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BRIEF COMMUNICATIONS

Self-Oscillation Periods of Conical Jet Aerators with Various Apex Angles

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Abstract—The penetration of free hollow thin-walled turbulent water jets into water is considered. These jets are generated in conical jet aerators with various apex angles. Stable regular self-oscillation modes of this penetration process are studied experimentally. A dependence of self-oscillation periods on the apex angle α, where $45 \leq \alpha \leq 80°$, is analyzed for the jet discharge range $150 \leq Q \leq 550$ 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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The experiments conducted at the Moscow University Institute of Mechanics allowed us to show that one of the basic features of conical jet aerators is a wide range of constitutive parameters where the stable regular low-frequency self-oscillations are observed.

The generation mechanism of such self-oscillations is based on ejecting the air through water with the aid of a free turbulent water jet from the annular nozzle of the aerator, followed by rising gas bubbles.

A dependence of the self-oscillation period on the jet discharge Q, the height H of the annular nozzle from the free surface, and the width δ of this nozzle is studied in [1, 2] for the apex angle $\alpha = 60°$. It is also shown that the bifurcation change of self-oscillation modes may appear, a number of hysteresis effects can be observed for various heights of jets, and the self-oscillation period is strongly dependent on the shape and size of water vessels with penetrating jets. The intensity and character of air penetration into water are also discussed in [1, 2] for various values of Q and H.

It is obvious that the choice of optimal modes of conical jet aerators and the efficiency of their usage are dependent on the above hydrodynamic peculiarities of jet flows. It is strange that these effects are not taken into account in the well-known papers [3–5] devoted to conical jet aerators.

In this paper we discuss some results of the next stage of our experimental studies devoted to the penetration of free conical jets through the free surface of water in an aeration tank of size $118 \times 88 \times 100$ cm with the water level $h = 71$–72 cm. Here we analyze the effect of the apex angle α on the self-oscillation period of jet aerators.

Let us consider a jet aerator such that $\delta = 1$ mm and $d = 2.2$ cm, where δ is the width of its annular nozzle and d is the inner diameter of this nozzle. Let the jet discharge Q belong to the range $150 \leq Q \leq 550$ cm^3/s and the height H of this nozzle above the water surface belong to the range $1 \leq H \leq 28$ cm. We study a dependence of the self-oscillation period T on Q and H for $\alpha = 45$ and $\alpha = 80°$. Our experiments performed for $\alpha = 60°$ are described in [1, 2].

In [1, 2] it is found that the structure of the conical jet surfaces from aerators significantly affects the dependencies for the self-oscillation periods. Hence, it can be expected that the differences in the apex angles may essentially influence the boundaries of the bifurcation changes of self-oscillation modes, since, when the angle α increases, the continuity length of a conical jet decreases, and vice versa. If α is small, then the effect of the surface tension is also increases. Our experiments confirm the above discussion. At the same time, we discovered a number of new peculiarities.

A scheme of the mouthpiece arrangement, the description of our experimental facility, and our experimental technique are given in [1].

Based on the dimensionality theory, we can conclude that the dimensionless self-oscillation period can be represented as

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

where v_0 is the mean velocity of flow from the nozzle, l_i are the geometric parameters characterizing the shape and size of the mouthpiece and the vessel; ρ is the density of the liquid, g is the gravitational acceleration, ν is the kinematic coefficient of viscosity, and σ is the surface tension coefficient. A similar relation is valid for the self-oscillation frequency $f = 1/T$. As in [1, 2], the dependencies $T = T(Q, H)$ are given below in dimensional form.

The results obtained for $\alpha = 45°$ and $\alpha = 80°$ are compared with those obtained for $\alpha = 60°$.

Case $\alpha = 45°$. As in the case $\alpha = 60°$, the dependence $T = T(Q, H)$ allows us to distinguish three characteristic groups of values of Q in the range under consideration. Figure 1 illustrates the first group $200 \leq Q \leq 290$ cm^3/s for the dependence $T = T(Q, H)$. As compared to the case $\alpha = 60°$, the regular self-oscillations are observed in the wider range of H: $3 \leq H \leq 26$ cm. The range of T also becomes wider: $0.43 \leq T \leq 1.3$ s. As in the case $\alpha = 60°$, no hysteresis effects are observed when the values of H are varied. It is interesting to note that the dependencies are almost coincident for $Q \geq 250$ cm^3/s.

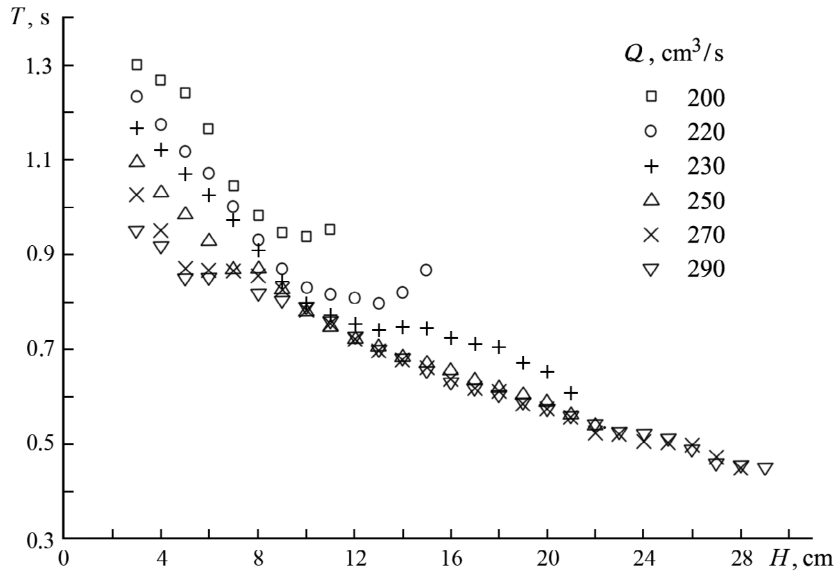

Fig. 1. The dependence $T = T(H)$ for $\alpha = 45°$ and $200 \leq Q \leq 290$ cm^3/s.

Figure 2a illustrates the dependencies for $300 \leq Q \leq 380$ cm^3/s. As in the case $\alpha = 60°$, two bifurcation changes of the self-oscillation modes are observed for $H \approx 7$ cm and $H \approx 31$ cm. The hysteresis effect is also observed with the appearance of one of the principal frequencies of self-oscillations.

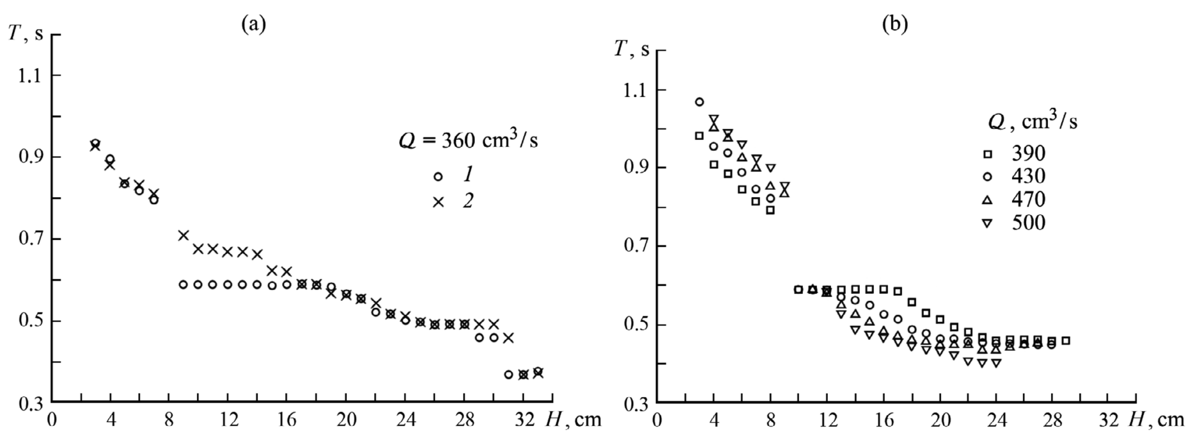

Fig. 2. The dependence $T = T(H)$ for $\alpha = 45°$. (a) $Q = 360$ cm^3/s and (b) $390 \leq Q \leq 500$ cm^3/s: (*1*) the experimental results with decreasing H and (*2*) the experimental results with increasing H.

Figure 3b illustrates the dependencies for $390 \leq Q \leq 550$ cm^3/s. The character of these dependencies is similar to the case $\alpha = 60°$ with the only exception: only one bifurcation change of self-oscillation modes is observed for $H \approx 10$ cm. This change corresponds to the appearance of low-frequency self-oscillations.

In the above range of Q, thus, the domain of regular self-oscillations is absent for the frequency 3 Hz (or $T \approx 0.3$ s). Our experiments show that such frequencies are observed only in some cases for $Q \geq 530$ cm^3/s; hence, such self-oscillations cannot be considered as regular ones. This observation can be explained by the fact that the free surface is strongly disturbed by the jet of the aerator (an intensive rise of waves).

Case $\alpha = 80°$**.** In this case the range of Q can also be divided into several domains according to the forms of the dependencies $T = T(Q, H)$. The most characteristic domains are shown in Figs. 3a–3d.

Figure 3a illustrates the domain $170 \leq Q \leq 250$ cm^3/s, where all the dependencies are close to one another and are almost linear, as opposed to the cases $\alpha = 45°$ and $\alpha = 60°$. The range of H corresponding to such self-oscillations becomes smaller: $1 \leq H \leq 13$ sm. The range of T also becomes smaller: $0.57 \leq T \leq 0.87$ s.

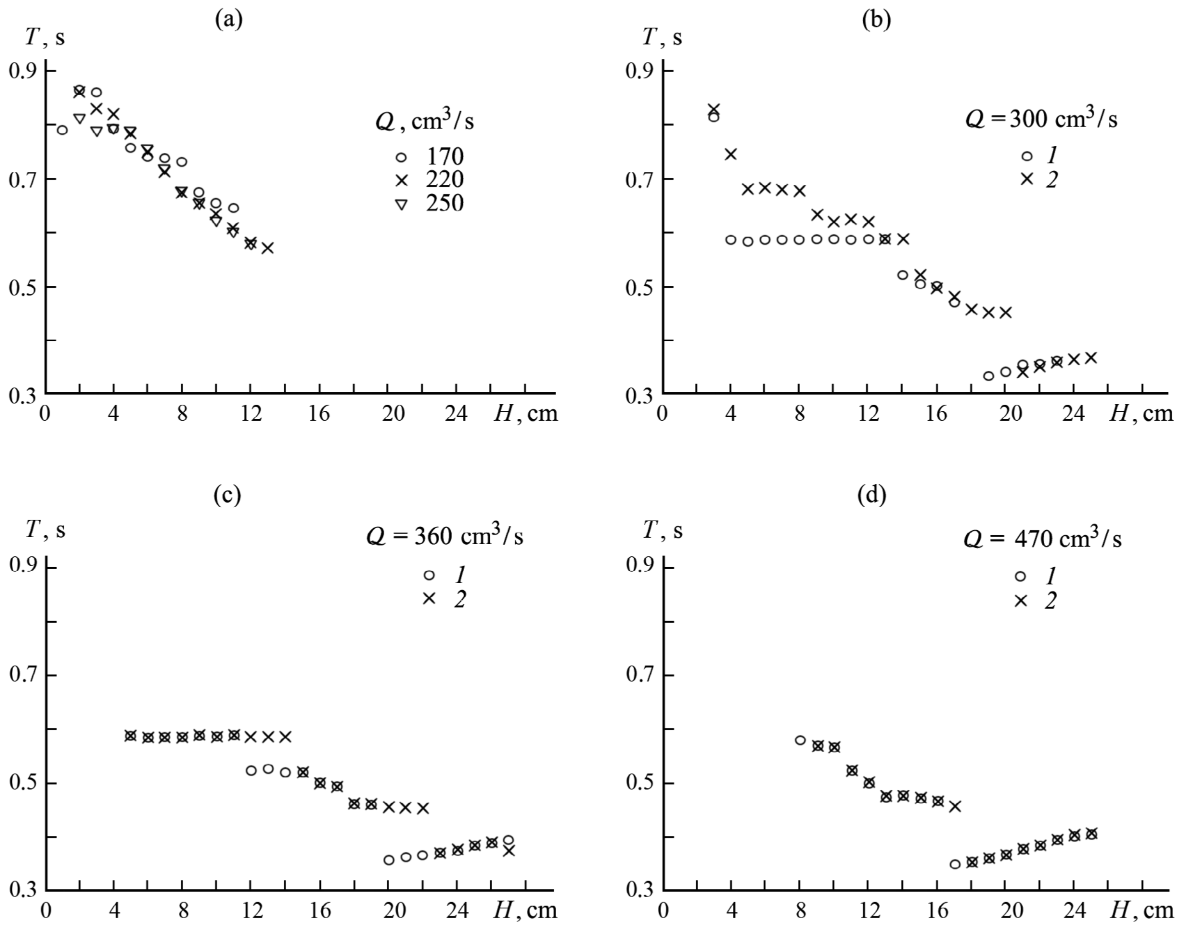

Fig. 3. The dependence $T = T(\delta)$ for $\alpha = 80°$. (a) $170 \leq Q \leq 250$ cm^3/s, (b) $Q = 300$ cm^3/s, (c) $Q = 360$ cm^3/s, and (d) $Q = 470$ cm^3/s: (*1*) the experimental results with decreasing H and (*2*) the experimental results with increasing H.

The hysteresis effects are observed for $270 \leq Q \leq 330$ cm^3/s. Figure 3b illustrates the dependence $T = T(Q, H)$ for $Q = 300$ cm^3/s. Contrary to the cases $\alpha = 45°$ and $\alpha = 60°$, the low-frequency self-oscillation modes are absent. The bifurcation changes of self-oscillation modes are observed: the self-oscillations with a frequency approximately equal to 3 Hz are replaced by the self-oscillations with a lesser frequency for $H \approx 19$ cm. The process of jump-like changes in the frequencies of self-oscillations is also observed for $H \approx 9$ cm and $H \approx 14$ cm.

Figure 3c illustrates the domain $360 \leq Q \leq 440$ cm^3/s, where the bifurcation changes appear. However, the hysteresis effects are observed only when the value of H becomes close to those values that correspond to the bifurcation changes.

Figure 3d illustrates the domain, where the above bifurcation changes disappear; only the bifurcation changes caused by the transition to the frequencies $f \approx 3$ Hz are observed for $H \approx 17$ cm.

With further increase in Q (e.g., $Q = 580$ cm^3/s), there exist the self-oscillations with a frequency approximately equal to 3Hz; as in Figs. 3b–3d, the dependencies $T = T(Q, H)$ are linear and the hysteresis effects are absent. From Figs. 3b–3d it follows that the ranges of H corresponding to the existence of regular self-oscillations become smaller when Q increases. The same phenomenon is observed for the ranges of T.

Our analysis shows that the apex angle variation leads to significant changes in the dependencies of T on Q and H. When the angle α is less than a certain value, the high-frequency self-oscillations ($f \approx 3$ Hz) are absent, whereas the low-frequency self-oscillations ($f \approx 1$ Hz) are absent when this angle increases. From our experiments it follows that the character of air penetration into water may also significantly change for various values of α.

Our experiments to study the penetration of conical thin-walled turbulent jets into water show the practical and hydrodynamic importance of this phenomenon. However, its numerical analysis is difficult, since it is necessary to take into account many factors: the multiphase character of flow, various mechanisms of interaction between air and water, the structure of turbulent jets, the unsteadiness of flows, etc.

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