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Numerical Investigation on Heat Transfer Enhancement of Graphene Oxide-Water Nanofluids in a Corrugated Channel

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Abstract

The present study represents the heat transfer enhancement of graphene oxide-water nanofluids in a corrugated channel. A uniform heat flux was subjected to the bottom surface of the channel and mixture model was applied to investigate parameters of five Reynolds number (133<Re<1515), four volume fractions (φ=0.139, 0.278, 0.417 and 0.556 %) and two amplitudes of the corrugated wall (a=5 and 10 mm). The numerical solution procedure includes the investigation of heat transfer and pressure drop characteristics with using finite volume method with standard k-ε turbulence model to solve the continuity, momentum, energy and turbulence equations in three dimensional domain. The results indicated that the heat transfer enhancement increased with decreasing of amplitude. The use of graphene-water nanofluids leads to increase in heat transfer and pressure drop over the smooth channel. The Nusselt number increased with increasing volume fraction and Reynolds number. In conclusion, to enhance heat transfer, graphene oxide-water nanofluids and corrugated surfaces can be widely applied wherever heat exchangers with channels are used.

Keywords: Graphene-water nanofluids, heat transfer, pressure drop, corrugated channels

INTRODUCTION

Heat transfer enhancement methods one of the most significant issue for saving energy and cost in heat transfer mechanism. Both passive and active techniques are used to enhance heat transfer in heat exchanger applications. Heat transfer increases with passive and active techniques but these methods required extra pumping power. For this reason, researchers started to investigate new methods to reach better thermohydraulic performance in heat transfer process. For the managing of heat transfer system and improving of heat exchangers coefficient, the physical properties of heat exchanger have been improved. Heat transfer fluids such as water, ethylene glycol or oil limit the performance of heat exchangers [1]. For this reason, researchers started to investigate alternative fluids which have better thermophysical properties when they used in heat exchangers. Nanofluids are suspension containing nanoparticles and thermal conductivities of nanofluids are significantly higher than those of base liquids [2]. The most notably property of nanofluid is enhance the heat transfer rate relatively and increase the pressure drop and pumping power slightly.

Many studies have conducted the advantages of nanofluids over base fluids by using SiO_2, TiO_2, Al_2O_3, CuO nanofluids. However, only limited researches have been performed about the thermohydraulic performance of graphene-water nanofluids. Duangthongsuk and Wongwises [3] experimentally investigated that effect of TiO_2-water nanofluid on heat transfer coefficient and friction factor in a double tube counter flow heat exchanger under turbulent flow conditions. They concluded that maximum heat transfer coefficient is obtained 26% higher than base fluid for 1.0 % volume fraction. Demir et al. [4] carried out forced convection flows of nanofluids consisting of water with Al_2O_3 and TiO_2 nanoparticles in a horizontal tube. Z. Yari Ghale et al. [5] investigate the heat transfer enhancement of a ribbed microchannel heat sink at laminar flow conditions, numerically. The experiments were carried out with water-alumina nanofluids and the single phase and multiphase CFD models were studied. A. Ghozatloo et al. [6] investigated the convective heat transfer behavior of graphene nanofluids through the shell and tube heat exchanger under laminar flow. They achieved that the improvement of thermal conductivity up to 31.83%. Abdolbaqi et al.[7] conducted a numerical study about the effect of water based CuO, TiO_2 and Al_2O_3 nanofluid flow through a straight square channel under constant heat flux.. The results showed that the highest Nusselt number values observed for CuO-water nanofluids. An experimental study on heat transfer and pressure drop of multi-walled carbon nano tubes-water nanofluid inside horizontal coiled wire inserted tube realized by Behabadi et al. [8]. It is found that 85% increase in heat transfer rate and 475% in pressure drop at the highest Reynolds number for experimental tube fitted with coiled wire inserts with highest wire diameter. T.Tharayil et al. [9] experimentally analyzed the heat transfer performance of miniature loop heat pipe with graphene-water nanofluid. D.K. Agarwal et al. [10] investigated the thermal performance of kerosene based nanofluid containing graphene nanoplatelets. The results showed that 49% enhancement in convective heat transfer coefficient was noticed.

In this study, heat transfer enhancement of graphene oxide-water in a corrugated channel numerically investigated. The analysis conducted with four different volume fractions (φ=0.139, 0.278, 0.417 and 0.556 %) of nanofluid, five different Reynolds number ranging from 133 to 1515 and corrugated channels with two different amplitudes. Constant heat flux of 20 kW/m² is applied on the outer surface of the test channel. It is assumed that the flow is under developed turbulent condition. The primal aim of this study to investigate the effect of different volume fractions of graphene oxide-water nanofluid and corrugation amplitude of the channel on heat transfer rate and friction factor coefficient at different Reynolds number.

NUMERICAL METHOD

Numerical Solution Procedure

In this study the two phase model has been applied in the modeling of nanofluid. There are two general approaches used for flow of solid-liquids mixtures Lagrangian-Eulerian for low solid volume fractions, for higher volume fractions Eulariene-Eulerian. Due to limitations of the software abilities, memory and CPU requirements the usage of Lagrangian-Eulerian model impossible. For this reason the mixture model has been used for this numerical investigation.

The three-dimensional continuity, momentum and energy of Navier-Stokes equations are solved by using finite volume method and the SIMPLE algorithm scheme is applied to examine the effects of turbulent flow on heat transfer and friction characteristics. Second order upwind discretization schemes were chosen on all the transport equations. The standard k-ε turbulence model was selected. In order to compute data with high accuracy, the residual sum was computed and set for each iteration and the convergence criterion was less than 10-6 for all equations.

Boundary Conditions

As illustrated in Figs.1 and 2, the smooth channel and corrugated channel were created with length of 50 mm, width of 1 mm and height of 1.5 mm. Two different corrugation amplitude was selected as 5 and 10 mm. A constant uniform heat flux of 20 kW/m² was applied onto the bottom surface of the channels, other surfaces were assumed well insulated to the surroundings. Reynolds number was in the range of 133 to 1515. The inlet fluid temperature was determined as 300 K. The graphene oxide-water nanofluid volume fractions were assumed φ=0.139, 0.278, 0.417 and 0.556 %.

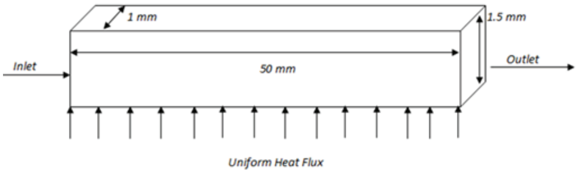

Figure 1. Geometrical properties of smooth channel

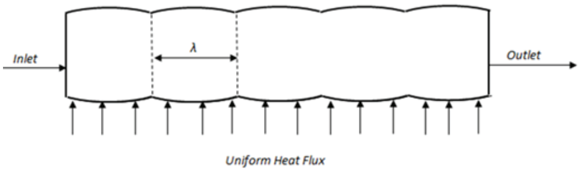

Figure 2. Geometrical properties of corrugated channel

Validation method and Grid Optimization

Numerical analysis need to be supported experimental results, for the best agreements different turbulence models and grid independency should be investigated. Ho and Chen [11] investigated the thermal performance of Al_2O_3/ water nanofluid in a microchannel heat sink. Morevaji and Ardehali [12] numerically validated the Ref. [11] and investigated different two phase models. In this present work both experimental and numerical investigation was validated in two different volume fractions. As in Figs. 3 and 4 good agreements for Al_2O_3 /water nanofluids are obtained with both experimental and numerical investigations.

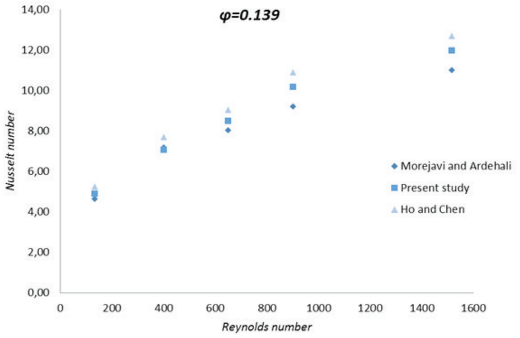

Figure 3. Comparison of Nusselt number versus Reynolds number present study with Refs. [11] and [12] for 0.139% Al_2O_3 /water nanofluids.

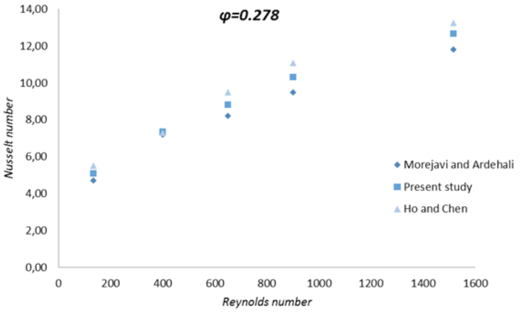

Figure 4. Comparison of Nusselt number versus Reynolds number present study with Refs. [11] and [12] for 0.278% Al_2O_3 /water nanofluids.

A careful check for grid independence is required for ensuring the validity and accuracy of numerical methodology. For this purpose, detailed grid indepence tests were conducted and according to the grid models. As in Fig 5 mesh models of smooth and corrugated channel were created with 600 x 18 x 12 nodes (600 grids in length, 18 grids in height and 12 in width). After 600 x 18 x 12 nodes Nusselt number has increased less than 2% conjunction with accrual of cells number.

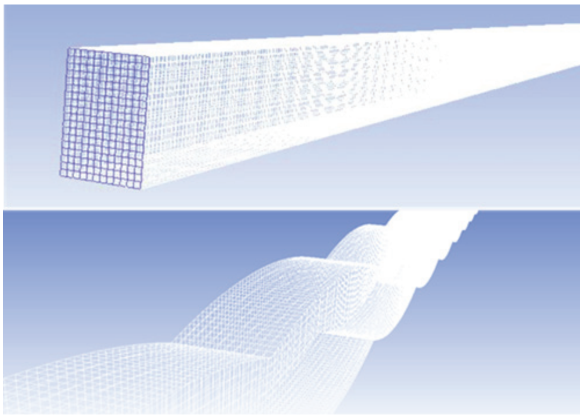

Figure 5. Mesh models of smooth and corrugated channel

Thermo-physical Properties of Nanofluid

Conventional heat transfer fluids can be easily used for heat transfer process. However, in order to provide better thermohydraulic performance different heat transfer fluid improved such as nanofluids. To determine thermo physical properties of nanofluid, following equations were presented by researchers.

The thermal efficiency of nanofluids can be determined by the heat transfer coefficient which is a function of a number of thermo-physical properties such as density, specific heat, thermal conductivity and viscosity.

The density of nanofluid expressed by B.C. Pak and Y.I. Cho [13]:

$$\rho_{nf}=(1-\varphi)\,\rho_{bf}+\varphi\rho_{np} \qquad (1)$$

Specific heat of nanofluid determined by Buongiorno J. [14]:

$$Cp_{nf}=\frac{((1-\varphi)\rho_{bf}Cp_{bf}+\varphi\rho_{np}Cp_{np})}{\rho_{nf}} \qquad (2)$$

For calculation the thermal conductivity of nanofluid Eq. 3 which was developed by Hamilton and Crosser [15] was used.

$$k_{nf}=\frac{k_{bf}[k_{np}+(n-1)k_{bf}-(n-1)\varphi(k_{bf}-k_{np})}{[k_{np}+(n-1)k_{bf}+\varphi(k_{bf}-k_{np})]} \qquad (3)$$

Dynamic viscosity was also calculated from the following equation,

$$\mu_{nf}=\mu_{bf}\,(123\varphi^2+7.3\varphi+1) \qquad (4)$$

Nanofluids composed from a base fluid and nanoparticles. The thermo-physical properties of nanofluids calculated with using above equations. In order to calculate, thermo-physical properties of grapheme-water nanofluid, density, specific heat, dynamic viscosity and thermal conductivity of graphene and water as given in Table 1.

Table 1. Thermo-physical properties of the nanoparticles graphene and water at T = 300 K.

Thermo-physical properties	Graphene[16]	Water
ρ (kg/m³)	2250	998.2
Cp (j/kgK)	710	4182
μ (kg/ms)	-	1.003E-03
k (W/mK)	2000	0.6

Calculation Heat Transfer and Friction Factor

The uniform heat flux applied to the channel can be written as;

$$q=\frac{Q}{\pi DL} \qquad (5)$$

The convective heat transfer coefficient through the channel is defined as;

$$h=\frac{q}{(T_{iw}-T_b)} \qquad (6)$$

Here, T_{iw} and T_b represent inner wall temperature of the numerical method and bulk temperature of fluid.

The Nusselt and Reynolds numbers can be calculated from;

$$Nu=\frac{hD}{k} \qquad (7)$$

where k is the conductive heat transfer coefficient of fluid.

$$\mathrm{Re}=\frac{UD}{v} \qquad (8)$$

where D is hydraulic diameter, U is velocity, v is kinematic viscosity.

The friction factor is defined as;

$$f=\frac{\Delta P}{(\frac{1}{2}\rho . U^2\, {}^{L}\!/_{D})} \qquad (9)$$

The overall enhancement efficiency (η) is introduced by Webb[17]:

$$\eta=(Nu_n/Nu_s)\,(f_s/f_n)^{1/3} \qquad (10)$$

RESULTS and DISCUSSIONS

In this work both an experimental and numerical study were validated and many numerical analysis were conducted. The results indicated that the heat transfer enhancement increased with decreasing of amplitude. The use of graphene-water nanofluids leads to increase in heat transfer and pressure drop over the smooth channel. The Nusselt number increased with increasing volume fraction and Reynolds number. In conclusion, to enhance heat transfer, graphene oxide-water nanofluids and corrugated surfaces can be widely applied wherever heat exchangers with channels are used.

Smooth Channel Results

The variation of convective heat transfer coefficient and friction factor coefficient characteristics for different volume concentration of graphene oxide-water nanofluid in smooth channel is given in Figs 6 and 7, respectively. Fig.6 shows that Nusselt number increases with the increment of volume fraction with reference to base fluid. The highest Nusselt number of 25,5 observed for φ=0.556 volume fraction at Reynolds number of 133. The friction factor decreases with the increasing of Reynolds number. The friction factor did not change effectively with the volume fraction as seen in Fig. 7.

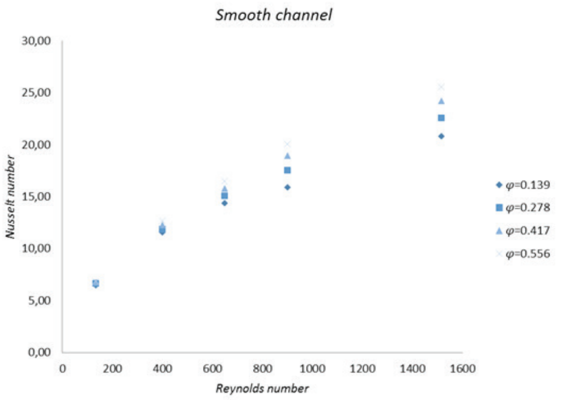

Figure 6. Nusselt number versus Reynolds number for smooth channel

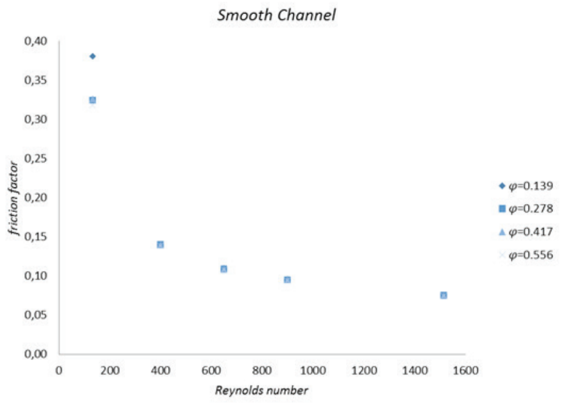

Figure 7. Friction factor versus Reynolds number for smooth channel

Corrugated Channel Results

The numerical analyses were conducted for two different corrugation amplitude. It is clearly seen in Figs. 8-11 both Nusselt number and friction factor values higher than the other corrugation amplitude at 5 mm. As in Figs. 8 and 9 both Nusselt number and friction factor values higher than smooth channel values. Fig. 8 also showed that the heat transfer rate increase with the increase of Reynolds number. Increment of the volume fraction also improves the heat transfer rate.

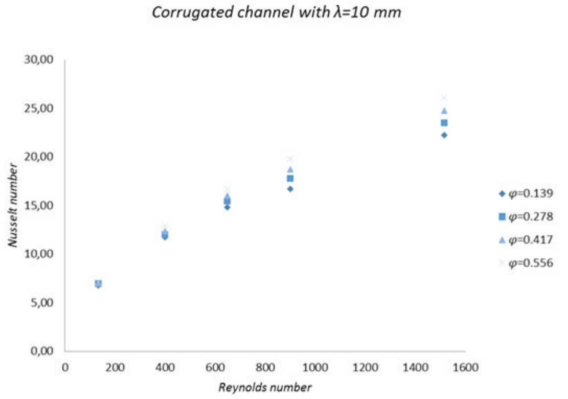

Figure 8. Nusselt number versus Reynolds number for corrugated channel at 10 mm amplitude

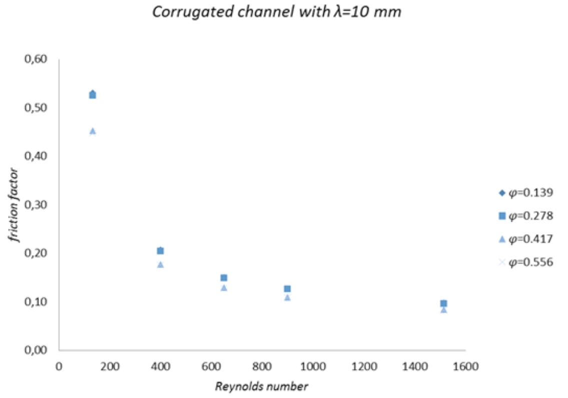

Figure 9. Friction factor versus Reynolds number for corrugated channel at 10 mm amplitude

The decrease in corrugation amplitude, provide better flow mixture in the channel enhanced the heat transfer rate effectively. As in Fig. 10 the highest Nusselt number of 26.62 achieved for $\varphi=0.556$ volume fraction at Reynolds number of 133 for lowest corrugation amplitude. The highest Nusselt number and friction factor values observed for this configuration showed in Figs 10 and 11. Since the amplitude of corrugated surface lower than the other corrugated channel, heat transfer enhanced with this model effectively.

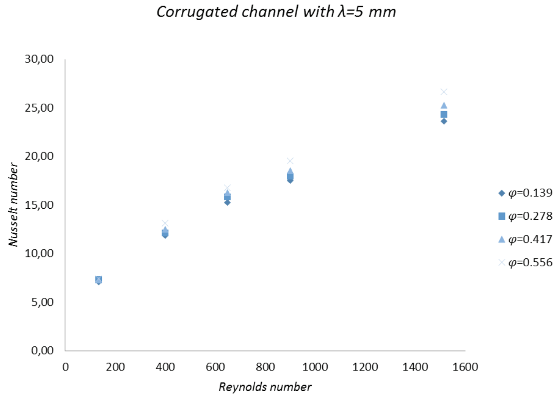

Figure 10. Nusselt number versus Reynolds number for corrugated channel at 5 mm amplitude

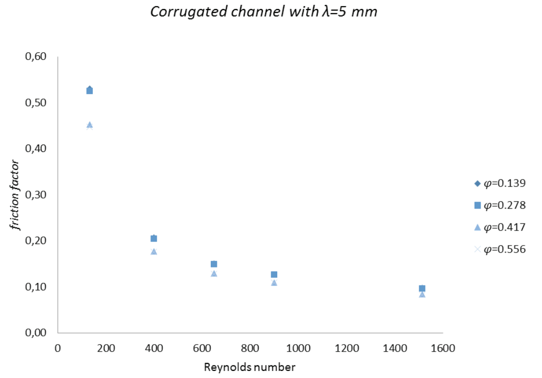

Figure 11. Friction factor versus Reynolds number for corrugated channel at 5 mm amplitude

Performance evaluation

Evaluation of the performance of corrugated and smooth channel using graphene-water nanofluid was inducted using the overall enhancement ratios. The ratios of overall enhancement increased or decreased depending on the Nusselt number and friction factor ratios.

The variation in the overall enhancement ratio (η) with the Reynolds number is shown in Fig. 12. The corrugation amplitude and graphene-water nanofluid cause not only an increase in Nusselt number but also an increase in the friction factor. Therefore, an analysis for the calculation of the net energy gain needs to done. If the overall enhancement ratio is greater than unity, the system achieves a net energy gain. According to the Fig. 12 thermohydraulic performance of all systems above unity, and the highest enhancement ratio of 1.84 achieved for $\varphi=0.556$ volume fraction at Reynolds number of 133 for lowest corrugation amplitude.

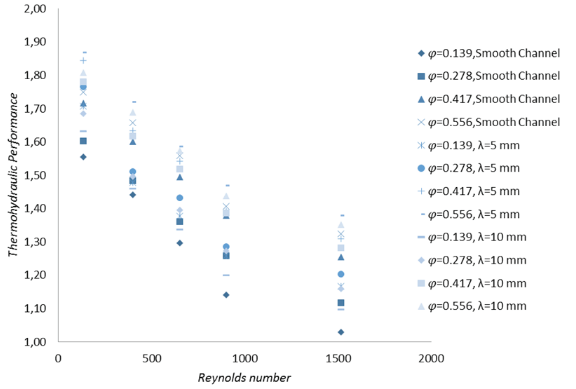

Figure 12. Thermohydraulic performance versus Reynolds number for all models

CONCLUSIONS

The present study represents the heat transfer enhancement of graphene oxide-water nanofluids in a corrugated channel. A uniform heat flux was subjected to the bottom surface of the channel and mixture model was applied to investigate parameters of five Reynolds number (133<Re<1515), four volume fractions (φ=0.139, 0.278, 0.417 and 0.556 %) and two amplitudes of the corrugated wall (a=5 and 10 mm). Heat transfer coefficient dramatically enhanced by the graphene-water nanofluids.The increment of the volume fractions were also positively affected on the heat transfer coefficients. The maximum enhancement ratio is 1.84 that occurs for 0.556 volume fraction and 5 mm corrugation amplitude at Reynolds number 133. There were not any remarkable differences occurred between the pressure drop of the all models. According to the numerical investigation results, the graphene-water nanofluid introduced a good performance to enhance the heat transfer coefficient; therefore, it can be more effective in heat transfer applications.

REFERENCES

[1] W. Yu, H. Xie and D. Bao, 2009. Enhanced thermal conductivities of nanofluids containing graphene oxide nanosheets. Nanotechnology. 21:7.

[2] H. Zhu, C. Zhang, S. Liu, Y. Tang, Y. Yin, 2006. Effects of nanoparticle clustering and alignment on thermal conductivities of Fe3O4 aqueous nanofluids. Applied Phsysics Letters. 89.

[3] W. Duangthongsuk, S. Wongwises, 2010. An experimental study on the heat transfer performance and pressure drop of TiO_2-water nanofluids flowing under a turbulent flow regime. International Communications in Heat and Mass Transfer. 53:334-344.

[4] H. Demir, A. S. Dalkilic, N. A. Kürekci, W. Duangthongsuk, S. Wongwises, 2011. Numerical investigation on the single phase forced convection heat transfer characteristics of TiO_2 nanofluids in a double-tube counter flow heat exchanger. International Communications in Heat and Mass Transfer. 38:218-228.

[5] Z. Yari Ghale, M. Haghshenasfard, M. Nasr Esfahany, 2015. Investigation of nanofluids heat transfer in a ribbed microchannel heat sink using single-phase and multiphase CFD models. International Communications in Heat and Mass Transfer. 68:122-129.

[6] A. Ghozatloo, A. Rashidi, M. Shariaty-Niassar, 2014. Convective heat transfer enhancement of graphene nanofluids in shell and tube heat exchanger. Experimental Thermal and Fluid Science. 53:136-141.

[7] Abdolbaqi M. Kh., Azwadi C.S.N., Mamat R., 2014. Heat transfer augmentation in the straight channel by using nanofluids. Case Studies in Thermal Engineering. 3:59-67.

[8] M.A. Akhavan-Behabadi, Mohamad Shahidi, M.R. Aligoodarz, 2015. An experimental study on heat transfer and pressure drop of MWCNT–water nano-fluid inside horizontal coiled wire inserted tube. International Communications in Heat and Mass Transfer. 63:62-72.

[9] T. Tharayil, L. G. Asirvatham, V. Ravindran, S. Wongwises, 2016. Thermal performance of miniature loop heat pipe with graphene–water nanofluid. International Journal of Heat and Mass Transfer. 93:957-958.

[10] D. K. Agarwal, A. Vaidyanathan, S. S. Kumar, 2016. Experimental investigation on thermal performance of kerosene–graphene nanofluid. Experimental Thermal and Fluid Science, 71:126-137.

[11] C.J. Ho, W.C. Chen, 2013. An experimental study on thermal performance of Al_2O_3/water nanofluid in a minichannel heat sink. Applied Thermal Engineering, 50:516-522.

[12] Mostafa Keshavarz Moraveji, Reza Mohammadi Ardehali, 2013. CFD modeling (comparing single and two-phase approaches) on thermal performance of Al_2O_3/water nanofluid in mini-channel heat sink. International Communications in Heat and Mass Transfer. 44:157-164.

[13] B. C. Pak, Y. I. Cho, 2007. Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. Experimental Heat Transfer. 11:151-170.

[14] J. Buongiorno, 2006. Convective transport in nanofluids. ASME J. Heat Transfer. 128:240-250.

[15] S. J. Palm, G. Roy, C. T. Nguyen, 2006. Heat transfer enhancement with the use of nanofluids in radial flow cooling systems considering temperature-dependent properties. Applied Thermal Engineering. 26:2209-2218.

[16] E. Pop, V. Varshney, A. K. Roy, 2012. Thermal properties of graphene: Fundamentals and applications. MRS Bulletin. 37:1273-1281.

[17] R.L. Webb, 1981. Performance evaluation criteria for use of enhanced heat transfer surfaces in heat exchanger design. International Journal of Heat Mass Transfer. 24:715–726.