A study of hybrid nanofluid ($NiZnFe_2O_4 + MnZnFe_2O_4$) in micro channel with partial slipsand convective conditions: Entropy generation analysis

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PAPER FOR THE YOUNG SCIENTIST AWARD

1. INTRODUCTION AND OBJECTIVES

Managing heat in electronic systems remains a significant challenge due to the growing demand for high performance and multifunctionality. Traditional cooling methods such as heat sinks and fans are limited to handling power densities of around 100 watts per square centimeter. Consequently, the electronics industry actively seeks more efficient cooling technologies. Recently, researchers have turned their attention to a category of materials known as "hybrid nanofluids." The goal of incorporating hybrid nanoparticles into the base liquid is to enhance the liquid's thermal properties, capitalizing on the thermophysical characteristics of these nanomaterials [8, 10, 9]. Rao et al. [32] conducted a study on the flow of a hybrid nanofluid (comprising engine oil, $NiZnFe_2O_4 + MnZnFe_2O_4$) in a microchannel between two vertical parallel plates. The research primarily focused on analyzing irreversibilities, exploring flow patterns, and studying heat transfer phenomena while taking into account magnetic field effects, porosity, and thermal radiation parameters.

In the same vein, a hybrid nanofluid comprising $NiZnFe_2O_4 + MnZnFe_2O_4$ and engine oil is examined, focusing on its influence on microchannel flow. This examination takes into account particle slip and convective boundary conditions. Furthermore, the study delves into the investigation of this hybrid nanofluid's behavior in the presence of magnetic effects. Additionally, the study explores ways to enhance entropy production, considering radiative heat, Joule heating, convective heating, and viscous dissipation. The findings offer valuable insights for both readers and thermal engineers to predict heating or cooling rates in a hybrid ferromagnetic nanofluid. It is also intriguing to compare the behavior of the hybrid nanofluid with that of a conventional nanofluid in microchannel flow.

2. RESULTS AND HIGHLIGHTS OF IMPORTMENT POINTS

Entropy analysis

- Figure 1 illustrates how entropy varies with different Brinkman number (Br) values. As Brinkman number (Br) rises, there is an increase in entropy production within the channel. This phenomenon occurs due to the changing equilibrium between two critical factors: fluid friction irreversibility and heat transfer irreversibility. With an increase in Br, it reduces the heat generated by viscous dissipation, thus making heat transfer irreversibility more pronounced and impactful, ultimately resulting in elevated entropy production.
- Figure 2 displays the Ns(ζ) field concerning Rd variation, which leads to an increased entropy rate within the microchannel. Entropy is lowest on the lower plate and highest on the upper plate due to the growing significance of friction irreversibilities as Rd increases. This shift occurs because viscous forces play a more substantial role in amplifying friction irreversibilities within the channel. Although the overall shape of the entropy profiles remains similar, their magnitudes can differ due to the dominance of heat transfer irreversibility and fluid friction irreversibility. Notably, for both lower and higher ζ values, the entropy rate is slightly higher for hybrid nanofluid compared to nanofluid, with no significant change observed for both in the middle (approximately $\zeta = 0.25$ to 0.65).

Flow analysis

- The viscous force of the suspension increases $as\ NiZnFe_2O_4$, and $MnZnFe_2O_4$ are added to engine oil (the base fluid), which causes $v(\zeta)$ to decrease. Due to higher viscosity liquid, the presence of $N\ iZnFe_2O_4$, and $MnZnFe_2O_4$ results in pressure drop. Hence $v(\zeta)_{nf} > v(\zeta)_{hnf}$ (see Figure 3).
- The slip effect has a crucial impart on the $v(\zeta)$ profile. The slip velocity at $\zeta = 0$ and $\zeta = 1$ increases with increasing A, which accelerates the liquid's velocity through the microchannel(See Figure 4). The

reason for this is that for grater slip parameter (A), the velocity gradient at the walls decreases, hence $v(\zeta)_{nf} > v(\zeta)_{hnf}$.

Heat transfer analysis

- Physically, source processes, viscous heating, and Joule heating expand the thermal field due to increased internal heat in the microchannel when using nanofluids. Figure 5 demonstrates the dual behavior of the temperature field $\theta(\zeta)$ in response to ϕ. Temperature field $\theta(\zeta)$ decreases for ϕ values up to approximately 0.25 from the microchannels lower wall. Beyond this point, the channel exhibits a different trend. Increasing ϕ from 0% to 20% enhances the thermal conductivity of engine oil, resulting in greater heat flux from the right side of the channel, which has a lower temperature, to the lower wall of the microchannel. Consequently, the thermal field $\theta(\zeta)$ near the channel's lower wall at about $\zeta = 0.25$ decreases, while it increases in the rest of the channel.
- $\theta(\zeta)$ rises in the lower section of the channel, specifically at $\zeta \approx 0.1$, while it decreases in the rest of the channel. This trend corresponds to the heat transport pattern from the hot fluid near the lower plate to the hybrid fluid as the Biot number (Bi) rises. Consequently, the thermal field of the hybrid nanofluid near the lower plate intensifies. Simultaneously, the rate of heat transfer from the hybrid nanofluid to the surroundings near the cold plate also increases with higher Bi. Consequently, in this specific region, the temperature of the hybrid fluid decreases, as depicted in Figure 6.

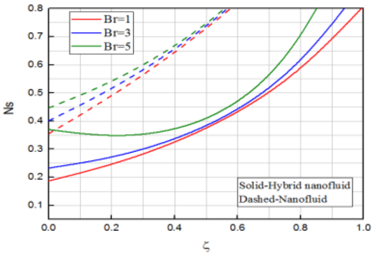

Figure 1: Effect of Brinkman number Br on Ns.

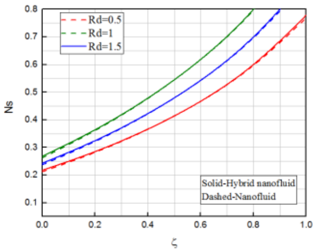

Figure 2: Effect of Brinkman number Rd on Ns.

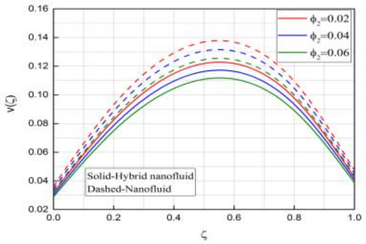

Figure 3: Effect of ϕ on v.

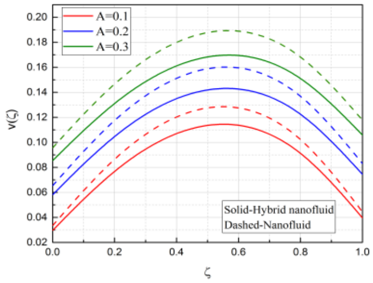

Figure 4: Effect of A on v.

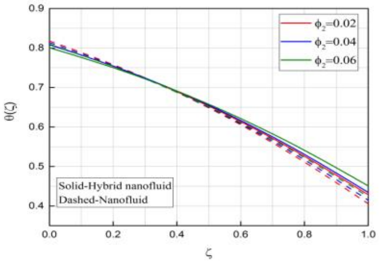

Figure 5: Effect of ϕ on θ(ζ).

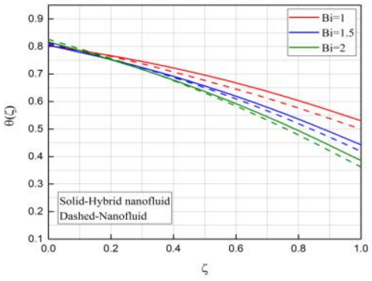

Figure 6: Effect of Bi on θ(ζ).

REFERENCES

1. Jana, S., Salehi-Khojin, A., & Zhong, W. H. (2007). Enhancement of fluid thermal conductivity by the addition of single and hybrid nano-additives. Thermochimica acta, 462(1-2), 45-55.
2. Leong, K. Y., Ahmad, K. K., Ong, H. C., Ghazali, M. J., & Baharum, A. (2017). Synthesis and thermal conductivity characteristic of hybrid nanofluids?a review. Renewable and Sustainable Energy Reviews, 75, 868-878.
3. Toghraie, D., Chaharsoghi, V. A., & Afrand, M. (2016). Measurement of thermal conductivity of ZnO?TiO 2/EG hybrid nanofluid: Effects of temperature and nanoparticles concentration. Journal of Thermal Analysis and Calorimetry, 125, 527-535.
4. Rao, D. P., Babu, M. J., Shehzad, S. A., & Qaisar, S. (2023). Entropy generation optimization in a radiative hybrid nanofluid (engine oil+ NiZnFe2O4+ MnZnFe2O4) flow through a convectively heated microchannel with cross-diffusion effects. Journal of Thermal Analysis and Calorimetry, 1-10.