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METHODOLOGY FOR THE DETERMINATION OF THE PNEUMATIC CURTAIN PARAMETERS OF THE WATER INTAKE SYSTEM

Khatiashvili Elizbar[1], Tsivtsivadze Nodar[1], Bregvadze Giorgi[1], Laghidze Lamzira[1], Ivanov Giorgi[1], Motsonelidze Nargizi[1], Paichadze Nino[1], Jorbenadze Natalia[2]

[1]Ivane Javakhishvili Tbilisi State University, I. Chavchavadze Ave., 3, Tbilisi, 0179, Georgia
[2]Nice University (France)

Abstract

Providing the population with safe drinking water is one of the most difficult problem of water supply management, since the quality of water is significantly determined not only by the cleaning works carried out at the treatment stations, but also by the ecological condition of the water that enters these stations. Today, as a whole, the problem has long gone beyond the private interests of any single agency of the country, as it significantly includes both meeting the daily needs of the population and protecting its health, as well as the country's security and its sustainable economic development. The project envisages focusing the attention of a wide range of society representatives and scientists on the problem of vital importance for the country's security and its population, providing people with the necessary amount of safe, quality drinking water that meets the requirements of the World Health Organization. In the presented article, one of the raw water treatment methods is discussed, which will allow us to maintain the organoleptic characteristics of drinking water through the arrangement of a pneumatic curtain at the head of the water intake system.

Key words: pneumatic curtain, aeration, macrophyte, air jet, pipe.

Introduction

The arrangement of a pneumatic-curtain for the water intake process improves the quality of raw water. The pneumatic barrier traps the bulk of macrophytes algae and macroscopic zooplankton (including small fish and their fries due to their low swimming speed of 0.05-0.5 m/sec), as well as various weighted impurities and sediments in the water. As a result, the probability of pump jamming, water contamination with biological organisms or other types of impurities is reduced as much as possible (by 90%). In the area of raw water intake points, the amount of oxygen dissolved in water increases under conditions of intensive aeration, due to which harmful anaerobic microorganisms are neutralized, therefore the quality of raw water is improved, including organoleptic indicators (smell, taste).

Determining the parameters of pneumatic curtains, actually relied on the theory of propagation of submerged vertical jets, is associated with considerable difficulties due to the complexity of the current processes and the small number of experimental data (a number of phenomenological constants are determined on the basis of experimental data in the theory of jets) [1].

A theoretical methodology was developed under the leadership of academician T.G. Voynich-Sianozhentsky with the participation of presented article’ researchers, on the basis of the conducted laboratory experiments, the calculation of the pneumatic curtains characteristic parameters was specified and established [2].

Experiments were carried out in a hydraulic channel, of the following dimensions: length $l \approx 16$ m, width $B = 1.0$ m, depth $H = 1.5$ m; To obtain the necessary air jet, a perforated metal tube was used, which was located in the channel section, the diameter of the holes was 3.0÷4.0 mm, with a distance of 20 cm between them. Experiments were conducted both for a single jet and for a combination of jets, during of which a continuous pneumatic curtain was created (see photo 1, 2). The air jet was created by means of a laboratory single-stage cylindrical compressor HZFR 806-40/2322. The compressor developed $P \simeq 0.9$ atmospheres, and its performance was $\simeq 1$ l/sec.

Photo 1

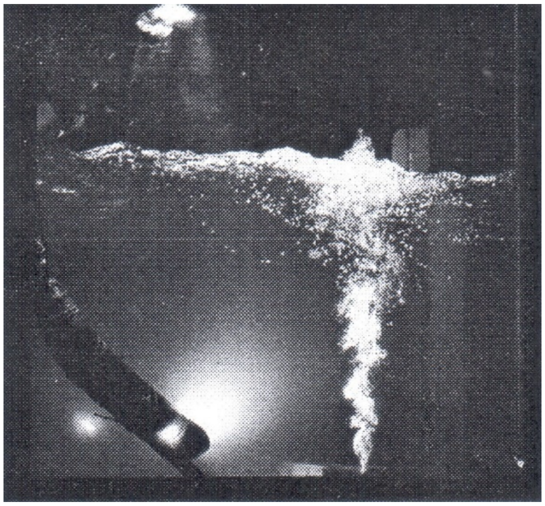
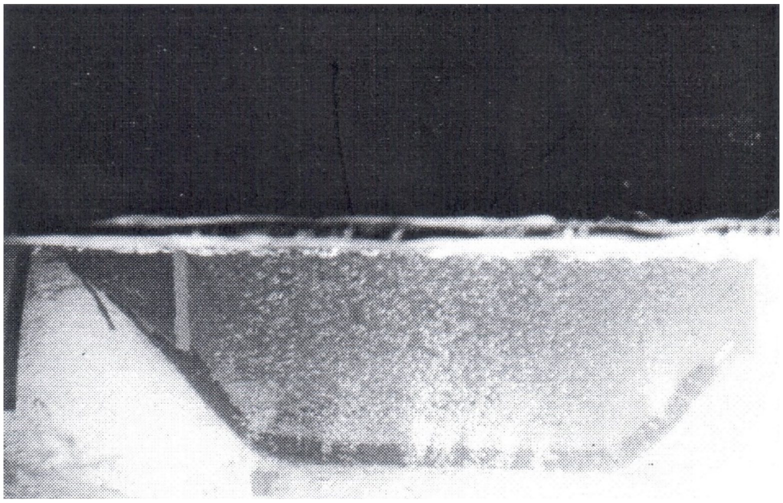


Photo 2



Based on the experiment, the parameters of the perforated pipeline were developed. In particular, it was determined that the velocity of the aerated jet for any depth Z can be described by the following phenomenological relationship [2, 3]:

$$V_z = V_{z0}\left[1 - 0.32\lg\left(\frac{z}{r_0} + 1\right)\right] \qquad (1)$$

Where V_{z0} - is the speed of the jet on the free surface, while it satisfies the Borda-Carnot condition [4], $\frac{V_{z=0}}{V_{perf.}} = 0.01$, the validity of which was established by experiments for jet processes, z - is taken from the initial cross section of the main area of the jet, with radius r_0 and with initial velocity V_{z0}.

On the basis of experiments, it was determined that the horizontal velocity of jet deflection (i.e., the velocity of deflection towards the end of the pipe), obtained by the theoretical way, is equal to [2]:

$$V_x = V_{x0}\left(1 - \frac{z}{H}\right)^n \qquad (2)$$

Where V_{x0} is the transfer velocity of the water flow to the suction pipes, n-is determined by with the T.G. Voynich-Syanozhetsky relation [2]

$$n=\frac{1}{2}\sqrt{1+4\sqrt{\frac{g}{\chi C_{chz.}}}} \qquad (3)$$

χ =0.4 is the Karman turbulence constant, $C_{chz.}$ - the Chezy coefficient, is in good agreement with experimental and natural data.

The deviation of the jet from the vertical i.e. pneumatic curtain deflection is calculated by the relation

$$x=\frac{q_0}{V_z}\left[1-\left(1-\frac{z}{H}\right)^{n+1}\right] \qquad (4)$$

Here it is meant that the actual given quantity is considered to be the initial specific consumption of required air q_0.

It should be emphasized that the obtained results are in good agreement with the theory of free jets (in our case submerged jets) developed by Abramovich [1].

On the basis of the obtained relations and theoretical methodology, it will be possible to determine the specified parameters of the pneumatic curtain for any water intake station on the different reservoirs.

Based on the theoretical studies conducted by the authors, a method for calculation of pneumatic curtain was developed, which can be used to determine: the speed of the upward jet coming out of the holes and its change along the vertical axis; Required air movement (movement with variable discharge) characteristic parameters for different sections of the perforated pipeline, taking into account the data of the compressor station; the amount of excess air pressure, which is necessary in the stage of pneumatic complex operation (to expel water from the pipes); The effect of changes in external pressure due to the placement of perforated pipes at different depths and changes in water levels in the reservoir, etc.

The velocity of the upward jet of the pneumatic curtain is determined based on the law of conservation of mass for two-phase flow. The continuity equation written in cylindrical coordinates (for stationary motion) has the following form:

$$\frac{\partial\left(S\rho_S V_z\right)}{\partial z}+\frac{1}{r}\frac{\partial}{\partial r}\left(S\rho_S V_r\right)=0$$

Here - V_z and V_r - are the vertical and radial components of air-liquid mixing flow rate; S - is the volumetric concentration of air bubbles; ρ_S - density.

From this relationship, the vertical velocity of the mixing jet flow is determined from the differential equation obtained as a result of a series of transformations, Reynolds averaging, and the Boussinesq procedure [4].

$$\bar{U}=1-0.405\lg\left(\beta\bar{z}+1\right) \qquad (5)$$

Where $\bar{U}$ and $\bar{z}$ are dimensionless speed and coordinate; $\bar{U}=\frac{V}{V_0}$, V_0 - speed at the initial area; $\bar{z}=\frac{z}{r_0}$, r_0 - radius of initial section; β =0.25.

The relationship (5) defines the speed of the rising jet for any section of the main area of movement (the speed in the initial area is determined according to the Borda-Carnot relationship [4]), particularly the height, after which the speed becomes equal to the hydraulic thickness of the bubbles $W_{h.th.} = 0.25 + 0.3$ m/sec.

$$Z_w = 4r_0 \left\{ \exp\left[5.72 \left(1 - \frac{W_{h.th.}}{V_0} \right) \right] - 1 \right\}$$

For example, if r_0 = 0.025 m, $W_{h.th.}$ = 0.3 m/sec, V_0 = 3.0 m/sec, Z = 28.0 m, when V_0 = 1.0 m/sec, Z = 22.0 m.

The steady flow of air in a perforated pipeline is described by the following equation:

$$\frac{1}{\gamma}\frac{dP}{dx} + \frac{1}{2g}\frac{dV^2}{dx} + \frac{\lambda V^2}{2gD} = 0 \qquad (6)$$

Where γ is the volumetric weight of air, which obeys Clapeyron's equation $P = \gamma R_x T$ during isothermal processes; P - is hydrodynamic pressure; V - the average velocity in the cross-section of the pipeline; λ - pipeline friction coefficient; D - pipe diameter. As a result of the transformation of the equation (6) and the continuity equation, we get P and G - to determine the weight consumption:

$$\left(A_1 PG - A_2 G^2 \right) dG = \left(A_1 G^2 - P^2 \right) dP \qquad (7)$$

Where $A_1 = \frac{P_{en.cr.s.}}{g w^2 \gamma_{z_{cr.s}}}$; $A_2 = \frac{\lambda P^2_{z_{cr.s}}}{2 g w^2 D^2 \gamma_{en.cr.s.} k_*}$; (en.cr.s.) - denotes the end cross-section; w - is the cross-sectional area of the pipeline.

$$k_* = \mu n_0 w_* \sqrt{2g \left[\frac{P_k}{\gamma_k} - \frac{P_w}{\gamma_w} \right]};$$

Here, μ - is the coefficient of flow consumption in the nodes; w_* - cross-sectional area of the pipe; n_0 - the number of holes per unit length of the pipeline; P_w, γ_w - the environment of the pipeline, i.e. water' pressure and specific gravity.

As a result of simplifying the solution of the equation (7), during which the error is less than 1% for the air weight consumption rate G and pressure P, we get

$$G = G_0 e^{-\frac{\lambda x}{2D}}$$

$$P = P_{en.cr.s.} \frac{\lambda e^{-\frac{\lambda x}{2D}}}{2 D k_* \gamma_k} G_0$$

Here G_0 is the consumption of the compressor [5].

During the movement of the compressed air in the perforated pipeline, when there is an impact of variable back pressure from the environment (when the pipeline is placed on an inclined slope, or when the reservoir level changes), the solution changes. In particular, we have an image to determine the k_* coefficient

$$k_* = \mu n_0 w_* \sqrt{2g\left[\frac{P_{en.cr.s.}}{\gamma_{en.cr.s.}} - \frac{P_w}{\gamma_w}\left(1 - \frac{z}{H_0}\right)\right]} \qquad (8)$$

Where the vertical coordinate of any cross-section of the z - pipeline is calculated from the maximum depth of the pipe; H_0 - maximum depth within the pneumatic pumping system.

In such a case, the regulation of the pressure in the pipeline is produced by changing the frequency of perforations and of pipe cross section space. The selection of these values per unit of pipeline length is possible by the relation

$$m_x w_{xz} = n_0 w_x \sqrt{\frac{\dfrac{P_{en.cr.s.}}{\gamma_{en.cr.s.}} - \dfrac{P_w}{\gamma_w}}{\dfrac{P_{en.cr.s.}}{\gamma_{en.cr.s.}} - \dfrac{P_w}{\gamma_w}\left(1 - \dfrac{z}{H}\right)}} \qquad (9)$$

During the development of the methodology, the value of the excess pressure required to expel water from the perforated pipeline was determined for the initial period of operation of the pneumatic complex.

$$P_0^* = \frac{4\gamma_w l}{gT^2\left[\dfrac{\lambda}{8R} + \dfrac{\lambda_1 w^2}{8 n_{0\xi}^2 w_{0\xi}^2 R} - 1\right]} \qquad (10)$$

l - is the length of the pipeline; R - its hydraulic radius; λ_1 - pipeline branch hydraulic resistance coefficient.

At the end, we will note that all the parameters of the pneumatic complex, which are necessary for its design, are determined by the dependences of the calculation methodology.

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