EFFECT OF HEATER VIBRATION ON THE BOILING PROCESS

V. V. Chekanov and L. M. Kul'gina

UDC 536.423.1

The effect of harmonic oscillations on bubble detachment frequency and its dispersion is considered. The experiments were performed at frequencies from 20 to 100 Hz, at oscillation amplitudes of 0 to $0.4 \cdot 10^{-4}$ m. It was established that vibration leads to a decrease in detachment frequency and dispersion.

In many cases (boiling of cryogenic oxidizers in reactive apparatus, vapor formation in boilers in motion) heat exchange between heater and liquid occurs with significant vibrations. But the physics of boiling on a vibrating heater has not been studied sufficiently. There do exist a few studies dedicated to this problem [1, 2], in which it was shown that increase in both a and f leads to intensification of heat liberation.

It is known that heat exchange in boiling is related to the frequency of bubble formation f_{det} on the surface, and thus it is of interest to study the dependence of f_{det} on heater vibration.

A block diagram of the experimental apparatus is presented in Fig. 1. The working vessel 2, made of stainless steel and 3 liters in capacity, is filled with distilled water. The water temperature was measured by a mercury thermometer to an accuracy of 0.2°C. Saturated boiling occurred on a plane horizontal heater ($68 \times 4 \times 0.07$ mm^3) of Getinaks foil.

The heater, fed by dc current, was used as a resistance thermometer in a double bridge circuit. The accuracy in measurements of mean thermal flux q was 0.4%, and in mean temperature measurements, T_s = 0.5%.

After mechanical processing with 000 sandpaper the plate surface was degreased with 96% ethanol. The heater was mounted on its support by wide conductive busbars. Harmonic oscillations from the mechanical oscillation generator 6 (GMK-1) were transmitted to the surface by a stainless steel rod 3 mm in diameter. The frequency f and amplitude a were controllable continuously by audio generator 8 (GZ- 33). The oscillation amplitude was recorded by objective micrometer 7. The oscillation frequency was determined from the dial of the GZ-33 generator.

Light from lamp 1 passed through the planoparallel walls of the vessel. Bubbles forming on the heater were projected by lens 3 on ground glass screen 4. The light from the diffusing screen fell on the cathode of the photomultiplier tube 5 (FÉU-28). The light beam was limited on the screen by a narrow vertical slit. As the growing bubble covers the slit, the light flux falling on the photomultiplier changes in proportion to the height of the bubble above the heater surface, and it was measured on oscilloscope 10 (CI-30).

I. Studies were made of the dependence of mean bubble detachment frequency $\bar{f}_{det}$ and its dispersion m_2 on amplitude a and frequency f of oscillation. Figure 2 shows curves of $\bar{f}_{det}$ and m_2 versus amplitude a for constant vibration frequency. It is evident from the curves that with increase in a, $\bar{f}_{det}$ and m_2 decrease. Very small amplitudes have no effect on $\bar{f}_{det}$. The effect of vibration on $\bar{f}_{det}$ begins at frequencies greater than 20 Hz.

Figure 3 shows curves of f_{det} distribution for various amplitudes at constant f. As is evident from the curves, the scattering of f_{det} about the mean value is large, and so to determine the characteristics of the effect of vibration on f_{det} it is necessary to use not only the first moment of the empirical distribution $\bar{x} = \bar{f}_{det}$, but also the following moments, the accuracy of whose values depends on the number of measurements made. To describe scattering characteristics of f_{det} relative to $\bar{f}_{det}$ the mean square deviation $S = \sqrt{m_2}$ is used.

Stavropol' State Pedagogical Institute. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 30, No. 1, pp. 44-48, January, 1976. Original article submitted October 16, 1974.

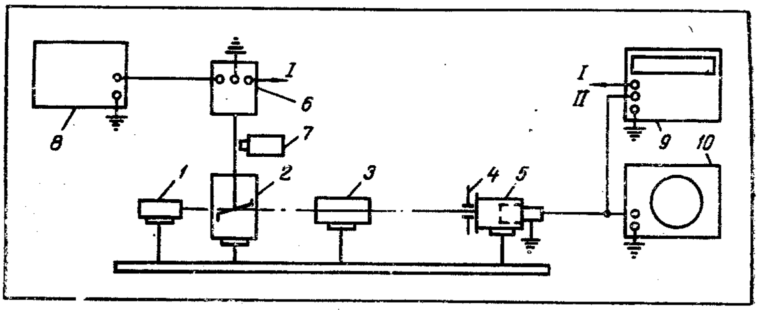

Fig. 1. Block diagram of experimental apparatus.

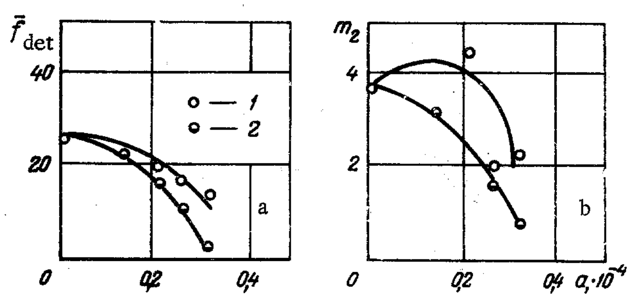

Fig. 2. Effect of oscillation amplitude and frequency on f_{det} (a) and dispersion (b): 1) f = 80 Hz; 2) 50 Hz.

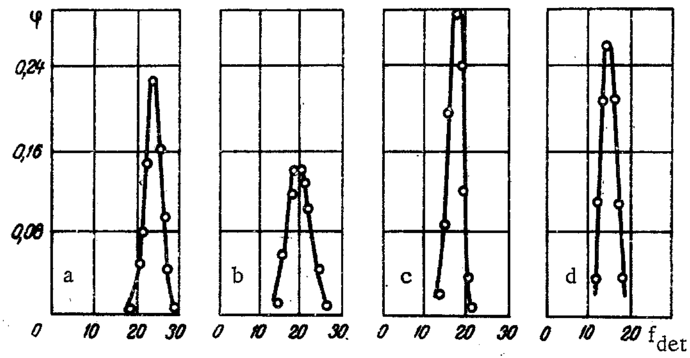

Fig. 3. Distribution of f_{det} for thermal flux of 10^7 W/m^2 and vibration frequency 80 Hz: a) a = 0; b) a = 0.216 mm; c) a = 0.256 mm; d) a = 0.328 mm.

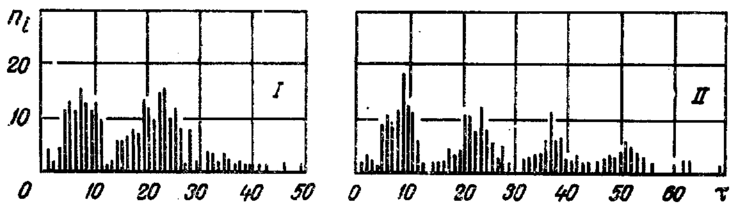

Fig. 4. Distribution of bubble formation phase and surface oscillation (I, a = 0.1; II, 0.24 mm).

The statistical estimates of the numerical characteristics were determined using the moments of the empirical distribution, which are justifiable estimates of the corresponding moment of the theoretical distribution.

A relatively high number of measurements were made in the experiments (150-200). Therefore, to evaluate the form of the theoretical distribution use was made of the third and fourth central moments, with the aid of which the asymmetry g_1 and excess g_2 were calculated. It developed that the f_{det} distribution is not symmetric, since in none of the cases studied was $g_1 \neq 0$.

TABLE 1

f, Hz	80			
a, mm	0	0,216	0,256	0,325
$\sigma_{\bar{x}}$, %	1,06	0,24	0,94	0,78
σ_{m_2}, %	28	30	21	26
σ_S, %	11,8	14,6	7,6	8,7

Since all statistical estimates obtained in processing of the experimental data are random, it is necessary to know how close they are to the characteristics of the theoretical distribution. The uncertainties in determination of $\bar{x}$, m_2, and S in one series of experiments are presented in Table 1.

The accuracy of the evaluations which use third- and higher-order moments is not great, even with 150 measurements being used. Therefore, the error in calculation of g_1 and g_2 was not determined. From the results obtained it can be concluded that to obtain reliable data a set of not less than 200 measurements is necessary.

II. The change in f_{det} with heater vibration may be related to change in temperature of the heat-liberating surface and pressure on the heater surface. Obviously, the latter is insignificant for the case studied, since calculation shows that near a surface less than 10^{-2} m in width for oscillation frequencies less than 200 Hz and amplitudes not greater than 10^{-3} m the pressure change does not exceed 10^{-4} atm.

With the vibration parameters chosen here liquid motion near the heater cannot be considered laminar [3], so that theoretical calculation of the surface-layer temperature is difficult. The surface temperature was measured experimentally.

The heater was powered by storage batteries. The mean temperature $\tilde{T}_s$ was measured with a P-239 double bridge. To determine instantaneous temperature changes the signal from the potential leads of the heated surface was applied to a CI-30 oscilloscope. Under surface vibration the CI-30 revealed the appearance of an ac voltage across the ends of the heater, connected with change in surface resistance with temperature oscillation. The maximum change in temperature from $\tilde{T}_s$ was 0.1-0.5°C and was dependent on a and f of the oscillations. It was established that the heater temperature varies according to a periodic law. The period of change of T_s may be equal to or a multiple of the period of the induced oscillations. In some cases the phase of the temperature change varied in a random manner.

A resistance thermometer determined the mean heater temperature. The time for temperature establishment across the foil thickness for the given heater was 10^{-4} sec [4], significantly shorter than the oscillation period. Therefore, the mean temperature can be considered to be the temperature of the surface on which the bubbles are formed.

III. Comparison of the phase of surface oscillation with the moment of bubble formation on the oscilloscope screen shows that bubbles are formed basically in the period of downward heater motion. The system of Fig. 1 was used for more accurate determination of bubble formation phase and statistical analysis.

The signal from the measurement winding of generator 6 was applied to the input shaper I of frequency meter 9 (ChZ-12). Input shaper II was fed with the photomultiplier signal. The frequency meter was triggered on by input I and off by input II. The time interval τ_i between pulses I and II was counted by decade circuitry to an accuracy of 1 msec; τ_i is the time between an arbitrarily chosen beginning of a positive pulse period from the measurement winding and the formation of the first bubble.

A total of n_i independent values of τ_i were obtained. Graphs were constructed (Fig. 4). The abscissa represents time intervals τ_i in msec; the ordinate, segments equal to the number of observations n_i in each time interval. It is evident from the graphs that the greatest probability of bubble formation in phase with the oscillating surface for a = 0.1 mm is equal to 0.3. For a = 0.24 mm, the probability is 0.42. The mean value of bubble-formation-phase dispersion is 4.1 msec^{-2} for a = 0.1 and 3.6 msec^{-2} for a = 0.24 mm.

NOTATION

a, vibration amplitude; f, vibration frequency; f_{det}, bubble formation frequency; $\bar{f}_{det}$, mean bubble formation frequency; m_2, dispersion; x, initial first-order moment; S, mean quadratic deviation; σ, measurement error; T_s, heater surface temperature; τ, time.

LITERATURE CITED

1. W. F. Calus and P. Rice, Intern. Heat Transfer, V. S. 4, 1. Boiling (1970).
2. Schmidt and Uitt, Teploperedacha, 94, C, No. 4 (1972).
3. K. Krishia, Prasad, and V. Ramanathan, Heat Mass Transfer, 6 (1972).
4. L. D. Landau and E. M. Lifshits, Mechanics of Continuous Media [in Russian], GITTL, Moscow (1944).
5. G. F. Abezgauz et al., Handbook of Probability Calculations, No. 2 [in Russian], Voenizdat, Moscow (1970).

TWO-DIMENSIONAL RADIATIVE HEAT TRANSFER WITH ALLOWANCE FOR SHADING

V. F. Kravchenko and V. M. Yudin

UDC 536.3

Radiative heat transfer with account taken for shading in an infinite cylinder whose contour is made up of arbitrary straight-line segments and which has variable temperature and emissivity on its two sides is examined.

Calculation of heating of high-speed aircraft structures reduces to solving problems of conductive and radiative heat transfer in complex systems of thin-walled elements with internal closed spaces. Because of the peculiarities of the structure geometry and the specific heating conditions it is possible in many cases to limit examination to problems of radiative heat transfer and heat conduction in a simple configuration.

We consider radiative transfer in an infinite cylinder in which the temperature and the optical properties of the internal surface, which is assumed to be gray and diffuse, do not vary in the axial direction. We consider the cylinder to be closed; an open cylinder can be closed in many cases by introducing a fictitious surface with emissivity $\varepsilon = 1$ and temperature $T = (q_\infty/\sigma)^{1/4}$, where q_∞ is the heat flux scattered from the surrounding medium.

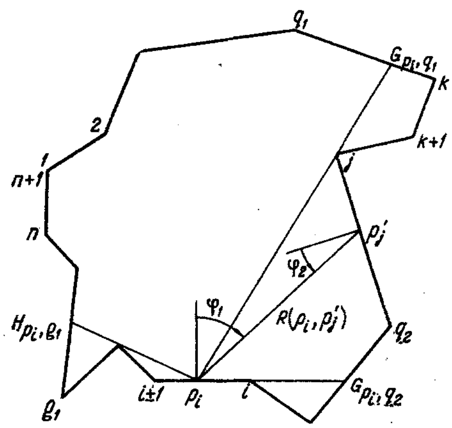

Fig. 1. Computational scheme.

N. E. Zhukovskii Central Aero-Hydrodynamics Institute, Moscow. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 30, No. 1, pp. 49-57, January, 1976. Original article submitted January 20, 1975.