Influence of capillary porous structures on intensification of the heat exchange process associated with liquids boiling

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The problem of heat exchange intensification is very urgent for boiling, what is confirmed by numerous researches in this field in CIS countries and abroad. One of the most perspective ways of its solution includes application of a capillary porous coating on the heating surface, where study and research of heat and mass transfer is of undeniable interest.

In a number of engineering branches operation modes of evaporators are characterized by extremely low thermal heads and, respectively, by very low heat flux densities. This refers to condensers-evaporators of air separators, to evaporators operated in the refrigerating industry, etc. Thermal head increase in the evaporators, which work as a part of refrigerating machines, is due to recession of energy indicators of a refrigerating unit as a whole. For example, reduction of temperature difference in cascade units from 5-7°C to 2-3°C results in reduction of power inputs with the same heat exchange surface by 10-15% [1]. However, heat flux to a cooling agent at these low temperature heads is transferred under conditions of undeveloped boiling, and therefore, heat transfer coefficient is small. This leads to very big dimensions of heat exchangers and their unsatisfactory weight characteristics.

Usually, mass of shell-and-tube Freon evaporators amounts 30-40% of metal mass in a whole refrigerating machine. Striving for reduction of overall dimensions of evaporators and metal consumption (especially expensive non-ferrous metals) for their manufacture made scientists seek opportunities for heat exchange intensification during boiling and methods for achieving the sustainable developed boiling at rather small temperature heads.

The following methods of heat exchange coefficient may be indicated (α):

1. Artificial increase of heat-release surface roughness (α increases by 1.5-2 times);
2. Finning of the heat-release surface (α increases by 2.5 times). Finning also makes it possible to reduce the mass of units and their dimensions by 1.5-2 times;
3. Surface coating with poorly wetted thin films or meshes (α increases by 5-8 times); however, drawbacks of these coatings include their low mechanical strength and poor contact with the heating surface;
4. Applications of porous metal coatings (α increases by 4-10 times and over).

The latter is the most effective and reliable method for heat exchange process intensification during boiling.

There are different methods of porous coatings application onto heat-release surfaces. Powder metallurgy methods are widely used. Articles with the preset porosity, required mechanical and thermophysical properties may be obtained by means of baking metal powders consisting of spherical particles. The powder, applied to the wall, is premixed with the filling paste (air-entraining admixture), which evaporates during baking. This results in formation of a porous layer with the extensive system of interconnecting capillary channels, through which vapour is released and the porous structure is replenished with the liquid, which flows here by the action of surface tension forces.

Properties of the porous structure are to be determined by the material used for making the powder, and they depend on sizes of particles, their shape and conditions of baking. Powders are made of various metals and alloys (copper, nickel, aluminium, iron, titanium, tungsten, molybdenum, chrome and nickel alloys, bronze).

There are some methods for obtaining the powders:

mechanical – chip or wire crushing;

melted metal sputtering – a liquid metal jet is delivered to a rotating disk, and centrifugal forces sputter metal drops (plasma cutters may be used for metal sputtering - plasma deposition).

Various physical and chemical methods are also used: restoration of metals from oxides and salts, hydrolysis of aqueous solutions, etc.

Construction of the porous structure is most vividly presented on the photos of the porous body fracture and microsections, which are shown in fig.1.

The number of existing evaporation centres sharply rises on capillary porous coatings during boiling, and rather favourable conditions are provided for generation and growth of vapour bubbles. This is due to high thermal conduction, reduction of liquid surges, capillary replenishment, the quantity of pores.

a b

Fig.1. Photos of porous layer (a) and microsection (b), bronze.

The coating of heat exchange surfaces of evaporators, vapour generators, heat pipes, etc. with capillary porous structures makes it possible to intensify heat exchange of the boiling process, to rationally organize liquid supply to the heat exchange surface and to provide uniform distribution of temperatures, Being so, heat release coefficients during bubble boiling increase by 5-10 times, and critical densities for heat flux increase by 2-4 times, as compared with smooth surfaces.

The complexity of boiling mechanism studying is conditioned by the fact that the vapour formation process takes place inside the porous structure, and the geometrical configuration of the porous layer frame is casual. Boiling characteristics, set up as a result of observations of the external surfaces (for example, frequency of opening bubbles, distribution of the existing pores on the surface), provide rather limited information. The number of experimental works directly dedicated to the vapour formation mechanism in porous bodies is low. However, these experimental works make it possible to reveal certain regularities, which are typical for the vapour formation process on porous coatings:

1. The vapour formation zone is located inside the fuse near the heated surface.
2. Position of vapour zones borders is notable for its stability.
3. Frequency and amplitude of temperature pulsation is much smaller than during bubble boiling on the smooth surface.

So, capillary porous coatings are effective means of heat exchange intensification during bubble boiling. In order to introduce this method of heat exchange intensification true models of the boiling process shall be developed on the surface with the capillary porous coating. A fairly large number of physical heat exchange models have been offered by the present time. Rather approximate assumptions were made during development of these models, which led to discrepant results. In avoidance of these discrepancies, the simplest model of the capillary porous structure is used – the system of cylindrical capillaries having the ideal connection. Its application makes it possible to describe the whole boiling curve, including the crisis (the Nukiyama curve). Dependence q on Δt is called the boiling curve. Heat exchange modes during vapour formation in a wide interval of Δt changing can easily be illustrated with the aid of the boiling curve.

Let us consider the scheme of diagrammatic arrangement of boiling curves on the smooth surface and on the surface with the porous coating (fig. 2).

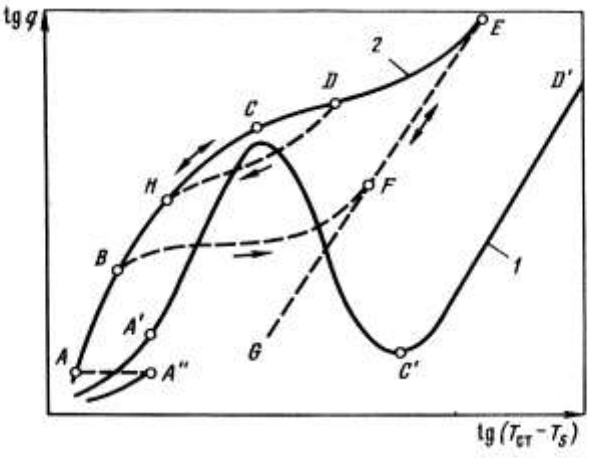

Fig.2. Generalized boiling curves

1- on the smooth surface;

2- on the surface with the capillary porous coating.

Liquid is boiled over on the porous surface at heat fluxes (point A), which are much smaller than on the smooth surface (point A'). In case of a coating with high permeability and high thermal conductivity coefficient the *ABCDE* boiling curve takes place. It lies higher than the boiling curve on the smooth surface. Usually, three sections may be pointed out on the *ABCDE* curve. In the beginning sharp growth of q is observed, when temperature head *(ABC)* increases, then the slope decreases, the curve becomes almost horizontal (CD), and, finally, at high temperature heads the slope increases a bit.

If the porous structure is such, that vapour outflow is hindered, we will have to move along the line *EFG* or *DH*, when thermal loading is reduced. The observed hysteresis is connected with the well-known capillary hysteresis phenomenon. The hindered penetration of liquid from small pores to big ones is one of the reasons of capillary hysteresis occurrence. Heat transfer coefficients on the *EFG* line are defined by thermal resistance of the porous coating. This is the mode of bubble boiling with a vapour film inside the porous layer. This heat transfer coefficient is defined by thermal resistance of the porous structure $\alpha = {}^{\lambda_{CK}}\!/_{\delta}$.

If the permeability of the porous coating is low, transfer to the mode with a vapour film is possible with heat fluxes, which are much lower than q_{KP1}, for example, on *BF* line.

In case of using the finely porous coatings boiling can be started at overheating (point *A''*), much higher, than in case of the smooth surface, due to obstructed boiling of the liquid in small pores.

It should be pointed out that mutual position of curves *1* and *2* is approximate. Depending on thickness of the coating, permeability and thermal conductivity curve 2 will retain its configuration, but it can be shifted by tens and even hundreds of degrees.

On the basis of the undertaken analysis the following conclusions can be made:

1. Application of the capillary porous coating onto the heating surface allows in many cases to sufficiently reduce overheating and heat fluxes of the boiling beginning in a big volume, to stabilize the boiling process and thereby to increase the heat exchange intensity.

2. The heat exchange intensity considerably depends on a number of factors: physical properties of liquid, coating type and its parameters (thickness, porosity, radius of pores, orientation of capillary channels, material of the coating, the thermal contact between particles and the surface, etc.), heat flux density and temperature head.

3. The porous coatings, which are obtained by baking the metal particles, are most perspective. The heat flux supplied to the vapour formation centre considerably increases in these structures by means of extra heat flows on the highly heat conducting frame of the coating by resulting in considerable (by 10 times) heat exchange intensification. Advantages of these coatings should include high mechanical properties, workability, which allows to steadily reproduce specifications of the porous structure, what is important for practical use.

Literature:

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