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Sintered Mesh Layers for the Production of Efficient Phase – Change Heat Exchangers

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Abstract. The paper focuses on the production and thermal performance of metal meshed heaters. The sintering process of sample production is described and the boiling heat transfer performance of multilayer meshed surfaces is discussed. The experimental results of nucleate boiling are compared with selected models and correlations available in literature.

Introduction

Metal meshes are commonly used in the industry (e.g. as sieves). They are cheap and offered in a large variety of sizes. The number of materials from which they are made is also wide. The application of meshes can be favourable to increase heat fluxes dissipated from heaters during pool boiling on horizontal and vertical surfaces, on tubes or in heat pipes.

Smirnov et al. [1] considered boiling of water and ethanol on a horizontally located heater that was covered with copper and brass meshes. These meshes were attached mechanically. Generally, heat flux was found to be independent of the structure height (namely, the number of layers) and weakly dependent on the structural material from which it was made. Asakavičjus et al. [2] testes the boiling of R-113, ethanol and water inside a heat pipe with an internal coating composed of two, eight and twelve meshes made of copper and stainless steel. They were mechanically attached to the heating surface. It was found that mesh layers improve boiling heat transfer performance comparing to the smooth surface, but this effect diminished with the increase of the heat flux value. The heat transfer coefficient for water was 1.8 – 3.5 times higher than for ethanol and R-113 with the same other process parameters. Franco et al. [3] presented results of boiling heat transfer of the R141b dielectric refrigerant on meshed surfaces. Stainless steel, aluminum, copper and brass meshes were used for the experiments. The meshes were clamped to the heater in a special mounting which enabled the control of the channels in the screen. It was proven that if meshes of different aperture are used together, the most significant enhancement is obtained for coatings of finer meshes at the base on the heater and coarser meshes higher. Li et al. [4] considered water boiling on meshes heaters. The microstructures were produced using sintering at the temperature of 1030^{o}C in the gas mixture of nitrogen and hydrogen. Up to nine meshes were used for the production of one sample layer. It was found out that the proper contact between the elements results in better heat transfer conditions and that all the meshed surfaces enhanced boiling in comparison with the smooth surface without such covering.

Material and method

The heating surfaces can be covered with meshes and, as a consequence, boiling heat transfer can typically be enhanced. However, there is a problem with the proper attachment of the mesh to the surface (and to other meshes if multilayer structures are to be used). Mechanical clamping is sometimes used, however, the clamps themselves may hamper the heat transfer. The application of epoxy or glues may not be effective either, due to the increased thermal resistance (low thermal conductivity of the joining material). Thus, sintering is the best technology for the production of meshed surfaces. The process occurs in the reduction of temperature to prevent oxidation of materials at the temperature which is slightly lower than the melting temperature. As a result, the materials are joined together to form one element and strong bonds are created between the mesh and the base surface (and the meshes with one another for the multilayer structures). The samples are sintered in the atmosphere of hydrogen and nitrogen and remain in this oxygen-free atmosphere until being cooled to ambient temperature.

Fig. 1a presents the sample consisting of a single copper mesh sintered onto a copper disc. Here, the wires are simply molten into the base surface. The problem, however, is the proper production of multilayer microstructures. Fig. 1b presents the SEM image of a multi-mesh microstructure. The wires in contact with the heater surface (top right-hand side of the picture below) are nearly molten into the surface. The majority of the wires in this microstructure of 4 layers of mesh are also in a very good contact, which minimises the thermal resistance and, thus, the structure is highly efficient for a heat transfer. It needs to be noted, however, that some elements underwent destruction (a crack is visible along the long wire at the bottom of Fig. 1b). This may be caused by too much pressing of the sample during sintering (the sample was located in the mechanical clamp). Such defects of the structure could result in the increased thermal resistance and reduced heat flux dissipated from the heater and, consequently, should be avoided.

a) b)

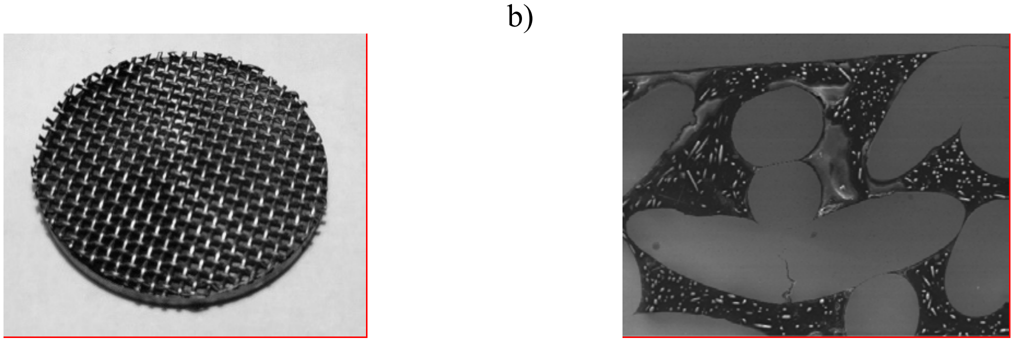

Fig. 1. Copper meshed surfaces on the copper base: a) photo of the single layer sample, b) SEM image of the cross – section of the multilayer sample

Results and discussion

The application of metal meshes on smooth surfaces can result in a significant increase in heat flux (q) dissipated from heat exchangers. Thus, such highly efficient heat exchangers can be smaller or transfer much higher heat loads at the same temperature differences (θ). Moreover, sintering produces stable bonds and such surfaces can be used in devices that undergo vibrations.

Fig. 2 shows the enhancement ratio, which is the ratio of heat flux transferred from the surface covered with the meshes (one to three) to the heat flux from the smooth surface. The data of heat flux changes with temperature difference was adopted from the paper by the co-author [5]. Three different values of temperature difference have been taken into consideration. As can be seen in Fig. 2, the use of a mesh layer can considerably improve heat transfer. Heat flux may be almost ten times higher than for the smooth surface without any additional covering. A typical phenomenon is that this highest enhancement occurs at lowest temperature differences. It needs to be noted that the application of more mesh layers favourably influences heat transfer. This may be linked with the increased surface area and higher density of active nucleation sites.

The description of physical phenomena which occur on the heater surface is another crucial problem for the proper design of heat exchangers. Models and correlations of boiling available in literature can provide equations for heat flux, but they are often inaccurate. Fig. 3 presents the comparison of the experimental data for a meshed surface with selected correlations from literature, namely those developed by Smirnov et al. [1, 6, 7], Nishikava et al. [8] as well as Xin and Chao [9]. Performing calculations according to the model presented by Xin and Chao was possible after introducing certain modifications as for the geometrical parameters used in their formulae. Namely, the width of a single cell had to be considered as the total of wire diameter and aperture and the width of the tunnel as aperture. The results of the calculations have been presented below for distilled water as the boiling liquid.

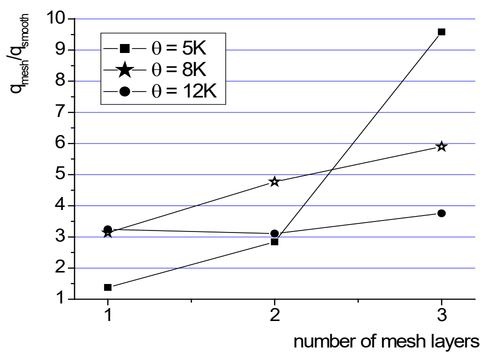

Fig. 2. Enhancement ratio for ethyl alcohol boiling

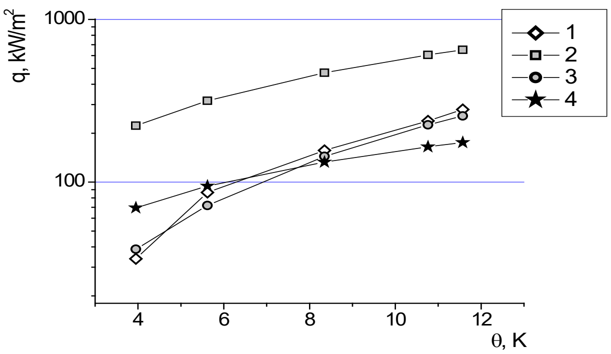

Fig. 3. Comparison of experimental data with the models; 1 - experimental results, 2 - calculation results according to Nishikava et al. correlation, 3 - calculation results according to Xin and Chao correlation, 4 - calculation results according to Smirnov et al. correlation

The model by Xin and Chao with modifications was the most accurate in this case, while the least effective – model by Nishikava et al., which is the simplest and does not consider many parameters of the microstructure.

Other surface treatment techniques are also possible and may include laser treatment of the surface as discussed by the co-author in [10, 11] and other surface treatment methods [12].

Conclusions

Sintered metal meshes can be highly effective in dissipating significant heat fluxes (even ten times higher than for the smooth surface) during pool boiling (although treated surfaces can also be very efficient in flow boiling [13]). The sintering production technology enables creating durable and strong bonds, which means that such heat exchangers can be used in vehicles or mechanical devices that undergo e.g. vibrations [14, 15]. Advanced materials science methods [16, 17], especially the image analysis of microstructures [18-21] and fuzzy assessment of uncertainty [22] seem to be useful in further investigations due to their previous usefulness in similar application in the electro-spark deposition and laser treatment of coatings [23].

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