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Modeling The Rotation Of A Turbulent Flow With A Variable Radius

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Abstract – The article presents the flow in the water supply nodes of the Karkidon reservoir, where waves of disturbance arise in the initial section of the turn, propagating along the length of the channel. It is determined that the smaller the radius of rotation, the greater the height of the waves of disturbance of the free surface. The turning section can be interfaced with the inlet and outlet sections in various ways. A formula is given for the velocity axis and the radius of curvature when the flow is rotated.

Keywords – Reservoir, Pipe, Hydraulic Shocks, Vibration, Fluid Movement.

I. BACKGROUND

In nature, all currents are mixtures, i.e. dispersed mixtures. In engineering practice, there are often models of hydraulic shocks that cause vibration in the entire system of the engineering structure.

Consider the flow of water in an engineering water supply system formed when the lower vintel is instantly opened at the moment $t = 0$ and we will determine the time of emptying the waters of the contained volume. At the same time, we assume that the flow is laminar, and the coefficient of friction resistance λ constant ($\lambda = 0,025$)([1], [2], [3]).

Fig 1.Hydraulic shock in the intake part of the Karkidon reservoir

With an instantaneous impact at the lower end of the pipe, the fluid movement will be unsteady (Fig. 1.) and for an arbitrary moment of time, the Bernoulli equation, taking into account the loss of pressure due to the inertial force, will be written as:

$$\frac{p_1}{\gamma}+\frac{V^2}{2g}+z(t)=\frac{p_0}{\gamma}+\lambda\frac{z(t)}{l}\frac{V^2}{2g}+z(t)\frac{j}{g} \tag{1}$$

Here: $j=\frac{dV}{dt}$ - inertial pressure; λ - the Darcy coefficient. Equation (1) can also be presented in differential form, which we will use to determine the average velocity of water in the $V(t)$ pipe.

$$\frac{dV}{dt}=g\sin\alpha-\frac{\lambda}{2d_0}V^2 \tag{2}$$

II. MATERIAL AND METHODS

The Bernoulli equation for a mixture of liquids, i.e. for a multiphase liquid, as we assumed during the formulation. it has the following form ([4], [5], [6]):

$$\begin{aligned}P_0+\frac{1}{2}\rho_1V_1^2+\frac{1}{2}\rho_2V_2^2+(\rho_1+\rho_2)gz=\\=P_0+\frac{1}{2}\rho_1V_1^2+\frac{1}{2}\rho_2V_2^2+\lambda_{см}\frac{z}{d}(\rho_1V_1^2+\rho_2V_2^2)-zg\rho.\end{aligned} \tag{3}$$

Here: ρ_1, ρ_2 - phase densities; V_1, V_2 - speeds of the first and second phases. The sum of the products of the true densities and velocities of the phases of the mixture can be represented as:

$$\rho_1V_1^2+\rho_2V_2^2=\Lambda V_{см}\rho_{1i}$$

Here: $\rho_{см}=\rho_{1i}f_1+\rho_{2i}f_2$; $\rho_{см}$ - density of the mixture;

$$\Lambda=\left(f_1+f_2\frac{\rho}{\rho-1}\right)^2\frac{1-(1-\rho)f_1}{f_1(1-f_1)}$$

Then the Bernoulli equation for a mixture of liquids takes the form:

$$\begin{aligned}P_0+\frac{1}{2}\rho_{1i}\Lambda V_{см}^2+\rho_{1ш}\left(f_1+f_2\frac{\rho_{2i}}{\rho_{1i}}\right)gz=P_0+\frac{1}{2}\rho_{1i}\Lambda V_{см}^2+\\+\lambda_{см}\frac{z}{d}\rho_{1i}\Lambda V_{см}^2+z\rho_{1i}\left(f_1+f_2\frac{\rho_{2i}}{\rho_{1i}}\right)z\frac{dV_{см}}{dt}.\end{aligned} \tag{4}$$

After the reduction of such terms containing the concentration coefficients of the phases of the mixture, the equation takes the form:

$$\rho_{1i}\left(f_1+f_2\hat{\rho}\right)gz=\lambda_{см}\frac{z}{d}\rho_{1i}\Lambda V_{см}^2+$$
$$+z\rho_{1i}\left(f_1+f_2\hat{\rho}\right)\frac{dV_{см}}{dt}\frac{1}{g}\frac{dV_a}{dt}+\frac{\lambda_{см}}{2gd}V_{см}^2. \tag{5}$$

Considering the resistance forces of the pipe wall negligibly small, we have:

$$\left(f_1+f_2\rho\right)\frac{dV_{см}}{dt}=\left(f_1+f_2\rho\right)g-\lambda_{см}\frac{\Lambda}{d}V_{см}^2$$

We find the change in the velocity of the mixture over time:

$$\frac{dV_{см}}{dt}=g-\frac{\lambda_{см}\Lambda}{d\left(f_1+f_2\rho\right)}V_{см}^2 \tag{6}$$

By entering the following notation

$$\frac{dV_{см}}{gdt}=\frac{dV}{d\tau},\ V_{см}=V\sqrt{H_0 g},\quad t=\sqrt{\frac{H_0}{g}}\tau, \tag{7}$$

equation (7) will be written in the form after the time of the action of the hydraulic shock - τ :

$$\sqrt{H_0 g}\sqrt{\frac{g}{H_0}}\frac{dV}{d\tau}=g-\frac{\lambda_{см}\Lambda H_0 g}{d(f_1+f_2\rho)}V_{см}^2$$

Having solved the equation with respect to the time of action of the hydraulic shock- τ , we obtain an ordinary differential equation [7]:

$$\frac{dV_{см}}{d\tau}=1-\lambda_{см}\frac{\Lambda H_0}{d(f_1+f_2\rho)}V_{см}^2 \tag{8}$$

III. Results

The resulting equation will be written in the form:

$$\frac{d\hat{V}_{см}}{d\tau}=1-\frac{V_{см}^2}{A^2}$$

Here : $$A=\sqrt{\frac{1}{H_0}\frac{f_{10}+f_{20}\rho}{\Lambda\lambda_{см}}} \tag{9}$$

$$\lambda_{см}=1+0.025$$

We transform the differential equation to a divided form:

$$\frac{dV_{см}}{A^2-V_{см}^2}=\frac{d\tau}{A^2}$$

Integrating in parts, we have:

$$\frac{2}{A}\ln\frac{A+V_{cм}}{A-V_{cм}}=\frac{d\tau}{A^2}$$

from here we get:

$$\ln\frac{A+V_{cм}}{A-V_{cм}}=\frac{d\tau}{2A}$$

Potentiating the expression, we find:

$$\frac{A+V_{cм}}{A-V_{cм}}=C\exp\left(\frac{d\tau}{2A}\right)$$

At the moment of opening the valve, the liquid in the pipe was in a state of equilibrium, and the velocity was zero. Therefore, from equality (10), $C=1$ we have:

$$V_{cм}=A\frac{1-\exp\left(\frac{\tau}{2A}\right)}{1+\exp\left(\frac{\tau}{2A}\right)} \tag{10}$$

Hence, according to the definition of the hyperbolic tangent function, we get

$$V_{cм}=Ath\left(\frac{\tau}{4A}\right) \tag{11}$$

Considering equality $V_{cм}=\frac{dz}{d\tau}$ and formula (11), we will make up the equation of the law of motion of the water mass in an inclined pipeline:

$$-\sin\alpha\frac{d\hat{z}}{d\tau}=th\left(\frac{\tau}{4A}\right)$$

or

$$\sin\alpha d\hat{z}=-th\left(\frac{\tau}{4A}\right)d\tau$$

The value is found from formula (8). Integrating, we obtain the equation:

$$\sin\alpha\left(\hat{H}_0-\hat{z}\right)=4A\ln ch\left(\frac{\tau}{4A}\right)\Big|_0^{\tau}$$

Hence follows

$$\sin\alpha\frac{\hat{H}-\hat{z}}{4A}=\ln ch\left(\frac{\tau}{4A}\right)$$

At the moment $t=T$ the pipe is completely emptied, therefore $z(T)=0$

Then, potentiating the last equality, we will have:

$$\left(\frac{\hat{H}}{4A}\right)\sin\alpha = \ln ch\left(\frac{\hat{T}}{4A}\right)$$

If we write in an exponential function, we have:

$$\exp\left(\frac{\hat{T}}{4A}\right)+\exp\left(-\frac{\hat{T}}{4A}\right)=2\exp\left(\frac{\hat{H}}{4A}\sin\alpha\right)$$

To reduce the field to a simple form, to determine the time of the hydraulic shock that causes the pipeline to vibrate, we have the equation:

$$\exp\left(\frac{\hat{T}}{2A}\right)-2\exp\left(-\frac{H}{4A}\sin\alpha\right)\exp\left(\frac{T}{4A}\right)+1=0$$

Solving the last equation for the time interval of the hydraulic shock, we find the moment and amplitudes of the hydraulic shock, which has the form:

$$\exp\left(\frac{T}{4A}\right)=\exp\left(\frac{\hat{H}}{4A}\sin\alpha\right)\pm\sqrt{\exp\left(\frac{\hat{H}}{2A}\sin\alpha\right)-1} \qquad (12)$$

IV. Discussion

In the water supply nodes of the Karkidon reservoir, waves of disturbance arise in the initial section of the turn, propagating along the length of the channel. The smaller the turning radius, the greater the height of the waves of disturbance of the free surface. ([8], [9], [10], [11])

The turning section can be interfaced with the inlet and outlet sections in various ways. Over the entire length of the turn, the radius can be performed decreasing from to $r\to\infty$ a certain value (a straight section) and then again to $r\to\infty$. At a certain length of rotation, its curvature may be constant. The axis of the velocity of a variable turning radius can be outlined, for example, by the curve ([12], [13]) (Fig.1.)

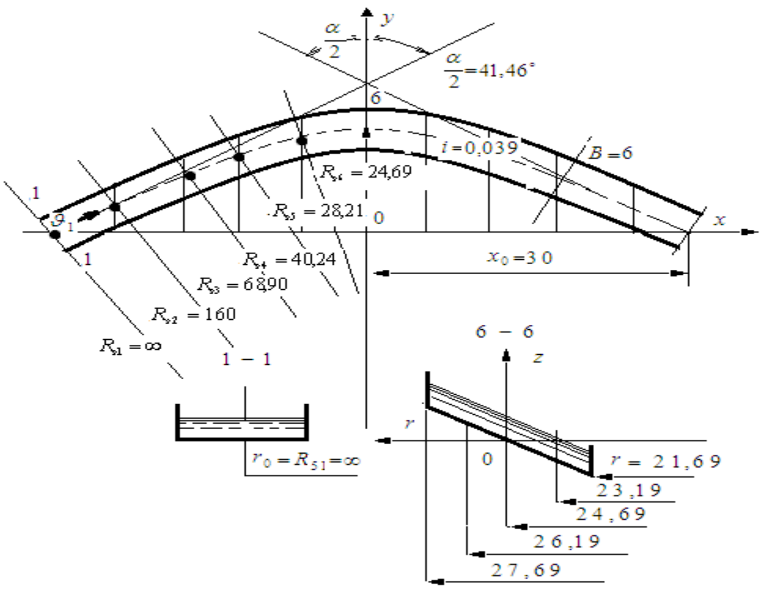

Fig. 2 Rotation of a turbulent flow in a channel with a variable radius

$$y = a_0 \cos\frac{\pi x}{2x_0} \qquad (13)$$

here a_0 - is a constant, its value is determined from the condition

$$\frac{dy}{dx} = tg\frac{\alpha}{2}$$

which should be performed at the ends of the turn section:

$$\frac{dy}{dx} = -\frac{\pi a_0}{2x_0}\sin\frac{\pi x}{2x_0}$$

By

$$x = x_0 \sin\frac{\pi}{2}\frac{x}{x_0} = 1$$

It is known that the radius of curvature is determined by the expression

$$R = \frac{\left[1+\left(\frac{dy}{dx}\right)^2\right]^{\frac{3}{2}}}{\frac{d^2y}{dx^2}}$$

Calculated and experimental data are given in pounds and feet per second, 1-by experiments; 2-by calculation.

$R_{s1} = \infty$ $R_{s2} = 160$ $R_{s3} = 68{,}90$ $R_{s4} = 40{,}24$ $R_{s5} = 28{,}21$ $R_{s6} = 24{,}69$

$$\frac{dy}{dx} = tg\frac{\alpha}{2}\sin\frac{\pi x}{2x_0}$$

$$\frac{d^2y}{dx^2} = \frac{\pi}{2x_0}tg\frac{\alpha}{2}\cos\frac{\pi x}{2x_0}$$

Therefore, for the velocity axis, the radius of curvature during rotation is determined by the following formula ([14], [15], [16]):

$$R_s = \frac{\left[1+\left(tg\frac{\alpha}{2}\sin\frac{\pi x}{2x_0}\right)^2\right]^{\frac{3}{2}}}{\frac{\pi}{2x_0}tg\frac{\alpha}{2}\cos\frac{\pi}{2}\frac{x}{x_0}} \qquad (14)$$

Here: $\frac{\pi}{2x_0}tg\frac{\alpha}{2}$ for a given velocity, there is a constant value.

V. Conclusions

The results of the research allow us to determine some numerical values of the coefficients of local resistances of the diffusor sections of pipelines during the movement of a liquid with small Reynolds numbers. In experimental studies, it is planned to further expand the range of experiments in the direction of increasing the Reynolds numbers in order to find out those limit values of Reynolds to which the degree of compression of the flow will be valid depending on.

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