Water Sampling Process for Ecological Monitoring of Water Bodies: Modeling and Calculation of Parameters

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The process of water sampling, carried out for the purpose of environmental monitoring of various water bodies, is labor-intensive and quite expensive. Therefore, it is necessary not only to ensure the objectivity of water sampling at various depths of water bodies, but also to have the ability to predict this process based on an analytical model. Despite many existing methods of water sampling, none of them contains a simulation model that could allow the implementation of this operation at various depths of water bodies, taking into account interrelated parameters, namely, the speed of water flow, pressure at various levels and the time of filling the bathometer – a device for collecting water samples. The most promising direction for monitoring water bodies is the use of unmanned aerial vehicles as environmentally friendly equipment, in contrast to surface watercraft. The article presents the first developed analytical model of the water sample process using a bathometer mounted on a quadcopter. This model allows for fairly accurate calculations of the parameters of the bathometer, taking into account the characteristics of water bodies at various depths. Analytical dependencies are given for calculating the time of filling the bathometer, taking into account the immersion depth, pressure, and water flow velocity. The results of modeling the specified process are presented in the form of graphs of changes in the parameters of the water sampling device depending on the characteristics of water bodies, and the results of the modeling are analyzed. The main motivation for the conducted research is to ensure the objectivity of collecting water samples and the possibility of predicting this process in order to save financial costs. Ultimately, the analytical model developed for the first time provides an opportunity for engineers and researchers in the field of environmental monitoring of a reservoir to create similar equipment, depending on other production tasks.

***Keywords**: water body monitoring, water sampling, bathometers, quadcopters, process modeling*

1. INTRODUCTION

Despite the variety of water sampling methods and even those supported by relevant standards, there is currently no mathematical model that would combine all the technical parameters of the specified process. Moreover, the specified analytical model should combine both the technical characteristics of water sampling devices and the properties of a particular reservoir, namely depths, flow velocity, and variable pressure at different boundaries of the reservoir. The need to solve the specified problems confirms the relevance of research in this field.

Among the variety of water sampling methods, there are no proposals for building an analytical model in the aggregate of technical parameters of devices for water sampling and current characteristics at different depth horizons of water bodies. There are also no graph-analytical dependencies, for example, in the form of graphs or diagrams, of the depth and speed of immersion of the bathometer from time and the trajectory of its movement at different depth horizons of water bodies, which is extremely necessary for predicting and ensuring the objectivity of water sampling. The aspect of engineering novelty includes a fundamentally new design of the bathometer with servo-actuated valves for water sampling holes, as well as a method for accurately measuring the depth of

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immersion of the bathometer in the water body. The scientific novelty of the research consists of the first-ever analytical dependences of the trajectory of movement, speed and time of filling the bathometer depending on the flow rate, pressure and depth at different edges of the reservoir, the kinematic and dynamic models of the functioning of the water sampling device and the graph-analytical dependences obtained as a result of modeling the water sampling process. The mathematical model proposed for the first time in the form of a set of analytical and graphical dependences of the parameters of the water sampling device and the characteristics of the reservoir flow allows researchers and engineers to simulate and predict the water sampling process, as well as to implement the synthesis of similar technological equipment for drones for environmental monitoring of reservoirs in accordance with other production tasks.

2. PREREQUISITES AND MEANS FOR SOLVING THE PROBLEM

In order to clarify the direction of research and the choice of tools for building an analytical model, the most significant achievements in this field should be considered. In works [1, 2], it is noted that water sampling for analysis (both chemical and bacteriological) is carried out in accordance with the developed State Standards. A number of requirements and recommendations are set out, which are of a general nature; others relate to a specific type of analysis and type of sources. But in these works, there is no modeling of the water sampling process. Actually, the methods of water sampling for bacteriological and sanitary-chemical research are quite carefully set out in works [3, 4], but also without providing an analytical model of the specified process. The original design of the device for water sampling, a bathometer, is presented in work [5], where the use of an unmanned aerial vehicle, i.e., a drone, is proposed to increase the objectivity of water sampling. A more detailed description of water sampling, procedure, purpose, methods, and equipment description is provided in the article [6]. Kinematic and dynamic analysis of the motion of a bathometer mounted on a gimbal is presented in [7], which provides an opportunity to investigate the orientation process of a water sampling device. Studies [8] confirm the feasibility of using drones to collect hydrochemical data from freshwater environments for biological and physicochemical water sampling.

The application of the so-called orthogonal mosaic method, which is created by an unmanned aerial vehicle [9] to estimate the amount of collected rainwater, is of great interest. In [10], a new approach in the science of studying water and aqueous solutions is proposed, which is based on near-infrared spectroscopy, which is used to analyze the interaction of water and hydrogenated nanomaterials. In order to improve the quality of water for agriculture, in studies [11], the use of unmanned aerial vehicles for monitoring water quality in irrigation canals is proposed. The practical approach to monitoring proposed in [12] is considered appropriate for promoting the sustainable development of wharves in terms of monitoring water quality and noise levels. However, the reviewed works lack analytical models of the actual process of water sampling.

Unlike previous studies, in [13] analytical dependencies are presented that link such parameters of water sampling as the length, width and speed of the water flow, as well as the temperature and pressure of the water flow, but without studying the process of immersion of the water sampling device, i.e. the bathometer, and its filling. Methodological work [14] provides an opportunity to systematize the processes of collecting, preserving water samples, and their field analysis. Of undoubted interest are studies [15], which compare dynamic models of quadcopter flight, and in the work [16], an assessment of the quadcopter altitude is presented using inexpensive barometric, infrared, and ultrasonic sensors. Both articles are of interest for the synthesis of quadcopter designs, but they do not consider the actual process of collecting water samples for environmental monitoring.

Thus, the task of modeling the process of water sampling for ecological monitoring of the state of various water bodies remains relevant.

3. FORMULATION OF THE PROBLEM

To ensure the objectivity of water sampling and the possibility of predicting this process, it is not enough to use various means of transport and effective bathometer designs; it is necessary to have an analytical model of the set of operations that make up the process of water sampling for the purpose of ecological monitoring of the state of various water bodies - rivers, lakes, reservoirs, etc. The absence of an analytical model that would link the technical parameters of the specified process, namely: calculation of the bathometer immersion depth, water filling time, and trajectory of its movement, taking into account the flow velocity and pressure at different depths of water bodies, makes it impossible to predict the water sampling process and ensure its objectivity.

4. SOLUTION OF THE PROBLEM UNDER CONSI–DERATION

First, let us consider a fundamentally new design [5] and the algorithm of operation of the sampling device, which will facilitate the understanding of the mathe–matical model provided below.

Drone construction

Figure 1 shows a general view of a drone for taking water samples. A winch is mounted on the bottom of the quadcopter, which has a drive in the form of an electric motor with an encoder to calculate the number of revolutions of the winch, and therefore the depth of the bathometer for taking water samples.

A fundamentally new design of the drone’s techno–logical equipment, the longitudinal section of which is shown in Figure 2, contains two coaxial cylindrical chambers, which are closed at the ends with lids with a seal. These lids have holes for water intake, the opening and closing of which is carried out by 3-leaf dampers driven by electric motors. The quadcopter is equipped with a winch with a drum, which is driven by an electric motor with an encoder – a device for converting the angle of rotation of the drum into an electrical signal.

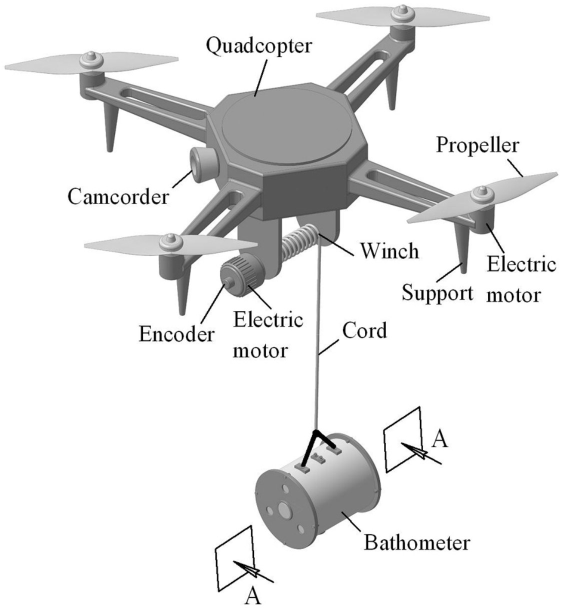

Figure 1. Drone for water sampling

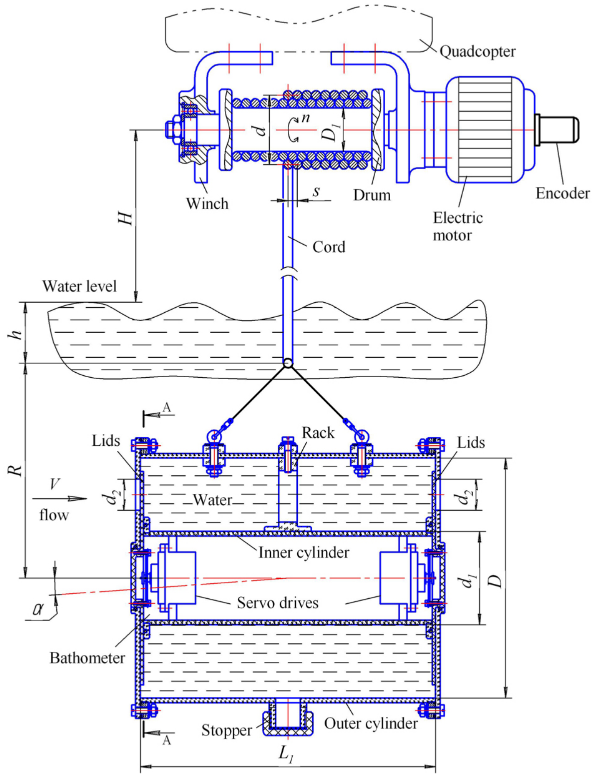

Figure 2. Design of drone technological equipment (See also A–A Figure 1)

A cable is wound in several layers on the winch drum, which is connected to a bathometer, a container for taking a portion of water for further laboratory analysis. Winding the cable on a drum in several layers involves the following parameters (see Figure 2): d – diameter along the axis of the cable turn on the drum; D_1 – diameter of the drum shaft; s - winding pitch of the cable turns; n – number of revolutions of the winch drum, measured by an encoder. The bathometer itself has an outer cylinder and an inner sealed cylinder, which is fixed to a stand. On the ends of the outer cylinder, three holes are made on both sides with a diameter for taking water samples. These holes are opened and closed by dampers that have an angular drive for turning 45 degrees from servo drives. The plug serves to drain water from the bathometer in the laboratory.

The drone flies to a point in the reservoir to take a water sample, and after turning on the winch engine, the bathometer is lowered into the water. In this case, the calculation of the value L of lowering the bathometer into the water is carried out according to the for–mula $L = H + h = H + n\sqrt{s^2 + (\pi d)^2} + R$, where H – is the height of the device above the water surface (see Figure 2); h – is the depth of the bathometer before opening its covers; n – is the number of revolutions of the winch drum; s – is the pitch of the cable turns; d – is the diameter along the axis of the cable turn on the drum; π – is a mathematical constant; R – is the distance from the axis of symmetry of the bathometer to the point of its attachment to the cable.

After reaching a given depth, which is determined by the specified formula, the servo drives are turned on, which rotate the flaps to a certain angle (for example, 45 degrees) and thereby open the holes (three on each side). After a certain time t (which is determined below), the bathometer is filled with water, after which the servo drives are reversed and the flaps close the holes d_2, then the bathometer is lifted to its original position and delivered to the laboratory.

5. MATHEMATICAL MODEL OF THE WATER SAM–PLING PROCESS

The mathematical model reflects the parametric synt–hesis of the process of immersion of a bathometer in a reservoir and contains the analytical dependencies of the trajectory of movement, speed, and time of filling of the bathometer depending on the current speed, pressure, and depth at different horizons of the reservoir.

The process of submerging a bathometer

To immerse a bathometer with a mass m, which has the shape of a circular cylinder with a diameter D and a length L_1, in a liquid, the condition must be met: the weight of the bathometer must be greater than the Archimedes force pushing the bathometer $G_A = \rho g \frac{\pi D^2}{4} L_1$ (where ρ – is the density of the liquid, for water ρ = 1000 kg/m^3; g=9.8 m/s^2 is the acceleration of gravity). In the following, we assume that the condition is met, i.e.

$$G > G_A . \tag{1}$$

The bathometer is attached to a cable and, by changing the cable tension, it is possible to regulate the process of immersing the device to the required depth, but the immersion time will be much longer than with zero effort in the cable, when the immersion occurs under the action of the bathometer's own weight. We choose the origin of the coordinate system on the surface of the reservoir. We direct the *Oy* axis vertically downward and the *Ox* axis in the direction of the reservoir flow. We will count the ordinate from the surface of the reservoir to the lower edge of the cylinder (Figure 3, a).

During movement, three vertical forces will act on the body (i.e., the bathometer): the force of the bathometer's own weight, the Archimedes force pushing the bathometer, and the force R_1 of the resistance of the medium, which depends on the square of the immersion speed u_2, the density ρ of the liquid and the area S_y of the characteristic cross section perpendicular to the axis *Oy*, namely: $R_1 = k\rho S_y u^2$, where k – is a dimensionless coefficient determined from the experiment.

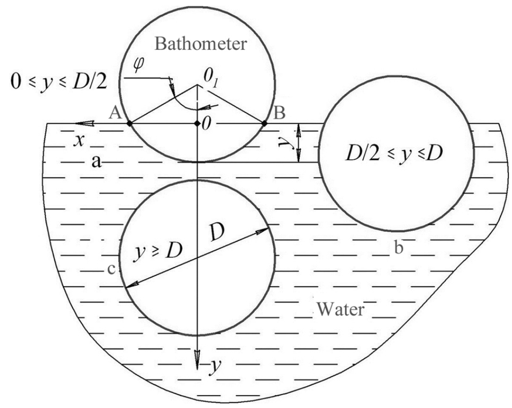

Figure 3. Stages of immersion of a bathometer in a body of water

Let us consider three stages of immersion. The first stage of motion corresponds to the position of the bathometer shown in Fig. 3 (a), when $0 \le y \le D/2$. The differential equation of motion of the body, i.e., the bathometer, will have the form

$$m\frac{d^2y}{dt^2} = mg - \rho g V_y - k\rho S_y u^2 \quad (2)$$

Where V_y – the volume of the displaced fluid; S_y – the area of the characteristic cross section; k – a dimensionless coefficient determined from the experiment, $k = \frac{(mg - \rho g V)}{u^2 \rho S_o}$; $u = \frac{dy}{dt}$ – the speed of immersion of the body; ρ – the density of the liquid; the volume of the bathometer $V = \frac{\pi D^2}{4} L_1$. From Fig. 3 (a) it is seen that $OO_1 = D/2 - y$, then $OA = OB = \sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - y\right)^2}$;

$\varphi = \arccos\left(\frac{OO_1}{D/2}\right) = \arccos\left(\frac{D-2y}{D}\right)$, and also:

$$V_y = \left(\varphi\left(\frac{D}{2}\right)^2 - \frac{1}{2} 2OA \times OO_1\right) L_1, \quad (3)$$

$$S_y = 2OA \times L_1 = 2L_1\sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - y\right)^2}. \quad (4)$$

Differential equation (2) can be solved numerically under initial conditions *t=0, u=0, y=0*. At the end of the first stage $t=t_1$, $u=u_1$, $y = D/2$.

At the second stage (Fig. 3, b) the ordinate changes within $D/2 \le y \le D$. Let us write the differential equation of motion of the body at the second stage

$$m\frac{d^2y}{dt^2} = mg - \rho g V_y - k\rho S_o u^2, \quad (5)$$

where $S_o = DL_1$, and V_y is calculated by the same for– mula (3) only for other values of y. Differential equation (5) can also be solved numerically under initial con– ditions $t=t_1$, $u=u_1$, $y = D/2$. At the end of the second stage $t=t_2$, $u=u_2$, $y = D$.

At the third stage (Fig. 3, c) the ordinate $y \ge D$, i.e., the bathometer is completely immersed in the liquid. Let us write the differential equation of motion of the body at the third stage

$$m\frac{d^2y}{dt^2} = mg - \rho g V - k\rho S_o u^2, \quad (6)$$

where $V = \frac{\pi D^2}{4} L_1$.

We solve the differential equation (6) analytically under the initial conditions $t=t_2$, $u=u_2$, $y = D$. We take into account that $\frac{d^2y}{dt^2} = \frac{du}{dt}$, substitute into equation (6), separate the variables, and integrate

$$\int_{t_2}^{t} dt = \int_{u_2}^{u} \frac{mdu}{mg - \rho g V - k\rho S_o u^2}. \quad (7)$$

After integrating (7), we obtain the equality

$$t = t_2 + \frac{m}{2\sqrt{g(m - \rho V)k\rho S}} Ln\left(\frac{q_1(u)q_2(u_2)}{q_2(u)q_1(u_2)}\right), \quad (8)$$

where marked: $q_1(u) = \sqrt{g(m-\rho V)} + \sqrt{k\rho S}u$; $q_2(u) = \sqrt{g(m-\rho V)} - \sqrt{k\rho S}u$.

On the other hand $\frac{d^2y}{dt^2} = \frac{du}{dt} = u\frac{du}{dy}$. Again, we substitute into the differential equation (6), separate the variables, and integrate

$$\int_{D}^{y} dy = \int_{u_2}^{u} \frac{mudu}{mg - \rho g V - k\rho S_o u^2}. \quad (9)$$

After integration, we obtain the equality

$$y-D=-\frac{m}{2k\rho S_o}Ln\left(\frac{mg-\rho gV-k\rho S_o u^2}{mg-\rho gV-k\rho S_o u_2^2}\right). \qquad (10)$$

Potentiate equality (10) and solve it with respect to the velocity

$$u=\sqrt{\frac{1}{k\rho S_o}\begin{pmatrix}mg-\rho gV- \\ -(mg-\rho gV-k\rho S_o u_2^2)e^{-q(y)}\end{pmatrix}}, \qquad (11)$$

where $q(y)=2k\rho S_o(y-D)/m$.

The reservoir has a flow velocity v1, and therefore the bathometer will also move in the direction of the Ox axis, namely $x= v1_t$. The parameter calculations were carried out with the following initial values of the quantities: m=2 *кг*, D=0.12 *м*, $\rho=1000$ *кг/м*^{3}, g=9.8 *м/с*^{2}, L_1=0.1 *м*, H=1 *м*, v_1=3 *м/с*, d_1=0.4D, d_2=0.02*м*.

Analysis of simulation results

As can be seen from the graphs below, the dimen–sionless coefficient k, which takes into account the ratio of the density of the liquid, the speed of immersion and the volume of the bathometer (see formula (2)), signi–ficantly affects the dependence of the depth, the speed of immersion and the movement of the bathometer on time. In the graphs of Figures 4, 5, and 6, the dotted lines correspond to the value $k = 0.001$, the solid lines to the value $k = 0.2$, and the dash-dotted lines to the value $k = 0.3$. Thus, from the graph of Figure 4, it is clear that at sufficiently small values of the specified coefficient, the process of immersion of the bathometer is signi–ficantly accelerated and, conversely, when increased, it is significantly slowed down.

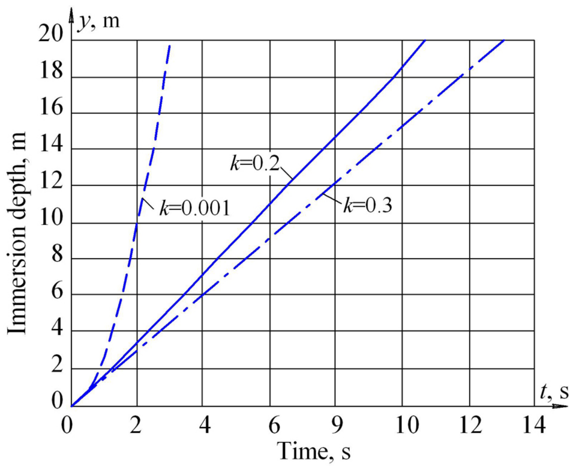

Figure 4. Dependence of the depth of immersion of the bathometer on time

The graph in Figure 5 shows that with the ratios of liquid density, immersion speed, and bathometer volu–me when $k = 0.2…0.3$, the bathometer immersion speed stabilizes, which is extremely important for program–ming the winch drive, on the cable of which the batho–meter is installed.

The graph in Figure 6 illustrates the dependence of the bathometer movement on time, namely, at small values of the specified coefficient, the bathometer movement is significantly accelerated, and, conversely, at increased values, it is significantly slowed down.

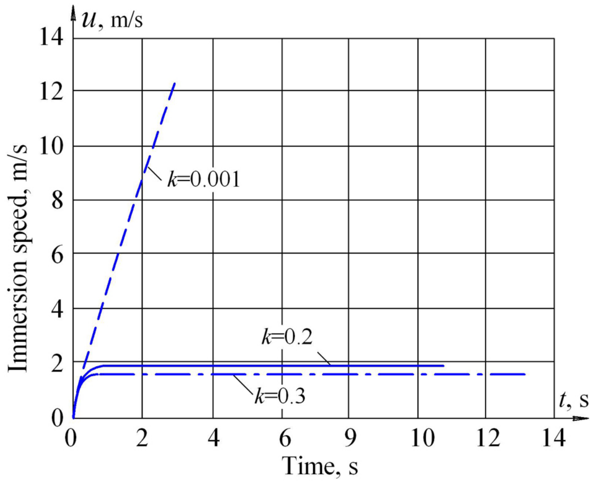

Figure 5. Dependence of the bathometer's sinking rate on time

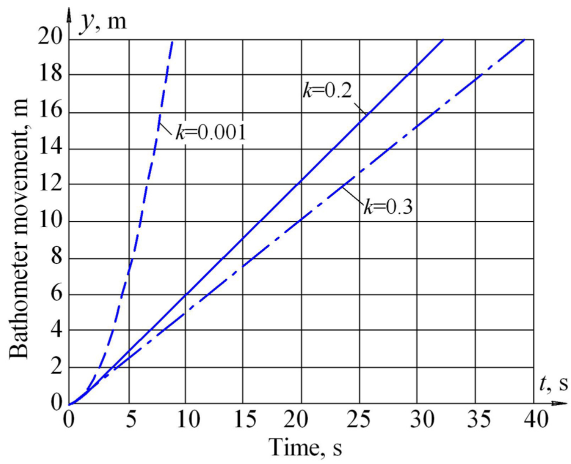

Figure 6. The trajectory of the bathometer

The required length of the hawser on which the bathometer is installed depends on both the depth of immersion of the bathometer and the speed of the current, namely:

$$L_t \geq \sqrt{(H+y_{\max})^2+(v_1 t_{\max})^2} \qquad (12)$$

The time it takes for the bathometer to rise depends on the angular velocity ω of the winch drum (see Figure 2)

$$t_4=\frac{2\sqrt{(H+y_{зан.})^2+(v_1 t_{зан.})^2}}{\omega d} \qquad (13)$$

Let us consider the process of filling a bathometer with water. We assume that after the device reaches the planned depth, the cable stops so that the current does not carry the device further. As is known from hyd–raulics, the flow rate Q of liquid per unit time through an opening with an area S is expressed by the formula

$$Q=\mu S\sqrt{2\frac{p_1-p_2}{\rho}} \qquad (14)$$

where the friction coefficient $\mu=0.6$, p_1, p_2 – pressure values, ρ – density of the liquid. In this case, for three holes, it is necessary to take into account the flow pressure, i.e. $p_1 = v_1^2\rho + p_a + y\rho g$, and for the other three holes $p_1 = p_a + y\rho g$ (p_a – atmospheric pressure). We assume that the pressure p_2 increases from pa in proportion to the filled volume, namely:

$$p_2 = p_a + \rho g y \frac{V_1}{V_o} \tag{15}$$

where V_1 – variable value of water volume ($0 \le V_1 \le V_o$), $V_o = \frac{\pi(D^2 - d_1^2)}{4} L_1$.

Let's substitute the expressions for pressures into the expression (14)

$$Q = 3\mu S_1 \sqrt{2}(\sqrt{v_1^2 + yg(1 - V_1 / V_o)} + \\ +\sqrt{yg(1 - V_1 / V_o)}) \tag{16}$$

where $S_1 = \frac{\pi d_2^2}{4}$ – area of one water inlet hole. Then the process of filling the bathometer can be described by the differential equation

$$\frac{dV_1}{dt} = 3\mu S_1 \sqrt{2}(\sqrt{v_1^2 + yg(1 - V_1 / V_o)} + \\ +\sqrt{yg(1 - V_1 / V_o)}). \tag{17}$$

Separate variables and integrate

$$\int_0^t dt = \frac{1}{3\mu S_1 \sqrt{2}} \int_0^{V_o} \frac{dV_1}{\sqrt{v_1^2 + yg(1 - V_1 / V_o)} + \sqrt{yg(1 - V_1 / V_o)}} \tag{18}$$

After integration, we obtain the bathometer filling time depending on the current speed and immersion depth

$$t = \frac{V_o\sqrt{2}}{9\mu S_1 g y v_1^2}(\sqrt{(v_1^2 + yg)^3} - v_1^3 - \sqrt{(yg)^3}) \tag{19}$$

Based on formula (19), the graphs in Figure 7 are constructed, where the dotted line corresponds to the current velocity v_1 = 1 m/s; the solid line – v_1 = 3 m/s; the dash-dotted line – v_1=5 m/s, the solid black line – v_1 = 0.01 m/s. As can be seen from Figure 7, with increasing immersion depth of the bathometer, its filling time decreases significantly, which is explained by the significantly higher pressure at great depths of water bodies.

In the case of flow velocity approaching zero, that is, when in formula (19) both the numerator $v_1 \to 0$ and the denominator tend to zero, and therefore it is necessary to find the limit

$$t = \frac{V_o\sqrt{2}}{9\mu S_1 g y} \lim_{v_1 \to 0}\left(\frac{\sqrt{(v_1^2 + yg)^3} - v_1^3 - \sqrt{(yg)^3}}{v_1^2}\right). \tag{20}$$

To find the limit, we use L'Hôpital's rule, according to which we need to take the derivatives with respect to the variable v_1 separately from the numerator and denominator, i.e.

$$t = \frac{V_o\sqrt{2}}{9\mu S_1 g y} \lim_{v_1 \to 0}\left(\frac{\frac{3}{2}\sqrt{(v_1^2 + yg)}2v_1 - 3v_1^2}{2v_1}\right). \tag{21}$$

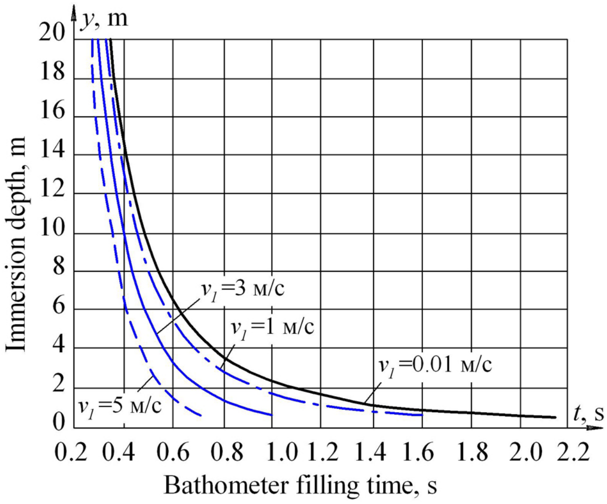

Figure 7. Dependence of the bathometer filling time on the immersion depth and the current speed in the reservoir

After reducing by v_1 and substituting v_1 = 0, we obtain the formula for the time of filling the bathometer in the absence of current in the reservoir

$$t = \frac{V_o\sqrt{2}}{6\mu S_1 \sqrt{gy}} \tag{22}$$

Therefore, at a given immersion depth, the total time for taking water samples consists of the time of immersion of the bathometer (determined by the graph in Figure 4), the time of its filling (determined by the graph in Figure 7), and the time of ascent of the bathometer, which is determined by formula (13).

6. DISCUSSION

Unlike sampling methods [3, 4], in this article, the authors proposed not only the sequence of operations for water sampling using a drone, but also provided analytical formulas for calculating the numerical parameters of the specified process.

The graphs in Figure 7, which are built on the basis of formula (19), provide numerical evidence of the reduction in the influence of water flow velocity on the time of filling the bathometer at great depths of the reservoir, where the pressure increases significantly.

Despite the study [11], which presents analytical dependencies that link such parameters of water sam–pling as length, width and water flow velocity, this work investigated the relationship between pressure and water flow velocity on the time of filling the bathometer with water, which makes it possible to calculate the time of hovering of the drone above the surface of the reservoir.

The analytical model of the process of water sampling for laboratory analysis, proposed for the first time, allows researchers to predict the specified process. Practical applications of this article include graphical dependencies of the diagrams Figures 4 □ 6, which allow determining the dependence of the depth and immersion rate of the bathometer on time, and the diagram Figure 7 provides the opportunity to practically determine the dependence of the filling time of the bathometer on the immersion depth and the speed of the current in the reservoir. Ultimately, these diagrams allow engineers in the field of environmental moni–toring to create similar equipment for other production tasks.

7. CONCLUSION

Equipping the bathometer with servo-driven valves al–lows not only for remotely control~~ling~~ the opening and closing of the water intake holes, but also to avoid turbulence in the flow of water entering the bathometer and to bring the flow regime of water entering the bathometer closer to a state close to laminar flow.

The developed mathematical model allows for the analysis and prediction of the water sampling process in the aggregate of the technical parameters of the bat–hometers and the current flow characteristics at different depths of water bodies. The processes of immersion and filling of the water sampling device have been studied, taking into account the ratio of its weight and the Archimedean force that counteracts the immersion of the bathometer, and the corresponding analytical depen–dencies have been provided.

The provided graph-analytical dependencies of the bathometer immersion depth, the time of its filling with water, and the trajectory of movement, taking into acco–unt the flow velocity and pressure at different depths of water bodies, provide the possibility of predicting the process of water sampling and contribute to increasing the objectivity of the specified process.

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DECLARATION OF CONFLICTING INTERESTS

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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ПРОЦЕС УЗОРКОВАЊА ВОДЕ ЗА ЕКОЛОШКИ МОНИТОРИНГ ВОДНИХ ТЕЛА: МОДЕЛИРАЊЕ И ИЗРАЧУНАВАЊЕ ПАРАМЕТАРА

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Процес узорковања воде, који се спроводи у сврху мониторинга животне средине различитих водних тела, захтева много рада и прилично је скуп. Стога је неопходно не само осигурати објективност узорковања воде на различитим дубинама водних тела, већ и имати могућност предвиђања овог про–цеса на основу аналитичког модела. Упркос многим постојећим методама узорковања воде, ниједна од њих не садржи симулациони модел који би могао да омогући спровођење ове операције на различитим дубинама водних тела, узимајући у обзир међусобно повезане параметре, наиме, брзину протока воде, притисак на различитим нивоима и време пуњења батометра – уређаја за сакупљање узорака воде. Најперспективнији правац за праћење водних тела је употреба беспилотних летелица као еколошки прихватљиве опреме, за разлику од површинских пловила. У чланку је представљен први развијени аналитички модел процеса узорковања воде помоћу батометра монтираног на квадрокоптер. Овај модел омогућава прилично тачне прорачуне параметара батометра, узимајући у обзир карактеристике вод–них тела на различитим дубинама. Дате су анали–тичке зависности за израчунавање времена пуњења батометра, узимајући у обзир дубину урањања, при–тисак и брзину протока воде. Резултати моделирања наведеног процеса представљени су у облику графикона промена параметара уређаја за узорко–вање воде у зависности од карактеристика водних тела, а резултати моделирања су анализирани. Глав–на мотивација за спроведено истраживање је оси–гурање објективности прикупљања узорака воде и могућност предвиђања овог процеса како би се уштедели финансијски трошкови. У крајњој линији, аналитички модел развијен по први пут пружа могућност инжењерима и истраживачима у области праћења животне средине акумулације да креирају сличну опрему, у зависности од других производних задатака.