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Numerical and Experimental Investigation on Pool Boiling Heat Transfer Performance using Nanofluids

"Ph.D. Thesis Booklet"

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1. Introduction

In many heat exchange systems, boiling heat transfer and two-phase flow plays a significant role in transporting heat from one medium to another. Boiling heat transfer is an efficient heat transfer process among other heat transfer modes, and this is due to the latent heat of vaporization during the boiling phase change phenomenon. However, the nucleate boiling regime involves many industrial applications to remove high heat flux in relatively small superheat temperatures, which, in turn, makes these systems more durable and efficient. Nowadays, there is an increasing demand to develop new products with high heat flux and compact space. For these products with high thermal loads, the liquid-cooling systems with boiling phase change are more efficient compared to air-cooling systems **[1, 2]**. Adequate cooling liquids are needed to pass high energy from a heating surface to fluid by applying the smallest temperature difference per unit time and area in the solid surface. On the other hand, the active heat transfer modes, for example, nucleate boiling, will offer a lot of heat removal per unit area. Therefore, new and functional cooling fluids should be used to overcome the inherently limited thermal properties of conventional liquids such as water, ethylene glycol, and engine oil. During the last decades, considerable research effort devoted to finding new efficient thermal fluids with thermal properties that adequately satisfy the cooling requirements of these high heat dissipation products, as mentioned earlier. One of the essential passive heat transfer enhancement techniques is the use of ultrafine solid particles, which provide efficient thermal-transport properties compared to conventional fluids **[3, 4]**.

Nanofluids are engineered colloids of nanoscale solid materials (e.g., metallic, non-metallic, carbon, etc.) with base fluids (e.g., water, oil, ethylene, tri-ethylene-glycols, polymeric solutions, and refrigerants) **[5- 8]**. Materials widely utilized as nanopowders include metals (e.g., gold, copper, silver), metal oxides (e.g., alumina, ceria, silica, zirconia, titania etc.), metal carbides (e.g., silicon carbide, zirconium carbide, and tungsten carbide), metal nitrides (e.g., aluminum nitride, silicon nitride), carbon in different forms (e.g., diamond, graphite, carbon nanotubes, fullerene) and functionalized nanoparticles. It was widely reported that the solid materials have thermal conductivities that are larger than those of conventional cooling liquids. When dispersing those materials into base liquids to enhance thermal properties of the suspension (e.g., thermal conductivity property), the heat transport performance can be notably improved as reported in studies **[9, 10]**. Numerous studies in the literature indicated that the nanofluids thermo-physical properties, especially the thermal conductivity was enhanced when adding solid materials into conventional fluids, and this is due to the higher thermal conductivity of solid particles which, in turn, increase the conductive heat transfer between the solid particles and liquid molecules **[11-13]**. However, there were some critical issues regarding the other thermo-physical transport properties such as the viscosity, heat capacity, and density for those new thermal fluids, which need more extensive investigations to show the overall merits for using those liquids in the real industrial applications that involve heat transfer of single and two-phase flow regimes.

2. The motivation for this research

Nowadays, the demand for miniaturization of heat exchange systems with efficient operation resulted in increasing heat dissipation from such systems hence, reduce the efficiency of the systems. Such growth in heat fluxes is not a problem just in miniaturization systems such as microelectronic devices, but also for systems involved in thermal equipment, manufacturing industries, thermal power plants, nuclear reactors, etc. Therefore, to enhance efficiency as well as the life-time of these systems, we must overcome such high heat fluxes. For efficient heat removal adequate cooling system is required for heat transfer.

Boiling heat transfer is encountered in many industrial heat exchange systems due to the phase change represented by the latent heat of vaporization that could happen during this process. Two-phase flow heat transfer is an efficient process to remove high thermal energy from the surface. Systems that include boiling are extensively investigated during the last decades by many scientists and researchers. The nucleate boiling regime is a vital region among all boiling transition regimes, and this is due to the high heat dissipation that can be removed in relatively small superheat temperatures. In other words, the boiling heat transfer mode leads to significant heat transfer coefficients compared to single-phase convection processes. Because of the considerable heat transfer coefficients that appeared during the boiling process, it is considered as a desirable heat transfer process to thermal power engineers. For example, boiling is crucial for thermodynamic systems. In a power plant cycle, the working fluid (e.g., water) is usually heated inside the boiler, until phase change takes place, and the required vapor is used to drive the turbine.

Nanofluids are a new class of working fluids, which are made by dispersing ultrafine solid materials within a range of (1- 100 nm). As discussed before, and according to existing literature, the use of nanofluids could enhance the heat transfer performance in the application of single-phase systems, but the question are those working fluids applicable in two-phase flow systems? Applying nanofluids in the frontier research in two-phase flow, boiling heat transfer, and critical heat flux (CHF) in some heat exchange systems is another exciting topic, but there are also extraordinary challenges in this aspect. As indicated by many investigations and during the stage of collecting data to understand the gap of this topic, several issues in the related subject are reported and listed as follows:

- The absence of understanding related to the experimental results of the boiling heat transfer coefficient from different investigators.
- The absence of the theoretical background releated to mechanism of boiling heat transfer using nanofluids.
- There was no comprehensive understanding of the influence of nanomaterial type, size, and loading, as well as the heating element geometry on boiling heat transfer performance when using nanofluids.

- Up to date, there is no model to predict the boiling heat transfer of nanofluids employing both pool and flow boiling due to the contradictory experimental results in the literature regarding this subject.
- The absence of real applications of heat exchange systems related to nanofluids as a new thermal fluid, although this topic has been investigated for several years ago.
- What should we do to understanding the performance of boiling heat transfer and complex two-phase flow phenomenon when using nanofluids as working fluid.

The issues mentioned above were huge enough to motivate me to investigate the boiling heat transfer by using nanofluids with new types, size, dilute concentrations, and typical horizontal heated tube as the heating element to well understanding this mechanism.

3. The objectives

The objectives of this research are listed as follows:

- ➢ To build up a pool boiling apparatus for carrying out the pool boiling heat transfer performance test represented by pool boiling heat transfer coefficient PBHTC from a horizontal copper heated tube with a typical diameter (22 mm).
- ➢ To examine the effect of applied heat flux on the pool boiling heat transfer coefficient for deionized water and various types of nanofluids.
- ➢ To investigate different types of fairly stable nanofluids with various dilute volumetric concentrations, and compared the results to deionized water as a baseline case.
- ➢ To measure the thermal conductivity of different types of nanofluids with various volume concentrations and temperatures experimentally.
- ➢ To prepare new mono and hybrid nanofluids to examine the pool boiling heat transfer performance, and compared the results to the baseline case (deionized water).
- ➢ To visualize the bubble dynamics during the nucleate pool boiling regime for dilute nanofluids and comparing to deionized water.
- ➢ To compare the experimental results of deionized water with well-known correlations and empirical studies in the literature to see the reliability of the pool boiling chamber.
- ➢ To extend and correct the boiling model under the Eulerian-Eulerian multiphase approach by modifying the bubble waiting time coefficient, which involved in quenching heat flux partition of heat flux partitioning model (RPI).
- ➢ To validate the extended numerical model with experimental results of cerium oxide nanofluid under the atmospheric condition.

The necessity for measuring surface temperatures along with the heating element with a proper and accurate way was because the measuring of those surface temperatures could play a significant role in obtaining precise pool boiling heat transfer coefficient. Furthermore, efforts have been made during the fabrication of the heating element stage to fix the thermocouples on the tube surface to measuring surface temperatures from different axial and radial directions and ensure acceptable accuracy through measurement. Besides, to investigate the pool boiling process for various working fluids, Pool boiling apparatus was built at the Department of Energy Engineering, Faculty of Mechanical Engineering, Budapest University of Technology and Economics BME, (Hungary). All the experimental details will be discussed later on in chapter 3.

4. The main contributions

In the present research, numerical and experimental investigation on boiling heat transfer performance using different types of stable nanofluids were studied. In particular, this research was focused on pool boiling heat transfer performance that represented by pool boiling curves and pool boiling heat transfer coefficient PBHTC enhancement ratio of nanofluids relative to deionized water as baseline case from a typical horizontal heated copper tube at atmospheric pressure condition. A numerical CFD boiling model so-called heat flux partitioning model (RPI boiling model) was extended to simulate the deionized water and nanofluids from horizontal heated copper tubes and stainless steel flat plate heating surface at atmospheric pressure. The obtained numerical results were validated with experimental studies in the literature (***simulation No.1*** and ***simulation No.2***) as well as an experimental test rig, which is built in our laboratory for pool boiling from typical horizontal heated copper tube (***simulation No.3***) as described in chapter 3. The simulations were shown that to predicting pool boiling heat transfer using nanofluids; efforts should be paid to take into account the bulk properties effect of suspended nanoparticles and the surface modification effect during the deposition of nanoparticles on the heater surface. However, significant efforts have been made to modify the bubble waiting time coefficient to correct the quenching heat flux partition for pure water and nanofluids and correlate this coefficient to superheat temperature, as presented in chapter 2.

Moreover, the numerical results have been shown that quenching heat flux plays a significant role among other heat fluxes mechanisms. Finally, to introduce a comprehensive model of pool boiling using nanofluids, more data from experimental studies should be taken in the account in the future to obtain new closure correlations related to the bubble dynamics (boiling parameters) and surface modification during pool boiling of nanofluids. The present experimental setup was performed on pool boiling heat transfer performance of deionized water and different types of fairly stable mono-nanofluids (CeO_2, WO_3, MgO, AlN, Al_2O_3), and hybrid nanofluids so-called (Al_2O_3+CeO_2, Al_2O_3+MgO 50:50) based deionized water nanofluids from a typical horizontal heated copper tube at atmospheric pressure. The nanofluids were prepared by a two-step method with various volumetric concentrations, and then the stability was checked in two ways which are called sedimentation time method and zeta-potential measurements and all prepared nanofluids were revealed relatively stable criteria at less during the experiments. Before introducing the pool boiling heat transfer results, the thermal conductivity measurements were done for nanofluids via the plate source transient method. The results have been shown the thermal conductivity of nanofluids enhanced compared to deionized water a baseline case, and this enhancement was increased with increasing the volume concentration and temperature. The obtained results for pool boiling tests demonstrated that using nanofluids as working fluids in the pool boiling heat transfer process might degrade or enhance the pool boiling heat transfer coefficient. The pool boiling heat transfer coefficient enhancement ratio was improved and deteriorated depends on the nanomaterials type, size, concentration and the heating surface characteristics and configuration. The new kind of nanofluids, so-called ***hybrid nanofluids*** which are produced by adding complex nanopowders (hybrid ones) or by mixing two different nanofluids were prepared to investigate the pool boiling behavior in the present research. Results have shown that for both types of hybrid nanofluids that are used in this work, the pool boiling heat transfer performance was enhanced when using dilute volume concentrations. The following section summarized the main contributions from this research in the form of theses as listed below:

Thesis 1

The heat flux partitioning (RPI) model was used to predict the pool boiling heat transfer of water from the horizontal heated copper tube. The quenching heat flux partition was modified by correcting the bubble waiting time coefficient C_w according to the following sigmoidal function with the coefficient of determination ($R^2 = 0.9992$):

$$C_w = 0.1017 + 0.8336\left(1 - e^{(-1.1894\Delta T_{sup})}\right)^{2874.8098} \quad (1)$$

Where: C_w is the bubble waiting time coefficient [-], and it was introduced to correct the waiting time between the departures of sequential bubbles. The default value for this coefficient ($C_w = 1$) used in Ansys fluent solver; however, it is possible to correct this value as needed, but it can only set as a constant value. ΔT_{sup} is the superheat temperature [K]. The above correlation is valid for pool boiling of water from a horizontal heated copper tube with a range of superheat temperature $\left(5 \leq \Delta T_{sup} \leq 10 \text{ K}\right)$ at atmospheric pressure condition. **Related publications [P5, P13, P17]**.

Thesis 2

In case of pool boiling heat transfer from stainless steel flat plate surface using water and silica-based water nanofluid at atmospheric pressure. The bubble waiting time coefficient was corrected and correlated with superheating temperature to validate the RPI model for pool boiling of water. Moreover, the closure correlations from the literature regarding the pool boiling parameters of silica nanofluid were inserted as a user-defined function to validate the pool boiling using silica nanofluid. The following correlation was proposed for bubble waiting time coefficient with ($R^2 = 0.9986$):

$$C_w = 0.102 + 2.5448 \Big/ \left(1 + e^{\left(-\left(\Delta T_{sup} - 21.1792\right) / 2.6439\right)}\right) \quad (2)$$

Where: C_w is the bubble waiting time coefficient [-], and this coefficient was introduced to correct the waiting time between the departures of sequential bubbles. The default value for this coefficient utilized in Ansys fluent was ($C_w = 1$); however, it is possible to correct this value as needed, but it can only locate as a constant value. ΔT_{sup} is the superheat temperature [K]. The above correlation is valid at atmospheric pressure for a range of superheat temperature $\left(6 \leq \Delta T_{sup} \leq 32 \text{ K}\right)$. **Related publications [P6, P16, P18]**.

Thesis 3

A horizontal typical heated copper tube with an outer diameter (22 mm) was used to examine the pool boiling heat transfer of deionized water and ceria-based deionized water nanofluids at atmospheric pressure. The quenching heat flux partition was modified by correcting the bubble waiting time coefficient for deionized water and ceria nanofluids and correlating this coefficient to superheat temperature as a boundary condition to validate the extended RPI model with experimental data for water and ceria-based water nanofluids. The following quadratic polynomial functions were determined as follows:

- For water case, ($R^2 = 0.994$)

$$C_w = 0.0002\Delta T_{sup}^2 + 0.0718\Delta T_{sup} - 0.3613 \quad (3)$$

- For (0.007% Vol.) CeO_2 based water nanofluids, ($R^2 = 0.9711$)

$$C_w = -0.005\Delta T_{sup}^2 + 0.1675\Delta T_{sup} - 0.4228 \quad (4)$$

- For (0.01% Vol.) CeO_2 based water nanofluids, ($R^2 = 0.9844$)

$$C_w = -0.0028\Delta T_{sup}^2 + 0.1234\Delta T_{sup} - 0.359 \quad (5)$$

Where: C_w is the bubble waiting time coefficient [-], and it was introduced to correct the waiting time between the departures of consecutive bubbles. The default value for this coefficient is ($C_w = 1$) in Ansys fluent solver; however, it is possible to correct this value as needed, but it can be only as a constant value. ΔT_{sup} is the superheat temperature [K]. The above correlations are valid for a range of superheat temperatures $\left(3.9 \leq \Delta T_{sup} \leq 14.1 \text{ K}\right)$ and atmospheric pressure conditions.

Thesis 4

Thermal conductivity of three types so-called nanofluids (aluminum oxide, cerium oxide and their hybrid (50:50) by volume) based deionized water nanofluids at the range of dilute volume concentrations (between 0.01% - 0.5% Vol.) and various temperatures (35, 40, 45 and 50 ºC) was measured. Results demonstrated that the higher thermal conductivity enhancement ratio $\left(k_{nf}/k_f\right)$ for Al_2O_3, CeO_2, and their hybrid nanofluids were 1.053, 1.033, and 1.083 respectively at a higher volume concentration (0.5% Vol.) and a higher temperature (50 ºC) compared to the deionized water case. Proposed correlation for thermal conductivity enhancement ratio of hybrid nanofluid was introduced, and it shows good accuracy with measured experimental data with the maximum margin of deviation of 4.2% as following:

$$\frac{K_{nf}}{K_f} = 1.21 - 0.009581\mathrm{T} - 0.223\varphi + 0.0001223\mathrm{T}^2 + 0.006598 \times \mathrm{T} \times \varphi \qquad (6)$$

Where: K_{nf}, is the thermal conductivity of nanofluids, K_f is the thermal conductivity of water, T is the temperature of the nanofluids, and φ is the volume fraction. **Related publication [P8]**.

Thesis 5

It was found that the thermal conductivity of tungsten oxide WO_3 nanoflakes based deionized water nanofluid increased by increasing the volume concentration and temperature of the nanofluids. The thermal conductivity enhancement ratio (K_{nf}/K_f), was revealed to be (1.066) at higher volume concentration (0.05% Vol.) and temperature (90 °C) compared to deionized water as a baseline case. **Related publication [P10]**.

Thesis 6

The pool boiling heat transfer performance using cerium oxide (CeO_2) nanoparticle-based water nanofluids from the horizontal heated copper tube at atmospheric pressure was experimentally investigated. The pool boiling heat transfer coefficient PBHTC measurements revealed that the maximum PBHTC ratio $\left(PBHTC_{nf}/PBHTC_{water}\right)$ was 1.7 compared to the deionized water baseline case at dilute volume concentration 0.007% Vol. and low heat flux $(15\ \mathrm{kW/m^2})$ when the surface roughness of the heated tube was ($R_a = 0.115$ µm). The results also demonstrated that the PBHTC enhancement ratio decreased as volume concentrations increased (i.e., 0.01% and 0.04% Vol.), whereas it was still improving compared to the deionized water case.

$$PBHTC\ enhancement\ ratio = PBHTC_{nf}/PBHTC_{water} \qquad (7)$$

Where: $PBHTC_{nf}$ and $PBHTC_{water}$ are the pool boiling heat transfer coefficients of nanofluids and deionized water, respectively. **Related publication [P7]**.

Thesis 7

Dilute volume concentrations within a range of (0.001% to 0.5% Vol.) were tested to investigate the pool boiling heat transfer performance of different types of mono nanofluids so-called aluminum oxide Al_2O_3, aluminum nitride AlN, magnesium oxide MgO nanoparticles as well as tungsten oxide WO_3 nanoflakes based deionized water nanofluids with a tube surface roughness of ($R_a = 0.382$ μm) at atmospheric conditions. The pool boiling performance represented by pool boiling heat transfer coefficient PBHTC ratio was measured. The obtained results indicated that the PBHTC ratio ($PBHTC_{nf}/PBHTC_{water}$) was enhanced for dilute volume concentration (i.e., less than 0.01% Vol.) for all prepared nanofluids, and the maximum PBHTC enhancement ratio was (1.40, 1.33, 1.22, and 1.067) at heat fluxes (15.251, 28.954, 102.952, and 14.527 $\mathrm{kW/m^2}$) for Al_2O_3, AlN, MgO nanoparticles, and WO_3 nanoflakes -based deionized water nanofluids, respectively. **Related publications [P9, P10]**.

Thesis 8

Under the atmospheric pressure conditions, the pool boiling heat transfer performance from a typical horizontal heated copper tube with a surface roughness ($R_a = 0.382$ μm) using different types of mono nanofluids, which are aluminum oxide Al_2O_3, aluminum nitride AlN, magnesium oxide MgO nanoparticles, and tungsten oxide WO_3 nanoflakes -based deionized water nanofluids was studied. The influence of various dilute volumetric concentrations within a range of (0.001% to 0.5% Vol.), and applied heat flux ranging from ($14 - 120\ \mathrm{kW/m^2}$) for pool boiling heat transfer coefficient and pool boiling curve were studied. It was revealed that the PBHTC ratio ($PBHTC_{nf}/PBHTC_{water}$) was degraded for volume concentrations (i.e., above 0.01% Vol.) for all types of nanofluids, and the maximum PBHTC reduction ratio was (0.83, 0.82, 0.85, and 0.85) at heat fluxes (65.504, 14.933, 14.397, and 87.140 $\mathrm{kW/m^2}$) for Al_2O_3, AlN, MgO nanoparticles, and WO_3 nanoflakes based deionized water nanofluids, respectively. **Related publications [P9, P10, P15]**.

Thesis 9

A new types of nanofluids, so-called hybrid nanofluids, which consists of two kinds of nanopowders (aluminum oxide Al_2O_3 and cerium oxide CeO_2 50:50 by volume) and (aluminum oxide Al_2O_3 and magnesium oxide MgO, 50:50 by volume) with different volume concentrations (0.01%, 0.05% and 0.1% Vol.), were prepared via two-step method. The effect of volume concentration and applied heat flux were studied to assess the pool boiling heat transfer coefficient enhancement ratio from a typical horizontal heated copper tube with a surface roughness ($R_a = 0.382$ μm) and atmospheric pressure conditions. Results demonstrated that both hybrid nanofluids enhanced the pool boiling performance for all concentrations, compared to the deionized water baseline and the maximum PBHTC enhancement ratio was (1.37 and 1.44) at moderate heat flux (44 kW/m^2) and volume concentration (0.01% Vol.) for Al_2O_3+CeO_2 and Al_2O_3+MgO hybrid nanofluids, respectively. **Related publication [P11]**.

5. The list of publications

❖ *Journals publications*

[P1] Kamel, M. S., Lezsovits, F., Hussein, A. M., Mahian, O. & Wongwises, S. Latest developments in boiling critical heat flux using nanofluids: A concise review. *International Communication in Heat and Mass Transfer*. 98, 59–66 (2018). https://doi.org/10.1016/j.icheatmasstransfer.2018.08.009 **(Appeared)**, **(Q1, WoS, IF = 4.127)**

[P2] Kamel, M. S. & Lezsovits, F. Simulation of nanofluids laminar flow in a vertical channel. *Pollack Periodica*. 13, 147–158 (2018). DOI: 10.1556/606.2018.13.2.15 **(Appeared)**, **(Q3, Scopus)**

[P3] Kamel, M. S. & Lezsovits, F. Boiling heat transfer of nanofluids a review of recent studies. *Thermal Science*. 23, 109–124 (2019). https://doi.org/10.2298/TSCI170419216K **(Appeared)**, **(Q3, WoS, IF = 1.541)**

[P4] Kamel, M. S., Lezsovits, F. & Hussein, A. K. Experimental studies of flow boiling heat transfer by using nanofluids: A critical recent review. *Journal of Thermal Analysis and Calorimetry*. 2, (2019). https://doi.org/10.1007/s10973-019-08333-2 **(Appeared)**, **(Q2, WoS, IF = 2.471)**

[P5] Kamel, M. S. & Lezsovits, F. Predicting of pool boiling heat transfer from a horizontal heated tube by using two fluids multiphase model. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, (**Accepted**), (2019). **(Q3, Scopus),** (***Related to thesis***).

[P6] Kamel, M. S., Sobhi, M., Lezsovits, F. & Mahian, O. Simulation of pool boiling of nanofluids by using Eulerian multiphase model. *Journal of Thermal Analysis and Calorimetry*. (2019). doi:10.1007/s10973-019-09180-x. (**Appeared online**) (2019). **(Q2, WoS, IF = 2.471),** (***Related to thesis***).

[P7] Kamel, M. S. & Lezsovits, F. Enhancement of pool boiling heat transfer performance using dilute Cerium oxide/ water nanofluid: An experimental investigation. *International Communication in Heat and Mass Transfer*, (**Accepted**), (2020). **(Q1, WoS, IF = 4.127),** (***Related to thesis***).

[P8] Kamel, M. S., Al-Oran, O. & Lezsovits, F. Thermal conductivity of Al_2O_3 and CeO_2 nanoparticles and their hybrid based water nanofluids: An experimental study. *Periodica Polytechnica Chemical Engineering*. (**Accepted**), (2020). **(Q3, WoS, IF = 1.382),** (***Related to thesis***).

[P9] Kamel, M. S. & Lezsovits, F. Experimental study on pool boiling heat transfer of magnesium oxide nanoparticles based water nanofluid. *Pollack Periodica*. (**Accepted**) (2020). **(Q3, Scopus),** (***Related to thesis***).

[P10] Kamel, M. S. & Lezsovits, F. Experimental Investigation on Pool Boiling Heat Transfer Performance Using Tungsten Oxide WO_3 Nanomaterial Based Water Nanofluids. *Materials*. (**Under Review**), (2020). **(Q2, WoS, IF = 2.972),** (***Related to thesis***).

[P11] Kamel, M. S. & Lezsovits, F. Intensification of pool boiling heat transfer performance using a new type of hybrid nanofluids: An experimental study. *Chemical Engineering and Processing: Process Intensification*, (**Under preparing**), (2020). **(Q1, WoS, IF = 3.031),** (***Related to thesis***).

❖ *Conference proceeding and abstracts publications*

[P12] Kamel, M. S. & Lezsovits, F. Recent progress in flow boiling heat transfer of nanofluids, *In Proceedings of the 13th Conference of Heat Engines and Environmental Protection (HEEP)*. Budapest (Hungary), 202, 123-137 (2018).

[P13] Kamel, M. S. & Lezsovits, F. Simulation of pool boiling heat transfer using RPI model. *In Proceedings of the 14th Conference of Heat Engines and Environmental Protection (HEEP)*. Budapest (Hungary), (2019).

[P14] Kamel, M. S. & Lezsovits, F. Numerical and Experimental Investigation of Boiling Heat Transfer Using Nanofluids in a Vertical Channel. *13th Miklós Iványi International PhD & DLA Symposium*, University of Pecs, 3-4 Nov, (2017). **(Published in book abstract)**.

[P15] Kamel, M. S. & Lezsovits, F. Experimental study on pool boiling heat transfer of MgO/ Water nanofluid from a typical horizontal heated tube. *15th Miklós Iványi International PhD & DLA Symposium*, University of Pecs, 27-28 Oct, (2019). **(Published in book abstract)**.

[P16] Kamel, M. S., Al-agha, M. S. & Lezsovits, F. Pool boiling of nanofluid using heat flux partitioning model (RPI): CFD investigation. *2nd Journal of Thermal Analysis and Calorimetry Conference and 7th V4 (Joint Czech-Hungarian-Polish-Slovakian) Thermo-analytical Conference (JTACC+V4)*, 18-21 June 2019, Budapest (Hungary). (2019), (**Published in book abstract**).

❖ *Others*

[P17] Kamel, M. S. & Lezsovits, F. Simulation of pool boiling heat transfer using RPI model. *Poster in 14th Conference of Heat Engines and Environmental Protection (HEEP)*. Budapest (Hungary), (2019).

[P18] Kamel, M. S., Al-agha, M. S. & Lezsovits, F. Pool boiling of nanofluid using heat flux partitioning model (RPI): CFD investigation. *Poster in 2nd Journal of Thermal Analysis and Calorimetry Conference and 7th V4 (Joint Czech-Hungarian-Polish-Slovakian) Thermo-analytical Conference (JTACC+V4)*, 18-21 June 2019, Budapest (Hungary), (2019).

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[11] Cheng, S. C. & Vachon, R. I. The prediction of the thermal conductivity of two and three phase solid heterogeneous mixtures. Int. J. Heat Mass Transf. 12, 249–264 (1969).

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