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Numerical Simulation of Convective Heat Transfer of Nano-Encapsulated Phase Change Material Slurries in Micro-Channels with Sinusoidal Cavities and Rectangular Ribs

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ABSTRACT: The purpose of this research is to investigate the performance of hybrid Darrieus-In the present study, the Thermo-hydraulic performance evaluation of nano-encapsulated phase change material slurries was undertaken in a micro-channel heat sink. The present research was motivated by the urgent need for the performance enhancement of micro-sized heat sinks for the electronic cooling application. A micro-channel with sinusoidal cavities and rectangular ribs was chosen as the flow domain in the present study and the steady laminar flow of nano-encapsulated phase change material slurries was investigated inside the micro-channel. A single-phase model was adopted for the simulation of slurry flow and heat transfer using the well-known finite volume method. Ansys Fluent software was used to solve the governing equations and simulate the flow. In the current study, Nusselt number, friction factor, and performance factor were used to measure the thermal-hydrodynamic performance of the studied slurries. Numerical simulations were performed for Reynolds numbers ranging from 200 to 1000 and nanoparticle concentrations ranging from 0 to 30%. It was shown that adding nano-encapsulated phase change material to a base fluid like water enhanced the thermal performance of the resulting slurry. A 6% to 48% increase in the Nusselt number was reported along the microchannel.

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1- Introduction

The concept of a Microchannel Heat Sink (MCHS) was first proposed by Tuckermann and Pease [1] in 1981 and proved to be effective. In primitive designs of MCHS, simple rectangular microchannels were used to dissipate the generated heat using conduction in solid substrate and convection in the fluid flowing across the heat sink. In a three-dimensional simulation, Ghani et al. [2] evaluated a new geometric design for a microchannel heat sink. In this design, walls with sinusoidal cavities with rectangular ribs in the middle of the channel were used to create turbulence and mixing in the fluid flow path in order to enhance the overall thermal performance of the heat sink. The performance factor of this new geometric design in Reynolds number 800 is reported to be 1.8, which has much better thermal performance than the sinusoidal wall geometric design in the absence of ribs and the smooth wall geometric design in the presence of rectangular ribs. In recent years, phase change materials have received much attention due to their ability to reduce the volume and weight of microchannel heat sink to be used in the cooling applications of electronic components. In its general definition, a phase-changing material is a substance that can generate a useful amount of cooling/heating in a heat control device by changing the phase from solid to liquid or vice versa in the desired temperature range [3].

In a new study, Rahman et al. [4] investigated the simultaneous effect of using Nano-Encapsulated Phase Change Materials (NEPCM) by designing hydrofoil ribs on microchannel heat-sink walls with a three-dimensional numerical analysis and a significantly improved heat transfer rate (up to 2.68 times larger than water-cooled heat sink with an identical geometric design) reported. Studies to date have shown that combining the use of new geometric designs and mixtures containing phase-change particles as the cooling agent fluid is a reliable approach to improve the thermal performance of microchannel heat sinks.

Therefore, in the present study, the use of a nano-encapsulated phase change materials slurry in a microchannel including sinusoidal wall cavities in the presence of rectangular ribs in the middle of the duct will be investigated as a new solution to increase heat transfer rate within microchannel heat sinks.

2- Problem Description

Fig. 1 shows schematics of the micro-channel heat sink modeled in this work which has a width of 0.3 mm, a height of 0.4 mm, and a length of 10 mm. Heat flux of 100 W/cm2 is applied at the bottom plate of the heat sink, where the electronic chip is assumed to be directly attached to the base plate of the heat sink.

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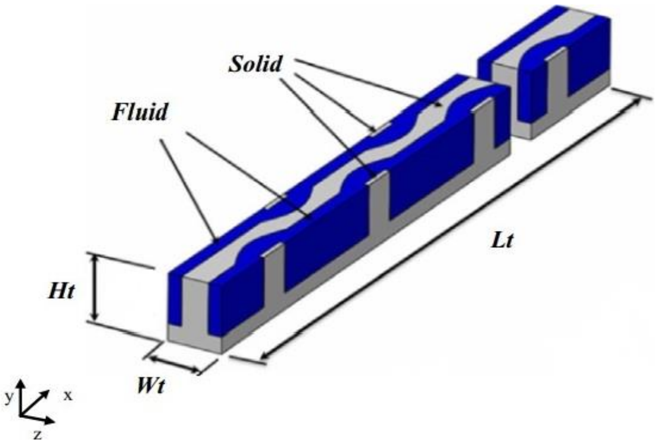

Fig. 1. The geometry of the microchannel heat sink

3- Governing Equations and Performance Indexes

In the present study, the flow and heat transfer of a layered, stable, and incompressible homogeneous mixture carrying nano-encapsulated phase change has been investigated. A single-phase model has been used for numerical modeling of these slurry flows, and the effects of viscous heating and slip on the solid-liquid contact surface have been neglected. Therefore, the governing equations of the present problem could be presented as follows [5]:

$$\nabla.(\rho_{eff}\vec{V})=0 \tag{1}$$

$$\nabla.(\rho_{eff}\vec{V}\vec{V})=-\nabla P+\nabla.(\mu_{eff}[\nabla\vec{V}+\nabla\vec{V}^{T}]) \tag{2}$$

$$\nabla.(\vec{V}(\rho_{eff}C_{p,eff}T))=\nabla.(k_{eff}\nabla T) \tag{3}$$

The average friction factor along the microchannel is:

$$Nu=\frac{q''_{w}D_{h}}{k_{b}(T_{wall}-T_{avg})} \tag{4}$$

The average friction factor along the microchannel is:

$$f=\frac{2D_{h}\Delta P}{L_{t}\rho_{eff}U^{2}} \tag{5}$$

The overall performance of the proposed design is measured using the performance factor (Pf), which represents the Nusselt number ratio over friction factor ratio to the power of one-third. The value of Pf indicates the extent of the thermal effectiveness relative to the pressure drop penalty. The increment of Pf over 1 indicates the superiority of thermal performance overpressure drop penalty and vice versa if the value is less than one. Therefore, the design is considered acceptable if the value of Pf is higher than unity. The equation of Pf is given by:

$$pf=\frac{\frac{Nu}{Nu_{0}}}{(\frac{f}{f_{0}})^{\frac{1}{3}}} \tag{6}$$

4- Results and Discussion

In Fig. 2, the variation of the mean temperature of the microchannel bottom plate with the volumetric concentration of nanoparticles in 5 different Reynolds numbers is depicted. As can be seen, in the whole range of Reynolds numbers studied in the present study, with the addition of encapsulated nanoparticles, the temperature of the microchannel bottom plate decreased, and as a result, the thermal performance of the heat sink was enhanced by increasing the heat capacity of the working fluid.

Fig. 3 shows the effect of the Reynolds number and the concentration of encapsulated nanoparticles on the mean Nusselt number relative to the base state. According to Fig. 3, the Nusselt number is an increasing function of nanoparticle concentration which confirms the desirable effect of using encapsulated phase change materials for the electronic cooling application.

As can be seen in Fig. 4, for the entire range of Re studied here, thermal performance factors higher than unity have been reported for the phase change slurries. According to Fig. 4, with the increasing volume concentration of nanoparticles, a notable increase in the overall thermal performance of the slurry is obtained. As the concentration of phase change particles increases, the fluid's heat absorption and heat storage capacity increase. This trend enables the phase change slurry to store more heat when it flows across the microchannel, which prompts a more efficient cooling of the electronic component. Also, the maximum performance factor is 1.54, which is achieved for the lowest Reynolds number and the highest nanoparticle concentration.

5- Conclusions

The results showed that adding phase change materials in the form of nano-scale capsules to a common base fluid such as water increases heat transfer and improves the thermal performance of a microchannel heat sink. An increase of up to 48% in the Nusselt number in this study is evidence for this claim. At the same time, an increase in the overall pressure drop and friction factor is also observed with the addition of nanocapsules. However, at identical Re numbers, a higher than unity thermal performance factor is acquired which corroborates the desirable thermal performance of phase change slurries despite the observed pressure drop penalty. Finally, it was concluded that the use of NEPCM is more effective in low Reynolds numbers, and increasing the Reynolds number reduces the thermal efficiency of NEPCM slurries.

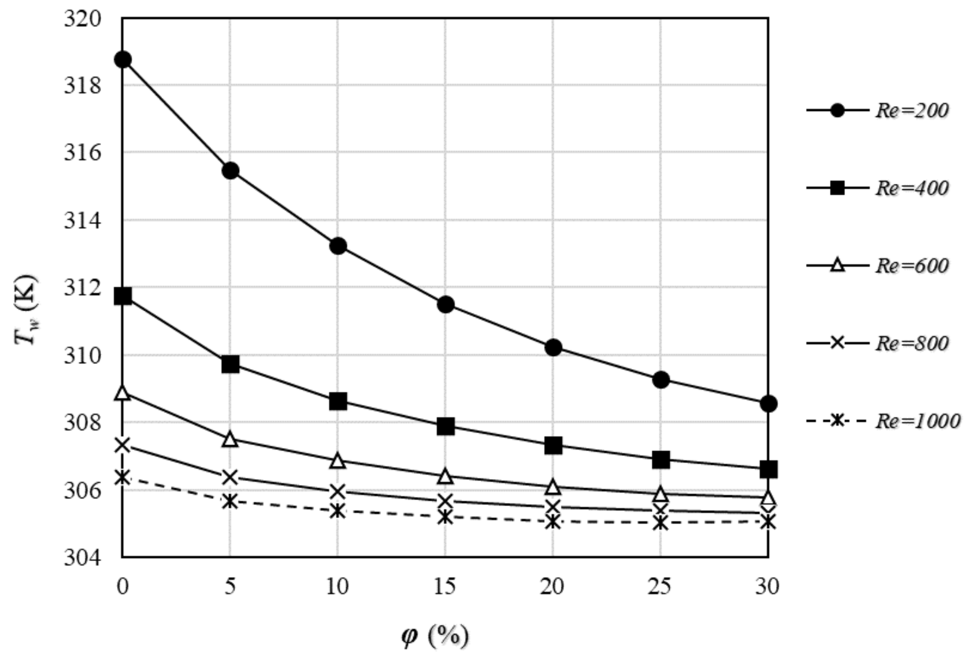

Fig. 2. Effect of volume concentration of NEPCM on average microchannel bottom temperature in different Reynolds numbers

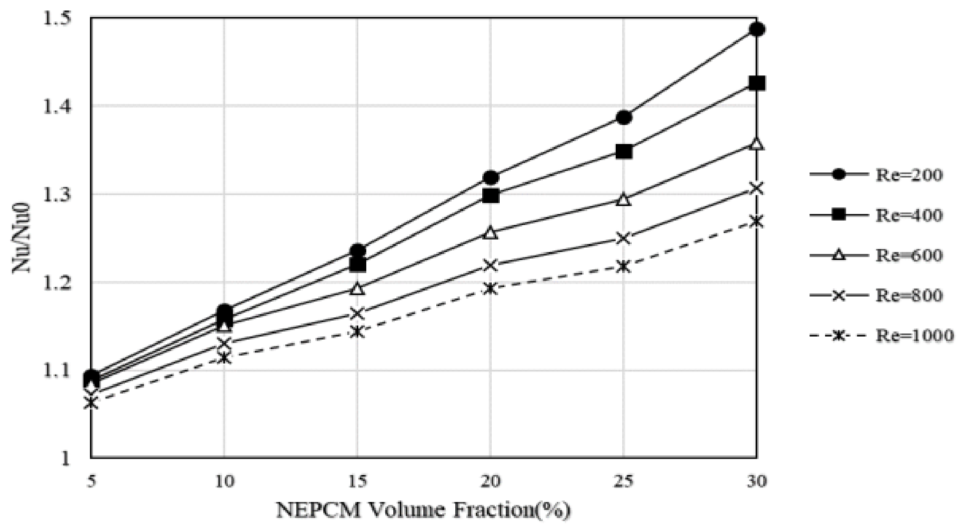

Fig. 3. Effect of volume concentration of NEPCM on Relative mean Nusselt number in different Reynolds numbers

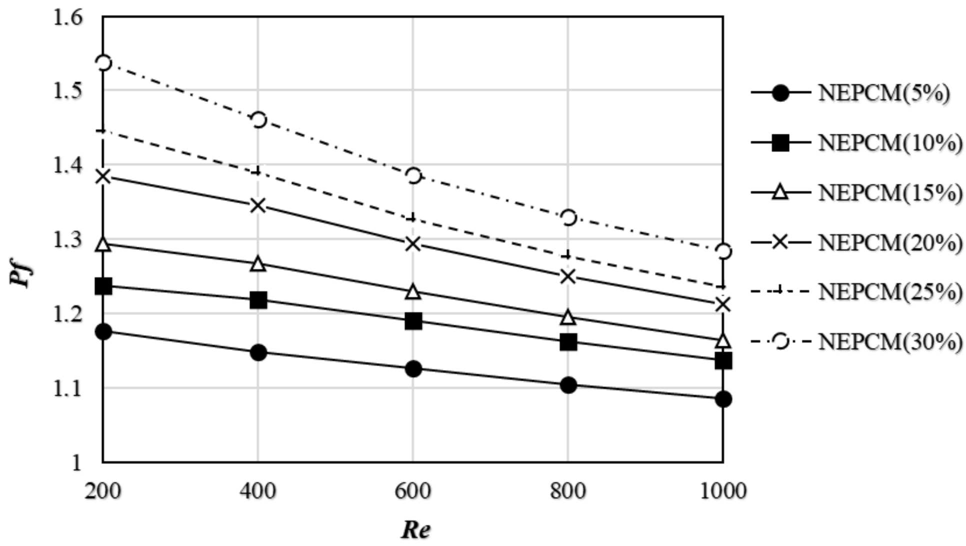

Fig. 4. Effect of volume concentration of NEPCM on performance factor in different Reynolds numbers

References

[1] D.B. Tuckerman, R.F.W. Pease, IIIB-8 implications of high performance heat sinking for electron devices, IEEE Transactions on Electron Devices, 28(10) (1981) 1230-1231.

[2] I.A. Ghani, N. Kamaruzaman, N.A.C. Sidik, Heat transfer augmentation in a microchannel heat sink with sinusoidal cavities and rectangular ribs, International Journal of Heat and Mass Transfer, 108 (2017) 1969-1981.

[3] B. Zalba, J.M. Marín, L.F. Cabeza, H. Mehling, Review on thermal energy storage with phase change: materials, heat transfer analysis and applications, Applied Thermal Engineering, 23(3) (2003) 251-283.

[4] M. Mohib Ur Rehman, T.A. Cheema, M. Khan, A. Abbas, H. Ali, C.W. Park, Parametric evaluation of a hydrofoil-shaped sidewall rib-employed microchannel heat sink with and without nano-encapsulated phase change material slurry as coolant, Applied Thermal Engineering, 178 (2020) 115514.

[5] S. Sabbaghi, S. Mehravar, Effect of Using Nano Encapsulated Phase Change Material on Thermal Performance of Micro Heat Sink, International Journal of Nanoscience and Nanotechnology, 11(1) (2015) 33-38.

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