TURBIDIMETRIC MEASURING OF THE SUSPENDED SEDIMENT CONCENTRATION IN THE COASTAL ZONE

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Abstract

The construction peculiarities of the new model of turbidimeter for measurement of instantaneous values of suspended sediment concentration are described in this paper. The presence of optic negative feed back is the basic feature of this turbidimeter, which allows to eliminate practically completely the temperature instability of light source and of its electronic units. A new model of turbidimeter has given a possibility to create a three-dimensional lattice for the investigations of suspended particle spatial shift. One turbidimeter of the lattice cell is recording continuously the background transparency of examined liquid in a real scale. It gives possibility of continuous controlling not only of the light radiation flux attenuation by suspended particles but and of a ratio between the light flux absorption in researched water column with suspended particles and the light flux absorption in "clean" water. During the field experiments with the help of turbidimeters new data about physical mechanisms of sediment suspension above a smooth and rippled bottom were received.

Introduction

Till now there is no strict mathematical description of regularities of twophase flux motion. Determination of empirical dependencies describing a process of sediment transport is not possible without instrumental measurements of the suspended sediment concentration. That's why a selection of a reliable method of measuring of instantaneous values of suspended sediment concentration is one of the most urgent tasks.

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Optical methods which are the most quick-acting ones afford to research high-frequency non-stationary processes within the bottom layer where the concentration of sufficiently large particles of inorganic origin are rather high $(> 10 \text{ g/dm}^3)$.

There are two basic methods of determination of suspended material concentration in water which are based on the optical principle: measurements of attenuation of the light flux radiation (turbidimetry) and measurements of light energy scattered by particles under angles different from zero ones with respect to the direction of incident light (nephelometry). Nephelometers are seldom applicable for the measurements in the coastal zone since calibration characteristics of nephelometers depend greatly on the size of particles suspended in water. For this reason nephelometers are used, as a rule, for measurements of low concentration of homogeneous particles at comparatively large depth.

Brief theory of turbidimetry

Bugger's law is in the basis of turbidimetry. In compliance with it the initial flux of Φ_0 radiation passes the distance *l* in a certain medium and is attenuated by this medium to Φ level according to formula:

$$\Phi = \Phi_0 \exp(-\varepsilon l), \tag{1}$$

where ε is the index of light flux attenuation by given medium.

And the fundamental equation of turbidimetry can be written (Onishchenko, Kos'yan, 1989) as:

$$S = bA \frac{1}{l} \ln \frac{I_0}{I},\tag{2}$$

where $b = \frac{2}{3}\rho_s$;

S - weight concentration;

A is a parameter defining the suspended sediment composition;

 I_0 and I are output signals for «clean» water and water with suspended sediment consecutively.

And linear dependence between suspended sediment concentration and measured value of $\ln \binom{I_0}{I}$ remains only when the following parameters keep to be invariable in the course of measuring and meet the calibration conditions: suspended sediment composition (parameter A); density of grains ρ_s ; base of instrument l; parameter I_0 , that characterizes optical properties of clean water. When designing

turbidimeter, only measuring base l is strictly controlled parameter from four mentioned ones. Suspended sediment composition and density of grains ρ_s causes a methodical error of turbidimetric method, the value of which can be estimated on experimental data and results of calibration. In general case the parameter I_0 can also lead to additional methodical error. But if an additional channel which gives an information about optical properties of water will be provided in the construction of measuring system, methodical error caused by the change of I_0 parameter can be considerably diminished.

To control I_0 parameter it is necessary to define precisely the term «optical properties of water». In our case under optical properties of water we mean the transparency not a clean water but water with such a part of suspended sediments which do not settle and are transported together with water flow. It is known that particles with diameter less than 100 mkm form the transported part of suspended matter. That's to say, to record I_0 it is necessary to create such an additional zone of measurements where only suspended particles with diameter < 100 mkm are present.

Two turbidimeters were worked out and constructed for experimental turbidimetric research (Kos'yan et al., 1995). When designing these turbidimeters a task to restrict in size of construction was not raised. That's why turbidimeters turned out to be bulky and heavy.

Results of field research important for turbidimetry

The turbidimeters were used in several field experiments. In the course of the Russian field experiment «Novomikhailovka-93» a strongly pronounced interrelation between fluctuations of suspended sand concentration and kinetic turbulent energy were revealed in the bottom layer of the surf zone (Pykhov et al., 1995). According to obtained measuring data temporal and spatial scales of turbulent vortexes which have been formed when waves are breaking were also calculated and estimated.

The Russian-German experiment «Norderney-94» confirmed the existence of turbulent mechanism of sand suspension and afforded to determine the scales of variability of turbulent kinetic energy and concentration of suspended sand (Kos'yan et al., 1997).

The analysis of recordings has shown the presence of a sharp increase of suspended sand concentration which coincide in time with corresponding turbulent fluctuations of cross-shore and along-shore velocities.

A typical example of solid particle suspension is given in Figure 1. Wave breaking with the crest spilling occurred at the depth of \bar{h} = 2.36 m. Increase of turbulent fluctuations of velocity and splash of concentration may be provoked by horizontal advection of turbulent vortexes with captured sand to the region of the gauge installation.



Figure 1. An example of a single moment of suspension. Recording 6a.

H(t) is the height of free surface oscillations; u(t)and u'(t) is cross-shore velocity and its turbulent component; v(t) and v'(t) is along-shore velocity and its turbulent component; C(t) is concentration of suspended sand. Recording was made when wind wave parameters were: $H_s = 1.07$ m, $T_p = 8.7$ s, \bar{h} = 1.53 m, Sp.

2 shows Figure а chronogram of turbulent pulsations of velocity and their hodograph for the case which is demonstrated in Figure1. An end of vector of turbulent component of velocity shown on the hodograph describes two complete cycles during one second. This indicates the passing of the chain of four vortexes through the gauges, as it is shown in the right lower part of Figure 2. Then neighbor vortexes rotate in opposite direction.

The assess of spatial scales of turbulence afforded to reveal vortex structures from 1 to 10 m. Passing of vortex structure through the measuring point corresponded to the cases of intensive sand suspension. Linear dimensions of some vortexes varied from 0.3 m to 1.5 m, and they were different within one vortex structure. Maximum but not mean values of the vortex dimension were used for the determination of interrelations between vortex dimensions and a distance from the bottom to the surface, because it was

not possible to define whether the turbulent vortex had passed through the gauge area by its central or marginal part. The dependence between dimensions of the largest vortex in series and the distance between the bottom and the surface is presented in Figure 3. It demonstrates how vortex diameter grows with the increase of the distance between the bottom and the surface. Such a dependence confirms a classic idea about the proportionality between vortex dimensions and flux parameters.

One can determine precisely the dimensions of turbulent sandy vortexes by using for measurements of three-dimensional grating, in which the distance between gauges may be roughly selected from the diagram shown in Figure 3. Thus, for



Figure 2. Time scales of turbulent vortexes.

example, when measuring in the coastal zone where the distance between the bottom and the surface was 2 m, the largest diameter of vortex was 1.1 m (see Figure 3). Therefore, in order to record extreme values of vortexes of turbulence and concentration, the length of each side of measuring grating must be not less than a half of the largest vortex diameter for coherent conditions of research. In given case it must be not less than 0.55 m. Then the distance between gauges on every side must be





0.275 m, if there are three gauges on this side. Roughly calculated dimensions of grating demand rather rigid requirements for the size of measuring instruments installed on it. It should be added also that the vortex size within one vortex structure may be different.

After complex estimation of the results of field data processing it became clear that turbidimeters of old construction are useless for investigations of spatial-temporal characteristics of vortex structures. Overall dimensions of turbidimeter of old construction allow to place not more than two gauges in calculated volume of measuring grating. This was the reason for working out a new construction of turbidimeters of less size.

Structural block-diagram of the turbidimeter

To be more demonstrative, the structural block-diagram of the turbidimeter is divided into two basic parts (Figure 4): underwater block and above water unit. Underwater block includes: a source of reference voltage, comparator (differential amplifier of error signal), coordinating amplifier, modulator, generator, hardly stabilized current amplifier with a loop of negative feed-back, two light sources with the length of radiated light wave being $\lambda = 0.67$ mkm, optical negative feed-back channel and measuring channel. Each of channels includes photoreceiver, photocurrent amplifier and demodulator with filter. Measuring channel differs from optical negative feed-back channel only by presence of the current amplifier with a loop of negative feed-back that is necessary for matching with communication line.

The formation of a beam of light occurs in the following way. Reference voltage formed by the source comes to modulator through the comparator. The modulator makes the modulation of this voltage with the frequency of internal generator. Ripple (pulsating) voltage controls two identical light sources, the role of which is played by luminous radiating diodes with built-in mirror and narrow radiation pattern. Introduced modulation of the light flux eliminates completely the influence of flare spot when working at the shallow depth and thereby considerably decreases an instrument error.

The beam of light from the source 1 passing through investigated water column is attenuated in accordance with the law of light absorption and is perceived by photoreceiver 1. A signal from photoreceiver is amplified by precise photocurrent amplifier, is demodulated, is filtered and in analog form (as a current) comes to the above water unit by communication line. Silicon photodiode serves as photoreceiver. Its dimensions are small, its sensitivity is high. It has temperature stability and a small non-linearity. An angle of registration of a light beam in the receiver is reduced with the help of diaphragm (membrane). Time constant of the measuring channel does not exceed 0.01 s.

The channel of optical negative feed-back is destined for a hard stabilization of measuring parameters of the turbidimeter under the influence of different disturbing factors. Its structure is similar to that one of the measuring channel. Photoreceiver of this channel takes the light from its light source not through the investigated volume of water but by a special light channel. Output signal of the channel of optical negative feed-back is transmitted to the second input of comparator (differential amplifier of error signal) which controls emissive power. As a result, the emissive power is set in such a way, that output current of photoreceiver of the feedback channel is stabilized.



The impact of any disturbing factor (temperature, aging, etc.) provokes the change of output signal of feed-back channel. In its turn the change of this signal leads to the change of error signal, the phase of which is displaced for 180°. As a



Figure 5. The turbidimeter.

result, the units of automatic control of initial current of photoreceiver change the power of luminous radiation. An initial value of photoreceiver current of the channel of optical negative feed-back is restabilized in conditions. new Since the channels (measuring and feed-back) are identical, the regularities of current stabilization of photoreceivers also concur in them. Here, a possible dispersion of parameters of light sources and photoreceivers is the factor of instability. And this demands rather strict requirements for the selection of identical pairs. The difference of this construction of turbidimeter from the previous one is the presence of a special (additional) source of light for the feed-back channel. Stability of characteristics of such a structure is somewhat less (Kos'van et al., 1998). But the technological effectiveness and reliability of the construction is higher, and the cost of turbidimeter is sizably less.

The turbidimeter is connected with the above water unit by the four-core cable. Supply voltage $\pm 15V$ and midpoint (centroid) is transmitted by three cable lines.

Information signal (as a current) functionally connected with suspended matter concentration is transmitted by a separate line. Electronic unit forming the current is made as a self-tuning loop with negative feed-back, the parameters of which (to a certain degree) do not depend on the cable resistance.

In above water unit information signal is transformed into voltage. Then a direct component is removed from the information signal with the help of comparator and reference voltage source. Information signal on the output of comparator of above water unit exists as a voltage functionally connected with the suspended matter concentration. Comparator is built in such a way that in it besides the compensation of a direct component of a signal there is a possibility to change the conversion conductance of the information signal. This simplifies the matching of calibration functions of different specimens of turbidimeters to a single type. (Providing that the linear interrelation is kept between suspended matter concentration and the

attenuation index, as it was mentioned before). And, finally, an information signal passes through the amplifier, which has voltage transmission factor equal to 1, and power amplification factor being 80 dB. Such a power isolation allows to use recorders with different input impedance without distortion of transmitting function of turbidimeter. And the range of input impedance may vary within very broad limits: from 10 to 10^7 Ohms.

Appearance of the underwater block of turbidimeter is shown in Figure 5.

Laboratory study

Laboratory research was carried out with the view to calibrate the turbidimeter and to assess the influence of different disturbing factors upon the precision of instrument reading.

Sand collected in the course of «Ebro-delta-96» experiment was used for this research. Its granulometric composition is given in Figure 6.



Figure 6. Curve of granulometric composition of sand used for laboratory study.

Testing of turbidimeter was fulfilled in the tank of 50 liters. The diagram of the installation for these investigations is presented in Figure 7. Two turbidimeters (2 and 3), propeller (4) connected through a drive (5) with electric engine (6), tube for sampling water with suspended sediments were placed into the tank simultaneously.

The electric engine was connected with the power source by the rpm governor (7). A signal from the turbidimeters was loaded into computer through multy-channel

analog-to-digital converter. Sand was poured to the tank bottom. Fluctuations of suspended particle concentration were created by the change of the rotation velocity of the propeller and the change of sand amount. The distance between the water surface and turbidimeter sensors was 21 cm. The thickness of the water column was 37 cm.



Figure 7. Diagram of installation for laboratory study:

1 - tank, 2 - turbidimeter 1, 3 - turbidimeter 2, 4 - propeller, 5 - drive, 6 - engine, 7 - revolutions-perminute (rpm) governor.

A signal from the turbidimeter was recorded continuously. Sampling of suspended sand was done with the help of siphon roughly during one minute. Values of concentration in codes were averaged during the period of sampling. Before the start of measuring turbidimeter readings were recorded for clean water.

Figure 8 shows a calibration characteristics of turbidimeter for sand with above mentioned granulometric composition.

Figure 9 demonstrates a diagram of fluctuations of suspended particle concentration near the sensors of turbidimeter in the course of calibration. Digits on the diagram show values of concentration obtained by sampling with the help of siphon. The position of the digits on the diagram corresponds to the time moments when sampling was performed.



Figure 8. Calibration characteristics of turbidimeter.



Figure 9. Diagram of fluctuations of suspended particle concentration near the sensors of turbidimeter in the course of calibration.

Figure 10 shows the change of suspended particle concentration in different places of the laboratory tank. Measurements were performed synchronously by two turbidimeters. These diagrams give an ides of the uniformity of suspended matter distribution in the whole tank space, and allow to judge about the replication of the transmission characteristics of different copies of measuring instrument. In concrete case one equation for two turbidimeters was used for the calculation of concentration. With the help of operating means the coefficients of the turbidimeter transmission functions are made equal ones.



Figure 10. Synchronous change of suspended particle concentration in different zones of the laboratory tank.

It is evident that particles with grain size being <0.1 mm settle in the flux much longer than larger particles. This affords us to consider suspension with particles <0.1 mm as non-settling one, and in such a way to determine optical properties of «clean water», i.e. background. Measuring zone of one turbidimeter must be protected with filter with cell being 0.1 mm. A device that continuously

records values of the background must be additional one to the total number of gauges.

Appearance of the turbidimeter measuring head with filter is given in Figure 11.



Figure 11. Turbidimeter measuring head with filter.

Conclusions

During the field experiments with the help of turbidimeters new data about physical mechanisms of sediment suspension above a smooth and rippled bottom were received. On its base the contribution of different wave frequency into the formation of sedimentary flux was assessed. The origin of some components of the sedimentary flux was revealed.

Laboratory testing has demonstrated that turbidimeters of proposed structure ensure precise measurements of suspended sediment concentration in a broad range of temperature fluctuations of the environment.

The construction of turbidimeter gives the possibility to build threedimensional grating for the research of suspended particle spatial shift.

These features makes the turbidimeter an effective instrument when studying sediment transport in the coastal zone.

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