Dependence of the Self-Oscillation Period for a Conical Jet Aerator Cap on the Jet Width in the Nozzle Outlet

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Abstract—The penetration of free hollow thin-walled turbulent water jets into water is considered. These jets are generated in a conical jet aerator whose apex angle is $60^\circ$. The periods of steady regular self-oscillations appearing during the process of penetration are studied experimentally. A dependence of these periods on the annular nozzle gap width $\delta$, $0.07 \leq \delta \leq 0.12$ cm, is analyzed for the jet discharge range $160 \leq Q \leq 550$ cm$^3$/s when the height $H$ of the annular nozzle above the water surface belongs to the range $1 \leq H \leq 28$ cm.

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Various jet aerators are widely used to saturate water by a gas. Their operation mechanism is based on the ejection of air by a free turbulent water jet through the water surface. Among them are conical jet aerators when the free water jet from annular nozzles is hollow and cone-shaped. The studies [1] devoted to the oxygen saturation of water show that such aerators are more efficient than the aerators with solid jets.

The studies conducted at the Moscow University Institute of Mechanics allowed us to discover a number of characteristic features in the process of penetration of hollow cone-shaped thin-walled free water jets into water [2]. The main of them is the existence of steady regular self-oscillation modes in the transverse displacements of the walls of the jet cap for various values of $Q$, $d$, $\delta$, $H$, and $\alpha$, where $Q$ is the jet discharge, $d$ is the inner diameter of the annular nozzle, $\delta$ is its width, $H$ is the height of this nozzle above the water surface, and $\alpha$ is the apex angle. It is also shown that the bifurcation change of self-oscillation modes may appear, a number of hysteresis effects can be observed, and the self-oscillation period is dependent on the shape and size of a water vessel with a penetrating jet.

In [2] three possible dependencies of the self-oscillation period $T$ on the discharge $Q$ are described for $\delta = 0.1$ cm, $\alpha = 60^\circ$, $160 \leq Q \leq 550$ cm$^3$/s, and $1 \leq H \leq 28$ cm. In this paper we analyze these dependencies for $0.07 \leq \delta \leq 0.12$ cm.

A free hollow cone-shaped turbulent water jet penetrates into a water vessel from the mouthpiece [2] through an annular nozzle whose inner diameter $d$ is equal to 2.2 cm. The vessel is of rectangular shape, its size is $118 \times 88 \times 100$ cm, and its depth is 70–72 cm.

Our experiments performed for the above range of $\delta$ showed that the character of the dependencies of $T$ on $Q$ and $H$ is similar to that discussed in [2] for $\delta = 0.1$ cm. As in this case, in the dependence $T = T(Q, H)$ for each $\delta$ we can distinguish three groups of values of $Q$ for which the characters of changes in $T$ are radically different under changes of $H$.

For the first group, the regular self-oscillation modes appear only when $H \leq 16$ cm. No bifurcation changes of self-oscillation modes and no hysteresis effects are observed.

For the second group, two bifurcation changes of self-oscillation modes and the hysteresis phenomenon are observed when the value of $H$ decreases or increases.

For the third group, two bifurcation changes of self-oscillation modes are also observed, but the hysteresis phenomenon is absent. When $\delta = 0.1$ cm, this situation takes place for $Q > 400$ cm$^3$/s.

The above three situations are discussed in [2]. Below we analyze the dependencies of $T$ on $\delta$ for the third group of $Q$.

Based on the dimensionality theory, we can conclude that the dependence of $T$ on the above constitutive parameters can be written in the form

$$
\frac{T}{\sqrt{d/g}} = \varphi \left( \frac{v_0 \delta}{\nu} \cdot \frac{H}{d} \cdot \frac{\delta}{d} \cdot \frac{\nu}{g^{1/2} d^{3/2}} \cdot \frac{\sigma}{p g d^2} \cdot \frac{l_i}{d} \right),
$$

76
where \( l_1 \) are the geometric parameters characterizing the shape and size of the mouthpiece and the vessel, \( \nu \) is the kinematic coefficient of viscosity, and \( \sigma \) is the surface tension coefficient. In our experiments, the first three arguments were variable.

In our further discussion, as in [2], the dependencies \( T = T(H, v_0, \delta) \) are represented in dimensional form. In our experiments performed with \( \delta = 0.1 \text{ cm} \), only the first two arguments were variable.

Figure 1 illustrates the dependencies \( T = T(H) \) for \( \delta = 0.07 \text{ cm} \) and for various values of the initial velocity \( v_0 = Q/S \) of the free jet (here \( S \) is the area of the nozzle’s gap). As in the case \( \delta = 0.1 \text{ cm} \), the first bifurcation change of self-oscillation modes is observed for \( H \approx 6 \text{ cm} \). The second bifurcation change is observed for various values of \( H = H_1 \) and is dependent on \( v_0 \).

If \( 1 \leq H < 6 \text{ cm} \), then the self-oscillation period increases with increasing \( v_0 \) for fixed values of \( H \); if \( 6 < H \leq H_1 \text{ cm} \), then the self-oscillation period decreases with increasing \( v_0 \). When \( H > H_1 \), this period slowly increases according to a linear law. For the other values of \( \delta \), the dependence of \( T \) on \( v_0 \) is similar.

Of interest is the dependence \( T = T(H) \) illustrated in Fig. 2 for various \( \delta \) when \( v_0 = 660 \text{ cm/s} \). In this case the following situations are observed with increasing \( \delta \): (i) the period \( T \) increases when \( 1 \leq H < 6 \text{ cm} \), (ii) this period decreases slowly or rapidly when \( 6 < H \leq H_1 \), and (iii) the period is almost constant when \( H > H_1 \). The above dependence \( T = T(H) \) remains the same for other values of \( v_0 \).

The dependence of \( T \) on \( \delta \) is illustrated in Fig. 3 for \( v_0 = 660 \text{ cm/s} \) and \( v_0 = 730 \text{ cm/s} \) when \( H = 3, 14, \) and \( 26 \text{ cm} \). From this figure it follows that the period increases with increasing \( \delta \) when \( H = 3 \text{ cm} \), the period decreases when \( H = 14 \text{ cm} \), and the period is almost constant when \( H = 26 \text{ cm} \). The period increases with increasing \( v_0 \) for \( 1 \leq H < 6 \text{ cm} \), decreases for \( 6 < H < H_1 \), and remains almost the same for \( H > H_1 \).

It is obvious that, for the second group of \( Q \) and for \( H = 14 \text{ cm} \), the self-oscillation modes correspond to two different periods obtained when using two opposite directions of changes in \( H \), i.e., when the hysteresis phenomenon is observed.

CONCLUSION

The results discussed in this paper and in [2] show that it is necessary to take into account the above effects caused by the existence of steady regular self-oscillations when designing conical jet aerators and when choosing the optimal modes of their operation. The intensity of gas penetration into water is closely related to these effects. Our experiments performed with \( \delta = 0.07 \text{ cm} \) for \( H = 14 \text{ cm} \) showed that the amplitude of self-oscillations in the lower part of the cap of radius \( r \approx 9 \text{ cm} \) is equal to 2–3 cm. For this value of \( H \), this amplitude decreases with increasing \( \delta \) and \( Q \), but the penetration depth of the jet increases.