SOME ASPECTS OF RESEARCH OF BOILING ON THE SURFACES WITH POROUS COATINGS AND STRUCTURES

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Abstract

Some aspects of a modern state of research on the heat transfer at boiling on surfaces *with* porous coatings and structures are considered. Influence of characteristics of porous structures on the 1) value of a temperature pressure of the beginning of boiling; 2) intensity of the *heat* transfer at boiling; 3) critical densities of the *heat fluxs* are analyzed.

KEYWORDS

capillary structures, heat pipes, thermosyphons, structural characteristics, fibrous and powder materials

INTRODUCTION

Phase transformations of liquids (including boiling) on the technical surfaces with porous coatings and structures represent now significant interest for developers of modern *heat-exchange equipment*. Presence of porous materials on the *heat-exchange* surfaces changes the *heat exchange* mechanisms, typical for the smooth surfaces, allowing to intensify the *heat exchange* at phase transformations, and to increase the critical (limiting) densities of the *heat fluxs, as well*. The last is essential for economizing materials and resources at designing and exploitation of the heat-stressed equipment, in particular, devices of refrigeration technique (technical equipment) and air-conditioning. It is doubtless, that reliable test results at widely varied values of defining parameters of such materials are necessary for successful application in technique (technical equipment).

THE RESULTS OF RESEARCH AND DISCUSSION

Systematized (basically) results are obtained in the Institute for problems of materials science NAS of Ukraine for *metal-fiber porous* structures (MFPS, PS) - *high-porous* and, accordingly, for high-perme-able materials possessing a number of *technical and operational advantages* in comparison with other similar materials. Such porous materials, as powder, cellular, *metal-foamy porous*, mesh, etc also exist. It is interesting to compare the basic characteristics of various types of porous materials aimed at analysis of their possible *application in the future*. For comparison of the listed structures it is offered to consider their application in the following practically important modes of *heat-exchange, typical* for *porous heat-exchangers*, particularly, for *heat pipes (HP) and thermosyphons*: 1) a mode of boiling in conditions of free movement of liquids ("liquid fullness " or "flooding" of a porous surface); 2) evaporation and boiling in conditions of "capillary transport » of liquids (a mode typical for *heat pipes*); 3) limiting (critical) *heat fluxs.*
Let's note some results obtained in IPMS for MFPS.

1. Influence of structural characteristics on *thermophysical* processes at phase transformations of liquids (in particular, at boiling). For MFPS it is established, that increase in porosity up to the highest possible values ($\cong$ 95 %) reduces a little the intensity of *heat transfer* at boiling, both at a gulf, and at capillary transport of a liquid. Use of moderate-*porous* MFPS (porosity Θ =40-50 %) allows to increase ten times intensity of *heat transfer* in comparison with technically smooth surfaces. At boiling of low-tempera-ture-*boiling* liquids (ethers, freons, spirits) the *heat-efficiency* factor α can increase 12-13 times. Increase in average and maximal porous size (that can be achieved at identical porosity by varying the length and diameter of *fibers-single particles*) increase the intensity of *heat transfer*, however the most important factor here is heat conductivity of a porous material λ. Influence of the pores size distribution and the contact phenomena, as well, are studied insufficiently. Hysteresis of the boiling curves, typical for powder structures, is absent on the surfaces with MFPS. Our examination has shown, that processes of evaporation and boiling in a mode of capillary transport coexist (while, not in the full range of density of *heat fluxs*).

2. Influence of thermophysical characteristics of structures. According to the suggested in IPMS model of influence of characteristics of MFPS on the mechanism of phase transformation of a liquid (evaporation), increase in heat conductivity of MFPS (both frame (skeletal), and effective (integrated), taking into account heat conductivity of both a porous material, and a liquid) results in significant increase of intensity of *heat transfer*. Heat conductivity of porous coatings and structures positively influences on α both in the modes of capillary transport of a liquid, and in the critical modes of *heat transfer* at a gulf. For the last case it is important to use *high-porous* structures (Θ > 80-90 %), produced from the metals (alloys) *with high- heat conductivity, such as* copper, well attached to a heating surface by sintering. At such conditions the first critical density of a *heat flux* at boiling can increase 3-4 times in comparison with the values typical for smooth surfaces.

3. Influence of geometrical characteristics of the structures. These involve thickness of the structure (coating) and the sizes of initial monoparticles (fibers). The fibers size has an influence, firstly, on structural and *thermophysical param*eters of MFCS and, secondly, on the *heat transfer,* while the thickness of structure has significant influence on the intensity of the *heat exchange*. At the optimum thickness of MFPS equal to 0,5-1,0 mm for various MFPS the highest values of factors of *heat-efficiency* α and of critical densities of heat fluxs q_{crit} are observed. The effect of presence of optimum thickness of porous structures is explained by suggested by us in [3] physical models of processes, in particular, the minimal sum of heat resistance of heat exchange (consisting of a number of particular heat resistances depending on various factors). Influence of thickness of MFPS on intensity of heat exchange is not investigated yet for different materials (steel, nichrom, aluminium, etc.), and also at boiling of various liquids. Considering the other above mentioned types of porous materials, it is necessary to note, that systematized thermophysical results for these materials are similar to ours, are almost absent. Only few results are known, however, without preliminary research of structural and thermophysical characteristics. The last concerns both domestic, and foreign works in the given area. The explanation can consist both in complexity of such investigation, and in absence of correct statement of the given problems (tasks). Nevertheless, the expediency and necessity of carrying out of the systematic research exists. This is necessary first of all for management of characteristics of porous structures and materials at various heat-exchange processes. Studying of influence of defining characteristics of porous coatings and structures is also extremely necessary for creation of the conventional theory of heat exchange at phase transformations (in particular, for boiling - the widespread heat process in many productions). The last is actual and for increase of energy-saving and resources-economy characteristics of the equipment.

To our opinion, special attention should be given to the following problems of heat transfer in considered subjects. First of all, these are complex research of influence of defining characteristics of porous structures (thickness, heat conductivity, porosity, pores size distribution). Separate results cannot be a basis for application of high-performance porous structures in technique (technical equipment). Investigation of structures, perspective for heat pipes and liquid-wick thermosyphons, first of all, of metal fiber-porous and *metal foamy-porous* are of great importance. The last are characterized by a small amount of deadlock and semi-open pores, that provides high transport abilities of PS. The next are the structures produced by the methods of gas-thermal spray-coating. Metal powder PS, now in use, have a plenty of deadlock pores, that results in the undesirable phenomena for operation of HP the heat hysteresis appearing at periodic increasing and decreasing of brought power. A separate question is comparison of characteristics of gas evolution in MFHP and MPHP. Occurrence of PS of new types, in particular, of the combined structures (last development IPMS NAS of Ukraine), is also possible.

Briefly note the basic aspects of perspective, to our opinion, researches.

1. Influence of characteristics of PS on temperature pressures of the beginning of boiling of liquids on porous surfaces. Coating of the carrying surface with PS essentially reduces $\Delta T_{нк}$. Explanation of this effect is not the purpose of the given work, however it is obvious, that presence of ПС changes parameters of near-wall (boundary) layer, facilitating process of activation of potential steam germs. As our research has shown [3], increase in heat conductivity of PS reduces $\Delta T_{нк}$, that, to our opinion is due to the better heating of the near-wall layer. However, with growth of λ_{to} porosity of PS and the maximal size of pores decreases. Accordingly, the appearance of a steam phase becomes more difficult, and temperature pressures of the beginning of boiling increase $\Delta T_{нк}$. Our research did not allowe to establish essential distinctions in sizes $\Delta T_{нк}$ for conditions of "flooding " and «capillary transport». Existing differences are small and within the accuracy of experiment. Influence of the pressure and nature of liquid on the $\Delta T_{нк}$ is the subject to the further research. In works of authors [9] the problem was investigated a little, however continuation of experiments is necessary.

2. Mode of the advanced boiling. The majority of available works is devoted to this mode. Already in work [8] essential influence of heat conductivity PS on intensity of heat exchange has been shown. Unfortunately, not all researchers studying boiling on surfaces with PS, possess a reliable information on characteristics of researched structures and coatings. It is necessary to note, that absence of reliable formulas for precomputations of defining characteristics of PS does not allow to generalize the results of research of boiling. To our opinion, the future research will be directed on the following topics: 1) determination of an optimum thickness of PS depending on heat conductivity PS, nature of a liquid, pressure; 2) determination of influence of the quality of contact of PS with a carrying surface on α; 3) determination of influence of pressure (in particular, at $P< P_{атм}$) on α. The special attention should be given to techniques of generalization of the results obtained. In our works it is offered to generalize the results as simple *semi-empirical* formulas as

$$\alpha = c \cdot q^{n} \cdot \delta_{пс}^{m} \cdot \lambda_{пс}^{p} \cdot \Theta_{пс}^{b} \cdot D_{эф}^{d} \cdot A, \tag{1}$$

where q - the density of a heat flow calculated by the known formulas for boiling on smooth technical surfaces; $\delta_{пс}$, $\lambda_{пс}$,$\Theta_{пс}$, $D_{эф}$ - the dimensionless coefficients numerically equal to the values, accordingly, of thickness, heat conductivity, porosity and effective (average) diameter of pores of PS; A - complex of characteristics and the parameters, taking into account influence of a sort of a liquid and pressure;
n, m, p, b, d - empirical exponents.

Attempts of generalization of experimental results as criterion dependences at a present stage of research, from our point of view, have debatable character.

3. Limiting (critical) heat fluxs at boiling on the surfaces with PS. There is a lack of works devoted to the given problem. Only in the works [4, 6] the attempts of modeling approaches to an explanation 2 … 4-fold increase $q_{кр1}$ are undertaken in comparison with smooth technical surfaces. In our works [10] the equations similar to (1) were received, however the further research is necessary. Examination of influence of all above factors on $q_{кр1}$ are expedient.

Except for ascertaining the fact about the lack of experimental data in the field of investigation of influence of PS on intensity of heat exchange in zones of a heat-conducting path (condensation), it is necessary to mention also debatable until recently question on existence of actually boiling on surfaces with PS in a mode of capillary transport of a liquid. Our experiments and, first of all, visual examination allow to state, that boiling on rather "thin" PS ($\delta_{пс} < 0{,}5$ mm) exist and is distinctly observed, first of all, - in large pores. However, the typical process of growth and destruction of bubbles exists only in rather small ranges of density of a thermal stream. When q growth, landing of meniscuses of a liquid into the pores of PS occurs, and occurrence of bubbles is not observed. We have also established the fact that with increase of q, the temperature gradient along the length of a carrying surface occurs. Calculation of the coefficients of *heat-efficiency* in a zone of heating in a mode of capillary transport, typical for the work of HP, thus, becomes more complicated (especially at rather extended zones). This fact, from our point of view, needs additional examination, in particular, for various liquids and of wetting conditions "liquid - surface".

THE CONCLUSION

Some aspects and problems of investigation of processes and parameters of boiling (steam formation) on technical surfaces with the porous structures, in the conditions typical for heat pipes and thermosyphons are briefly considered. The considered questions allow to pay attention of researchers and developers to the problems of heat transfer, poorly investigated till now, however actual for technical progress as in the field of an intensification of heat transfer, so for creation highly effective heat-exchange devices. The systematic results obtained in IPMS (models, formulas, nomograms) allow to create the theory of heat exchange at phase transformations of liquids on the surfaces with the porous non-uniform structures possessing certain distribution of the pores in size. These results were obtained mainly for water and acetone. Their development assumes investigation in the future with application of some other liquids, important for technique (technical equipment), in particular-low-boiling (ethers, freon, ammonia, spirits, etc.) and middle-tempereture liquids (glycols, sulfur and new middle-tempereture liquids-heat-carriers developed recently in Ukraine). Examination of the contact conditions, beginning of boiling, influence of gravitation (that is important for the space equipment) and other factors, heat exchange at condensation on porous surfaces will be subjected to examination. Investigation of the pressure influence on the heat exchange at the above conditions are important, particularly, at pressure, below atmospheric. Till now, this question is not absolutely clear.

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