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Mathematical Modeling of Soil Dredger Absorption Processes in the Underwater Bottomhole

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The mathematical design of particles motion processes in the submarine face basic areas is executed. Analytical dependences for determination of characteristic rates of particles movement in the submarine face basic areas are obtained. The system of differential equalizations of particles motion in areas, adjoining to the suction union coupling is developed.

Keywords: UNDERWATER BOTTOMHOLE, MOVEMENT OF PARTICLES, ABSORPTION, DREDGER, EQUILIBRIUM RATE

Introduction

Performance of physical modeling of soil dredger absorption in the underwater bottomhole [1] allowed to break it down into specific areas: the area of deposition of erosion zones, the area of erosion during soil absorption, the boundary of the erosion zone, deposition area of the zone of weighted soil absorption, absorption area of weighted soil, boundary of the absorption zone of weighted soil. Mathematical modeling of the processes occurring in these areas of soil dredger of underwater bottomhole will allow the following: establish the real boundaries of the weighted soil absorption zone, build soil absorption field, establish a criterion for application of hydraulic disintegrants to intensify the process of extraction of soil. In this regard, implementation of mathematical modeling of the processes accompanying the motion of particles in the underwater bottomhole dredger is an important scientific and technical task that will reduce energy consumption in underwater mining of cohesionless soils.

Results and Discussion

Let us consider the process of moving a single soil particle in the deposition area of the underwater bottomhole (**Figure 1**). Particle is moved by the following forces: gravity, Archimedean, environmental resistance. The free fall of a particle is quite a studied process, which refers to an isolated deposition in an infinite

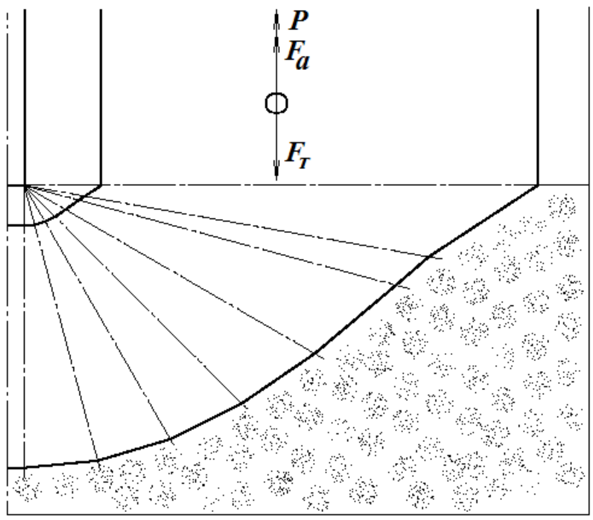

Figure 1. The design scheme of particle motion in the deposition area of the underwater bottomhole

medium, in the absence of mechanical and hydrodynamic interactions between the particles [2, 3]. When moving particles only the resistance of the medium is experienced.

Let us simplify the process description by introducing the following assumptions:

a) absorbed soil particles represent balls of equal dimensions $d_1 = d_2 = d_n = ... = d_{av}$. Particle diameter is taken from the range d_{av} = 0,16-5 mm;

b) density of the fluid acting on the soil particles equals the density of pseudo-pulp ρ_p with kinematic pseudo-viscosity ν_p.

According to the diagram of Rayleigh range of adopted particle size corresponds to the transition region, which is characterized by the influence on the particles of viscosity and dynamic resistance.

The transition area is characterized by the presence, in free fall isolated grains in unlimited serene environment, the effect of the following forces:

- the weight force, subject to the Archimedes force $F_т = (\rho_{sk} - \rho_p)\frac{\pi d^3}{6} g$, N, where ρ_{sk} – density of the soil skeleton, kg/m^3; d - particle diameter, m; ρ_p – medium density (pseudo-pulp), $\frac{kg}{m^3}$;

- the resistance force to the medium particle motion $P = \theta U_{oc}^2 d^2 \rho_p$, N, where θ – resistance coefficient, $\theta = f(\mathrm{Re})$; Reynolds number is shown by the dependence $\mathrm{Re} = \frac{U_0 d}{\nu_p}$.

General differential equation of motion of a single particle in the deposition area of the underwater bottomhole will look like this

$$m\frac{dU}{dt} = (\rho_{sk} - \rho_p)\frac{\pi d^3}{6} g - \theta U_{oc}^2 d^2 \rho_p, \quad (1)$$

where $m = \frac{\pi d^3}{6}\rho_{sk}$ - particle mass, kg.

In the fall of particles in the pseudo-pulp of in the deposition area of the time with the acceleration of its motion is negligible. For further consideration of the process of accelerated motion is set to zero, i.e. $\frac{dU}{dt} = 0$. After the transformation equation for the final velocity U_{oc} in the in the deposition area of the underwater bottomhole becomes

$$U_{oc} = \sqrt{\frac{\pi d g(\rho_{sk} - \rho_p)}{6\theta\rho_p}}, \text{m/s} \quad (2)$$

Let us consider the process of moving a single soil particle in the suction area of the underwater bottomhole (**Figure 2**). Particle is moved by the following forces: elevating, gravity, Archimedean and medium resistance.

We define the interaction forces acting on the particle, given the assumptions above.

The particle is affected by the following forces:

- elevating force $F_p = C_f \frac{\pi d^2}{4}\rho_в \frac{U_a^2}{2}$, N,

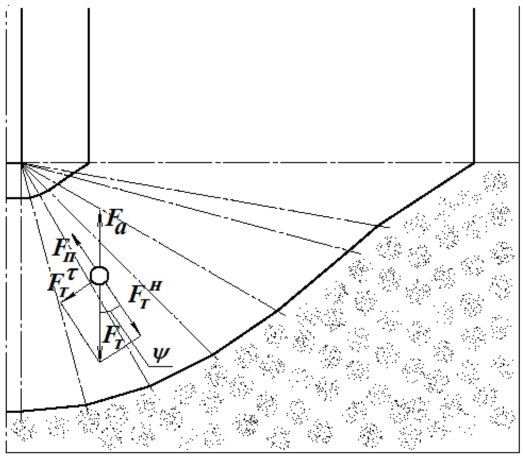

Figure 2. The design scheme of particle motion in the absorption area of the underwater bottomhole

where C_f – front resistance coefficient of the particle; U_a – rate of the absorption flow of fluid acting on the particle, m/s;

- the weight force, subject to the Archimedes force $F_т = (\rho_{sk} - \rho_p)\frac{\pi d^3}{6} g$, N,

where ρ_{sk} – density of the soil skeleton, kg/m^3; ψ – angle of inclination of the forming pulp absorption zone , grad.

Normal component of the weight force on the axis, given in polar coordinates (**Figure 2**), equals

$$F_т^н = (\rho_{sk} - \rho_в)\frac{\pi d^3}{6} g\cos\psi, \text{ N},$$

where ψ – angle of inclination of the forming pulp absorption zone , grad.

General differential equation of motion of a single particle of soil in the area of absorption zone of the underwater bottomhole will look like this

$$m\frac{dU}{dt} = C_f\frac{\pi d^2}{4}\rho_p\frac{U_a^2}{2} - (\rho_{sk} - \rho_p)\frac{\pi d^3}{6} g\cos\psi \quad (3)$$

After simplifying description of the process by introducing a zero value of acceleration of particle motion in the area of absorption the dependence to determine the final rate U_a takes the form

$$U_a = \sqrt{\frac{8g}{6}\left[\frac{d}{C_f}\left(\frac{\rho_{sk}}{\rho_p} - 1\right)\cos\psi\right]} \quad (4)$$

In the study of particle motion in the underwater bottomhole greatest interest is the possibility of constructing a border for absorption zone for particles of set parameters. To do this, we consider the process of the underwater absorption previously washed and suspended in the bottomhole space of soil suction port (**Figure 3**). To simplify the description of the particle motion, we introduce the

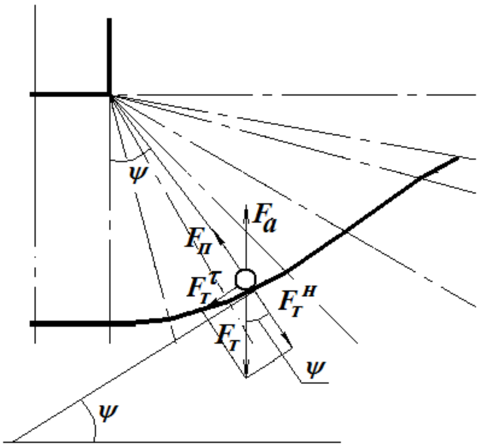

Figure 3. The design scheme of particles at the boundary of the underwater bottomhole

assumptions above.

For the construction of boundaries of the zone of absorption of particles in the underwater bottomhole we define conditions necessary for the equilibrium state of a particle acted upon by elevating forces $F_{п}$ under the influence of the velocity head in polar coordinates and the force of gravity taking into account the Archimedean force.

Given the forces, type of recording which is given above, the general differential equation of motion of a single particle of soil on the boundary of the absorption zone of the underwater bottomhole takes the form

$$m\frac{dU}{dt} = C_{f}\frac{\pi d^2}{4}\rho_{в}\frac{U_{bz}^2}{2} - (\rho_{sk} - \rho_{в})\frac{\pi d^3}{6}g\cos\psi \quad (5)$$

To determine the boundaries of the zone of the underwater bottomhole it is necessary to consider the equilibrium state of the particle, which is characterized by a zero velocity, and thus the acceleration, i.e. $\frac{dU}{dt} = 0$. Thus, the equation of equilibrium of the particle takes the form.

$$C_{f}\frac{\pi d^2}{4}\rho_{в}\frac{U_{bz}^2}{2} - (\rho_{sk} - \rho_{в})\frac{\pi d^3}{6}g\cos\psi = 0. \quad (6)$$

Let us simplify the expression (6) and obtain the dependence for determining the rate of suction flow at the boundary of the underwater bottomhole U_{bz} for which a particle under gravity, Archimedes force and dynamic pressure is in equilibrium. Thus, the dependence for determining the rate of suction flow U_{bz} on inclined forming zone takes the form

$$U_{bz} = \sqrt{\frac{8g}{6}\left[\frac{d}{C_{f}}\left(\frac{\rho_{sk}}{\rho_p} - 1\right)\cos\psi\right]}.$$

or, at $g = 9{,}81 \quad m/s^2$

$$U_{bz} = 3{,}62\sqrt{\frac{d}{C_{f}}\left(\frac{\rho_{sk}}{\rho_p} - 1\right)\cos\psi}. \quad (7)$$

Graphical analysis of the dependence obtained for quartz sand shown in **Figure 4**. Dependence (7) allows determining the flow rate of absorption U_{bz} at which the particles with size d are in equilibrium at different inclination angles ψ of the forming zone of absorption.

Thus, the result of consideration of the process of particle motion in the area close to the suction nozzle is the system of differential equations in the form

$$\begin{cases} m\frac{dU}{dt} = (\rho_{sk} - \rho_p)\frac{\pi d^3}{6}g - \theta U_d^2 d^2 \rho_p - \\ \textit{deposition area}; \\ m\frac{dU}{dt} = C_{f}\frac{\pi d^2}{4}\rho_{p}\frac{U_a^2}{2} - (\rho_{sk} - \rho_p)\frac{\pi d^3}{6}g\cos\psi - \\ \textit{absorption zone}; \\ m\frac{dU}{dt} = C_{f}\frac{\pi d^2}{4}\rho_{в}\frac{U_{bz}^2}{2} - (\rho_{sk} - \rho_{в})\frac{\pi d^3}{6}g\cos\psi - \\ \textit{absorption boundary zone}. \end{cases}$$

With simplification of the process of consideration by the introduction of the zero acceleration of particle motion, that is $\frac{dU}{dt} = 0$, the rate equation of particle motion in the fields in question takes the form of the system

$$\begin{cases} U_{d} = \sqrt{\frac{\pi d g(\rho_{sk} - \rho_p)}{6\theta\rho_p}} - \textit{deposition area};; \\ U_a = \sqrt{\frac{8g}{6}\left[\frac{d}{C_{f}}\left(\frac{\rho_{sk}}{\rho_p} - 1\right)\cos\psi\right]} - \\ \textit{absorption zone}; \\ U_{bz} = 3{,}62\sqrt{\frac{d}{C_{f}}\left(\frac{\rho_{sk}}{\rho_p} - 1\right)\cos\psi} - \\ \textit{absorption boundary zone}. \end{cases} \quad (8)$$

The performed mathematical modeling of processes in the underwater bottomhole dredger will set the actual boundaries of the zone of absorption of weighted soil and as a result, build the pulp absorption field for the particle size in the range d = 0,15-5 mm.

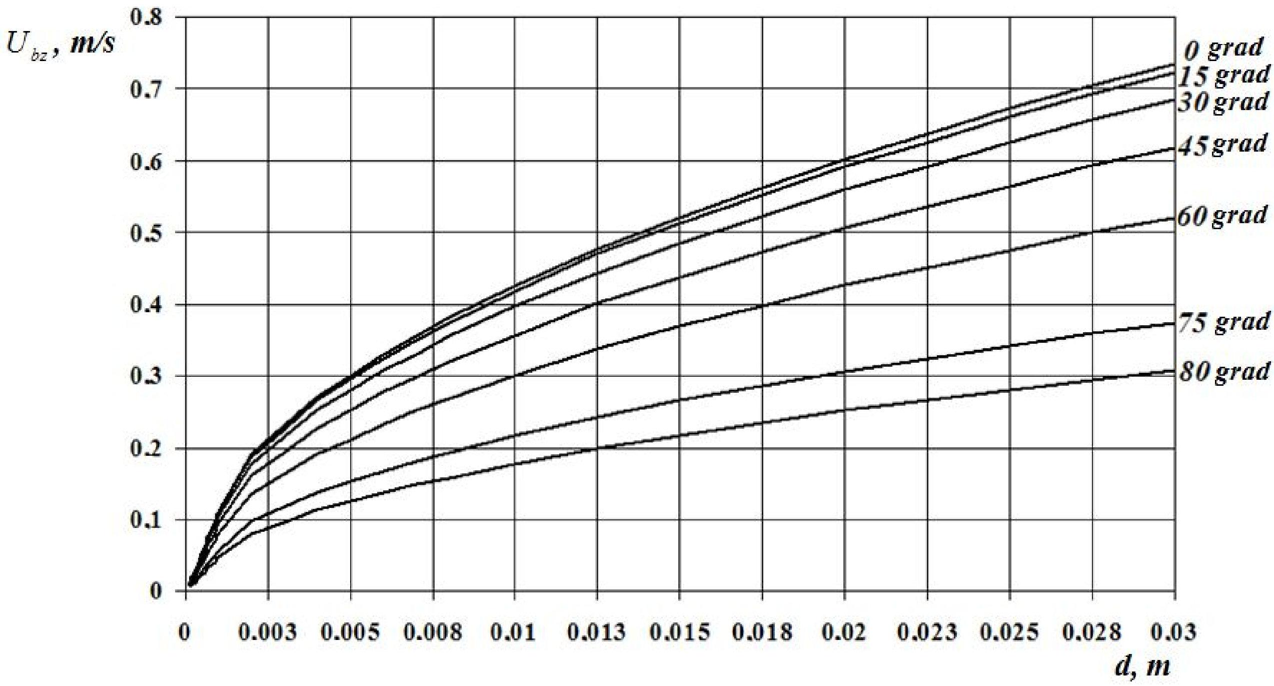

Figure 4. Value of the equilibrium rate of absorption flow at the boundary zone of weighted soil in the underwater bottomhole

Conclusions

1. The mathematical modeling of the soil absorption and movement of particles in the main areas of the underwater bottomhole.
2. Analytical dependences to determine the characteristic velocity of the particles in the main areas of the underwater bottomhole as well as the equilibrium rate of suspended particles were obtained.
3. As a result of modeling processes of absorption of the pulp a system of differential equations of motion of particles in the areas adjacent to the suction nozzle dredger was designed.

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Математическое моделирование процессов при всасывании грунта земснаряда в подводном забое

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Выполнено математическое моделирование процессов движения частиц в основных областях подводного забоя. Получены аналитические зависимости для определения характерных скоростей движения частиц в основных областях подводного забоя. Составлена система дифференциальных уравнений движения частиц в областях, прилегающих ко всасывающему патрубку землесосного снаряда.