Journal of Engineering Physics and Thermophysics, Vol. 71, No. 6, 1998

SPECIAL FEATURES OF BOILING OF A SLIGHTLY SUBCOOLED LIQUID

E. I. Nesis and A. G. Zvyagintsev

UDC 536.24

Slightly subcooled boiling is characterized by the fact that vapor bubbles that form at active sites on the heater surface grow continuously and, having attained a maximum size, separate and float. The frequency of bubble separation, which determines the rate of heat transfer, depends on the degree of subcooling of the boiling liquid.

1. As is known, subcooled (local) boiling differs from ordinary, saturated boiling by the fact that, except for a thin liquid layer directly adjacent to the heater, whose temperature is somewhat higher than the boiling point T_s, the entire main mass of the liquid is at a temperature $T_0 < T_s$. The quantity $\Delta T = T_s - T_0$ is a measure of subcooling of the locally boiling liquid. It should be noted that heat transfer in subcooled boiling is more intense than in saturated boiling, and therefore in high-temperature engineering, when rapid removal of heat is necessary, local boiling is widely used [1].

The special features of subcooled boiling have been studied by many researchers [2-7]. We take a quick look at the basic results obtained in these works. At minor subcooling ($\Delta T \approx 2$ K) the process of local boiling differs slightly from saturated boiling: vapor bubbles appearing at active sites of the heater surface grow, monotonically increasing to a certain maximum size V_m after which they separate and float to the free surface of the liquid, where they collapse.

But at greater subcooling ($\Delta T \approx 6$ K), a bubble that form at a site grows and, having attained a size V_m, separates and begins to float; here, due to condensation in the cold liquid, the bubble diminishes and, as a rule, collapses, not succeeding in reaching the free surface.

At even greater subcooling ($\Delta T \geq 12$ K) the formed bubbles virtually do not separate from the site, they fluctuate on the heating surface, first growing to some limiting size and then deteriorating to complete disappearance.

We decided to study in greater detail the special features of the process of vapor generation in boiling of a slightly subcooled liquid. For this purpose a special experimental setup was constructed [8]. A microspiral made of thin copper or platinum wire and fastened to a solid surface submerged in water served as an active center. Direct electric current was supplied to the wire center, so that the temperature at the center exceeded somewhat the saturation temperature T_s. The first series of experiments was devoted to determination of the dependence of the frequency of vapor-bubble separation f on the degree of subcooling ΔT and the power W of the current supplied to the active center. The data obtained are presented in Table 1, from which it follows that the frequency of bubble separation f decreases with increase in the subcooling ΔT, but it increases with the power. These results seem quite natural since an increase in the power of the current that heats the active center leads to a higher heat input and acceleration of vapor-bubble growth; an increase in subcooling of the liquid results in intensification of cooling of the center and, consequently, in deceleration of growth of the bubble existing at the center.

2. Earlier a number of researchers noted that in the process of the bubble-generation action of an active center the temperature of the latter experiences periodic fluctuations. However, the character of these temperature fluctuations and its dependence on the conditions of subcooled boiling have not been studied sufficiently thoroughly as yet. Meanwhile, the mechanism of the bubble-generation action of active centers and, in particular, the functional interrelation between temperature fluctuations of a center and the conditions of phase conversion of liquid to vapor

---

Stavropol State University, Russia. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 71, No. 6, pp. 993-995, November-December, 1998. Original article submitted July 30, 1997.

TABLE 1. Dependence of the Frequency of Bubble Separation f on the Degree of Subcooling ΔT of the Liquid and the Power W of the Current Supplied to the Active Center

Power W, W	f at $\Delta T = 2$ K	f at $\Delta T = 8$ K
0.35	8	2
0.38	10	6
0.41	12	9
0.44	14	10
0.47	16	14

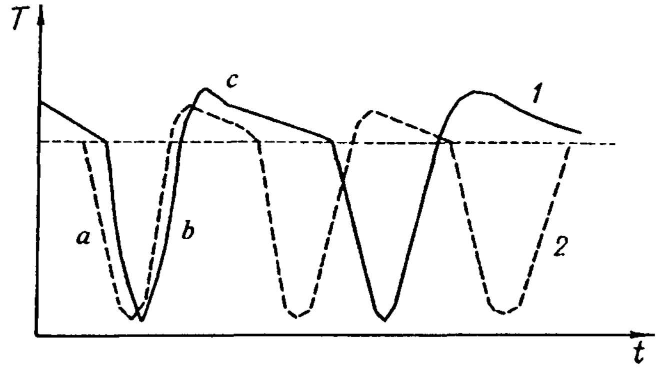

Fig. 1. Variation of the temperature of an active center of boiling during growth and separation of vapor bubbles.

are of undoubted interest for the physics of subcooled boiling. To clarify the problem mentioned we performed a second series of experiments.

In boiling with slight subcooling, microscopic vapor bubbles appear periodically at active centers, and these bubbles grow due to evaporation of a thin layer of overheated liquid adjacent to the center and, having attained a maximum size V_m, separate from the center and float.

We denote the duration of the life of a bubble at a center by τ_+, and after separation the active center is in a state of expectation of the appearance of a new bubble for a time τ_-. Thus, the period τ of the bubble-generation action of a center consists of two parts – the time of bubble growth τ_+ and the time of expectation τ_-: $\tau = \tau_+ + \tau_-$.

Figure 1 presents curves of temperature fluctuations of the wire center of boiling during the growth (a) and floating (b) of a vapor bubble, and portion (c) corresponds to the "silence" period of the center. Curve 1 refers to the case where the power of the current that heats the wire center was $W_1 = 0.5$ W, and curve 2, $W_2 = 0.7$ W.

We note that the maximum amplitude of temperature decrease at the center, attained approximately at the moment of bubble separation, does not virtually depend on the current power W or the degree of subcooling ΔT (within the limits of $\Delta T = 2-10$ K). The temperature amplitude is to a certain degree related to the type of wire that forms the center.

3. Acoustic accompaniment carries certain information about the process of formation, growth, separation, and floating of a vapor bubble in slightly subcooled boiling. In [9] it was shown that the acoustic pressure produced by a varying spherical bubble of a radius $R(t)$ is equal to

$$P_{ac} = \frac{\rho}{r} R (2\dot{R}^2 + R\ddot{R}) . \tag{1}$$

Since in subcooled boiling the bubble radius first increases from $R = 0$ to $R = R_m$ and then decreases to zero, it is easy to determine the character of the acoustic signal produced by the bubble. At small R the quantity $2\dot{R}^2$ is obviously greater than the product $R\ddot{R}$, and therefore, according to (1), $P_{ac} > 0$ (at this stage the bubble produces

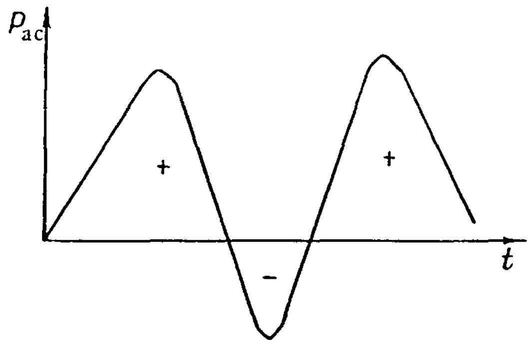

Fig. 2. Characteristic shape of the acoustic pulse produced by a vapor bubble in boiling of a subcooled liquid.

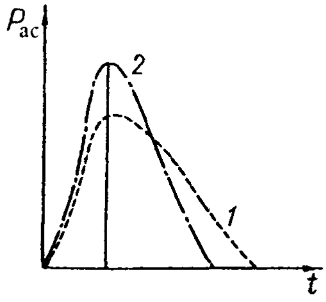

Fig. 3. Change in the shape of the first compression wave of the acoustic pulse produced by a vapor bubble with a change in the subcooling of the liquid: 1) $\Delta T = 3$ K, 2) 8.

a compression pulse). When $R \approx R_m$, the first derivative is $\dot{R} \approx 0$, and the second derivative is negative, $\ddot{R} < 0$, and consequently, a rarefaction pulse is produced during this period of the life of the bubble ($P_{ac} < 0$). Then, a third stage where the bubble again diminishes ($R \to 0$) occurs, and $2\dot{R}^2 + R\ddot{R} > 0$, so that $P_{ac} > 0$, i.e., a compression wave is produced (Fig. 2).

Experiments performed that were devoted to the study of the character of the first compression wave in subcooled boiling gave the following results: the amplitude of the compression wave P_{ac}^{m} increases with the subcooling ΔT, but the duration of the compression pulse decreases, although the time interval t_m during which the acoustic pressure P_{ac} increases and attains a maximum value P_{ac}^{m} is virtually constant. In other words, as ΔT increases, the curve of the acoustic pulse is deformed somewhat due to shortening of the time interval of the pressure drop (Fig. 3).

REFERENCES

1. E. I. Nesis, Boiling of Liquids [in Russian], Moscow (1973).
2. K. Niscikawa and H. Kusuda, Bull. JSME, 7, No. 26, 406 (1964).
3. M. Ellion, Jet Propulsion Laborat., Mem., 22 (1954).
4. F. Gunter, Trans. ASME, 73, No. 2, 115 (1951).
5. G. G. Treshchev, Teploénergetika, No. 5, 44 (1957).
6. D. A. Labuntsov, Inzh.-Fiz. Zh., 4, No. 9, 83-85 (1961); 6, No. 4, 33-39 (1963).
7. S. Bankoff, Chem. Eng. Progr. Symp. Ser., 57, No. 32, 156, 164 (1961).
8. A. G. Zvyagintsev, B. M. Dorofeev, and E. I. Nesis, Proc. of the XLII Scientific-Methodological Conf. "University Science to the Region," Stavropol (1997), pp. 71-73.
9. E. I. Nesis, Two-Phase Flows [in Russian], Leningrad (1988), pp. 68-74.