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Short Communication

Radioisotope investigations of compound two-phase flows in an open channel

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ABSTRACT

The paper presents possibilities for use of gamma-ray sealed sources for analysis of two-phase compound flows in an open channel as an example of a mud slurry suspension hydrotransport investigation. The objective of the research was to model the Flysch Carpathian formation as a result of the suspension stream and measurements of slurry flow rate. Due to the specific properties of muds the gamma-ray absorption and ultrasonic methods were used for flow measuring and the correlation analysis was applied to the recorded signals. The constructed testing installation was described in details and examples of measurement results were given. The obtained data allow the vertical solid particle velocity distribution in a channel to be determined. That information facilitated with the additional photo documentation enables the forming geological structures to be identified.

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1. Introduction

The characteristic geological structure of the Carpathians, where clastic rock complexes with a big thickness occur alternately: sandstone, mudstone, clay, shale, diatomite, etc. is called Carpathian Flysch [1]. The structures discussed were formed over millions years as a result of activity of the so called slurry suspension currents at the sea bed, which had been present in the Carpathians area before an orogeny i.e. before the formed silts were folded and uplifted due to the Alpine orogeny. The present geological structures, resulting from the solid particle hydrotransport and sedimentation have often become traps for natural gas and oil [ibid]. The slurry suspension hydrotransport is an example of a compound fluid and solid particles movement. So the examination of such flow is difficult due to a complicated mathematical description and interaction between the phases [2,3]. Therefore it has been decided to build an experimental testing installation for modeling of the slurry suspension hydrotransport and to use two independent measuring methods: an ultrasound meter for recording of the liquid phase velocity and the gamma-ray absorption set combined with the cross-correlation analysis of signals for determining of the solid phase velocity at a selected depth of the stream. In this case the flowing slurry suspension was a mixture of water and crushed rocks like muds and diatomite [4].

Diatomite (diatomaceous earth), a mud partially contaminated, obtained from lake sediments in Borovany (the Czech Republic), was used for the tests described. This rock is built from opal diatom shells, bound with opal cement, with various degree of recrystallization into chalcedony and microquartz [5]. It is characterized by a high porosity (up to 90%), therefore it has a low density ranging 0.4–0.96 g/cm^3 [ibid]. That has a significant impact on the accuracy of measurements, as the diatomaceous earth has a low content of heavy elements and density, thus the gamma absorption in this mixture is considerably lower than for sands or muds. Therefore the absorption signal to noise ratio was a fairly weak. That signal analysis is described in the following sections. Fig. 1 presents the example of the geological structure formed as a result of the sedimentary slurry flow, typical for Flysch Carpathians. Similar investigations were carried out for different geological reconstruction structures, as for example research of a laminar and near-laminar flows morphodynamics: [6], and a vertical turbulence structure in non-equilibrium currents [7]. Often in that application such methods like: ADCP applied in Acoustic Doppler Current Profiler [8], and [9], PIV (Particle Image Velocimetry) [10,11], electromagnetic flow meter [12], radiotracer investigation [2,4,13,17], etc. were used. Each of them has special advantage in a selected range of flow parameters.

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Nomenclature

FFT	Fast Fourier Transform
A	normalization factor of the Gauss function [(ms)·(cpms)^2]
D	depth of the channel [mm]
d	depth of the flow analysis (distance between mixture surface and γ-ray beam) [mm]
H	high of the channel wall [mm]
$I_x(t)$, $I_y(t)$	recorded count rates
L	measuring distance (gap between two γ-ray beam) [mm]
N	number of samples
W	with of the channel [mm]
$R_{xx}(\tau)$, $R_{yy}(\tau)$	autocorrelation functions
$R_{xy}(\tau)$, *CCF*	cross-correlation function
R_0	normalization level of the Gauss function [(cpms)^2]
t	time [s]
u_A, u_B	standard uncertainties
u_c	combined standard uncertainty
$x(n)$, $y(n)$	discrete-time series
Δt	sampling time [ms]
σ	standard deviation [ms]
τ	temporary time delay [ms]
τ_0	the most probable transportation time [ms]
υ_S	average velocity of solid phase [cm/s]
υ_{SM}	temporary velocity of solid particles [cm/s]
υ_{UW}	average velocity of water [cm/s]

2. Laboratory stage

The general view of the testing installation is presented in Fig. 2. It was built in the Sedimentological Laboratory of the Faculty of Geology, Geophysics and Environment Protection of the AGH University of Science and Technology in Krakow. The installation diagram is presented in Fig. 3. It comprises of an open channel $W=500$ mm width and $D=200$ mm depth, $H=400$ mm high (1) with glass walls, used for observation and examination of slurry sedimentation and transport. The flow through the trough is gravitational from the feed tank (2), which is connected via a pipe (5) and a sludge feed pump (4) to an overflow tank (3). The sedimentation compound prepared beforehand may be supplied to the installation through the overflow tank (3) or a rock spall conveyor (8). The slurry rate may be control by the adjustment of the stream height (6) and throttle valve (7) position. Moreover, the channel inclination angle may be changed by the screw support adjustment. The gamma absorption set was placed on a special measuring trolley (9), while the ultrasound meter (10) was secured directly to the trough wall. The trolley (9) enables not only the absorption set to be installed, but also other equipment e.g. a depth gauge or a camera. The applied Controlotron UNIFLOW 990E ultrasound meter allows the measurements of liquid velocity with an uncertainty not exceeding 1%. In addition, the installation was equipped with a brief water-level gauge (11), used like the ultrasound meter for evaluating of the averaged water velocity, but with a lower accuracy.

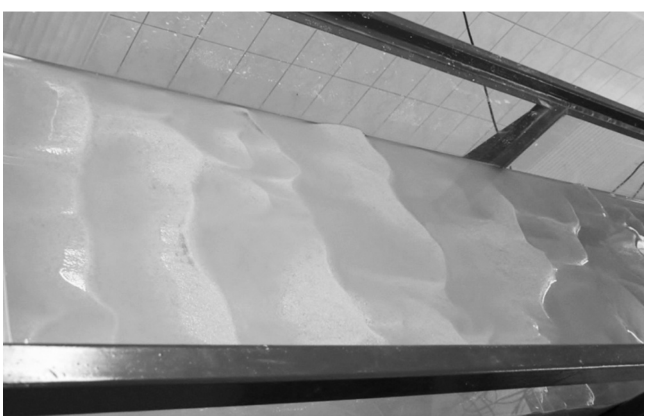

Fig. 1. The bed structure formed as a result of the sedimentary suspension flow, which is often encountered in the area of the so called Carpathians flysch. The picture was obtained after the channel emptying.

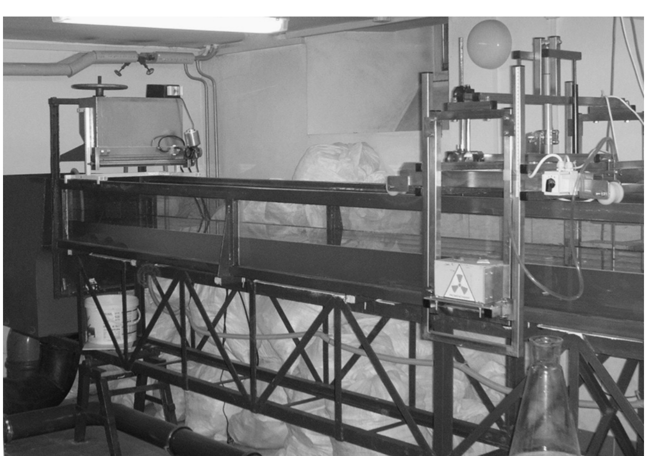

Fig. 2. The general view of the research installation with the radioisotope absorption set installed on the measuring trolley.

3. Measurement of the velocity of the solid phase transportation

3.1. Radioisotope absorption method

A measurement based on the gamma-ray absorption effect in the flowing slurry was used for evaluation of the mean solid particles velocity [4,23]. Fig. 4 shows a measurement section of the channel with the installed absorption set, comprising two sealed radioactive sources and two scintillation probes. As source of the gamma radiation, two sealed isotopes of ^{137}Cs (2) with activities of 70 and 100 mCi, placed in collimators (3) spanned $L=90$ mm were applied. Exactly at the opposite trough side a couple of probes (5) with NaI(Tl) scintillation detectors were installed in the collimators (4). The photon beam (6), which is shaped by the source collimator, pass through the flowing slurry, some photons were absorbed depending on density and content of the flow. The rest of the photons reaches the probes, and produces $I_x(t)$ and $I_y(t)$ counts rates. Deliver in this way the stochastic signals describing the instantaneous stream composition in a given cross-section. The analysis of those signals using cross-correlation [14–23] allows determination of the most probable transportation time τ_0 and next mean solid particle velocity by the following equation:

$$\upsilon_S = \frac{L}{\tau_0} \tag{1}$$

The constructed measuring trolley (1) allows the velocity of suspension along the channel to be measured, as well as

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