Available online at www.sciencedirect.com

SCIENCE DIRECT®

International Journal of Heat and Mass Transfer 48 (2005) 1219–1221

International Journal of HEAT and MASS TRANSFER

www.elsevier.com/locate/ijhmt

Comments on paper "Study on propagative collapse of a vapor film in film boiling (mechanism of vapor-film collapse at wall temperature above the thermodynamic limit of liquid superheat)" by Hiroysu Ohtake and Yasuo Koisumi published in Int. J. Heat Mass Transfer 47 (2004) 1965–1977

S.A. Zhukov *

Institute of Problem of Chemical Physics, Russian Academy of Sciences, 142432 Moscow Reg., Chernogolovka, Russian Federation

Received 7 April 2004; received in revised form 20 May 2004

The paper under consideration is interesting without doubt. The authors touch upon the questions which are very important for understanding the mechanisms of critical phenomena. But unfortunately, as it can be seen from paper, they are not informed about a number of works which are the basis for autowave theory of boiling crisis. Therefore, I am afraid this fact can generate the incorrect understandings in this sphere of knowledge among the readers.

I would like to begin with the main problem authors tried to overcome: Why do the big differences between the measured values of minimum-heat-flux (MHF) occur? If we analyze this phenomenon from the viewpoint of the published earlier works, the answer won't be too complicated. There is an obvious statement that the boiling curve represents a diagram of steady-states of the heater with uniform temperature distribution. In other words a heater may be treated in terms of localized systems. Under these conditions the critical points ($q_{\max}$ and $q_{\min}$) are semi-stable and they are achievable in experiment.

The real heaters invariably contain the zones of temperature nonuniformity. For example, as to electric heaters, there are zones of local temperature minimum near the current terminals and local temperature maximum near the middle of the heater. This causes that the boiling crisis on the surfaces with temperature nonuniformity originates in local point and a new regime propagates with constant velocity in the form of thermal wave on the whole surface, long before the "true" critical parameters are reached.

For the first time the existence of autowave mechanism of boiling regimes transition has been discussed in [1] in detail. It was shown that on nonlocalized heater in the zone of study-states ambiguity ($q_{\max} > q > q_{\min}$) it is possible to initiate the autowave transition of boiling regimes by local disturbance.

The direction of process evolution depends on a sign of heat source (the difference between heating and cooling). Thus, when heat source is equal to zero, stability of both bubble and film regimes are the same. If under these conditions the zones of bubble and film regimes are generated on heater, the front dividing the boiling regimes will stay without moving (state of neutral equilibrium or equilibrium heat flux—"q_{eq}" in terms of [2]).

If the heater source sign is positive, a film regime is stable. In this case under the action of local disturbances the heater regime can be changed from bubble to film mode spontaneously in the whole range of thermal loads $q_{\mathrm{eq}} < q < q_{\max}$. This transition will be carried out in the

---

[*] Tel.: +8 09652 48 2 49; fax: +7 96 5155 420.
E-mail address: zhukov@cat.icp.ac.ru

doi:10.1016/j.ijheatmasstransfer.2004.09.034

form of autowave with constant velocity—the running boundary of boiling regimes.

When the sign of heat source is negative, the direction of process evolution will reverse. In the range of heat loads $q_{\min} < q < q_{\mathrm{eq}}$ the film regime will be unstable. That is why it becomes possible to initiate such a wave that can change the whole heater into the bubble boiling regime. The calculation methods for values of dangerous disturbances are given in [3–5].

If the experiments are carried out on wires heated by electric current the bubble regime remains stable up to relatively high values of heat loads because in that case the probability of dangerous disturbances (i.e. fraction of zones where the temperature of heater exceeds mean-integral value) is not very high. Absolutely different situation is realized on the film regime branch. The temperature of heater at its ends is close to temperature value of liquid due to the heat removal from the ends into electrodes. That is, under these conditions the strong thermal perturbation of necessary sign is always presents on the heater. This perturbation will initiate the wave of bubble regime as soon as proper conditions are formed, i.e. when the heat flux value decreases below q_{eq}. Because of that fact the experimentally measured value of $q_{\min}$ on electrically heated elements is close to that of q_{eq}. The wave is initiated at different heat flux values depending on the degree of nonuniformity of the temperature field. Namely this fact causes disagreements in data obtained by different investigators [1,7].

Reading the paper under consideration I couldn't understand why the authors used procedure of arranging "hot" ends of heater to measure minimal heat flux values. However, this problem also has its own history. For the first time this technique was introduced in [2] proceeding from the analysis of stability of "heater–boiling liquid" system, namely in order to organize the correct measurements of minimal flux values. To organize "hot" ends the suggestion was done to make a wire (heater) of U-shaped form and to remote its vertical parts from liquid into gas (vapor) atmosphere. Owing to remarkable difference in heat transfer coefficients one part of heater placed in gas atmosphere was heated up to higher temperatures in comparison with another part of heater that was in liquid. This technique first allowed the minimal flow values close to "real" ones to be obtained on current heated wires. Nevertheless, the method possesses some disadvantages. In particular, it is impossible to control the temperature in the hot zone and to control the heat flux in the operating section. When combustible liquids are used, the technique becomes fire hazardous. Moreover, it was found in [6] that conditions of film existence on vertical and horizontal parts significantly differ. This causes film early breaking from the heater in the place of conjunction of its vertical and horizontal parts.

A new technique [7] eliminates the above-mentioned disadvantages. Using this technique it becomes possible to achieve specific heat flux values of the order of $q \sim 5 \times 10^3$–$1.5 \times 10^4\,\mathrm{W\,t/m^2}$ with 1.5 mm heater made of Ni–Cr alloy. These values are at least an order of magnitude lower than those obtained by the authors of paper under consideration. In this case the temperature of "hot" ends was kept in the range of 800–1100 °C.

Data given in the reviewing paper (see Figs. 3–5, 7, 9) point to the fact that authors succeeded in increasing to some extent the stability of film regime. Nevertheless, they couldn't achieve the real values of minimal heat flow. Frankly speaking, the so-called second mechanism of vapor–film collapse, when the wave arises near the potential electrode, doesn't differ from the first mechanism at all. The authors themselves give the experimental data identifying that in that point the minimal temperature is observed because of the heat removal into electrode ends. Namely this circumstance leads to initiation of bubble boiling wave.

There is also another debatable result. I am talking about the measured values of the wave propagation velocities. As follows from the autowave theory of crisis the velocity of heat wave for water is on the order of 1 sm/s. Much the same values were also obtained during our experiments [1]. Therefore, it seems to me the value 1 m/s given by authors is surprising.

The authors compare their experimental results with the data obtained from the model simulations in quoted Ref. [15]. In the mid-1960s–early 1970s this model was of most interest indeed because it was the first model in category of autowave models. Nevertheless, to my mind its usage at present is not worthwhile. The fact is that the above model contains very strong assumptions (in particular, here the heat flux on the film boiling branch sets to zero). That is why the calculation results inevitably possess qualitative character. Recognizing this fact the authors try to modify their model. As a result they come to a case that was thoroughly studied 25 years ago [1]. I would like to emphasize that an analytical results obtained in [1] via simplified model of boiling curve gives the velocity of wave propagation in liquid nitrogen with an accuracy of 0.5% [8].

Numerical modeling of vapor-film collapse of autowave propagation and the influence of boiling curve shape on this process were also studied in the reviewing paper. Unfortunately, the reason why they decided to transform the boiling curve (Fig. 14) in their numerical simulations is not explained here. However, long before we proposed the suggestion [1] that boiling curve may have not N- but Z-shaped form (precisely Z-shaped curve makes possible to realize hydrodynamic mechanism of boiling crisis under the isothermic conditions).

The investigations in [7] were aimed at attempts to prove this suggestion experimentally. At the same time we worked at numerical modeling of autowave process (the results on N-shaped boiling curves are given in [9,10]; the effect of curve shape on autowave velocity was studied in [11]).

In conclusion I would like to note that the authors investigated the peculiarities of nonstationary equation for heat conductivity. This makes much difficult to get the numerical solution. At the same time Ya.B. Zeldovich has proposed a classical substitution of variables which allowed a quasistationary autowave equation to be used. In that case it becomes possible to solve such a problem by easier "tracer" method (in detail see [12]).

References

[1] S.A. Zhukov, V.V. Barelko, A.G. Merzhanov, Wave processes on heat generating surface in pool boiling, Int. J. Heat Mass Transfer 24 (1) (1980) 47–55.

[2] S.A. Kovalev, An investigation of minimum heat fluxes in pool boiling of water, Int. J. Heat Mass Transfer 9 (1966) 1219–1226.

[3] L.A. Zhukova, S.A. Zhukov, E.N. Gelman, Numerical simulation of initiation of autowave transitions from bubble to film boiling regimes by thermal perturbation, Teplophizika, Vysokikh Temperatur 25 (1988) 1025–1028 (in Russian).

[4] L.A. Zhukova, S.A. Zhukov, E.N. Gelman, Initiation of autowave transitions to film boiling regime by local declining of thermal removal, Teplophizika Vysokikh Temperatur 27 (1989) 189–192 (in Russian).

[5] S.A. Zhukov, L.A. Zhukova, S.Yu. Afanasev, Modeling of initiation process for film boiling regime, Thermophys. Aeromech. 9 (4) (2002) 561–583.

[6] S.A. Zhukov, L.F. Bokova, V.V. Barelko, Certain aspects of autowave transitions from nucleate to film boiling regimes with cylindrical heat generating element inclined from a horizontal position, Int. J. Heat Mass Transfer 26 (2) (1981) 269–275.

[7] S.A. Zhukov, V.V. Barelko, Nonuniform steady states of the boiling process in the transition region between the nucleate and film regimes, Int. J. Heat Mass Transfer 26 (8) (1983) 1121–1130.

[8] A. Pavlenko, I. Starodubtseva, Thermal stability and development of film boiling sites, Experiment and modeling, The 2nd International Conference on Heat Transfer and Transport Phenomena in Multiphase Systems KIELCE, Poland, May 1999, pp. 313–322.

[9] L.A. Zhukova, S.A. Zhukov, E.N. Gelman, Study on autowave transitions from bubble to film boiling regimes by different procedures of initiation, International Forum on Heat-Mass Exchange, Minsk, 1988, section 4.

[10] L.A. Zhukova, S.A. Zhukov, K.V. Pribitkova, Numerical simulation of unsteady autowave model of rewetting. Int. Sympos. Phys. Heat Transfer Boiling Condens. Institute for High Temperature, RAS, Russia, 1997.

[11] S.A. Zhukov, N.P. Timchenko, K.G. Shkadinsky, V.I. Phedorov, Effect of source nature on autowave process in system "heating surface–boiling liquid", Heat Transfer—Soviet Research 16 (1) (1984) 67–74.

[12] Ya.B. Zeldovich, et al., Mathematical theory of combustion and explosion, Science, Moscow, 1980, 478 p (in Russian).