrated by radiotracers during steady conditions of the flow. The paper presents the results of a full-scale test in a laboratory installation where the stream of water is transporting upwards naturally dispersed nodules through a ø150 mm vertical pipe. A specially designed equipment allows the control of mixture density as well as the measurement of water and the velocity of particular nodules. The obtained results illustrate the capabilities of radiotracers and possibilities how they can be applied in different two-phase flows, when both density and velocity of the components significantly vary during observation.

Key words two-phase flow • radiotracers • gamma transmission technique • velocity and density distributions • cross-correlation technique

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Introduction

Although two-phase flows are commonly applied in industrial processes, there is still a lack of their sufficiently accurate evaluation methods. In the case of stationary flows, this gap is often filled out with the adoption of a single-phase flow meter calibrated by radiotracers. In practice, there are some limitations of that method, and search for new solution becomes justified. Especially, the evaluation of solid particles transported by water with a possible low velocity is very difficult. On the one hand, selecting of such conditions assures a minimal amount of energy spent for transportation, on the other hand it demands a continuous pump control and protection of the installation from clogging. Moreover, this economically justified range of flow reveals a high difference between water and the velocity of particular solid particles. This phenomenon, called 'slip velocity', depends on the solid phase concentration and practically eliminates application of traditional flow meters. Additionally, the estimated manganese nodules have a size varying from 5 to 50 mm and the concentration of solid phase in the transported mixture may vary from 5% to above 60%. In consequence, the hydraulic exploitation of nodules should be facilitated by a continuous examination of flow density and rate. The

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control of pumps, which force the flow, is based on this information. Among different solutions, application of two gamma-absorption gauges delivering the information about concentration and velocity of solid phase in the flow was proposed [3].

The projected equipment was tested and calibrated in a laboratory installation at the University of Agriculture in Wrocław, by a series of radiotracer experiments. These experiments gave the opportunity to develop a new radioisotope method for the non-stationary flow analysis.

Laboratory experiments

A detailed investigation of nodule transport conditions in a vertical pipe demanded a construction of special hydraulic installation, where the stream of water is transporting upwards solid particles in a ø150 mm plexiglass pipe. In the experiments, the natural nodules were replaced by ceramic models resembling the same shape, density and surface characteristics. As in the nature, the typical density of solid particles was roughly equal to 2.0 Mg/m^3.

The most interesting features of the flow was examined at the first 7 meters of the vertical pipe by four scintillation probes measuring the radiation emitted by a tracer and four gamma-absorption sets. A description of the solid particles dispersion and movement of both phases was the task of the experiment. Layout of the probes along the measuring distance is presented in Fig. 1.

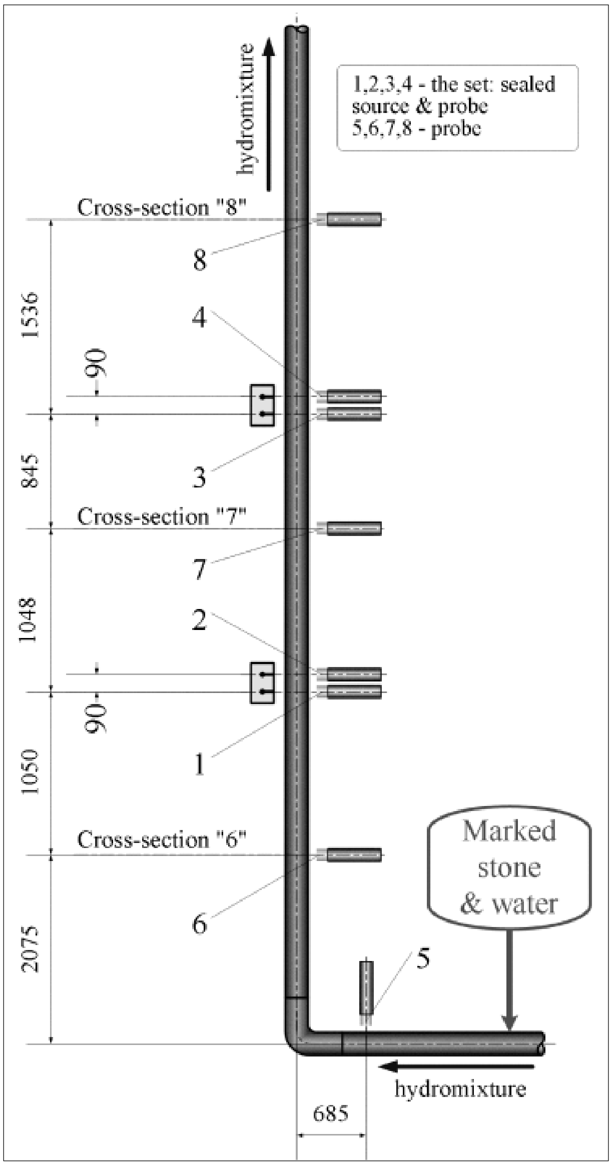

Fig. 1. The scheme of the measurement.

Application of the sealed sources

A detailed observation of the flow characteristics, especially the solid particles distribution, concentration and velocity, was arranged by the equipment based on the sealed gamma radiation sources and the scintillation detectors. The detailed geometry of the paired gamma absorption equipment is shown in Fig. 2.

Due to the application of a linear ^{241}Am source, the central part of the pipe cross-section was continuously penetrated by 59 keV photons. Intensity of the radiation recorded by the probes affords information about the concentration variation of the solid particles in the flow. For illustration of this investigation, the WRQ031 experiment was selected, where stochastically distributed solid particles were added to the water stream in the supplying horizontal pipe. Counts rate submitted by each probe was sequentially sampled every 1 ms. As a result, each gamma-absorption set allowed to record photons

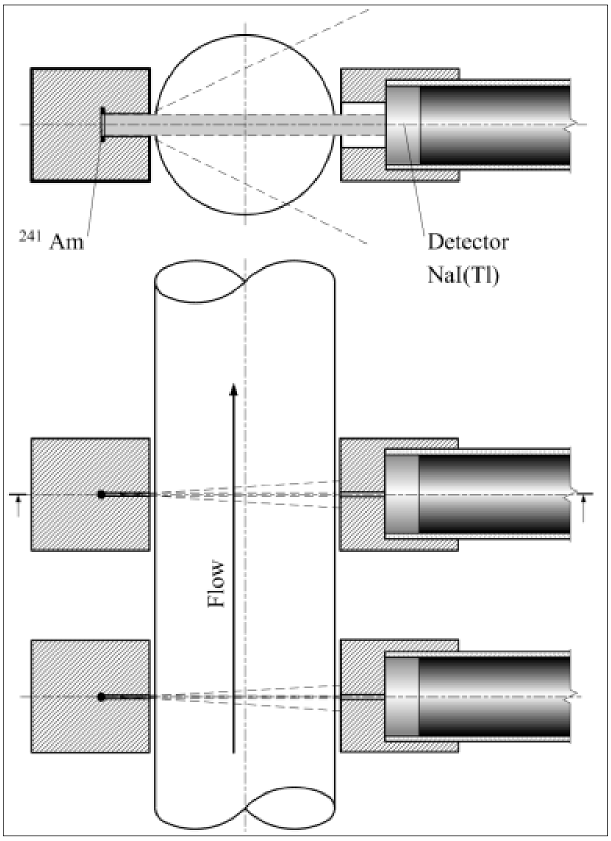

Fig. 2. View of the photon transmission through the flow.

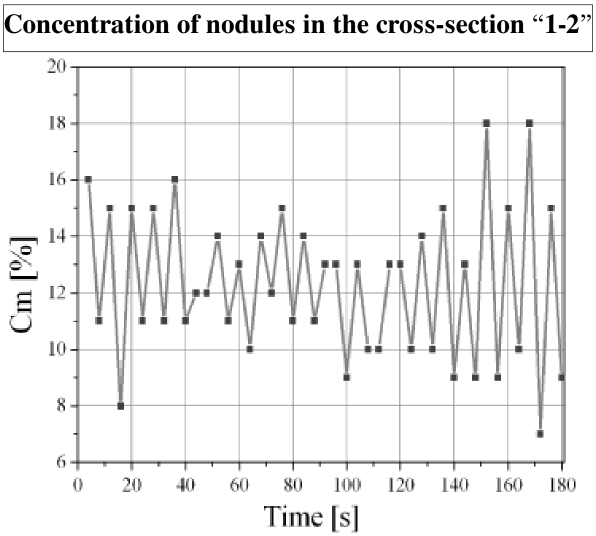

Fig. 3. Variations of the solid particles concentration observed in the WRQ031 experiment.

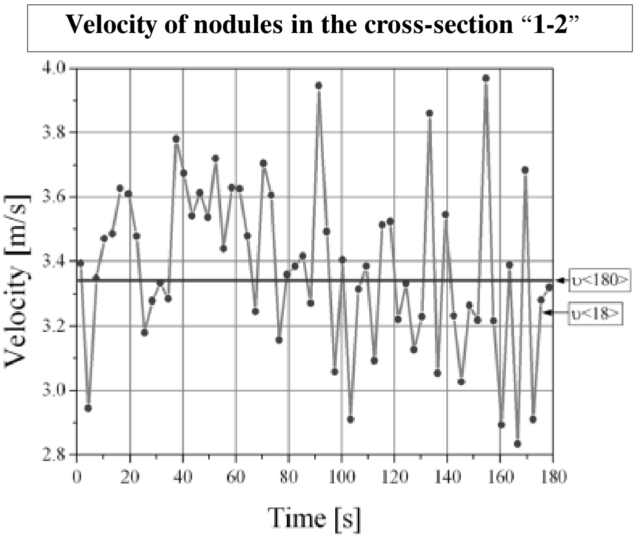

Fig. 4. Variations of the solid particles velocity observed in the WRQ031 experiment.

passing through the particular cross-section. Consequently, probes 1 and 2 analysed the cross-section located 3170 mm above the horizontal pipe. In the WRQ031 experiment, variation of the solid phase concentration is shown in Fig. 3. This record allows recognition of several groups of nodules transported upwards by the water stream.

Similarly, the set, which is presented in Fig. 2, makes it possible to determine the solid phase velocity by means of correlation analysis. The statistical evaluation of signals submitted by each probe allows the elimination of high frequency noise and low frequency variation of the flow density. Obtained ergodic signals, thanks to the filtration proposed by Petryka and Oszajec [2], allow to find out the most probable transportation delay between each pair of the cross-sections by the cross-correlation distribution:

$$R_{ij}(\tau) = \lim_{T\to\infty} \frac{1}{T}\int_0^T I_i(t) I_j(t-\tau)dt$$

where: τ – transportation delay; T – time of observation; $I_i(t)$ – first signal of the selected pair; $I_j(t)$ – second signal of the selected pair.

In practice, a sufficiently long time of observation (T) may be limited depending on statistical properties of the flow. For example, during the experiment WRQ031 two times of observation were selected: T_1 = 18 s, T_2 = 180 s.

As a result, both the short time variation and averaged transportation conditions of the solid fraction in the flow were observed. In this case, a set of at least 3 probes, showed in Fig. 1, allows the determination of mean velocity in a particular cross-section determined by each probe. An example of such procedure applied to WRQ031 experiment is shown in Fig. 4. The solid horizontal line represents mean velocity of nodules measured during 180 s.

On the other hand, cross-correlation analysis allowed estimation of the shortest possible time delivering yet proper cross-correlation distribution. In that installation, this time was equal to 18 s.

Repeating these calculations with 18 s increment, the dotted distribution shown in Fig. 4 was obtained.

Cited example illustrates how the proposed method allows observation of both short time fluctuations and long time lasting variations of the solid fraction transportation in the flow. By this way, it is possible to observe the flow kinetics even in the unsteady conditions of transportation.

Radiotracer measurements

Independently from previously described procedure, mean transportation of a particular phase, as well as a specific size of nodules, was examined in a series of radiotracer experiments. In these measurements, for labelling water and selected nodules, a tracer containing ^{99m}Tc isotope, acquired from the low activity medical Mo-Tc generator, was used. Due to that, the examination of transportation of the most typical size of nodules in the expected flow conditions was arranged [1].

Description of the flow

A detailed examination of the gathered nodules at the beginning part of the vertical pipe and the manner of transportation were arranged by the combination of both the sealed sources and the radiotracer measurements. An example of the application of this procedure to the results obtained in the WRQ031 experiment allows an accurate determination of the most probable water and solid particle velocities along the vertical pipe, in the section between 2 and 7 meters away the horizontal pipe.

Moreover, the uncertainty of every transportation delay between each pair of probes were obtained below 1 ms. In consequence, examination of the energy and the momentum transfer between the liquid and the solid

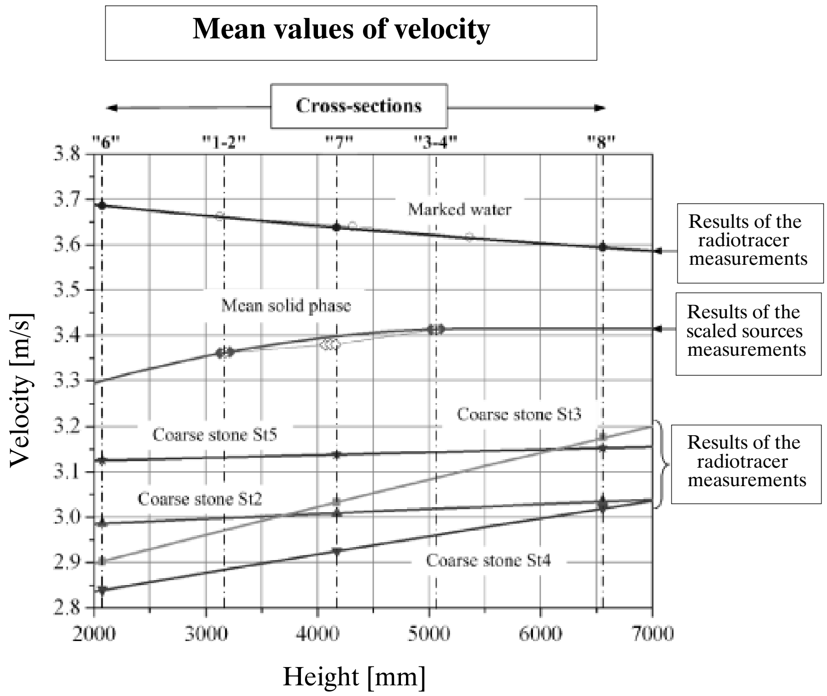

Fig. 5. Results obtained from the sealed sources and the radiotracer measurements in the WRQ031 experiment.

phases, as well as a conservation of the flow continuity, were possible.

All of these results collected in the WRQ031 experiment, in conjunction with the velocity variation of coarse nodules (above 50 mm), can be observed in Fig. 5.

Conclusion

In the proposed method, based on the application of both the linear sealed sources and the low activity radiotracer tests, due to statistical signals processing and the cross-correlation analysis, obtaining a transportation delay uncertainty below 1% is possible. Moreover, the completed tests proved that the elimination of the low frequency variations from the recorded signals allows the examination of the unsteady flows with almost the same accuracy.

The obtained results permit description of such phenomena as the slip velocity of the solid phase in relation to the liquid one, and the acceleration of solid particles in the critical, beginning part of the vertical pipes, as well as determining their limitations. Due to that, the proposed method may be applied to the analysis and control of similar installations in which non-stationary two-phase flows occur.

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