QPI 2019, volume 1, issue 1, pp. 433-439

PHASE CHANGE HEAT EXCHANGERS MADE OF PIN-FINS FOR BOILING ENHANCEMENT

doi: 10.2478/cqpi-2019-0059
Date of submission of the article to the Editor: 28/03/2019
Date of acceptance of the article by the Editor: 28/05/2019

Łukasz J. Orman[1] – *orcid id: 0000-0002-2221-1824*
Norbert Radek[1] – *orcid id:* 0000-0002-1587-1074
Jacek Pietraszek[2] – *orcid id: 0000-0003-2851-1606*
Dariusz Gontarski[1] – *orcid id: 0000-0002-4454-4785*
[1]Kielce University of Technology, **Poland**
[2]Krakow University of Technology, **Poland**

Abstract: The paper deals with the important issue of boiling heat transfer enhancement using mechanical treatment of the heater surface. The surface has been modified in such a way that microfins have been produced. The application of such a structure leads to highly increased heat fluxes in relation to the smooth surface as has been presented and discussed in the paper. The experiments including distilled water and ethyl alcohol on the horizontal copper samples of 3 cm diameter have been considered. The heat flux value of microfinned surface was even nine times higher than the heat flux dissipated from the smooth surface without any coating. It proves a considerable enhancement of boiling with the application of the mechanically treated surfaces of heat exchangers.

Keywords: boiling heat transfer, microfins, microstructure

1. INTRODUCTION

Surface microgeometry is a vital parameter that affects boiling heat transfer and the phase – change heat exchangers' thermal performance. In (Nishikawa et al., 1982) tests of the impact of pressure and surface roughness on boiling of R-11, R-21, R-113 and R-114 on vertical smooth copper surfaces of diameter 20 mm and 40 mm were presented. Reduced pressures varied from 0.03 to 0.98. Roughness, according to DIN 4762, amounted to 0.022 μm – 4.31 μm. The authors found that the most important influence of roughness on the heat transfer coefficient could have been observed under small pressure values, and for higher pressures this effect diminishes and disappears when pressure is critical. In (Ribatski and Saiz Jabardo, 2003) the effects of roughness were analysed and it was found out that a rise in heat flux with surface roughness is related to a bigger number of vapour producing active nucleation centers. Consequently, heat flux is enhanced on surfaces of higher roughness. In (Hosseini et al., 2011) experimental study of boiling of R-113 on horizontal copper surfaces of different average roughness: 0.901 μm, 0.735 μm, 0.65 μm and 0.09 μm has been presented. It was found that the value of the heat transfer coefficient increased with increasing roughness. The specimen whose roughness was equal to 0.901 μm provided 38.5% higher value of the heat transfer coefficient in relation to the smoothest surface of 0.09 μm. The already mentioned paper by (Ribatski and Saiz Jabardo, 2003) also considered an influence of the heater surface material that – as it was stated in the article – is dependent on the working fluid. For the agent R-11 and roughness value of 0.16 μm the best results were obtained for the brass heater. Nevertheless, the boiling curves for R-12 and brass as well as copper surfaces were almost identical. Generally stating, for the tested fluids (apart from the agent R-12) the highest heat flux values were recorded for brass, then copper and lowest for stainless steel samples.

At the same time, it needs to be noted that boiling offers significant possibilities in terms of heat transfer. Further increase in dissipated heat flux is possible with the application of additional coatings on the smooth surface and the production of treated surfaces to enhance heat transfer. Such specially made surfaces can be used both in pool boiling (e.g. (Orman, 2016; Pastuszko, 2010; Pastuszko, 2018) and flow boiling (e.g. Maciejewska B., Piasecka M., 2017; Maciejewska B., Piasecka M., 2017; Strąk K. et al., 2018). Although, the presented paper deals with flat surfaces, experiments on mechanically treated tubes are also available in literature. For example in (Passos and Reinaldo, 2000) test results of R-113 boiling inside aluminum smooth and grooved tubes have been shown. The produced grooves had the depth of 310 ± 59 μm and the distance between each amounted to 250 μm. The heat transfer coefficient of the grooved tube proved to be higher than that of the smooth tube.

The current paper is focused on boiling enhancement with the application of pin-fins, namely small – scale fins arranged regularly on heater surfaces. However, highly efficient might be a combined application of surface extension with the use of microfins and another technique, for example sintering perforated foil on the pin-fin array as presented in (Pastuszko, Wójcik, 2015). Some other methods also seem possible to be used, especially for heat pipe applications as discussed in (Nemec et al., 2009; Čaja et al., 2014 and Nemec et al. 2017).

2. MATERIAL AND METHOD

The experimental analysis has been focused on mechanically treated heater surfaces with the microfins of different geometry. The samples had the diameter of 3 cm and the height of 3 mm. The height of the pin-fins was 0.40 mm and 0.90 mm, while the distance between neighbouring fins: 0.64 mm and 0.85 mm. Figure 1 presents an example sample.

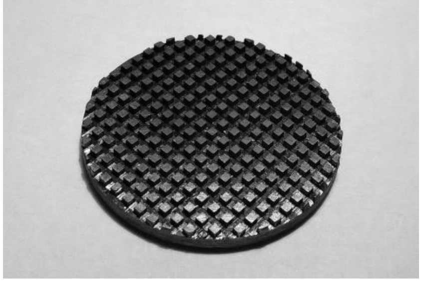

Fig. 1. Sample of the copper microfin structure

The tests on the copper samples were performed on the experimental set – up, whose main element has been presented in Figure 2. The produced specimens containing microfins were soldered to the copper heating block. There was an electric resistance heater located in it that produced heat, which was later conducted to the samples (the block was insulated from the surroundings with high temperature thermal insulation). The power of the heater was increased steadily during the measurements using the autotransformer with given steps to provide a few data points which enabled to draw the boiling curves.

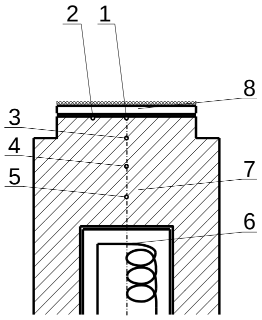

Fig. 2. Main unit of the experimental set-up: 1, 2 – thermocouples under the sample, 3, 4, 5 thermocouples in the axis of the heating block, 6 – electric cartridge heater, 7 – copper block, 8 – sample with the mesh [Orman, 2013]

The obtained boiling curves under ambient pressure contained information about the thermal performance of each sample in the nucleate boiling regime of heat transfer and the importance of each geometrical parameters' combination with regard to boiling enhancement.

3. RESULTS AND DISCUSSION

The experimental analysis on boiling heat transfer on microfinned surfaces has been done on the samples of pin – fin height of 0.40 mm and 0.90 mm and presented by the co-author in (Orman, 2016). Based on the data of boiling performance of the treated surfaces in the form of the boiling curves for both considered liquids (distilled water and ethyl alcohol), it is possible to analyse the phenomenon of boiling enhancement. Below the graphs of the enhancement ratio (the ratio of heat flux dissipated from the microfinned surface to the heat flux from the smooth surface) vs. superheat value (defined as the temperature difference between the heater and the liquid) have been presented basing on the data from (Orman, 2016).

First of all, the performance of the sample with higher pin-fins seems to be much better (Fig. 3), if the boiling agent is distilled water. It proves the statement that the application of higher (longer) fins leads to higher heat flux values than shorter ones (at the same distance of 0.64 mm between the microfins). Thus, the surface extension might be responsible for such elevated heat fluxes and better thermal performance of such sample and not the number of active nucleation sites available on the heater surface at located between the microfins.

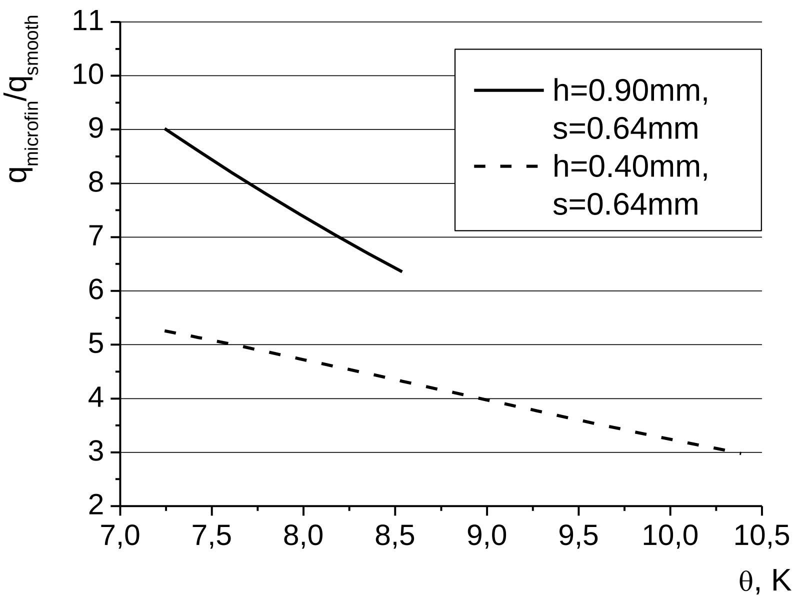

Fig. 3. Enhancement ratio of the microfinned surfaces – distilled water boiling.

In the considered case the length and, consequently, the surface area for heat exchange, is over twice higher for the longer microfins. Thus, the surface extension is significant. It needs to be noted, however, that the dependence on Figure 3 is almost linear, which is related to the small range of superheat under investigation.

A broader range of temperature differences has been analysed below in Figure 4 for ethyl alcohol (of 99.8% purity) boiling heat transfer and two samples of significantly different microfin lengths and the distance between them of 0.64 mm and 0.85 mm.

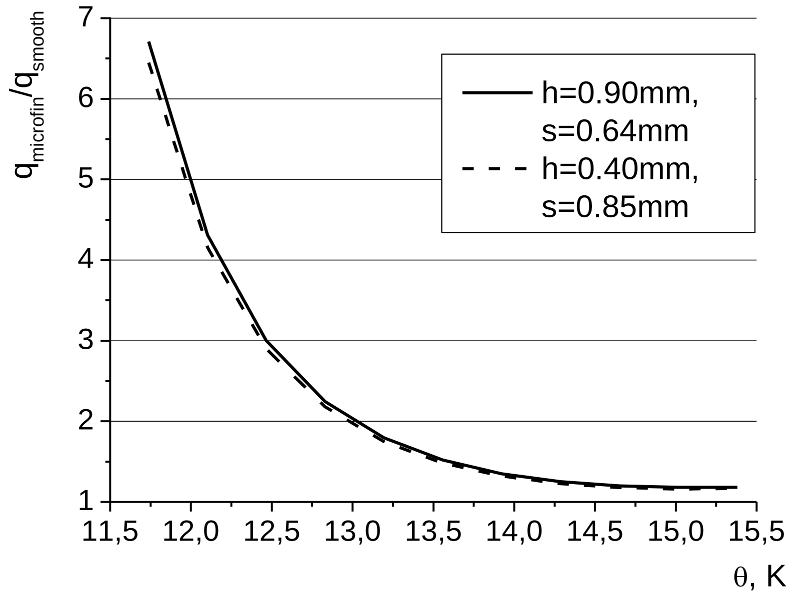

Fig. 4. Enhancement ratio of the microfinned surfaces – ethyl alcohol boiling.

The curves are almost identical, despite different geometrical parameters of the specimen, as opposed to the research data for distilled water. This might be related to the low viscosity and wetting properties of this liquid. The vapour bubbles are smaller for ethanol and the boiling performance might not be linked to the distance between the fins, where bubbles might grow and join together before departure from the surface. The performance of the smaller pin-fins might be improved due to the larger surface of the heater in the case of the distance of 0.85 mm. This surface has higher temperature and, as a result, boiling might be more intense (reaching values recorded for the longer fins). It needs to be stated that temperature falls significantly on the microfins and, thus, smaller microfin density might be advantageous for heat transfer intensification, as can be concluded from the presented figures.

For both the liquids, it needs to be noted that as the superheat increases the values of heat flux recorded for the microfinned surfaces become similar to those of the smooth surface. It is clearly visible in the case of ethyl alcohol, however, the phenomenon might be the same for distilled water if data on higher heat fluxes was presented. It backs the observations of other researchers in this area, which also report such phenomena.

3. CONCLUSION

Boiling heat transfer can be significantly improved if pin – fins are applied onto the heater surface. The performance of such phase – change heat exchangers can be very good with heat flux values much higher than the those recorded during testing of the smooth surface. In the presented article the highest enhancement has been given as even nine times higher value for the microfinned surface. Consequently, such heat exchangers can dissipate much more heat at the same temperature difference. Further tests on different boiling agents are necessary and could increase the experimental database on the considered issue.

The research methodology applied in this research may be inspiring for other researcher, especially focused on fluid flow (Domagala et al., 2018a; Domagala et al., 2018b), on hydraulic components of heavy-duty machines (Filo et al., 2018a; Filo et al., 2018b; Krawczyk and Sobczyk, 2018) and their possible failures (Fabis-Domagala et al., 2018). Methods allowing fast and effective boiling should be also of interest for a combustion technology (Opydo et al., 2016), power plant branch (Dwornicka, 2014) and biotechnology sector (Skrzypczak-Pietraszek et al., 2018). Material aspects of this research may be also interesting for materials science researchers focused on modification of materials properties (Lipinski, 2015), its surface layer (Kmita and Bara, 2012; Bara et al., 2016) and related analytical methods (Gadek-Moszczak and Wojnar, 2009; Gadek-Moszczak et al., 2014). Finally, in order to strengthen the research function of the university (Kozien and Kozien, 2017), the mentioned results should be widely disseminated, among others in form of scientific and industrial databases (Gawlik et al., 2015; Karpisz and Kielbus, 2018).

REFERENCES

Bara, M., Kmita, T., Korzekwa, J., 2016. *Microstructure and properties of composite coatings obtained on aluminium alloys*. Arch. Metall. Mater., 61, 1107-1112. DOI: 10.1515/amm-2016-0238

Čaja, A., Nemec, P., Malcho, M., 2014. *Influence of the ambient temperature during heat pipe manufacturing on its function and heat transport ability*, EPJ Web of Conferences, 67, art. 02012, DOI: 10.1051/epjconf/20146702012.

Domagala, M., Momeni, H., Domagala-Fabis, J., Filo, G., Krawczyk, M., 2018a. *Simulation of Cavitation Erosion in a Hydraulic Valve*. Materials Research Proceedings, 5, 1-6. DOI: 10.21741/9781945291814-1

Domagala, M., Momeni, H., Domagala-Fabis, J., Filo, G., Kwiatkowski, D., 2018b. *Simulation of Particle Erosion in a Hydraulic Valve*. Materials Research Proceedings, 5, 17-24. DOI: 10.21741/9781945291814-4

Dwornicka, R., 2014. *The Impact of the Power Plant Unit Start-Up Scheme on the Pollution Load*. Advanced Materials Research, 874, 63-69. DOI: 10.4028/www.scientific.net/AMR.874.63

Fabis-Domagala, J., Filo, G., Momeni, H., Domagala, M., 2018. *Instruments of identification of hydraulic components potential failures*. MATEC Web Conf., 183, art. 03008. DOI: 10.1051/matecconf/201818303008

Filo, G., Fabis-Domagala, J., Domagala, M., Lisowski, E., Momeni, H., 2018a. *The idea of fuzzy logic usage in a sheet-based FMEA analysis of mechanical systems*. MATEC Web Conf., 183, art. 03009. DOI: 10.1051/matecconf/201818303009

Filo, G., Lisowski, E., Domagala, M., Fabis-Domagala, J., Momeni, H., 2018b. *Modelling of pressure pulse generator with the use of a flow control valve and a fuzzy logic controller*. AIP Conf. Proc., 2029, art. 020015. DOI: 10.1063/1.5066477

Gadek-Moszczak, A., Radek, N., Wronski, S., Tarasiuk, J., 2014. *Application the 3D image analysis techniques for assessment the quality of material surface layer before and after laser treatment*. Adv. Mat. Res. Switz., 874, 133-138. DOI: 10.4028/www.scientific.net/AMR.874.133

Gadek-Moszczak, A., Wojnar, L. 2009. *Objective, quantitative and automatic x-ray image analysis of the bone regenerate in the ilizarov method*. ECS10: The 10th European Congress of Stereology and Image Analysis, Milan, Int. Society for Stereology, 453-458.

Gawlik, J., Kielbus, A., Karpisz, D., 2015. *Application of an integrated database system for processing difficult material*. Solid State Phenomena, 223, 35-45. DOI: 10.4028/www.scientific.net/SSP.223.35

Hosseini, R., Gholaminejad, A., Jahandar, H., 2011. *Roughness effects on nucleate pool boiling of R-113 on horizontal circular copper surfaces*, World Academy of Science, Engineering and Technology, 55, 679-684. DOI: 10.5281/zenodo.1078068

Karpisz, D., Kielbus, A., 2018. *Selected problems of designing modern industrial databases*. MATEC Web Conf., 183, art. 01017. DOI: 10.1051/matecconf/201818301017

Kmita, T., Bara, M., 2012. *Surface oxide layers with an increased carbon content for applications in oil-less tribological systems*. Chemical and Process Engineering-Inzynieria Chemiczna i Procesowa, 33, 479-486. DOI: 10.2478/v10176-012-0040-z

Kozien, E., Kozien, M.S., 2017. *Academic governance as a determinant of efficient management of a university in Poland - legal and comparative perspective*. ESD 2017: Economic and Social Development Conf., Madrid, Varazdin, 38-47.

Krawczyk, J., Sobczyk, A., 2018. *Tests of New Methods of Manufacturing Elements for Water Hydraulics*. Materials Research Proceedings, 5, 200-205. DOI: 10.21741/9781945291814-35

Lipinski, T., 2015. *Double modification of AlSi9Mg alloy with boron, titanium and strontium*. Arch. Metall. Mater., 60, 2415-2419. DOI: 10.1515/amm-2015-0394

Maciejewska, B., Piasecka, M., 2017. *Trefftz function-based thermal solution of inverse problem in unsteady-state flow boiling heat transfer in a minichannel*, International Journal of Heat and Mass Transfer, 107, 925-933, DOI: 10.1016/j.ijheatmasstransfer.2016.11.003.

Maciejewska, B., Piasecka, M., 2017. *An application of the non-continuous Trefftz method to the determination of heat transfer coefficient for flow boiling in a minichannel*, Heat and Mass Transfer, 53(4), 1211-1224, DOI: 10.1007/s00231-016-1895-1.

Nemec, P., Caja, A., Lenhard, R., 2009. *Analysis of heat transfer limitation of wick heat pipe*, Int. Conf. Experimental Fluid Mechanics 2009, Liberec, Czech Republic, 229-234.

Nemec, P., Malcho, M., Kaduchova, K., 2017. *Experimental measurement, calculation and thermal visualization condenser temperature of cooling device with a heat pipe technology*, EPJ Web of Conferences, 143, DOI: 10.1051/epjconf/201714302078.

Nishikawa K., Fujita Y., Ohta H., Hidaka S., 1982. *Effect of the surface roughness on the nucleate boiling heat transfer over the wide range of pressure*, International Heat Transfer Conference, Munchen, Germany, 4, PB10, 61-66.

Opydo, M., Kobylecki, R., Dudek, A., Bis, Z. 2016. *The effect of biomass co-combustion in a CFB boiler on solids accumulation on surfaces of P91 steel tube samples*. Biomass & Bioenergy, 85, 61-68. DOI: 10.1016/j.biombioe.2015.12.011

Orman, Ł.J., 2013. *Boiling heat transfer on single phosphor bronze and copper mesh microstructures*, Int. Conf. Experimental Fluid Mechanics 2013, Kutná Hora, Czech Republic, 519-522. DOI: 10.1051/epjconf/20146702087

Orman, Ł. J., 2016. *Enhancement of pool boiling heat transfer with pin-fin microstructures*, Journal of Enhanced Heat Transfer, 23, 137-153, DOI: 10.1615/JEnhHeatTransf.2017019452.

Passos, J. C., Reinaldo, R.F., 2000, *Analysis of pool boiling within smooth and grooved tubes*, Experimental Thermal and Fluid Science, 22, 35-44, DOI: 10.1016/S0894-1777(00)00008-X.

Pastuszko, R., 2018. *Pool boiling heat transfer on micro-fins with wire mesh Experiments and heat flux prediction*, International Journal of Thermal Sciences, 125, 197-209, DOI: 10.1016/j.ijthermalsci.2017.11.019.

Pastuszko, R., 2010. *Pool boiling on micro-fin array with mesh structures*, International Journal of Thermal Sciences, 49, 2289–2298, DOI: 10.1016/j.ijthermalsci.2010.07.016.

Pastuszko, R., Wójcik, T. M., 2015. *Experimental investigations and a simplified model for pool boiling on micro-fins with sintered perforated foil*, Experimental Thermal and Fluid Science, 63, 34-44, DOI: 10.1016/j.expthermflusci.2015.01.002.

Ribatski, G., Saiz Jabardo, J. M., 2003. *Experimental study of nucleate boiling of halocarbon refrigerants on cylindrical surfaces*, International Journal of Heat and Mass Transfer, 46(23), 4439-4451, DOI: 10.1016/S0017-9310(03)00252-7.

Skrzypczak-Pietraszek, E., Reiss, K., Zmudzki, P., Pietraszek, J., 2018. *Enhanced accumulation of harpagide and 8-O-acetyl-harpagide in Melittis melissophyllum L. agitated shoot cultures analyzed by UPLC-MS/MS*. PLoS ONE 2018, 13, art. e0202556. DOI: 10.1371/journal.pone.020255610.1371/journal.pone.0202556

Strąk, K., Piasecka, M., Maciejewska, B., 2018. *Spatial orientation as a factor in flow boiling heat transfer of cooling liquids in enhanced surface minichannels*, International Journal of Heat and Mass Transfer, 117, 375-387, DOI: 10.1016/j.ijheatmasstransfer.2017.10.019.