ANALYSIS OF THE ACOUSTIC SIGNAL HEARD DURING BOILING ON A HEAT CONDUCTING MASSIVE BODY

Yu. P. Denisov and V. S. Zabelina

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The acoustic signal has been analyzed which is heard when a liquid boils on a heat conducting massive body. The parameters of that signal have been established on the basis of which the first critical boiling mode can be predicted.

From the theory of an acoustic radiator [1] there follows a relation between the parameters of the acoustic signal heard when a liquid boils and the thermal parameters which govern the boiling rate.

As is well known [2, 3], the sound intensity increases from bubble boiling to film boiling and becomes "saturated." A similar trend was noted in [5].

The existence of a unique relation between acoustic and thermal characteristics of the boiling process has been established in [4].

The study of boiling modes and characteristics on heat conducting massive bodies in [6], where the acoustic signal was used as one means of obtaining information about phenomena at the heat transfer surface and inside the ambient volume, has revealed the pulse character of this signal stemming from the effect of the phase self-separation phenomenon during bubble formation on massive bodies with a relatively low thermal resistance between nucleation centers.

This study, the first results of which had been reported at the Fourth All-Union Conference on Heat Transfer [7], was concerned with establishing a correlation between the parameters of the acoustic pulse signal and the parameters of heat transfer during the boiling of liquids on heat conducting massive bodies with natural convection under atmospheric pressure. As a massive body the authors used a copper block weighing 3 kg with a cylindrical transition segment joining it to a 500 mm^2 large heat transfer surface in contact with the liquid enclosed in a glass cylinder between a top and a bottom lid. The copper block was shaped and installed on the bottom of the vessel so as to ensure isothermality of the heat transfer surface with rather little heat loss. The temperature of the liquid T_L was maintained constant within 0.5°C by an automatic regulation system. The thermal variables of the boiling process (thermal flux density q and temperature drop ΔT) were recorded with a two-coordinate plotting instrument.

Information about the acoustic signal heard during boiling was obtained through piezo transducers installed inside the liquid volume. After amplification, the signal was recorded on magnetic tape. The amplifier and the transducer characteristics were known. A time base was provided in the instrumentation as a common reference for both the thermal and the acoustic characteristics. For analyzing the parameters of the acoustic signal, the latter was transcribed from the magnetic tape onto photographic paper (Fig. 1). This was done at fixed values of variables q and ΔT at several points along the boiling curve $q = f(\Delta T)$ The recording time was 10-30 sec per point. The magnetophonic records of the acoustic signal at two different points along the boiling curve were separated by a short pause marker in the form of a sinusoidal signal of definite frequency and amplitude. During the transcript onto photographic paper with a loop oscillograph, a signal of a definite frequency was recorded on one track to serve as the time base. Both the pause marker signals and the time-base signal were generated by an audio oscillator. At the same time, the signal recorded on magnetic tape was also picked up on another oscillograph.

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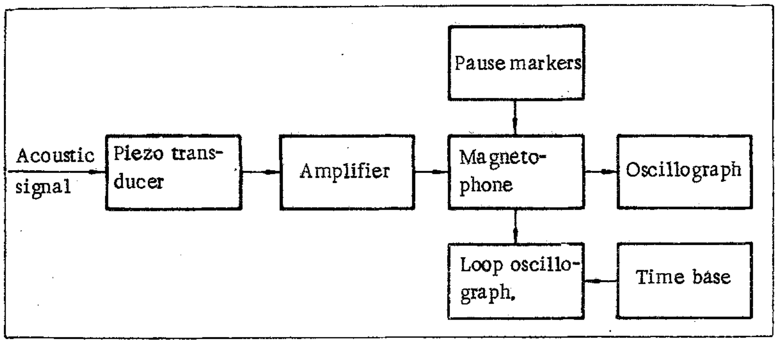

Fig. 1. Schematic block diagram for the acoustic signal.

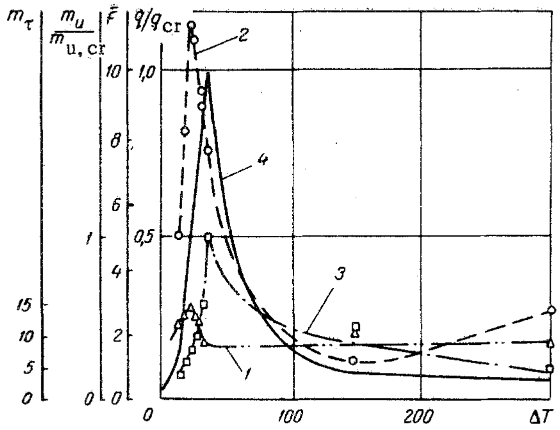

Fig. 2. Acoustic parameters of the boiling process, as functions of the temperature drop ΔT (°C): amplitude $m_u/m_{u,\,cr}$ (1), width m_τ (μsec) (2), repetition rate $\bar{F}$ (Hz) (3), boiling curve (4).

The acoustic signal thus recorded was a sequence of bipolar radio pulses at a packing frequency of the order of several hundred hertz (which happened to be the natural frequency of the system) and at a variable amplitude, width, repetitionrate, and risetime. Inasmuch as the parameters of each individual pulse were random quantities, the signal recording was a statistical process.

The statistical mean pulse amplitudes and widths were determined according to the formulas in [8]:

$$m_u = \sum_{i=1}^{k} u_i p_{u_i}, \quad m_\tau = \sum_{i=1}^{k} \tau_i p_{\tau_i},$$

with u_i and τ_i denoting the mean amplitudes and the mean widths in a burst, p_{u_i} and p_{τ_i} denoting the i-th burst frequencies with regard to amplitudes and widths respectively, and k denoting the number of bursts. These statistical mean values were then used for characterizing the acoustic signal heard during boiling in known q, ΔT, T_L modes. The mean pulse repetition rates corresponding to each boiling mode was determined according to the formula

$$\bar{F} = \frac{n}{t_{rec}},$$

with n denoting the number of recorded pulses and t_{rec} denoting the duration of a signal record measured along the time base.

The statistical mean relative pulse amplitudes $m_u/m_{u,cr}$, pulse widths m_τ, and pulse repetition rates $\bar{F}$ as functions of the temperature drop ΔT during pool boiling of distilled water at 103°C have been plotted in Fig. 2, the points representing average values based on nine tests. On the same diagram is also shown the boiling curve $q/q_{cr} = f(\Delta T)$ obtained by the procedure in [6].

According to the graph, the pulse width, the pulse amplitude, and the pulse repetition rate curves characterizing the acoustic signal correlate closely with the boiling curve. The relative changes in amplitude and repetition rate are much greater than the change in pulse width during transition through the first critical boiling mode.

This found correlation can be useful for predicting a critical boiling mode. In order to utilize it thus, it is necessary to determine the precritical (q close to q_{cr}) pulse repetition rate of the acoustic signal $\bar{F}_{p,cr}$. For this purpose, an additional series of tests was performed to determine $\bar{F}_{p,cr}$ under the said conditions: for $\bar{F}_{p,cr}$ = 12, 7.2, 9.7, 7.3, and 12 Hz.

The mean precritical pulse repetition rate was, on the basis of this and earlier tests, equal to 10.1 Hz.

Further studies were made concerning the parameters of the acoustic signal which correspond to water temperatures below the saturation point and to other boiling liquids. The results will be reported in a separate article.

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