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Passive methods of boiling heat transfer enhancement

Pasywne metody intensyfikacji wymiany ciepła przy wrzeniu

Abstract

The paper presents the issue of boiling heat transfer enhancement with the use of different passive techniques, namely the application of wire mesh coatings, capillary porous layers, pin – fins and laser treatment. Enhanced boiling heat transfer has been described as well as the research data of the authors that deals with microstructural coatings. The conducted experimental tests confirm the possibility of increasing heat fluxes transferred at the same superheat value due to the use of heat transfer enhancing techniques.

Keywords: boiling heat transfer, microstructures

Streszczenie

W artykule przedstawiono zagadnienie intensyfikacji wymiany ciepła przy wrzeniu poprzez zastosowanie różnych pokryć tj. struktur siatkowych, kapilarno – porowatych, mikrożeber czy obróbki laserowej. Przybliżono zagadnienie intensyfikacji wymiany ciepła przy wrzeniu i opisano wyniki badań autorów, dotyczące intensyfikacji wrzenia na mikropowierzchniach strukturalnych. Przeprowadzone badania potwierdzają możliwości zwiększenia gęstości odbieranych strumieni ciepła przy tym samym przegrzaniu.

Słowa kluczowe: wymiana ciepła przy wrzeniu, mikrostruktury

1. Introduction

Nucleate boiling enables the transfer of significant heat fluxes as small temperature differences. Such phase – change heat exchangers are widely used in many engineering applications such as refrigeration, cooling of electronic devices, etc. The enhancement of heat transfer can occur through passive or active techniques (which require the supply of additional energy and, thus, are much less common). The use of specially designed microstructural coatings is a passive method and is the focus of this paper.

The article deals with metal wire meshes, capillary porous structures produced with fine metal fibers, pin – fins made with mechanical treatment as well as laser treated surfaces. Generally, any surface modification can influence heat flux dissipated from the heaters, however, some methods of heat transfer enhancement are very efficient, while others produce the opposite effect and actually reduce heat flux transferred from the surface.

2. Boiling heat transfer on microstructure coated surfaces

There are many kinds of microstructures used for boiling heat transfer enhancement. They range from surface treatment with emery paper (to produce proper roughness) to specially designed and produced coatings.

Capillary porous structures made of stainless steel were investigated by Kalawa et al. [3] and made of copper by Wójcik [8]. The microstructures were produced by sintering in the reduction atmosphere. The results prove a favourable impact of the covering on heat flux enhancement in comparison to the smooth surface.

Finned surfaces are also widely known to enhance heat transfer. Pin – fins used for boiling augmentation can be effective in both pool and flow boiling. Pastuszko [6] performed tests of FC-72 and water pool boiling on the fin arrays covered with a porous structure and without any covering. Microfins of two heights were used: 0.5 mm and 1.0 mm. It was reported that in comparison with plain microfins, heat transfer coefficient of structures covered with the porous layer could be two times as high. Orman [4] presented experimental results of water and ethyl alcohol boiling on horizontal surfaces covered with microfins of various heights and distance between them. The application of such pin – fins considerably enhanced boiling in relation to the surface without the fins. Heat flux was even ca. eight times higher for the microstructure covered heater.

Hasegawa et al. [2] investigated a different type of coating, namely meshes. The tests were performed on a horizontal heater of 15 mm in diameter and covered with one or two meshes made of stainless steel and bronze. The considered meshes had the wire diameter of 0.065 –0.295 mm. It was stated in the conclusions that the application of mesh layers improves heat transfer. Asakavičjus et al. [1] considered boiling of R-113, ethyl alcohol as well as water in the heat pipe. The meshes were made of copper and stainless steel, while their number was 2, 8 and 12 layers applied on the surface. The authors also noticed a favourable impact of the meshes on boiling heat transfer. However, this effect diminishes with rising heat flux values. Heat transfer coefficient was 1.8 to 3.5 times higher in the case of water boiling then of ethanol and R-113. The material from which the coating was made also played a significant role. The use of the copper mesh led to heat transfer coefficient being 1.3 times higher than in the case of stainless steel coating.

The experiments performed by the authors of the present paper generally confirm the possibility of heat transfer intensification with the application of mesh microstructures. Fig. 1 presents the ratio of heat flux dissipated from the heater (on which copper meshes were sintered) to the heat flux dissipated from the smooth heater – without any coating. The number of meshes forming each coating ranged from one to three. Two values of superheat (the difference between the heater temperature and the saturation temperature of the liquid) have been selected for analysis, namely 7 K and 10 K.

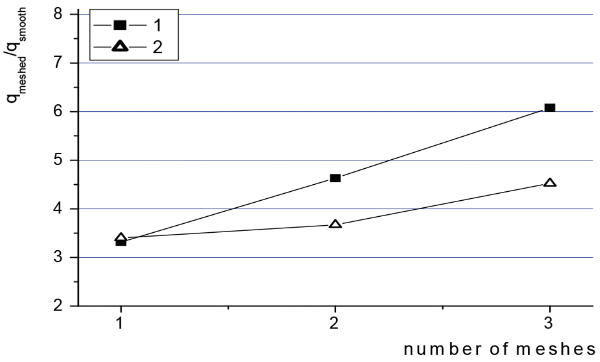

Fig. 1. The enhancement ratio for different number of mesh layers and two superheat values (1–7 K, 2–10 K) – data according to [5] for distilled water as the boiling liquid

The analysis of the above figure indicates that the highest enhancement possibilities within the considered superheat values are offered by the coating that consists of three mesh layers. In this case the heat flux transferred from the heating surface with the microstructural covering was over six times higher in comparison with the smooth surface. The lowest value of the ratio amounted to ca. 3.4 and was almost identical for both temperature differences. However, it needs to be noted that the most significant enhancement occurred for the lower value of superheat. This observation typically confirms literature data on this issue.

3. Laser treated heat exchangers

The authors' tests were performed on a resistance ribbon (Fig. 2) whose dimensions are ca. 40 mm x 4 mm x 0.5 mm. The ribbon itself served as a heater surface as electricity was supplied to it. The subsequent laser treatment was performed with a Nd:YAG type laser working in the pulse mode. The laser spot diameter was 0.7 mm, the beam shift rate: 1200 mm/min, the nozzle-sample distance: 6 mm, while the pulse duration was 0.45 ms.

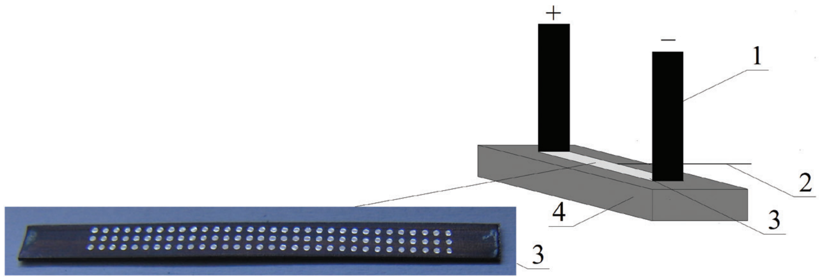

Fig. 2. Heater unit: 1 – electrical connections, 2 – thermocouple, 3 – sample (heater surface), 4 – bakelite insulation plate

As a result of the laser treatment, the morphology of the heater surface was changed. Cavities of different geometry are produced. Figures 3–5 present the morphological details of three laser treated samples.

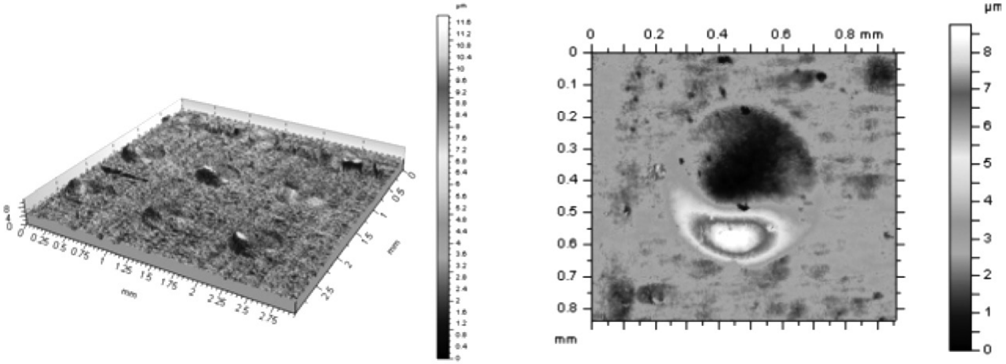

Fig. 3. Sample no 1; cavity depth: 1.9 μm, cavity diameter: 0.22 mm

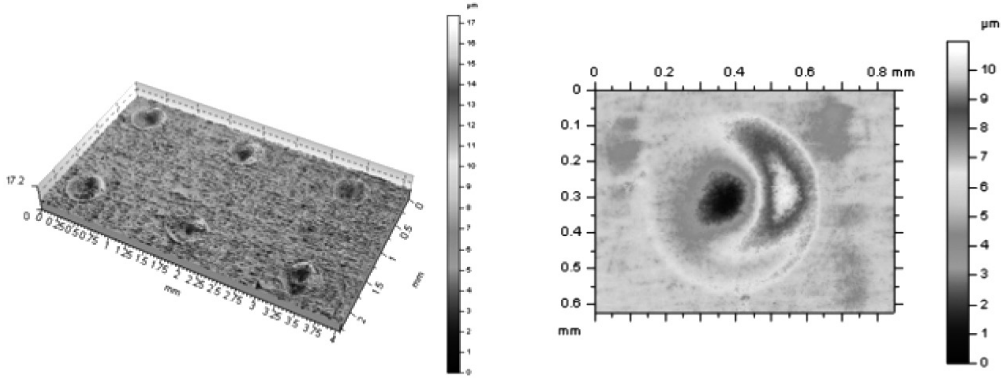

Fig. 4. Sample no 2: cavity depth: 4.0 μm, cavity diameter: 0.21 mm

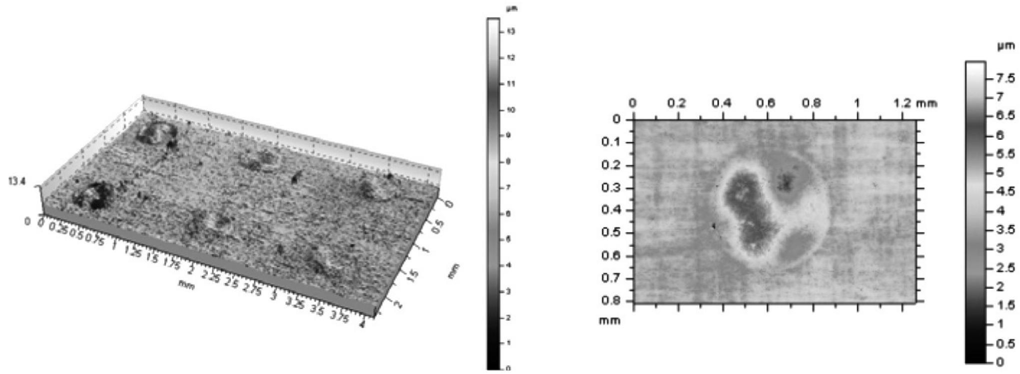

Fig. 5. Sample no 3: cavity depth: 2.0 μm, cavity diameter: 0.20 mm

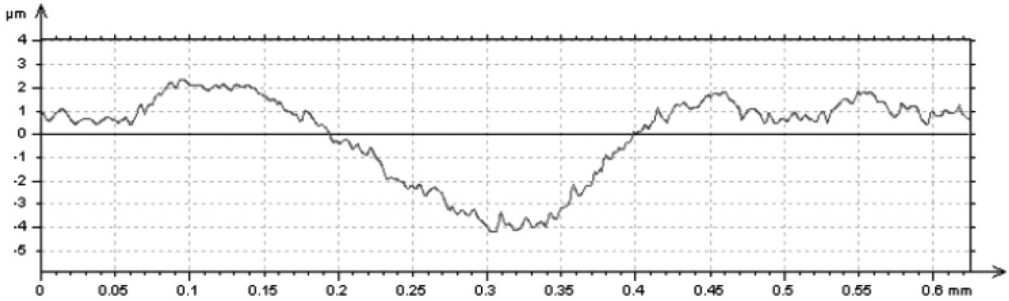

Fig. 6. Surface profile of sample no 2.

The tests were carried out in such a way that the experimental stand presented in Fig. 2 was located in the pool of liquid (distilled water and ethyl alcohol). Electric current supplied to the resistance ribbon of known electrical resistance value increased its temperature as well as the temperature of the liquid in the vessel. This supply was controlled and changed with the autotransformer. The temperature of the heater was determined with a K-type thermocouple. During the measurements, temperature was recorded as a function of rising heat flux value. As a consequence, the thermal performance of the surface modified with the laser bean could be determined as a function of increasing heat flux dissipated to the pool of liquid vs. superheat values.

The testes were primarily focused on the enhancement ratio, which considered heat flux transferred from the laser treated surfaces to the heat flux dissipated from the smooth reference surface of the ribbon. The best performance was provided with sample no 1. In the case of this surface the heat flux was almost two times higher than for the smooth surface of the resistance ribbon without any additional modification. Consequently, the produced heat exchangers can be smaller (and, thus lighter, which is vital for practical applications) or transfer twice as much heat at the same temperature difference as in the case of using smooth heat exchanging surfaces. Differences between the two boiling liquids used in the experiments (water and ethanol) have been observed for different samples. Boiling of ethanol produces smaller bubbles (due to the lower value of surface tension for this alcohol) and, thus, the thermal performance of surfaces with smaller cavities produced with the laser beam should be better.

4. Conclusions

Boiling heat transfer is a phase – chance phenomenon and provides a possibility of dissipating considerable heat fluxes. These values can be even higher if special surface modification techniques are used, for example metal mesh microstructures, capillary porous coatings, microfins or laser treatment of the heaters. As a consequence of the application of these methods, heat flux values dissipated from the heating surfaces at the same temperature differences can be much higher than in the case of smooth surfaces. Also, heat exchangers produced with such surfaces can be smaller due to reduced surface areas. Although the test results presented in the paper deal with pool boiling mode, microstructures can also affect the enhancement of flow boiling heat transfer as indicated by Piasecka [7].

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