Materials Research Proceedings **24** (2022) 9-14 https://doi.org/10.21741/9781644902059-2

Boiling Heat Transfer Performance of Pin-Fins During Boiling of Water and Ethanol

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Keywords: Boiling, Thermal Performance, Water, Ethanol

Abstract. In the article, heat transfer during boiling of two liquids: water and ethanol was described and test results were shown. Two samples of pin-fins were researched – of different heights of the microfins (namely 0.3 and 0.6 mm) made of pure copper. The higher fins performed better than the lower for both the liquids used in the experiments. It must be caused by larger surfaces and better heat exchange conditions during this phase change process. The results can be used in the industry for the production of heat exchangers.

Introduction

Pin–fins provide surface extension and can be thought of as successful heat exchangers that can exchange big amounts of heat during phase-change and not phase-change processes. In the case of boiling any structures that change the morphology of the heaters might cause the increase of heat fluxes as presented by Piasecka et al. [1, 2] regarding e.g. laser texturing used in the flow boiling mode. Kaniowski and Pastuszko [3] presented data on water boiling on the surfaces with microchannels (that created long fins 0.2 - 0.5 mm deep). It was presented that the maximal heat flux was even almost 2.5 times higher in comparison to the sample without such structure. On the other hand, the average diameter of the departing vapor bubbles rose and the departing frequency fell with the increasing heat flux values. Another paper by these authors [4] refers to the application of FC-72 as the boiling agent on such microstructures. Also in this case an improvement over the surface without any modifications was very clear. The heat transfer coefficient rose by over 500% and the values were comparable to those obtained in the case of using nanotubes. The authors also concluded at the end of the paper that the boiling process depends on surface wettability, its roughness, and contact angle. Orman et al. [5] investigated laser treatment for the development of longitudal microfins on horizontal copper substrates. The height of the fins was 0.25 mm and 0.55 mm, their widths 0.5 mm and 1.1 mm, and the groove's widths 0.60 mm and 1.15 mm. The results indicate significant possibilities of increasing the heat fluxes during boiling of water and ethyl alcohol if such microfins are used. In particular, a shift to the lower values of temperature differences was seen. Moreover, a modified correlation has been proposed for such structures based on the model presented in the literature for meshed heaters. Radek et al. [6-8] considered the laser treatment for the development of other types of surfaces with modified morphology for the improvement of tribological parameters.

The application of microstructures can be most favorable for heat pipes as their internal coatings. In this case, elevated heat fluxes can also be achieved as presented by Hrabovsky et al. [9] and Nemec [10]. Such structures might also find applications in ventilation systems and air handling units for heat recovery. Thus, higher thermal comfort for room users could be achieved as discussed by Kolková et al. [11] and Majewski et al. [12].

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The present manuscript discusses the potential of pin–fins for heat transfer during the boiling of water and ethanol. The obtained data can also be used for the design applications of such heaters in the industry.

Samples and Experiment

The experiments were done on micropins whose height was 0.3 mm and 0.6 mm, while other parameters (copper as the material, distance between the fins of 0.4 mm) were kept the same for both the specimens. The samples were made with micromachining. Thus, the spaces between the fins had increased roughness, which was not measured due to the fact that the roughness height was still much lower than the microfins. Fig. 1 presents the example photo of the specimen of the pin's height of 0.3 mm.

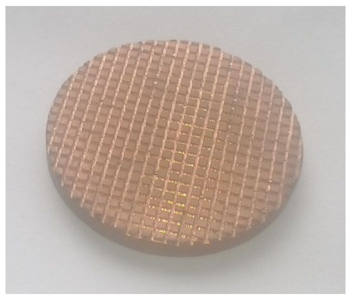

Fig. 1. *Sample with pin – fins (height 0.3 mm).*

Boiling heat transfer performance was determined with the sample acting like a heater located in the pool of water and ethanol. During the testing temperatures were recorded and, as a consequence, heat flux values could be calculated. The consecutive values of the heat fluxes were determined for the rising heat flux.

Results and Discussion

The tests were done under atmospheric pressure with vapor being returned to the vessel. The data obtained during the boiling of water have been presented in the form of boiling curves. Fig. 2 shows the test results for distilled water for both the specimens.

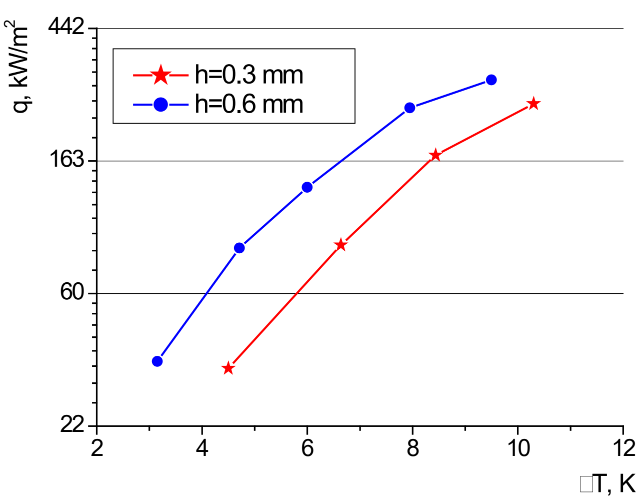

Fig. 2. *Boiling performance of the pin – fins: distilled water*

It is very clear from the figure above that the higher microstructural sample performed better during the whole experiment and exchanged more heat flux (q) at the same temperature differences (ΔT). The curve for the micropin of 0.6 mm height was always higher than the curve for the 0.3 mm height. But at big temperatures, these differences were not so large. Maybe if more heat was provided to the samples from the electric heater those two curves could eventually meet, if film boiling conditions did not start first. Otherwise, the experimental procedure would need to be quickly stopped so that the experimental stand would not be burnt and destroyed (film boiling leads to very high temperatures under the specimens due to the problem of heat removal via the vapor blanket that acts as an insulator).

The same phenomenon of both these curves meeting at the end of the experimental procedure could be observed when the boiling agent was ethyl alcohol (which happened after water was removed from the vessel and the alcohol was provided there). The data for this liquid have been shown in Fig. 3 below.

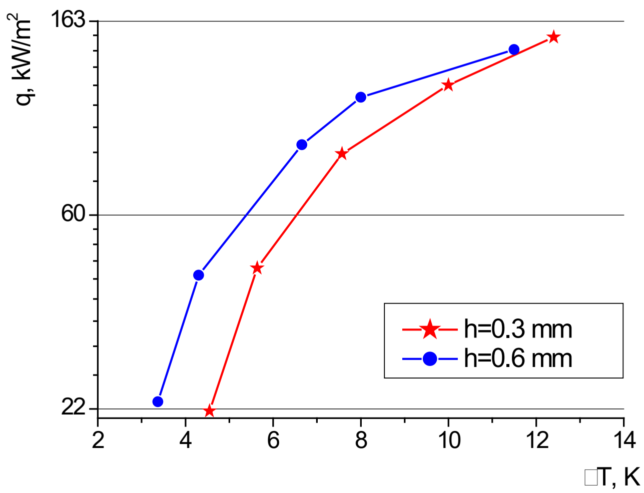

Fig. 3. *Boiling performance of the pin – fins: ethanol*

Here the results for the sample of 0.6 mm height were very close to the curve of 0.3 mm height at the largest heat fluxes (although the heat fluxes for water were higher than for ethanol). The fact that the longer microfins are better can be easily explained just by the bigger surface area that can exchange more heat and provide better cooling as a consequence. But when the heat flux increases and more vapor bubbles are made on the surface, the process undergoes a transformation into a different mode of heat transfer.

The improvement of heat transfer with the longer fins has the same character for both the liquids used in the experiments. Fig. 4 presents the enhancement ratio denoted as (k), which is a heat flux value from longer fins divided by a heat flux value from shorter fins. The changes for water and ethanol are of a similar type as evidenced by the figure below.

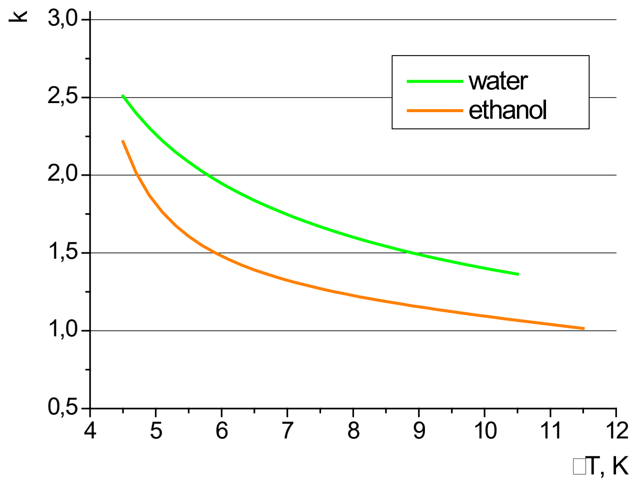

Fig. 4. *Enhancement ratio (k) for both boiling liquids.*

The performance of the samples can be determined with some models. Their development is important for all engineering sciences and various techniques are used in terms of mathematical modeling [13-15]. In the present paper, Smirnov et al. [16] model will be first used, because it was made for the regular geometry microstructures and can be applied here. The comparison of the test results generated with the above-mentioned model and the experimental data for the pin–fins has been presented in Fig. 5 and Fig. 6. It needs to be mentioned that the model required porosity, height, and other parameters and due to the fact that it was developed for the meshes, some modifications had to be made in order to generate the calculation results presented below.

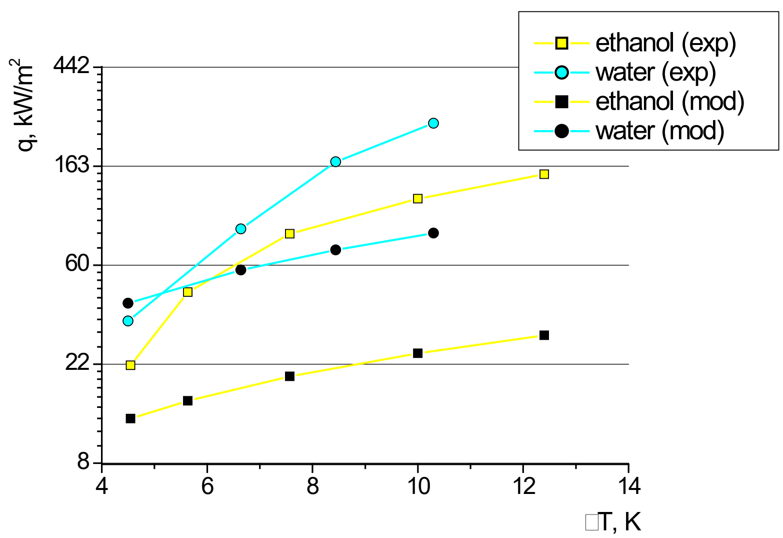

Fig. 5. *Comparison of the experimental results and the selected model (h = 0.3 mm).*

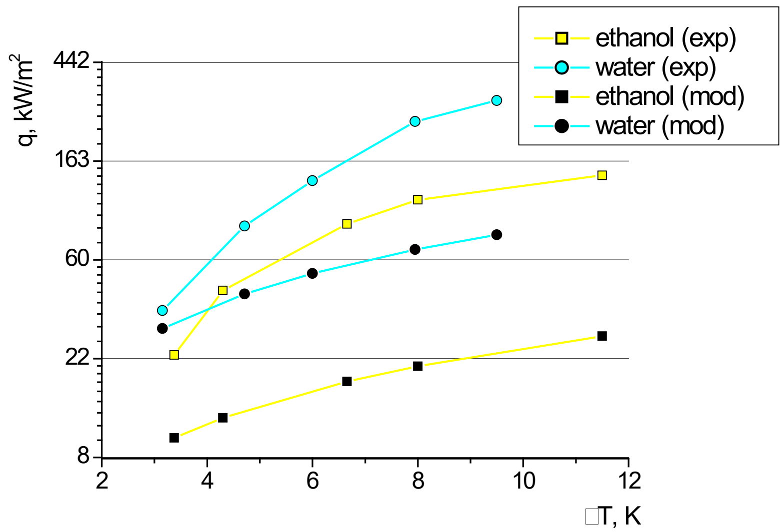

Fig. 6. *Comparison of the experimental results and the selected model (h = 0.6 mm).*

In the case of both kinds of microstructures, the model was only successful for water and it was only in the low range of temperature differences (up to 3 K). For larger ones (in the case of water) and generally for ethanol, the differences were quite large. Maybe a new model can be developed based on the existing one and modified – that will be able to provide better results for the pool boiling conditions of pin–fins boiling.

Summary and Conclusions

The paper presented the test results of boiling water and ethanol under atmospheric pressure conditions. Two specimens of different heights of the microfins were tested under the pool boiling conditions of heat transfer mode. It was clearly observed that higher pin–fins dissipated more heat than lower ones. The easiest explanation might be that the surface area is larger for convection (boiling) heat transfer mode. Thus, their performance will be better. Both the samples generate similar results at high-temperature differences, which can be explained by the dominant role of bubbles' movement and the creation of vapor film from the generated bubbles. In this case, the morphology of the microstructure might play a smaller role. In future research work, the experiments should be extended to other liquids used more commonly in the industry, for example, ammonia or commercially available fluids typically applied to refrigeration systems, where such structures can be used.

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