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Possibilities of radioisotope measuring in control of an unstable solid particles hydrotransport

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Abstract. The paper presents γ-radiation proposal to control a multiphase flow, independently from circumstances. So this method may be applied even in compound industrial or environmental processes. Moreover in many cases, it is the only method for applications for dense mixture containing coarse angular grains. The constructed equipment allows continuous measurement of density as well as solid phase for both concentration and average velocity. Due to pressure loss, it gives the output digital signal convenient for cybernation of the control process. The proposed procedures were tested at a laboratory installation modeling conditions expected during planned excavation of nodules from Pacific bottom.

1 Introduction

Hydrotransport is often applied in many branches of industry. Commonly in this operation, solid particles are transported by water through a pipe or open channel. However, the management of such process is being subject to numerous physical and economicl restrictions. For example, the size of the grains may vary and decreasing of the velocity would cause sedimentation of the solid phase. Moreover, even small modification of viscosity or the wall roughness may radically change head losses and turbulence of the flow [1, 2].

For a staff, it is evident how improper concentration of solids or flow velocity might result in high energy loss, over-wearing of pipes or even their clogging [3]. For example, in the typical hydrotransport installation with dry mineral throughput of 10,000 tons per hour, where minimal velocity preventing sedimentation is 3 m / s, the operating takes place with velocity of 4 or even up to 6 m / s. In consequence all pipes are used no longer than for 2 years [4].

Necessity of such flow control demands continuous measurements of at least solid particles' concentration and velocity, but this idea is really a great challenge, especially in harsh industrial or environmental circumstances, when ultrasonic flowmeters fail. As an example, transport of tough mineral particles may quickly wear down any probe insight the flow. Bearing that in mind, the proposal of nuclear method based on gamma radiation passing through both pipe and flowing mixture is often desirable [5].

The paper presents a gamma absorption method and describes results of laboratory tests demanded to formulate the proposal of control of the Pacific nodules exploitation.

2 Nuclear method of two-phase flow control

Hydraulic transport of solid particles is an example of two-phase flow especially convenient for an analysis by gamma radiation, due to photons transmission through pipes and delivering digital signals related to density of flow and averaged velocity of solid particles [6, 7].

2.1 Density measurement

In a hydrotransport analysis, a concentration of solid phase in a flowing mixture or its density belongs to the most important parameters and is commonly applied in the largest installations [3, 4 and 8].

The idea of gamma-ray absorption measurement is presented in figure 1. This procedure is based on exponential decreasing of narrow monoenergetic photon beam intensity in function of composition and geometry of absorbent. In this figure the sealed radioactive source emits incident gamma radiation beam shaped by collimator (1). Photons pass through the pipeline with analyzed mixture (3) and achieve the probe (2) contains a scintillation detector.

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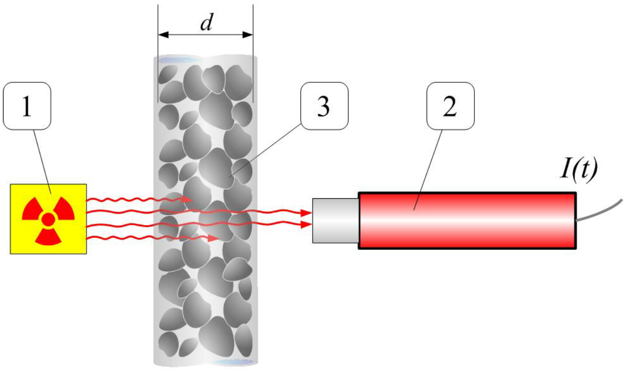

Figure 1. The principle of gamma absorption measurement: 1-gamma radiation source in collimator, 2 – scintillation probe, 3 – pipe with a hydromixture.

However in contrary to typical nuclear equipment, Authors decided to apply a twin absorption set shown in figure 2. That solution allows both, increase accuracy of density measurement and ensures solid particle's velocity determination exactly in the same part of the flow.

In result, the count rates intensities provided by both probes 1 and 2 shown in figure 2, allow determination of the intensity of photons *I** which pass through the investigated flow:

$$I^* = I - I_B \tag{1}$$

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

The above idea is illustrated by an arbitrary selected part of the experiment Wrs70, which is an example of a nonstationary flow typical for conditions anticipated throughout nodules excavation [7].

During selected measurement:

$$I_B = const \tag{2}$$

and received data in sections x and y determined by probes shown in figure 2, are plotted in chart 3.
In this figure 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 noise, despite of small distance between probes, which in that experiment was equal only 90 mm. So the new signal is:

$$I_{xy}^*(t) = \sqrt{I_x^*(t) \cdot I_y^*(t)} \tag{3}$$

Consequently, that signal is more adequate for describing the content of the flow and may be used for its monitoring. Moreover, in connection with the calibration, one may obtain the density or solid phase concentration plot [2, 3].

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

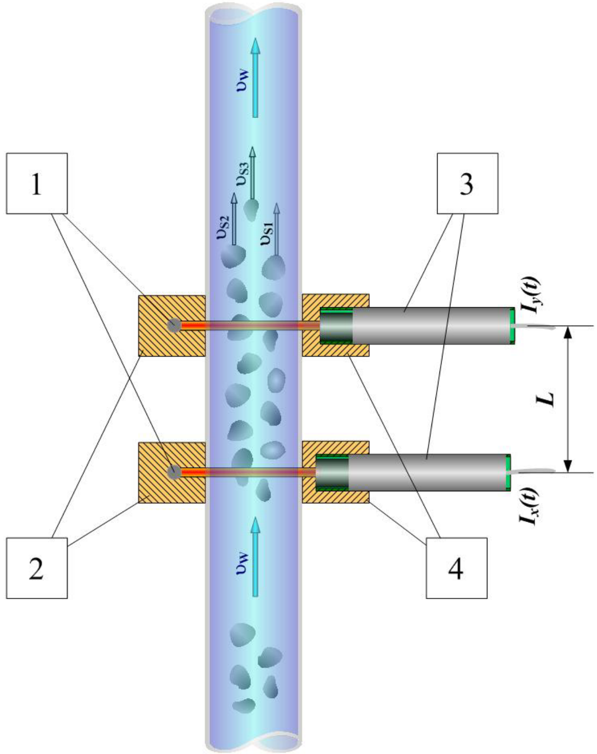

Figure 2. The twin absorption set used to both the improved density and grain's velocity measurement: 1 – sealed radioactive source, 2 – collimator of the source, 3 – scintillation probe, 4 - collimator of the detector, υ_{si} – velocity of a particular grain i, υ_w – average velocity of water.

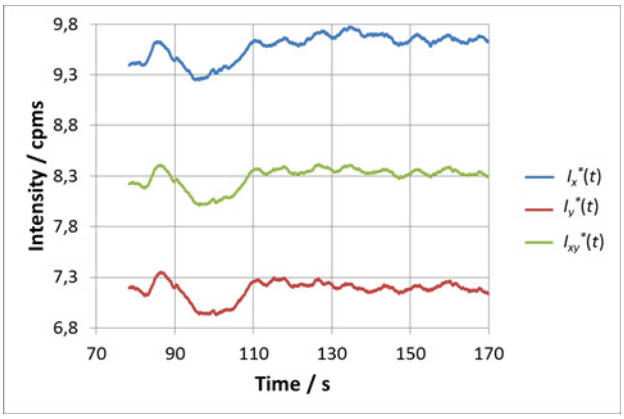

Figure 3. Signals recorded and calculated in the experiment Wrs70

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

$$I^* = I_0^* \exp(-\mu_m \cdot \rho_m \cdot d) \tag{4}$$

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

The obtained averaged mixture density distribution is presented in figure 4.

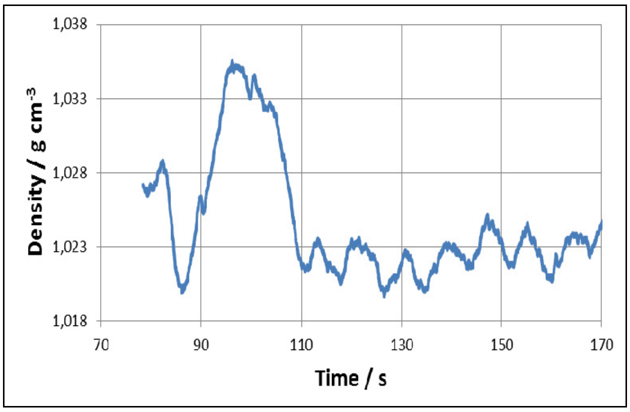

Figure 4. Mixture density estimated in the experiment Wrs70

Consequently the volumetric concentration of solid phase in the analyzed part of flow was calculated by:

$$C_V = \frac{V_S}{V_M} = \frac{V_S}{V_L + V_S} \tag{5}$$

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 investigated part of flow is shown in figure 5.

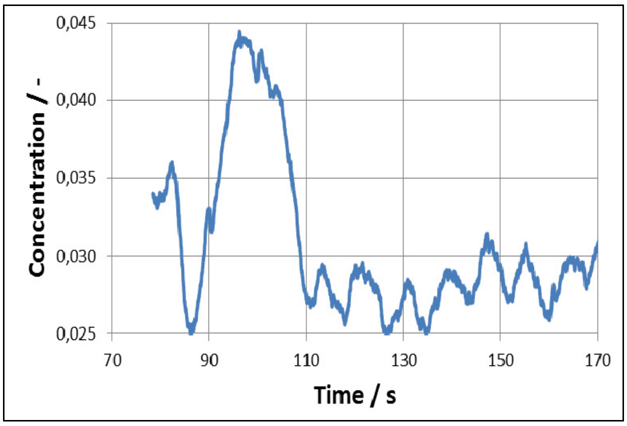

Figure 5. Volumetric concentration estimated in the experiment Wrs70

2.2 Grains velocity measurement

The two γ absorption sets shown in figure 2, illustrate the idea of the solid phase velocity measurement.

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

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:

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

where T is approximation time sufficient for grains' transport evaluation, s; τ time delay, s [9-14].

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

$$\upsilon_S = L / \tau_0 \tag{7}$$

During transportation by liquid, each solid particle i moves with the coaxial part of velocity υ_{Si} depending from its position in a pipe cross-section and interactions with other grains. In consequence, the velocity of grain i is function of its coordinates in cross-section and time, $\upsilon_{si}(x,y,t)$. So the average coaxial velocity:

$$\upsilon_s = \frac{\sum_{i=1}^{n} \upsilon_{si}}{n} \tag{8}$$

where n is number of grains in the volume determined by γ radiation plane passing to first probe (I_x) at the beginning of the velocity measuring time T, and similar plane passing to second probe (I_y) at end of T.

The velocity measuring time T depends from a geometry and density of the flow as well as activity of the radioactive sources and presence of such rapid fluctuations of a flow as turbulences, whirling and transitory fluctuations. In practice, its' reliable determination demands evaluation of the particular flow during a standard exploitation.

In the experiment Wrs70 the approximation time $T = 10$ s was sufficient to estimation the average velocity of solid particles distribution $\upsilon(t)$ shown in figure 6.

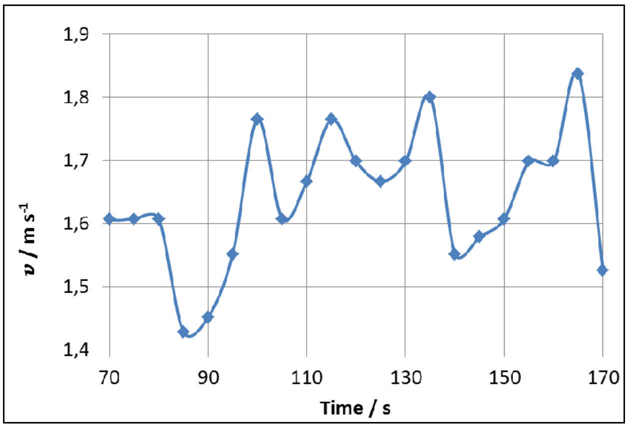

Figure 6. Velocity of solid phase estimated in the experiment Wrs70

In that view, the proposal of the nodules hydrotransport during excavation from Pacific bottom was preceded by construction of a laboratory installation suitable for modelling conditions of the full scale exploitation.

3 Laboratory tests

At Wroclaw University of Environmental and Life Sciences an installation was constructed which allows the study of phenomena expected during possible exploitation of the Pacific nodules [7].

During tests, specially designed ceramic models were applied to study manganese nodules transportation. The experimental pipe loop shown in figure 7 was equipped with 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.

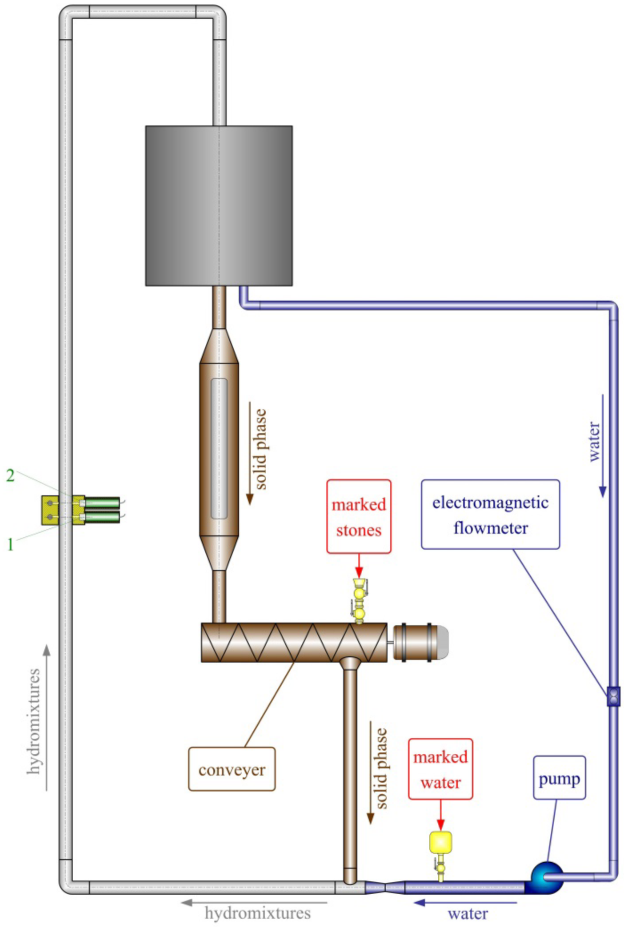

Figure 7. The experimental pipe loop [3]

In addition, the installation gives an opportunity to control flow rate of centrifugal pump with a 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 ms^{-1} and vary concentrations of solid particles to simulate the flow conditions during the expected undersea transportation.

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.

Careful analysis of nodules hydraulic transportation facilitated authors to construct the measuring equipment consisting of two radioactive sources and two detectors as shown in figure 2. In this set, such isotopes as ^{241}Am, ^{137}Cs, or ^{60}Co may be used, depending on the pipe material and diameter.

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, TTL 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 PC memory, and may be observe on a monitor [3].

A selected part of the experiment Wrs70 illustrates a non-stationary flow typical for anticipated Pacific nodules excavation and was convenient for the flow control evaluation.

4 Pressure loss determinations

The most convenient signal for the flow dynamic visualisation seems to be one proportional to the pressure loss recorded in the installation. This parameter may be determined from the Darcy–Weisbach equation:

$$\Delta p = f_D \cdot \frac{L_p}{d} \cdot \frac{\rho u^2}{2} = c \cdot \Delta p^* \qquad (9)$$

where f_D is Darcy friction factor, L_p / d is the ratio of the length to diameter of the pipe, ρ is the density of the fluid, u is the mean flow velocity and c is dimensionless coefficient.

Due to the above, the signal proposed for the flow control:

$$\Delta p^* = \rho_m \cdot \upsilon_s^{\,2} \qquad (10)$$

The exemplary shape of that signal is shown in figure 8.

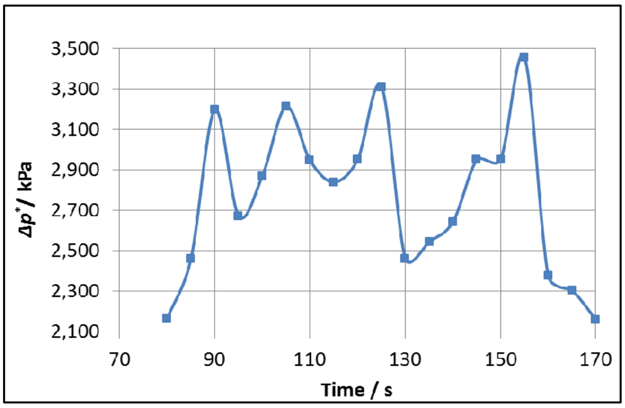

Figure 8. The signal proportional to the pressure loss estimated in the experiment Wrs70

5 Conclusions

The proposed control of a flow gives possibility to reduce velocity of solid phase transportation without hazard of the pipe clogging and promising high profit due to longer lasting safe exploitation of the industrial installation.

Moreover, the completed test confirms possibility of limited extension of nuclear methods applied only for the density examination in a particular flow. In many cases, the establishment of the second gamma absorption set, identical to the existing one, would allow realizing the offered method in limited cost.

Confirmation of the prepared solution in the laboratory installation modeling unstable conditions expected during the nodules exploitation suggests more easy application in typical industrial installations.

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