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Letter to the Editors

Comments on papers: I.L. Pioro, W. Rosenow, S.S. Doerffer, “Nucleate pool-boiling heat transfer, 1: review of parametric effects of boiling surface”, IJHMT 47 (23) (2004) 5033–5044 and I.L. Pioro, W. Rosenow, S.S. Doerffer, “Nucleate pool-boiling heat transfer, 2: assessment of prediction methods”, IJHMT 47 (23) (2004) 5045–5057

The papers [1,2] present literature survey of the effects of major boiling surface parameters influencing nucleate boiling heat transfer [1] and results of assessment of methods of prediction of nucleate boiling heat transfer coefficient (HTC) [2].

It is shown that boiling surface characteristics have interlinked influence on HTC. The conclusion is made that “there still not enough data available to solve this complex problem” and only separate influences may be considered [1]. According the assessment [2] the Rosenow and Pioro correlations (with different constants and powers for the Prandtl number for different surface-fluid combinations) are more accurate (cryogenic liquids and liquid metals are not taken into consideration). Primary priority attention to boiling surface features is not supported further by involvement of any concrete surface parameter at the stage of correlation.

At the same time, the papers [1,2] lack of consideration of some basic investigations on physics of nucleate boiling [3–10] directly related just to complex understanding of boiling surface effects. It also is left aside built upon these investigations model [11–16] providing adequate description of experimental data on boiling of all classes of liquids without matching different constants and powers to different surface-fluid combinations. An attempt to close in a certain degree these gaps is made below.

Revelation of specific local pulsations of boiling surface temperature [3] qualitatively has deepened understanding of boiling heat transfer phenomenon. This and further investigations [4–7] have led to establishment of fundamental causal relationship between maximum local superheating of boiling surface and overcoming by a nuclei of critical (minimum) radius of curvature at nucleation site. This key feature of boiling heat transfer has formed a basis for development of a model postulating controlling role of thermodynamic conditions at nucleation sites through establishment of average HTC [11–16]. Besides, an effective radius (ER) of nucleation site (equal to aforementioned critical size) has gained the role of main influencing parameter of boiling surface.

In general ER depends from nucleation site geometry, wetting angle, surface tension and prehistory of the process (from a degree of liquid penetration into the site). Among variety of possible cases it deserves of particular interest boiling surface with near-conical recesses with apex angles less than doubled contact wetting angle. In this case ER always is equal to upper radius of the recess [17] and thereby turns to be a single-valued function of site geometry (regardless of listed above other parameters).

This case creates basis for introduction of one-parameter model of boiling surface incorporating unlimited number of identical stable active and potential nucleation sites characterized by invariable level of superheating triggering the growth of the first and following bubbles [11–16]. Corresponding correlation of developed boiling heat transfer involves ER as a single influencing parameter of boiling surface.

Correlation [11–16] describes wide experimental data on boiling of all classes of single-component liquids (water, ethyl alcohol, benzene, biphenyl, refrigerant 12, refrigerant-22, refrigerant-142, helium, hydrogen, neon, nitrogen, carbon monoxide, nitric oxide, ethane, ethylene, sodium, cesium, potassium, mercury and others) on commercial surfaces (mainly rolled stainless steel tubes). Besides, all commercial surfaces are attributed by single constant average value of ER (5 μm) [11].

The results of correlation fully support initial basic assumption about availability at commercial surfaces of numerous nucleation sites (always exceeding the number of operating sites) with ER within narrow limits. Average value of ER is roughly constant in wide range of saturation pressures and heat fluxes, besides ER remains constant through transition of any potential site into operating one or vice-versa.

From the viewpoint of boiling surface influence it also presents of particular interest simultaneous analysis of exclusive experimental studies of boiling of water [8], R-12 and R-22 [9] and sodium [10] reporting together with heat transfer data characteristics of nucleation sites.

“Natural” nucleation sites are studied through immediate optical observation during boiling of water at three massive experimental surfaces with different standard roughness parameters (0.1 μm, 0.125 μm and 0.4 μm) [8]. Despite certain weak stratification of experimental data

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with surface finish classes, boiling curves correspond to known empirical equation for developed boiling of water at atmospheric pressure at commercial surfaces $\alpha = 3 \cdot q^{0.7}$ (α is HTC; q is heat flux) within usual accuracy of measurement of HTC. This fact allows ranking of surfaces [8] among commercial boiling surfaces.

In line with data on HTC, distribution of operating nucleation sites also shows certain weak stratification of experimental data with different surface finish classes. However, fixed radii of overwhelming majority of nucleation sites drastically differ from standard roughness parameters and vary within rather narrow limits (from 3 μm to 10 μm with comparatively great share of small sites). Presented distributions (together with HTC data) allow characterizing of these surfaces by average value of ER accepted earlier for all commercial surfaces (5 μm) [11]. It is noteworthy also insignificant influence on HTC of four-fold change of standard surface roughness parameter.

In contrast with [8] rather big identical stable nucleation sites of experimental boiling surfaces [9,10] have been created artificially (with ER equal to 86 μm in the case of refrigerants [9] and ER equal to 50 μm in the case of sodium [10]). Really these experiments verify predicted by the model [11–16] boiling heat transfer enhancement law: $\alpha \sim \rho_0^{0.4}$ (ρ_0 is ER). Enhancement factor over commercial surface achieves 3.1 at the surface [9] and 2.5 at the surface [10] in full accordance to this law.

It may be noted also that aforementioned experimental boiling surfaces have been made from different materials (cooper [8], steel 10 [9], stainless steel and nickel [10]).

However, despite of significant differences between physical parameters of boiling substances, thermal conductivities, thicknesses and standard roughness parameters of boiling surfaces, correlation [11–16] quite satisfactorily describes experimental data [8–10] using ER as a single influencing parameter of boiling surface.

At the same time, together with aforementioned one-parameter idealization of boiling surface, the approach [11–16] envisages feasibility of much more complex combinations of characteristic sizes and distributions of the active and potential sites. These combinations allow interpretation of diversity of boiling heat transfer curves that is observed in the part of experiments (mainly at surfaces with recesses with apex angles more than doubled contact wetting angle when ER stops to be single-valued function of site geometry especially characteristic for cryogenic liquids).

For instance, the phenomenon of boiling hysteresis may be interpreted by two-parameter model of boiling surface reflecting dependence of ER from liquid penetration into a site [13–16]. In particular, two-parameter model allows description of specific family of heat transfer curves obtained in experiments on boiling of helium [18].

It should also be noted that in the framework [11–16] the cases with multi-factor dependence of ER still remain only at the stage of qualitative interpretation.

Finally, reasoning from the all above, general conclusion should be made that there is no way to develop adequate non-dimensional correlation of boiling heat transfer data without involvement of characteristic linear size of nucleation sites.

As a consequence even correlations assessed in [1,2] as more accurate fit to boiling HTC data only excluding from consideration entire classes of liquids and using different constants and powers for different surface–liquid combinations.

Against this background correlation of wide experimental data on developed boiling of all classes of liquids at commercial surfaces using invariable constants and powers and single value of ER demonstrates adequate representation by the model [4,11–16] of basic features of the process, first of all, of the role of boiling surface.

Omission of the model really putting in the forefront-controlling role of boiling surface is natural consequence of difficulties on the way to radical revision of initially fixed in this field of convection heat transfer approaches. Identified in [4,11–16] fundamental boiling heat transfer problem—establishment of interrelations between composition and characteristics of nucleation sites and diversity of boiling heat transfer curves—so far remains imperfectly understood. That is why only insignificant part of experimental investigations of boiling heat transfer includes treatment of nucleation sites.

Summarizing the foregoing we can say that the state of art in the field of boiling heat transfer deserves much more thorough consideration. Hopefully, in this way proper aiming will be achieved of further research of this important and complex problem.

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