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INVESTIGATION OF NOISES IN BOILING ON AN ELECTRICALLY HEATED WIRE

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An experimental investigation of noises in boiling on an electrically heated wire in a water volume has been carried out. Its results point to the fact that the type of heating of the heat-exchange surface has a significant influence on the processes of boiling and the noises appearing as a result of them. It is shown that heating by a pulsating direct current gives rise to effects that are not observed in the case of heating by an accumulator current.

Anomalous regimes of boiling of the heat-transfer agent in nuclear power systems are often investigated and modeled with the use of an electrically heated wire or tube [1]. However, in most cases, the authors, using an alternating or direct current for heating, do not specify the character of the direct current used. Below we present results of the experimental investigation of the peculiarities of noise formation in boiling on a wire heated by a direct current in a water volume.

The investigations were carried out on a setup whose diagram is shown in Fig. 1. Two types of heating current were used: nonsmoothed direct current rectified by a diode bridge (V50 diodes) and constant current from a lead-acid cell (Hitachi; 12 V; 6.5 A·h) connected in place of the diode bridge.

The setup represents a cuvette filled with water, on which a textolite plate with posts for fixation of the wire is installed so that the wire is in water at a given depth (45 mm). In the experiments, we used three cuvettes: a plexiglass cuvette with dimensions 120 × 55 × 80 mm and a silumin cuvette with dimensions 140 × 55 × 70 mm with a wall thickness of ~1 mm and a plastic cuvette of size 130 × 80 × 70 mm with a wall thickness of 0.3 mm. The natural frequencies of the cuvettes filled with water with the holder of the wire installed at their top were 218.0, 470.3, and 82.6 Hz, respectively. The natural frequency of the "dry" wire stretched between the posts of the holder was of the order of 1360.0 Hz.

Unsettled tap water and distilled water (condensate of atmospheric moisture) were used as the heat-transfer agent. The temperature of the water in the cuvette was determined by a mercury thermometer with an accuracy of 0.5^{o}C.

The voltage and the current were measured by M838V and M830V multimeters.

The boiling noises were detected by an MFK-003 capacitor microphone of the highest class (working range 20–20,000 Hz, sensitivity 4 mV/Pa) on the sound card of a personal computer (SB 16 Creative CT 2700) with a discretization frequency of 44.1 kHz and a resolution of 16 bit. The duration of recording of a sound signal was 2–3 sec in each regime. The microphone was positioned on a porolon base at a distance of 100 mm from the edge of the cuvette; its axis was perpendicular to the wall having a larger area.

Visual observations in heating by a rectified current have revealed the following effects. As the heating power increases, bubbles arise on the surface of the wire, and their size and number increase with increase in the heat load. However, when the heat load approaches a certain value dependent on the water temperature, the wire begins to vibrate much as was the case in air [2]. The size of the bubbles sharply decrease and the rate of their separation increases. The water becomes turbid because of the large number of small vapor-gas bubbles. In a predegassed water (boiled water), the turbidity is not so strong as in water saturated with gas. Because of the strong turbidity of the water, we cannot determine the behavior of the wire through the walls of the transparent cuvettes, but the observations through a mechanical stroboscope-tachometer under a bright lighting have shown that the wire vibrates with a fre-

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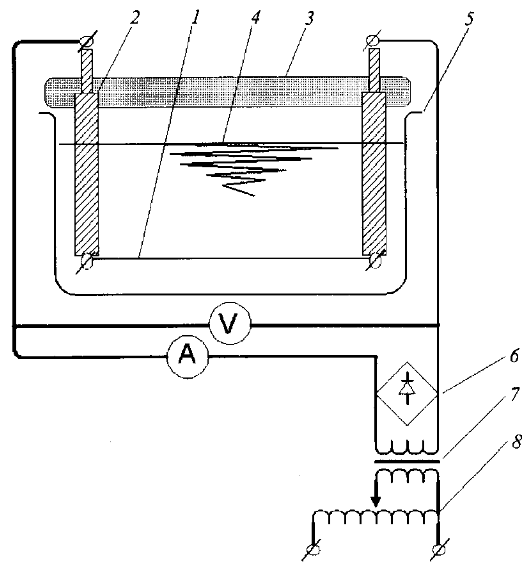

Fig. 1. Schematic diagram of the setup: 1) nichrome wire of diameter 0.2 mm; 2) posts for fixation of the wire; 3) textolite plate; 4) water level; 5) cuvette; 6) diode bridge; 7) step-down transformer; 8) autotransformer.

quency of 100 Hz and an amplitude of up to 1.0 mm. As this takes place, a relatively intense characteristic sound of boiling arises. An increase in the water temperature at a constant value of the heat flux intensifies the sound. However, when the temperature 75–80^{o}C is reached, the intensity of the sound begins to decrease and at a temperature of 80–100^{o}C the characteristic sound practically disappears and becomes similar to the sound of surface boiling on a heater with nonelectrocontact heating — a TÉN-type heater or fire heating.

In boiling accompanied by the characteristic sound, we observed hot-water jets on the wire which were directed from certain nucleation sites perpendicularly to the wire axis. Such jets were observed for the first time in [3], where the experiment was carried out with a platinum wire of diameter 0.15 mm and where it has been established that these jets pulsate with a frequency of the order of 1000 Hz. The analogous jets were also observed in [4] where boiling on a thin wire was investigated. It is probable that it is precisely these ejections of hot water into the cold core of the flow revealed in investigating thermoacoustic vibrations at supercritical pressure that were called pseudobubbles in [5]. In our opinion, these jets are a consequence of strong secondary flows in the neighborhood of the vibrating wire.

Connection of the cell as a current source sharply changed the character of the sound signals. First, the strong low-frequency component disappeared and the boiling sound was more similar to the "white" noise (as in the case of boiling of a kettle). Second, the total intensity of the boiling noise decreased at the same values of the heat power supplied. Third, the characteristic waves on the surface of the water in the cuvette appearing in heating of the wire by a pulsating current disappeared.

The observations of the wire with a stroboscopic tachometer have shown the absence of wire vibrations at all the parameters studied. The character of the behavior of the bubbles differed insignificantly from the behavior of the bubbles arising in boiling on the surface of isolated heaters of the TÉN type. The strong turbidity of the water, described above, was also absent in this case.

The oscillograms of boiling noises have shown that the boiling noises are very different in the cases of heating by a constant current and a pulsating current. A characteristic feature of the oscillograms obtained with a pulsating current was the presence of a modulation of 100 Hz (Figs. 2 and 3).

The oscillograms of the amplitudes of the acoustic signal and the heating current (Fig. 3a) show that the peak of the acoustic signal is delayed in phase relative to the peak of the current. The minimum level of the acoustic signal corresponds to the growing part of the sinusoid on the current curve, and the rise in the acoustic signal and its decay correspond to the dropping part. This modulating action of the oscillation of the current intensity can be explained in the following way.

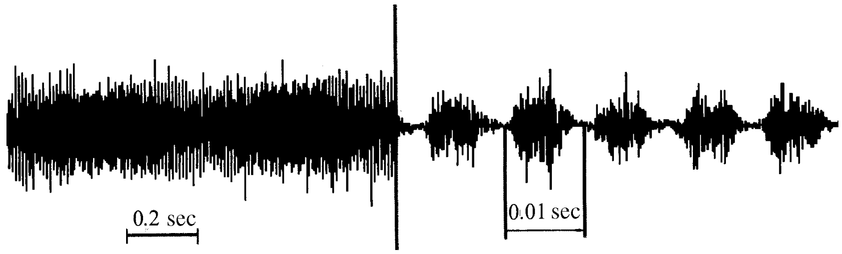

Fig. 2. Oscillograms of an acoustic signal in the case of heating by a pulsating direct current obtained in the plexiglass cuvette at 65°C and 1.2 MW/m^2 (different time bases of the noise signal).

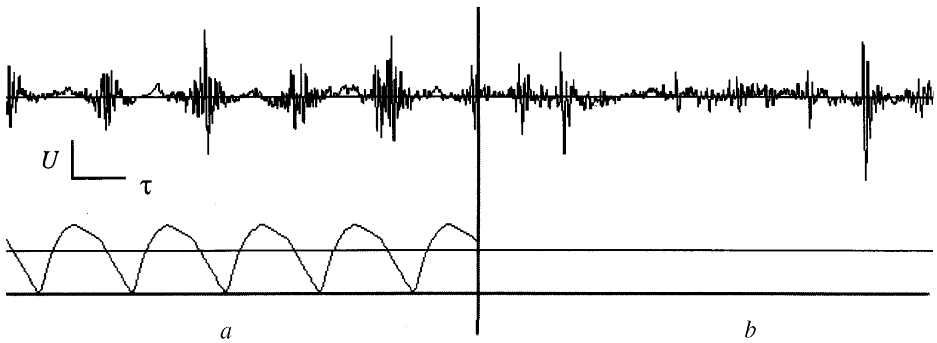

Fig. 3. Oscillograms of an acoustic signal in the case of heating by a pulsating (a) and a constant (b) current, obtained in the plexiglass cuvette at 72°C and 0.42 MW/m^2. The lower curve is the corresponding oscillograms of the heating-current amplitudes.

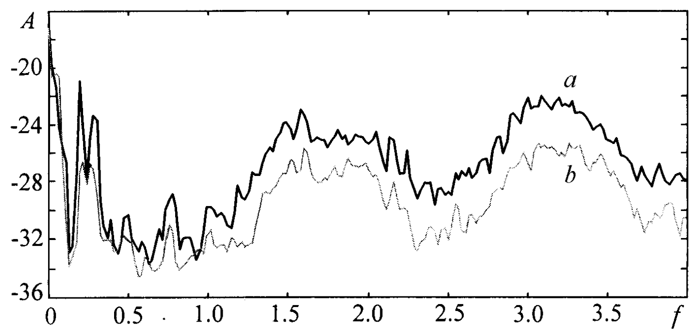

Fig. 4. Spectra of an acoustic signal, obtained in the plexiglass cuvette, at 72°C and 0.42 MW/m^2 in the case of heating by a rectified pulsating current (a) and a constant accumulator current (b).

When the current increases from zero to the maximum value, the wire vibrates due to the increase in the electrodynamic force determined by the rate of change of the current intensity and the increase in the heating of the wire by an increasing current. When the current reaches its maximum the electrodynamic force is also maximum and vibrations of the wire cease, whereas its heating reaches a maximum. At this instant of time, bubble explosion begins. It continues for a certain time as long as the oscillatory motion of the wire is enhanced under the action of a decreasing current and a weakening electrodynamic force. The heat power supplied to the wire decreases with decrease in the current. Bubbles are "blown away" from the wire under the action of the accelerating oscillatory motion of the wire, which is evidenced by the increasing acoustic signal. Its maximum corresponds approximately to the middle of the dropping portion of the current curve, i.e., the point where the velocity of oscillatory motion of the wire is maximum. In this case, the vaporization intensity is higher at the peak of the pulsating current, since the current in this case is higher than its mean (effective) value. This explains the increase in the acoustic signal of boiling in the case where the rectified current with an effective value equal to the accumulator current flows in the wire.

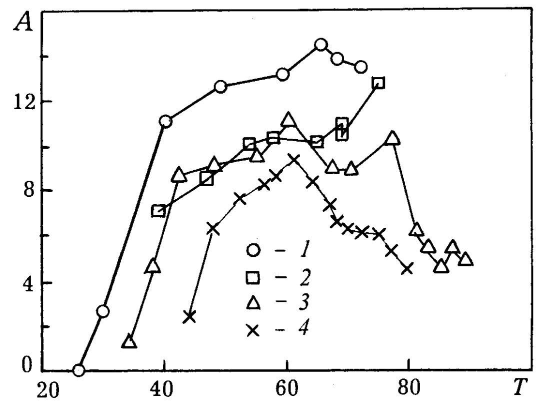

Fig. 5. Amplitude of an acoustic signal as a function of the water temperature in the cuvette: 1, 2) tap water and distilled water, respectively, in the plexiglass cuvette; 3, 4) distilled water in the silumin and the thin plastic cuvette.

A comparison of the spectra of acoustic signals obtained in the case of heating by a pulsating and a constant current has shown (Fig. 4) that practically throughout the frequency range studied (20–20,000 Hz) the amplitude of the acoustic signal obtained with a pulsating current exceeds the amplitude of the signal obtained with a constant current by 2–4 dB. In this case, the character of the signals obtained at frequencies higher than 1 kHz is practically identical. The maximum difference in the spectra of the acoustic signal between the two types of heating studied is observed at frequencies lower than 1 kHz, in particular, at frequencies of 197 and 295 Hz (second and third harmonics).

Investigation of the dependence of the amplitude of the acoustic signal (averaged over the sample) on the temperature has revealed the existence of the maximum at temperatures of 60 to 70^{o}C (Fig. 5), which is analogous to the maximum on the dependence of the pressure oscillations on the inlet temperature obtained in investigating thermoacoustic vibrations [6]. The boiling noise in the distilled and degassed water was weaker than the noise in the tap water approximately by 5 dB (Fig. 5).

Investigation of the wire after the experiment has shown that a scale is deposited on it in the regime of intense heating. In the case of heating of the wire by an accumulator current, the scale layer was uniform along the entire length of the wire and it was absent at the center of the wire where the amplitude of its vibrations is maximum if the heating is effected by a pulsating current.

The investigation carried out has shown that the type of heating of the heat-exchange surface has a significant influence on the boiling processes and the noise arising as a result of them. It is shown that for modeling of the heat-exchange processes on wire heaters, heating by an alternating or pulsating direct current gives rise to additional effects that are not observed in industrial setups, for example, with fire heating.

NOTATION

A, amplitude of the acoustic signal, dB; *f*, frequency of the acoustic signal, kHz; *T*, temperature of water in the cuvette, ^{o}C; *U*, voltage of the electric signal, V; τ, time, sec.

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