Vortex and Cavitation Flows in Hydraulic Systems

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Abstract—Experimental study of vortex and cavitation nonuniform flows in hydraulic heat generators demonstrated that the heating rate decreases with increasing liquid temperature because of the growing saturation vapor pressure in the cavitation bubbles. Voltage, electric current, slight radioactivity, and an increased water pH were detected in these flows. It was shown by mathematical modeling that the heat produced in the vortex and cavitation flows is several times greater than the electric power input. Experimental data confirmed the basic concepts of the models developed.

In hydraulic heat generators (HHGs) [1–5], heat results from changes in the physical and mechanical properties of the pumped liquid. These devices are thermally closed systems, since they do not take heat from the outside. The heat output of some HHG designs exceeds the electric power input [1, 2, 6], and, accordingly, their heat output coefficient is above unity:

\[ K_Q = \frac{Q}{N} > 1. \] (1)

Information available on the principle of operation of such HHGs does not clarify the physicochemical mechanism that provides the extra energy. However, in development and application of HHGs, it is necessary to know what processes cause this effect.

Here, we report our experimental studies on vortex and cavitation nonuniform flows and present mathematical model for energy production in HHGs.

Conversion of the potential energy (pressure) of a liquid into heat is carried out by the following techniques:

- once or multiply accelerating and swirling a liquid flow and then decelerating this flow through straightening [1–3],
- once or multiply changing the physical and mechanical properties of the flowing liquid by cavitation [4, 5], and
- multiply circulating the liquid in a pump–heat generator–pump circuit [1–5].

Flow acceleration is achieved by producing a vortex, as in vortex HHGs (Figs. 1a, 1b) [1–3], or by narrowing the flow in a confuser and then expanding it in the diffuser of a Venturi tube, as in cavitation HHGs (Fig. 1c) [5].

A vortex liquid flow in a cylindrical HHG may be continuous (Fig. 1a) or discontinuous (Fig. 1b). In the latter case, we have cavitation in the central zone of the flow. Cavitation flow is also observed in the diffuser of a Venturi tube (Fig. 1c).

Discontinuities in the central zone of the vortex flow (Fig. 1b) are caused by the centrifugal force. It was demonstrated experimentally [7–12] that cavitation occurs at a flow velocity at which the static liquid pressure is equal to the saturation vapor pressure. This flow velocity is given by the following formulas:

for vortex flow (Fig. 1b),

\[ W_{gt} = \frac{2P_g(P_0 - P)}{P \rho_l}, \] (2)

for cavitation flow in the diffuser of a Venturi tube (Fig. 1c),

\[ W_g = \frac{2(P_0 - P_g)}{\rho_l}. \] (3)

For a cross section of a vortex flow, the tangential velocity and static pressure are found by the following formulas [10]:

\[ \frac{W_i}{R} = \text{const}, \] (4)

\[ \frac{P}{P_g} = \frac{R^2}{R_g^2}, \] (5)

where \( R \) is the peripheral radius of the vortex and \( R_g \) is the radius of the region in which flow discontinuity or cavitation takes place (Fig. 1b). Bubbles filled largely with vaporized liquid form in this region [1–12]. The energy spent to produce the flow discontinuities is equal to the formation energy of the vapor bubbles:

\[ A_p = \sum A_{pi}. \] (6)

Here, \( A_{pi} \) is the energy (J) needed to produce one vapor bubble [8, 12]:

\[ A_{pi} = 4\pi r_g^2 \sigma + \frac{4}{3} \pi r_g^3 P_0 + \frac{4}{3} \pi r_g^3 P_g. \] (7)
In expression (7), the first term is the formation energy of the free surface of a bubble, the second is the formation energy of the cavity of the bubble, the third is the energy of the filling of this cavity with vapor, \( r_g \) is the bubble radius (m), \( \sigma \) is the liquid–vapor interfacial tension (N/m), \( P_0 \) is the pressure of the liquid surrounding the bubble (Pa), and \( P_g \) is the saturation vapor pressure at a given temperature (Pa).

Since flow discontinuities occur when the static pressure in the flow is equal to the saturation vapor pressure, we will take \( P_0 \) in expression (7) to be equal to \( P_g \). Expression (7) will then appear as

\[
A_{pt} = 4\pi r_g^2 \sigma + \frac{8}{3}\pi r_g^3 P_g. \tag{8}
\]

Upon the deceleration of the liquid–vapor stream, the bubbles collapse into liquid spheres and the liquid restores its original flow pattern.

The energy spent for bubble collapse can be calculated by the Rayleigh formula [13, 14]:

\[
A_{ci} = \int_{r_{\min}}^{r_g} 4\pi r^2 P dr = \frac{4}{3}\pi P(r_g^3 - r_{\min}^3) = \frac{4}{3}\pi P r_g^3. \tag{9}
\]

Here, \( P \) is the liquid pressure (Pa) at which the bubbles collapse and \( r_{\min} \) is the radius (m) of the liquid sphere resulting from the collapse (complete compression) of a bubble.

Let us compare the formation and collapse energies for a water vapor bubble with radius \( r_g = 1 \times 10^{-3} \) m. The formation energy of such a bubble is \( A_{pt} = 9 \times 10^{-6} \) J \( (T = 293 \) K; cavitation threshold or saturation vapor pressure, \( P_g = 1 \times 10^{3} \) Pa; surface tension, \( \sigma = 7.28 \times 10^{-4} \) N/m). The collapse energy of a bubble in a liquid at atmospheric pressure \( (P = 10^5 \) Pa) is \( A_{ci} = 4 \times 10^{-4} \) J. It is higher than the bubble formation energy by a factor of about 45.

This result suggests that, if a hydraulic system including an HHG is pressure-open, then the bubbles collapse under the pressure of the environment or, in other terms, the environment supplies energy to the system. To obtain 1 J of energy in a pressure-open hydraulic system, it is sufficient to convert \( 7.84 \times 10^{-8} \) kg of water into saturated vapor at 293 K and then condense this vapor at atmospheric pressure.