INFLUENCE OF PRESSURE OSCILLATIONS ON GAS-PHASE CONTENT IN GAS–LIQUID FLOW

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It has been shown experimentally that pressure oscillations in a gas–liquid flow lead to additional (in comparison with the steady case) liberation of gas phase from the dissolved state.

In the operation of most power stations, there are pressure oscillations of various amplitudes and frequencies in their hydraulic systems. Such oscillations may be due to cavitational self-oscillations in elements of the hydrosystem or the vibrational load of the supplying pipelines.

As shown by theoretical analysis [1], the presence of pressure oscillations in the supply pipeline of power plants with supply of gas-saturated liquid may lead to the appearance of additional gas liberation from the liquid in comparison with the steady-state case. Unfortunately, there are no experimental data confirming this theoretical conclusion as yet. At the same time, experimental results [2] show that additional gas liberation may lead to interruption of the supply-pump operation and correspondingly to loss in efficiency of the power plant. Therefore, there is a pressing need for experimental determination of the influence of pressure oscillations on the mass-transfer processes in gas–liquid flow.

A simplified scheme of the experimental apparatus – a hydraulic stand permitting saturation of the working liquid (in the present case, tap water) with carbon dioxide and excitation of pressure oscillations in the uniform section of the pipeline – is shown in Fig. 1.

Water saturated with carbon dioxide is fed under pressurization from reservoir 1 to pipeline 2, where it is subject to pressure oscillations excited by pulsator 4 in pipeline 6 and transmitted to pipeline 2 through tube 5. Then part of the flow Q_2' is fed to the measuring section 3, where the flow parameters are measured, and discharged to the reservoir. The other part of the flow Q_2'' is fed through tube 5 to pipeline 6, where it is mixed with the liquid fed to the pulsator using a booster pump, and then fed to the reservoir.

The influence of pressure oscillations on the gas liberation in the flow is determined by measuring: the pressure in the measuring section, the amplitude and frequency of the pressure oscillations, the liquid flow rate, the initial concentration of dissolved gas, and the relative volume gas content ϕ in the measuring section, defined as the ratio of the gas-phase volume to the mixture volume. The gas content of the flow is measured both with and without pressure oscillations. The additional gas liberation is determined from the difference of these quantities.

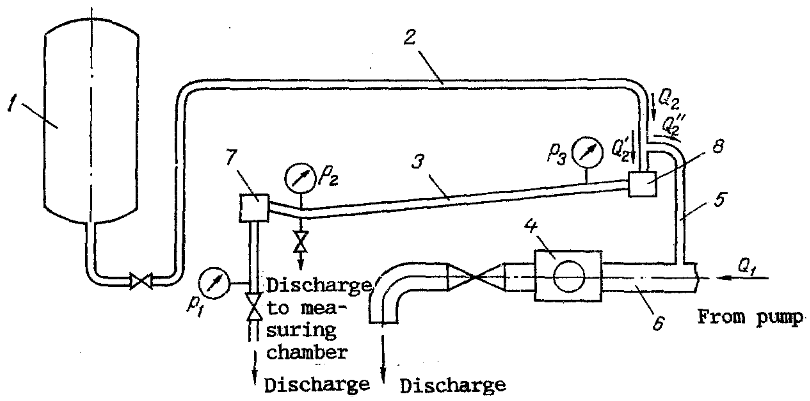

Fig. 1. Experimental apparatus.

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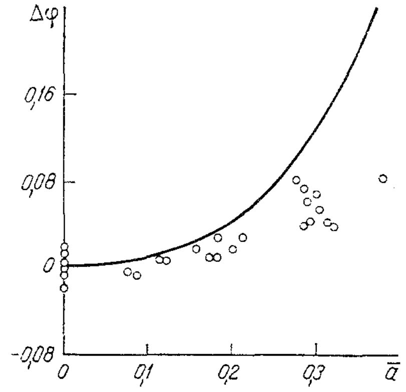

Fig. 2. Dependence of additional gas liberation $\Delta\varphi$ on relative amplitude of pressure oscillations $\bar{a}$.

The pressure is measured using sampling manometers and DD-10 pressure sensors, with recording on an N115 loop oscillograph. The liquid flow rate is determined from the pressure difference Δp_{3-1}. The initial dissolved-gas concentration in reservoir 1 is measured using a chromatographic method, taking liquid samples in special sampling devices. The relative volume content of the gas phase in the flow is determined by the cutoff method. The liquid volume in the measuring section is measured after the operation of the cutoff valves 7 and 8, and then recalculated. The limiting error in determining the relative volume gas content is 0.0062.

The measurement results are used to determine the relative amplitude of the pressure oscillations $\bar{a}$, equal to the ratio between the amplitude of the oscillations and the mean frequency of the pressure oscillations ν, and the additional gas liberation $\Delta\phi$

$$\Delta\varphi = \varphi - \varphi' - (\varphi_{eq} - \varphi'_{eq}). \tag{1}$$

The term $(\phi_{eq} - \phi'_{eq})$ in Eq. (1) takes account of the correction associated with the possible difference in mean pressure in the measuring section with pressure oscillations as compared with the pressure in the absence of oscillations. The limiting error in determining the additional gas liberation is 0.02.

Experiments are conducted in the oscillation-frequency range 7-30 Hz and with relative amplitudes of the pressure oscillations from 0 to 0.4 about a mean pressure value of $2.8 \cdot 10^5$ N/m^2. The maximum amplitude of the oscillations is achieved in the frequency range 10-16 Hz. At oscillation frequencies above 16 Hz and below 10 Hz, it is impossible to obtain a relative amplitude of the oscillations of more than 0.25.

Experimental results with various amplitudes in the frequency range 10-14 Hz are shown in Fig. 2, together with the theoretical dependence of the additional gas liberation on the relative amplitude calculated by the method of [1].

Analysis of the experimental data shows that the presence of pressure oscillations in the flow leads to the appearance of additional gas liberation in comparison with the steady-state case; this additional gas liberation increases with increase in relative amplitude of the pressure oscillations. The absolute magnitude of the additional gas liberation at a relative amplitude of 0.3 reaches approximately 0.06-0.07. The basic reason for the appearance of additional gas liberation is evidently the periodic variation in surface area of the phase boundary with pressure oscillations. Because of the compressibility of the gas phase, the surface area of the boundary is larger with reduction in pressure than with increase. Therefore, gas liberation prevails over solution, which leads to the formation of additional gas liberation.

Comparison of theoretical and experimental data shows that the theoretical dependence obtained on the basis of the mathematical model of [1] is in poor agreement with the experimental points. The theoretical values of the additional gas liberation are approximately twice as high as the experimental data; this is especially pronounced when $\bar{a} > 0.2$. As shown by theoretical analysis, this discrepancy arises because the relation for the mean bubble radius used in [1] does not ensure that the surface area of the gas phase is the same in the actual and equivalent monodisperse flows.

Summarizing, it may be concluded that the presence of pressure oscillations in gas–liquid flow leads to the appearance of significant additional gas liberation, which must be taken into account in the design and testing of power plants and other units and technological processes where there is gas-liquid flow in dynamic conditions.

NOTATION

$\bar{a}$, relative amplitude of pressure oscillations; p_1, p_2, p_3, pressure at different points of the pipeline; Δp_{3-1}, pressure difference; Q_1, liquid flow rate in pipeline 6; Q_2, liquid flow rate in pipeline 2; Q_2', liquid flow rate in measuring section; Q_2'', liquid flow rate in pipeline 5; ϕ, ϕ', actual relative volume gas content of flow in tests with and without pressure oscillations; ϕ_{eq}, ϕ_{eq}', equilibrium gas content of flow at mean pressure in the case of tests with and without pressure oscillations; $\Delta\phi$, additional gas liberation; ν, frequency of pressure oscillations.

LITERATURE CITED

1. É. V. Vengerskii, V. A. Morozov, and G. L. Usov, Hydrodynamics of Two-Phase Flows in Supply Systems of Power Plants [in Russian], Moscow (1982).
2. V. I. Petrov and V. F. Chebaevskii, Cavitation in High-Speed Rotary Pumps [in Russian], Moscow (1982).

HEAT TRANSFER IN CHANNELS WITH POROUS INSERTS DURING FORCED FLUID FLOW

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General analytic expressions are obtained to calculate heat transfer and temperature fields in a plane channel with a porous insert with allowance for the effective thermal conductivity of the heat carrier and the distribution of heat between the skeleton of the insert and the fluid in the boundary pores.

Porous media with various types of structures are finding increasing use in engineering to intensify the cooling of thermally-loaded objects when severe restrictions are placed on the temperature of the heat-transmitting surfaces. The studies [1-5] described methods of calculating the two-dimensional temperature distributions in a porous skeleton and in fluid moving through it. Convective heat transfer in a porous medium is usually described by using a system of equations based on two basic assumptions: 1) the Biot number for particles of the porous medium is small compared to unity; 2) all heat from the wall of the channel is transferred to the interior of the porous insert by conduction through the skeleton and is transmitted to the fluid by bulk heat transfer. Such an approximation is fully valid in the cases of the cooling of high-heat-conducting porous metals by water. If the thermal conductivity of the skeleton is negligible, then heat is transferred from the wall directly to the fluid moving in the boundary pores and is transferred into the interior of the porous layer by the effective thermal conductivity of the fluid due to its mixing in connected pores. This heat-transfer regime was studied in detail in [5, 6].

The laws governing heat transfer in the above-examined cases may differ considerably both qualitatively and quantitatively. Here, we propose a more general approach to calculating heat transfer in a channel with porous inserts: we consider the removal of heat from the wall by both the skeleton and the fluid and we examine the effect of the Biot number on bulk heat transfer. This problem is important for water-cooled structures made of steel, Invar, molybdenum, and other materials with pores and particles smaller than 1 mm when the thermal loads are approximately 10^6 W/m^2 or more. Most attention will be focused on the role of the effective thermal conductivity of the fluid and the heat distribution between the skeleton and the fluid in the formation of the temperature profiles and heat transfer in channels with porous inserts.

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