Numerical Study on Heat Transfer Characteristics of Minichannel with Fe_3O_4 Nanofluid Under Influence of Magnetic Intensity

Kunal Sandip Garud, Seong-Guk Hwang, Jeong-Woo Han, Moo-Yeon Lee
Dept. of Mechanical Engineering, Dong-A University
e-mail:mylee@dau.ac.kr

자계 강도 영향을 받는 Fe_3O_4 나노유체를 이용한 미니 채널의 열전달 특성에 관한 수치연구

쿠날 산딥 가루드, 황성국, 한정우· 이무연
동아대학교 기계공학과

Abstract

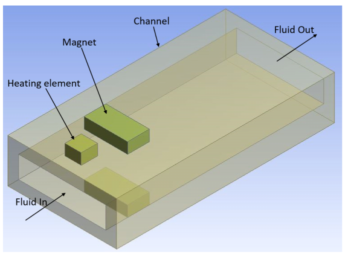
In the present work, the heat transfer characteristics of water and Fe_3O_4 nanofluid are investigated numerically under without and with magnetic intensity. The water and Fe_3O_4 nanofluid are flowing through a minichannel provided with heating element at the top near the inlet. The heat transfer characteristics of temperature difference, heat transfer coefficient and Nusselt number are compared for water and Fe_3O_4 nanofluid with various volume fractions. The ANSYS FLUENT commercial software is employed in the present numerical investigations. The simulated results show that all heat transfer characteristics are better for Fe_3O_4 nanofluid than water and improve as the volume fraction increases in both cases of without and with magnetic intensity. And the heat transfer characteristics for Fe_3O_4 nanofluid with all volume fractions are superior in case of with magnetic intensity compared to without magnetic effect. The highest values of temperature difference, heat transfer coefficient and Nusselt number are reported as 20.61 °C, 3672.44 W/m^2 K and 97.93, respectively for Fe_3O_4 nanofluid with 2.0% volume fraction under tmagnetic intensity.

1. Introduction

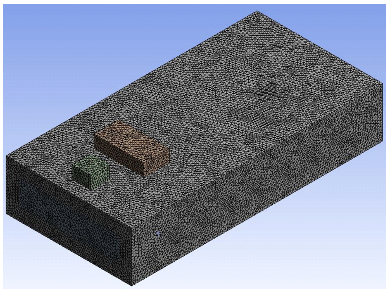
In the recent times, the heat transfer applications are demanding for the working fluids with superior thermophysical properties. Due to poor thermal conductivity of conventional working fluids namely, water, ethylene glycol and engine oil etc, the research trend is drastically shifting towards the nanofluids in heat transfer applications. The nanofluids enable the excellent thermophysical properties due to dispersion of solid nanoparticles into base fluids [1]. Especially, in the field of nanofluids, the Fe_3O_4 nanoparticles present magnetic characteristics along with superior thermal properties [2]. Ghasemian et al. have reported the heat transfer enhancement for Fe_3O_4 nanofluid flow in mini channel under the influence of constant and alternating magnetic fields [3]. Sundar et al. have presented 30.96% improved heat transfer coefficient for Fe_3O_4 nanofluid compared to water [4]. Seo and Lee have shown that the LED heat transfer and illuminance performances are improved by employing external magnetic field [5].

2. Numerical approach

The three-dimensional geometry of minichannel with water and nanofluid flow is depicted in Fig. 1. The heating element is arranged on the top of the minichannel near to the inlet. The heat transfer characteristics of water and Fe_3O_4 nanofluid are compared for the employed heat flux by the heating element. Three volume fractions of 0.5%, 1.0% and 2.0% are considered for Fe_3O_4 nanofluid. The Fe_3O_4 nanofluid has magnetic characteristics, the heat transfer characteristics are compared with and without magnet intensities. Two ferrite magnets are placed across the minichannel symmetrical near the inlet to impose the magnetic flux intensity on the nanofluid flow. The meshing with tetrahedrons and 600,428 mesh elements are adopted for the considered computational domain as shown in Fig. 2. The selected meshing configuration presents the variation of simulated results within 0.5%.



[Fig. 1] Three-dimensional geometry of minichannel with water and nanofluid flow



[Fig. 2] Meshing configuration for considered computational domain

3. Data reduction

The simulated temperatures during the numerical analysis are used to evaluate the heat transfer characteristics of various working fluids. The heat transfer characteristics namely, average heat transfer coefficient (h) and average Nusselt number (Nu) are evaluated using equations (1) to (3) [6].

$$h = \frac{Q}{A(T_w - T_{f,ave})} \tag{1}$$

$$Q = m_f c_p (T_{f,o} - T_{f,i}) \tag{2}$$

$$Nu = \frac{hD}{k} \tag{3}$$

The thermal conductivity of nanofluid is calculated using equation (4).

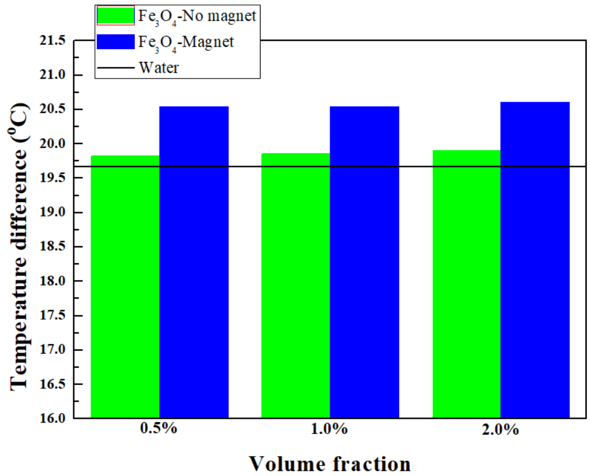
$$\frac{k_{nf}}{k_{bf}} = \frac{(k_{np} + 2k_{bf}) - 2\varnothing(k_{bf} - k_{np})}{(k_{np} + 2k_{bf}) + \varnothing(k_{bf} - k_{np})} \tag{4}$$

Here, T_w is average wall temperature (°C), $T_{f,o}$ is outlet fluid temperature (°C), $T_{f,i}$ is inlet fluid temperature (°C), $T_{f,ave}$ is average fluid temperature (°C), D is hydraulic diameter (m), k is thermal conductivity (W/m K), m_f is mass flow rate of fluid (kg/s), k_{nf} is thermal conductivity of nanofluid (W/m K), k_{bf} is thermal conductivity of basefluid (W/m K) and k_{np} is thermal conductivity of nanoparticles (W/m K).

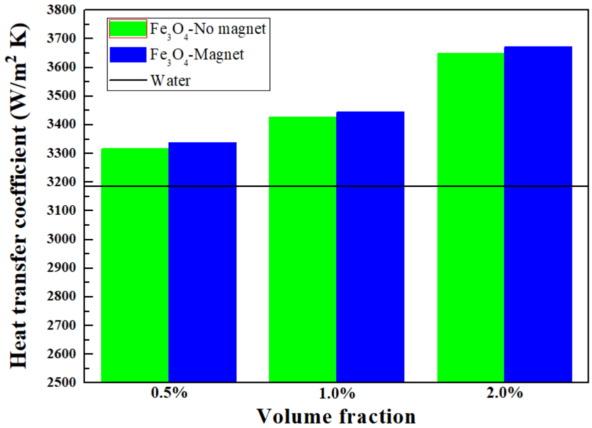
4. Results and discussion

The temperature differences across the minichannel for water and Fe_3O_4 nanofluid with various volume fractions are compared under the influence of without and with magnet intensities as shown in Fig. 3. In both cases of without and with magnet intensities, the temperature difference is higher than water for each volume fraction. The temperature difference enhances with increase in the volume fraction. The temperature difference increases by 0.39% and 0.33% for without and with magnet intensities, respectively when volume fraction increases from 0.5% to 2.0%. Compared to water, the temperature differences for without magnet and with magnet intensities are higher by 0.78~1.17% and 4.42~4.76%, respectively over the considered volume fraction range.

The heat transfer coefficients of Fe_3O_4 nanofluid with all volume fractions are higher than water for both cases of without and with magnet intensities as shown in Fig. 4. The improvement in the thermal properties of nanofluid compared with water has resulted in higher heat transfer coefficient. Over the range of considered volume fraction, the heat transfer coefficient improves by 4.09~14.48% and 4.74~15.22% for without and with magnet intensities, respectively. With increase in the volume fraction from 0.5% to 2.0%, the heat transfer coefficient enhances by 9.99% and 10.01% for without and with magnet intensities, respectively.



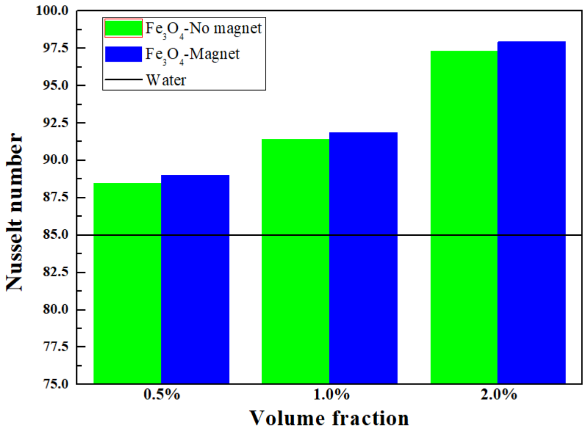
[Fig. 3] Temperature difference for water and Fe_3O_4 nanofluid with various volume fractions considering without and with magnetic effect



[Fig. 4] Heat transfer coefficient for water and Fe_3O_4 nanofluid with various volume fractions considering without and with magnetic effect

The Nusselt number comparison for water and water and Fe_3O_4 nanofluid with various volume fractions under without and with magnet intensities is depicted in Fig. 5. Due to improvement in temperature difference and heat transfer coefficient, the Nusselt number also enhances for Fe_3O_4 nanofluid with all volume fractions compared to water. The Nusselt number for water is evaluated as 84.99 and that for Fe_3O_4 nanofluid with all volume fractions is evaluated as 88.47~97.30 in case of without magnet intensity.

The Nusselt number improves by 0.48~0.65% in case of with magnet intensity compared to without magnet intensity for Fe_3O_4 nanofluid with all volume fractions. In addition, the Nusselt number increases with increase in the volume fraction.



[Fig. 5] Nusselt number comparison for water and Fe_3O_4 nanofluid with various volume fractions considering without and with magnetic effect

5. Conclusion

The heat transfer characteristics of Fe_3O_4 nanofluid with various volume fractions are compared with conventional fluid water under the influence of magnetic intensity. The temperature difference of Fe_3O_4 nanofluid is superior to water and improves as the volume fraction increases for without and with magnet intensities. The temperature difference in case of with magnet intensity is on average 3.54% higher than without magnet intensity case for all volume fractions. The heat transfer coefficient enhances by 10% for without and with magnet intensities as volume fraction increases from 0.5% to 2.0%. The enhancements of 8.71% and 9.35% in heat transfer coefficient of Fe_3O_4 nanofluid are reported for without and with magnet intensities, respectively compared to water over the considered range of volume fraction. The Nusselt number of Fe_3O_4 nanofluid has improved as volume fraction increases compared to water. In addition, Fe_3O_4 nanofluid with magnet intensity shows the highest Nusselt number of 97.93, which is 0.65% superior to without magnet intensity for 2.0% Fe_3O_4 nanofluid.

Acknowledgement

이 성과는 정부(과학기술정보통신부)의 재원으로 한국연구재단의 지원을 받아 수행된 연구임(No. 2020R1A2C1011555). This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. 2020R1A2C1011555).

References

[1] N. S. Pandya, H. Shah, M. Molana, A. K. Tiwari, “Heat transfer enhancement with nanofluids in plate heat exchangers: A comprehensive review”, *European Journal of Mechanics-B/Fluids*, Vol.81, pp.173-190, 2020.

[2] M. Hatami, S. Mohammadi-Rezaei, M. Tahari, D. Jing, “Recent developments in magneto-hydrodynamic Fe3O4 nanofluids for different molecular applications: A review study”, *Journal of Molecular Liquids*, Vol.250, pp.244-258, 2018.

[3] M. Ghasemian, Z. N. Ashrafi, M. Goharkhah, M. Ashjaee, “Heat transfer characteristics of Fe3O4 ferrofluid flowing in a mini channel under constant and alternating magnetic fields”, *Journal of Magnetism and Magnetic Materials*, Vol.381, pp.158-167, 2015.

[4] L. S. Sundar, M. T. Naik, K. V. Sharma, M. K. Singh, T. C. S. Reddy, “Experimental investigation of forced convection heat transfer and friction factor in a tube with Fe3O4 magnetic nanofluid”, *Experimental Thermal and Fluid Science*, Vol.37, pp.65-71, 2012.

[5] J. H. Seo, M. Y. Lee, “Illuminance and heat transfer characteristics of high power LED cooling system with heat sink filled with ferrofluid”, *Applied Thermal Engineering*, Vol.143, pp.438-449, 2018.

[6] J. H. Seo, M. Y. Lee, “Numerical Investigations on Heat Transfer Characteristics of Single Particle and Hybrid Nanofluids in Uniformly Heated Tube”, *Symmetry*, Vol.13(5), pp.876, 2021.