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POSSIBILITY OF USING MICROSTRUCTURES IN BUILDINGS' VENTILATION AND HEATING SYSTEMS

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Abstract

The paper discusses the issue of using microstructures as the heat enhancement technique that can be applied in ventilation and heating systems. The possibilities of usage are given and the experimental test results are presented. They prove that the application of microstructures may significantly improve the heat flux value exchanged during boiling of distilled water.

Keywords:

Heat transfer enhancement;
Meshes;
Microstructures.

1. Introduction

Highly efficient heating systems and heat recovery devices in ventilation units are more and more common in buildings. The design of such elements may include the application of specially designed microstructures. They cover the surfaces of heat exchangers are improve heat transfer conditions. They extend the surface area, which leads to elevated heat fluxes being exchanged at given conditions. However, in the case of phase – change, namely boiling, they also increase the density of active nucleation sites (locations where vapour bubbles are grown). As a result, heat transfer is enhanced in relation to the smooth surface without any coating. The paper discusses the usage of metal microstructures for the design of heating systems and heat recovery units in ventilation. It focuses on the advantages of the application of meshed surfaces due to the fact that they are cheap and commonly available on the market.

2. Microstructures in heating and ventilation

There are many kinds of microstructures that can be used to enhance heat transfer for example wire - meshes, fine metallic fibres, powders, pin – fins, grooves on the surface and other. They are applied to smooth surfaces with various methods such as mechanical means, sintering, thermal spraying and etc. Figure 1 presents example microstructures: pin – fins and wire - meshes.

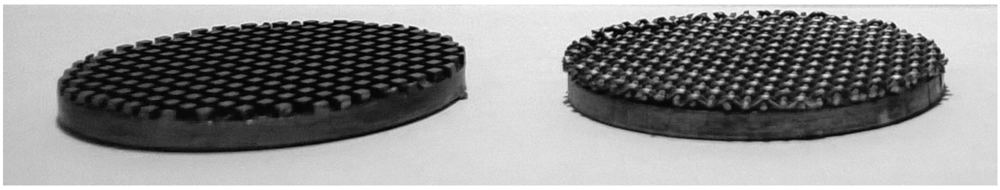

Fig. 1: Pin – fins (on the left) and wire – meshes (on the right) on copper discs of 3 cm diameter.

These microstructures typically improve heat transfer and, thus, their use in heat exchangers is favourable. They can increase the exchanged heat flux at the same temperature difference, or enable to produce smaller and more compact heat exchangers. Marto et al. [1] investigated R-113 boiling on copper tubes of the internal diameter 21.2 – 25.3 mm covered with commercial microstructures of different geometrical parameters. The enhancement produced with these structures expressed as the ratio of the heat transfer coefficient for the microstructures and the heat transfer coefficient for the smooth surface was 2 – 9. Consequently, much higher heat fluxes could be exchanged. Mertz et al. [2] presented test results of propane boiling on steel tubes covered with stainless steel thermally sprayed coatings of different porosity and height. The heat transfer coefficient was 2.5 – 3 times higher than for the smooth surface, which also proves a positive effect of the application of microstructures.

Microstructural coatings may find applications in many industries. Gottzmann et al. [3] investigated the use of a commercial metallic covering of 50 ÷ 65 % porosity. Basing on the experimental results of air conditioning evaporators with ammonia as the working fluid, it was concluded that it might be possible to elevate the heat flux value twice and at the same time reducing the temperature difference by about 1 K. The designed absorption ammonia chiller with the microstructure enabled to decrease the length of the cooling pipes 6 – 7.5 times in comparison to conventional systems.

The enhanced heat exchangers lower the overall mass of the devices and, consequently, the transportation and installation costs. What is more, the amount of working fluids is limited, which has favourable impact on the environment. For refrigeration and air conditioning applications channels with internal microfins are used, which results in small increase in pressure loss as compared to smooth pipes [4].

Porous microstructures are typically used as the internal coating of heat pipes, which are part of very efficient heat exchangers [5, 6]. In one end of a heat pipe (Fig. 2) vaporisation occurs and heat is dissipated from the cooled element with the change of phase. While on the other end heat is released to the surroundings and condensation takes place inside. The condensed fluid flows back to the evaporation part and the cycle continues. Such a heat exchanger is very reliable since there are no moving parts in it. The temperature difference along the heat pipe is small, which is the additional advantage. Consequently, it is widely used in the broad temperature range (from cryogenics to temperatures reaching 1600 ^{o}C).

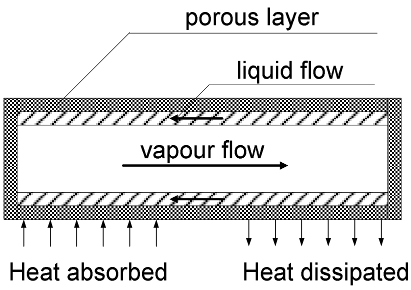

Fig. 2: Schematic of a heat pipe.

Due to a number of favourable features heat pipes (with different microstructures covering the internal side of them) can be used in heating systems. If, for example, a waste heat source is available heat can be efficiently transported to different rooms using the heat pipe concept as presented in Fig. 3.

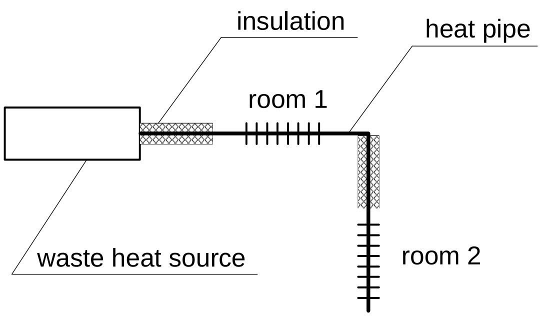

Fig. 3: Heating system constructed with heat pipes [5].

Abd El – Baky et al. [7] investigated a heat exchanger consisting of heat pipes, used to recuperate heat in air conditioning systems. The two ducts are present in this unit. One transports fresh air from the outside of temperature 32 – 40 ^{o}C and the other one with the cooled air of constant temperature 26 ^{o}C. The ducts are parallel to each other and joined with the heat pipe heat exchanger. Ratios of mass flow rate between the return and the fresh air were given as 1, 1.5, and 2.3. The results proved that effectiveness and heat transfer for evaporator and condenser sections are increased to about 48 %, when the fresh air temperature is increased to 40 ^{o}C. The rise in the ratio of the return to fresh air mass flow rate by about two times results in an increase in the temperature change of fresh air by ca. 20 % and effectiveness of the heat exchanger by ca. 26 %. Figure 4 presents the schematic of the studied heat pipe heat exchanger located in the ventilation ducts.

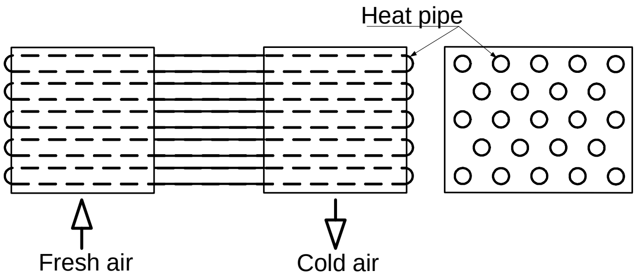

Fig. 4: Schematic of the heat pipe heat exchanger [7].

3. Test results and analysis

As mentioned earlier heat pipes contain porous microstructures for example wire meshes and they have been the focus of attention of researchers. Asakavičjus et al. [8] experimentally tested R-113, ethanol and water boiling heat transfer inside a heat pipe with the internal coating consisting of 2, 8 and 12 mesh layers. The microstructures were made of copper and stainless steel. It was reported that meshes improved heat transfer in relation to the smooth surface (without any microstructure), but this effect diminished with increasing heat flux. The heat transfer coefficient for water proved to be 1.8 – 3.5 times higher than for ethanol and R-113 with the same other parameters. It is also worth noting that the copper mesh produced 1.3 times higher heat transfer coefficient than the stainless steel structure.

The impact of the application of meshes will be considered for the copper mesh that covers a copper heater. Boiling of distilled water takes place on this heater while temperature sensors (K-type thermocouples) are used for data acquisition. During measurements heat flux (q) and wall superheat (θ) defined as a difference between the surface and saturation temperatures are calculated. The mesh of wire diameter 1.5 mm and aperture 0.32 mm (distance between the wires) of volumetric porosity of 82 % has been analysed. The results expressed as boiling curves both for the meshed and smooth surface have been given below in Fig. 5, as presented by the author in [9].

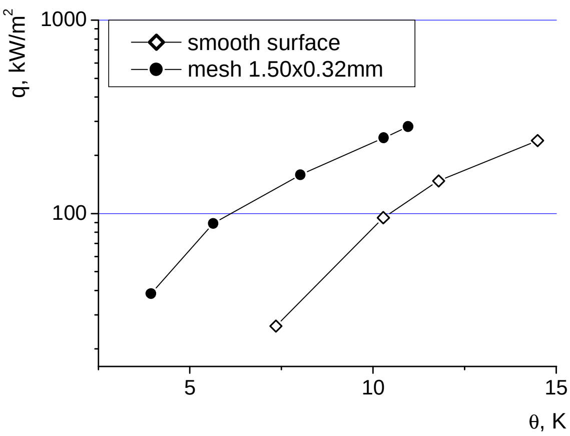

Fig. 5: Boiling curves of meshed and smooth surfaces.

It is clearly visible that the application of the mesh improves heat transfer – the value of its heat flux is always higher than for the surface without any coating. Thus, it is possible to exchange much higher heat fluxes than for the smooth surface. The improvement has been presented as the ratio of the heat flux dissipated from the meshed heater (q_{meshed}) to the smooth surface test results (q_{smooth}) – data from Fig. 5, and shown in Fig. 6 for clarity (data fitting with the second order polynomial has been used).

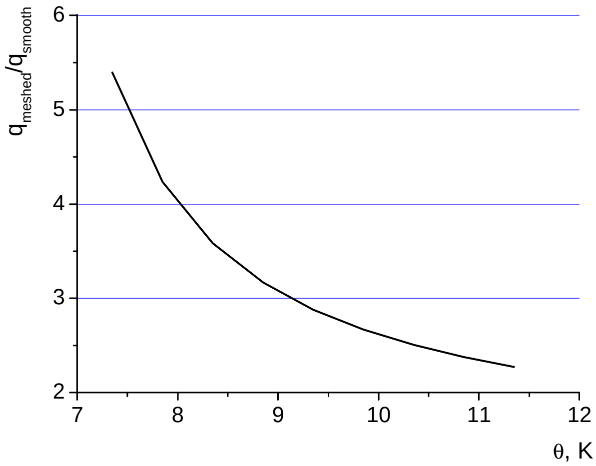

Fig. 6: Enhancement ratio as a function of wall superheat.

The analysis of the above figure proves a positive effect of the mesh. It enabled to increase the heat flux transferred during boiling over five times. This enhancement diminished with rising superheat. This phenomenon has been reported in literature, for example in [8].

Successful design of heat exchangers also requires proper modelling of heat transfer processes. The experimental results have been compared with correlations for heat flux from the literature. Three models have been selected, namely the ones proposed by Nishikawa et al [10], Rannenberg and Beer [11] and Xin i Chao [12]. In the case of the Xin and Chao model a modification had to be applied regarding the width of one cell to be considered as the total of wire diameter and aperture values, while the width of the tunnel as aperture. Figure 7 presents these calculation results.

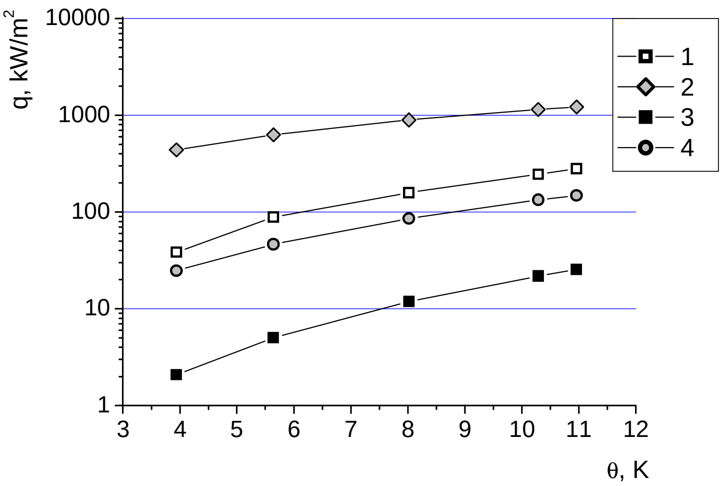

Fig. 7: Comparison of experimental results with selected correlations: 1 – experimental data as in Fig. 5; 2 – calculation results according to Nishikawa et al. [10] model; 3 – calculation results according to Rannenberg and Beer [11] model; 4 – calculation results according to the modified model by Xin and Chao [12].

As can be seen, none of the presented models provides correct calculation results. The largest congruence is observed for the modified Xin and Chao model. However, significant differences between experimental and calculation results occur – especially for large heat flux values.

4. Conclusions

The microstructures, such as meshes, can be used for the design of heat exchangers for ventilation and heating systems in buildings. They provide considerable enhancement in exchanged heat fluxes. In the analysed case a copper mesh of 82 % porosity enabled to produce heat fluxes over five times higher than for the smooth surface for the same temperature difference. The positive effect diminishes with time, but even at high superheats the meshes surface performs much better than the surface without the coating.

Heat exchangers produced with microstructures could be working with different fluids (for example nanofluids) and more tests are needed to determine the performance of these heat exchangers if other boiling agents are used. More tests and analysis could lead to the development of the design guidelines for the producers.

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