

Do ionic liquids replace water or nanofluids to enhance heat transfer in micro-channel systems?

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Abstract. This study explores the influence of different fluids in a uniform micro-channel geometry on conjugate heat transfer. Nanofluids used here, are SiO₂ and Al₂O₃ nanoparticles with various concentrations up to 4% in water as a base fluid under laminar flow. Nanofluids are compared to an ionic liquid called Butyl Methyl Imidazolium Tetrafluoroborate (BMIM BF₄) to examine the influence of heat transfer and fluid flow characteristics. Good agreement was found against previous micro-channel studies, numerical simulations with COMSOL Multiphysics® V5.2a are used at Reynolds number ranging from 50 to 1000 with a uniform heat flux of 100 W/cm² relevant to cooling systems. Advanced fluids might offer significant potential in combatting the challenges of heat transfer in the technological drive toward lower weight/smaller volume electrical and electronic devices. The results show that the lowest thermal resistance is for nanofluids followed by water, then the ionic liquid. Moreover, Al₂O₃-water offers lower thermal resistance than the SiO₂-water for all given nanoparticle concentrations. It is also found that there is no beneficial using ionic liquids in forced convection systems which work below boiling temperature conditions.

Nomenclature

<i>FEM</i>	Finite Element Method
BMIM (BF ₄)	Butyl Methyl Imidazolium Tetrafluoroborate
<i>k</i>	Thermal conductivity, W/m.K
<i>L</i>	Channel length, μm
<i>P</i>	Pressure, N/m ²
<i>q</i>	Uniform heat flux, W/cm ²
<i>Re</i>	Reynolds number
<i>T</i>	Temperature, K
<i>X</i>	Axial distance, μm

Greek Symbols

ϕ	Nanoparticles concentration, %
ρ_f	Density of fluid, kg/m ³
ρ_s	Density of solid particles, kg/m ³
μ	Viscosity, Kg/ms

Sub script

ave	Average
In	Inlet
Out	Outlet
S	Surface
Θ	Thermal resistance

1 Introduction

Micro-processor cooling systems are gradually becoming a wide area of interest for thermal system researchers due to

the rapid development of size shrinking and reduced weight in electronic devices, with the consequence of higher heat generation in limited cross-sectional areas. This brings to fore the need to eliminate the generated heat as it could adversely affect the electronic chip. This can be achieved in a number of ways, using air and water-based cooled heat sinks [1-4] and the use of mini- and micro-channel heat exchangers and/or advanced fluids [1, 5-7].

Micro-channel design is being modified rapidly to meet the recent improvement in electronic chips and to enhance the heat transfer rate [8].

Among different types of micro channel shapes, the rectangular micro-channel was considered to be of ideal geometry based on the numerical investigation by Xia et al. [9].

Heat transfer can as well be enhanced using advanced fluids such as nanofluids which are combinations of a base fluid and nano-sized particles (1-100 nm). Nanoparticles can be from materials such as metallic (Fe, Cu, Ag, Au, Al), carbon or metallic oxide (Fe₃O₄, CuO, Al₂O₃, TiO₂, SiC, SiO₂, ZnO). Nanofluids have high thermo-physical properties compared to the base fluid in terms of thermal conductivity [7]. Metallic dioxide nanoparticles are commonly used with water as a base fluid, however, Al₂O₃-water and SiO₂-water nanofluids offer highest heat

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transfer enhancement among the common nanofluids [2, 7, 10].

Ionic Liquids (ILs) are molten salts which are available at liquid phase under room standard conditions. These salts attracted many researchers due to their promising properties such as their low volatility, exhibit high thermal stability and their physical properties can be controlled easily by changing their chemistry [11]. Thus, ILs have been suggested to be employed in thermal applications for energy storage applications and for many other engineering aspects [11, 12].

In addition, two main points motivate researchers to investigate thermo-hydraulic performance of ILs; their high thermal stability which means that they can be used under extreme conditions and the high capability of controlling their physical properties by changing their chemistry. The conventional thermal decomposition of ILs are above 200 °C and the typical melting temperature is below 0 °C [12]. Besides, the variation of cation type, anion type, cation chain length and anion chain length can lead to a significant impact on their physical properties [13]. However, due to the lack of data of the thermal and hydraulic properties of ILs, thermal conductivity, specific heat capacity, viscosity and density all together. Only one IL is employed in this study when its properties are obtained from [12, 14].

From the above, the aim of this paper is mainly to suggest using ILs as coolants in various heat exchanging duties under extreme conditions and to compare between one IL with various nanofluids and water when they are employed as coolants for cooling electronic systems.

2 Analysis and Modelling

In this article, a rectangular uniform micro-channel is considered to examine the heat transfer and fluid flow performance using different fluids such as pure water, Al₂O₃ / water, SiO₂ / water and ionic liquid. The details of the modeling are found in [10].

The conjugate heat transfer model and validations against previous studies of the micro-channel is presented as in [1, 5, 6]. Al₂O₃ and SiO₂ nanoparticles are considered to be separated from each other and well distributed in water as a base fluid at all ranges of concentrations to offer homogeneous nanofluid. All required equations are found in [2, 15-18].

The influence of different effects on thermal resistance can be seen in Fig. 1, the effect of nanoparticles concentration up to 4% of the Al₂O₃ and SiO₂ nanoparticles in water with the pure water and ionic liquid in a uniform micro-channel. It is found that thermal resistance decreased as the concentrations of nanoparticles increased due to thermo-physical properties enhancement especially the thermal conductivity of nanofluids.

However, the ionic liquid does not offer a thermal resistance reduction, again because its thermal properties compared to nanofluids. Nanofluids offer low thermal

resistance compared to the pure water and ionic liquid, therefore the uniform channel can be presented as an example of heat transfer enhancement using SiO₂ and Al₂O₃ –water compared to water and ionic liquid.

In terms of nanofluids, Fig. 1 shows that Al₂O₃-water offered better heat transfer rate than SiO₂-water at the same concentration. This is because of the high thermal conductivity of the Al₂O₃-water compared to SiO₂-water.

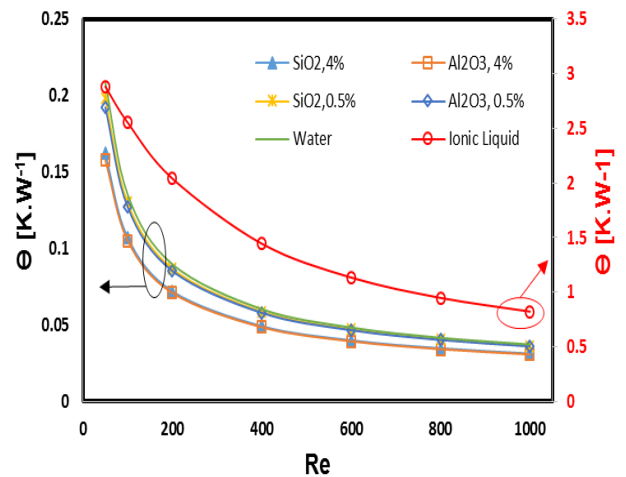


Fig. 1. Influence of different nanoparticles in the range of 0-4%, with ionic liquid and water in water on thermal resistance.

Fig. 2 presents the effect of different fluids on pressure drop. The results showed that the highest pressure penalty is for the ionic liquid, followed by nanofluids with high concentrations, while the lowest pressure drop is for water. Regarding to nanofluids, as to be expected that the pressure drop increased when nanoparticles concentration increased.

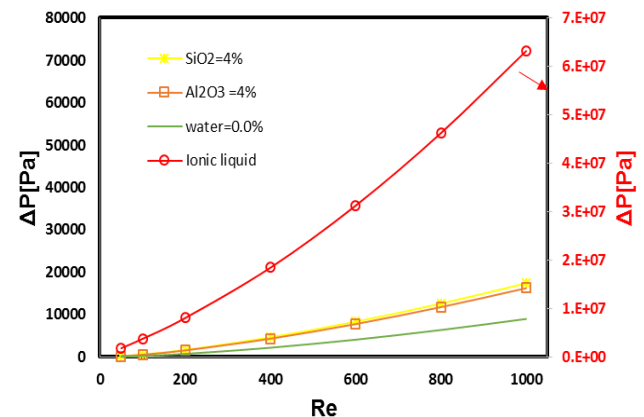


Fig. 2. Impact of different nanoparticles in the range of 0-4% in water with pure water on pressure drop.

3 Conclusions

Thermo-hydraulic comparison has been conducted to examine the influence of different fluids such as water, ionic liquid (IL) and nanofluids. The results reveal that in

this particular application and for this particular IL, nanofluids and water offer better heat transfer performance. However, the variation of IL chemistry can lead to a significant enhancement in its thermal properties. Thus, the investigation to find suitable IL for this application will be conducted in the future. Lastly, ILs can be employed as coolants under extreme conditions when the conventional fluids are either boiled or solidified.

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