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NANOFLUIDS AND CPU COOLING: REVIEW OF NANOFLUIDS HEAT TRANSFER FOR CPU COOLING

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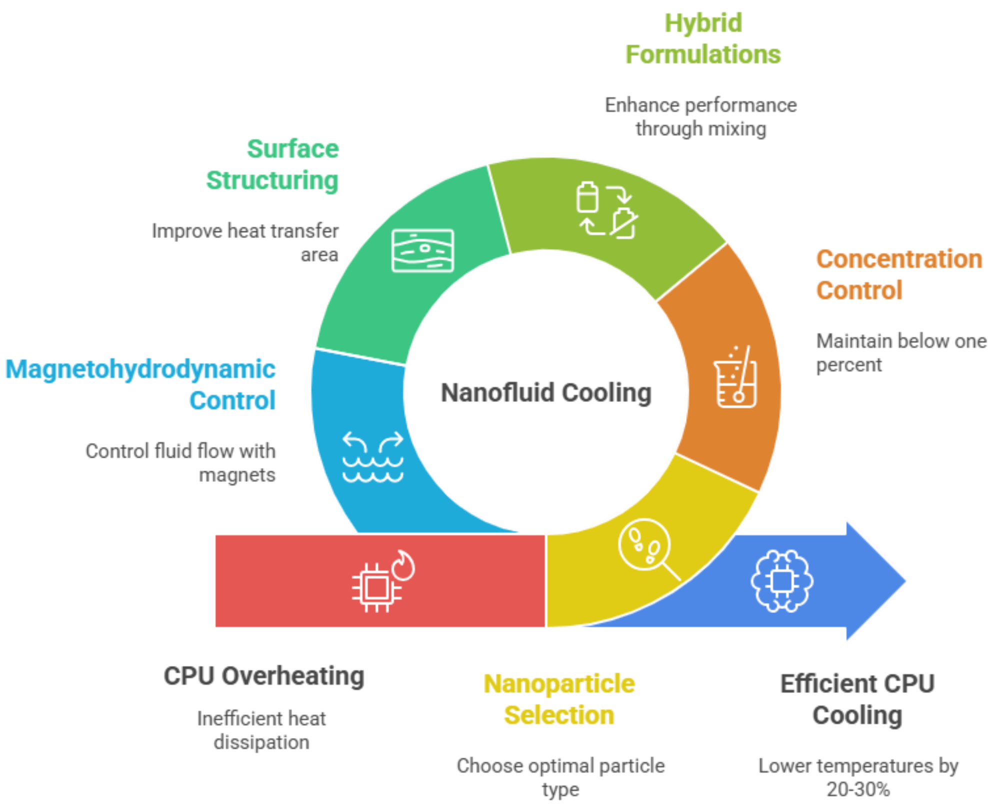
GRAPHICAL ABSTRACT



HIGHLIGHTS

- Nanofluids significantly enhance CPU cooling efficiency compared to pure water.
- Optimal nanoparticle concentration below 1% achieves best heat transfer stability.
- Hybrid & magnetic nanofluids improve temperature uniformity and entropy control.
- Porous and microchannel heat sinks further boost nanofluid cooling performance.
- Future work should integrate CFD, MHD, & experimental validation for CPU cooling.

ABSTRACT

Nanofluids have emerged as advanced heat transfer media with exceptional thermal properties, and nanofluids are increasingly recognized as key solutions for efficient thermal management in modern electronic systems. Among various cooling technologies, nanofluid-based solutions have proven to be highly effective for CPU cooling due to their superior heat transfer capabilities and tunable thermophysical characteristics. This review focuses on recent developments in nanofluid applications for CPU cooling systems, emphasizing the role of nanoparticle type, concentration, and morphology in enhancing convective heat transfer. Compared with conventional coolants such as water and ethylene glycol, nanofluid coolants demonstrate significantly higher thermal conductivity, enabling faster and more uniform temperature distribution across the CPU surface. Experimental and numerical investigations consistently reveal that nanofluid systems can lower CPU temperatures by up to 20–30 percent, depending on particle volume fraction and flow configuration. The optimal performance of nanofluid coolants typically occurs at particle concentrations below one percent, balancing improved heat transfer and fluid stability. Excessive nanoparticle loading, however, can cause agglomeration, increased viscosity, and clogging in microchannel heat sinks. Studies further indicate that nanofluid performance can be enhanced through hybrid formulations, surface structuring, and magnetohydrodynamic field control, all contributing to improved energy efficiency and reduced thermal resistance in CPU cooling systems. The application of nanofluid technology extends beyond laboratory research to practical implementation in high-performance computing, data centers, and electronic manufacturing. Future designs for CPU cooling should integrate nanofluid selection with optimized microchannel geometries, porous metal heat sinks, and real-time monitoring systems to ensure long-term stability and cost-effectiveness. This comprehensive mini-review underscores that nanofluid-based CPU cooling represents a promising pathway toward next-generation thermal management systems capable of supporting compact, energy-efficient, and reliable electronic devices.

Keywords: Nanofluid; CPU cooling; Heat transfer; Electronic devices; Heat sink; Microchannel; Thermal management

1. Introduction

To achieve sustainable development in energy systems, recent studies have been focusing on replacing traditional heat transfer mediums with novel ones. Nanofluids, owing to their great thermal conductivity and excellent thermal characteristics, have been used as the operating mediums for various energy systems, ranging from fuel cells, vehicle engines, photovoltaic thermal systems, and microchannels [1, 2]. In this review, we focus on the utilization of nanofluids for CPU cooling application. However, we start the discussion for other applications first.

The main objective of this mini-review is to critically evaluate the role of nanofluids in enhancing heat transfer for CPU cooling applications by integrating findings from both experimental and numerical studies. The review aims to identify key parameters influencing performance—such as nanoparticle type, concentration, size, and shape—and to assess how these parameters interact with heat sink geometry, flow configuration, and magnetic field effects.

The novelty of this review lies in its focused comparison of nanofluid-based cooling strategies specifically tailored for CPU systems, rather than general thermal devices. It introduces practical perspectives linking laboratory findings to industrial applications, including porous metal heat sinks, hybrid nanofluids, and magnetohydrodynamic-assisted systems. This work uniquely bridges the gap between academic investigations and real-world implementation by highlighting how nanofluid formulations and design optimization can advance next-generation electronic cooling technologies.

Nanoparticles, thanks to their heat transfer improvement, have been extensively utilised in numerous applications such as for the working fluid of solar collectors. The impacts of nanofluids and change in flow direction change may increase the Nusselt number in the solar collector pipes. It is known that the heat transfer between fluid and pipe takes place on the inner surface of solar collector pipes. If the fluid is replaced with a cooler fluid, heat transfer will increase. Therefore, the use of nanofluids along with geometry modification may potentially improve the heat transfer coefficient. Porous structures are also able to further improve nanofluids thermal performance.

He et al. [3] investigated heat transfer in a tube using twisted-tape inserts and CuO-water nanofluid for various solid concentrations ranging from 1 to 4 vol % on the performance, friction factor and Nusselt number as shown in Figure 1. They reported that the two-phase mixture model had better performance compared to the single-phase model with one twisted tape being preferred. It was found that the coefficient of peak performance efficiency in the tube with one and two twisted tapes are 2.18 and 2.04 respectively.

Saffarian et al. [4] investigated heat transfer in a flat plate solar collector using Al_2O_3/water and CuO/water nanofluids with volume fractions of 1% and 4%. Different flow path shapes were used with flow direction being altered to facilitate higher heat transfer coefficient as shown in Figure 2. It was found that utilising both wavy pipe and CuO/water, heat transfer coefficient would increase by nearly 80%.

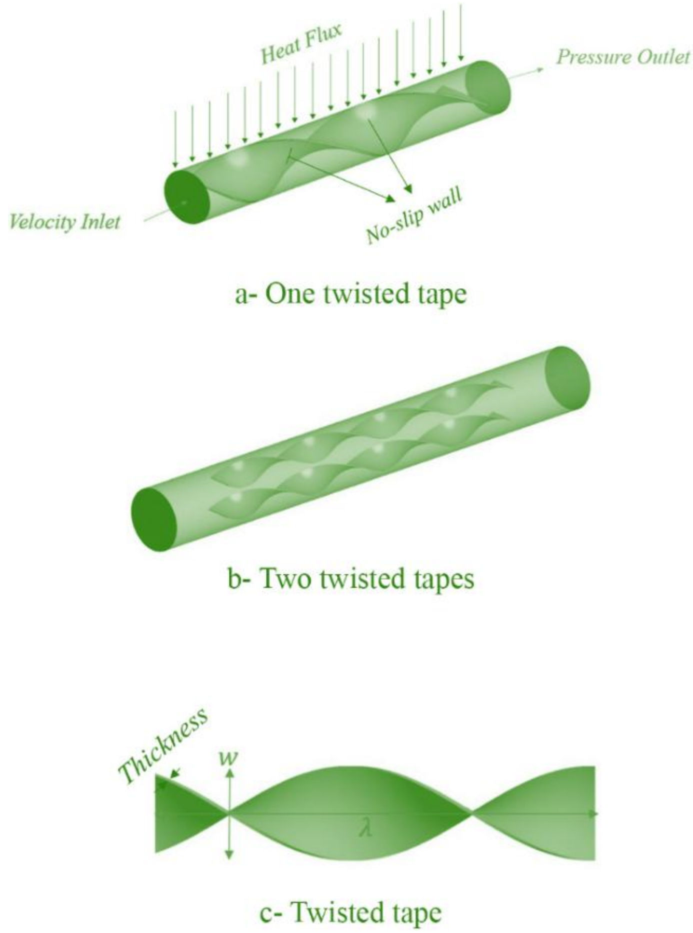


Figure 1. Schematic of the one tape and two twisted tapes, reproduced from [3].

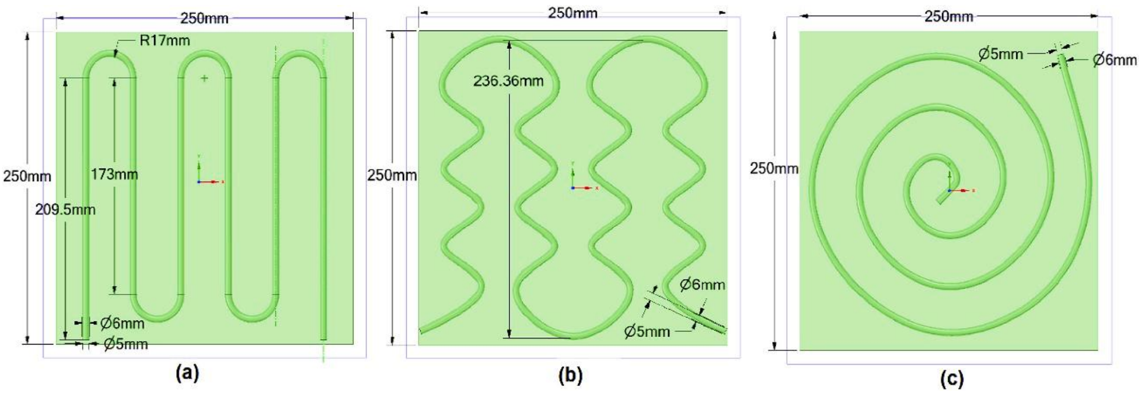


Figure 2. Geometries of a) U-shaped, b) wavy, and c) spiral pipe arrangements, reproduced from [4].

Bozorg et al. [5] investigated the fluid flow and heat transfer in a parabolic via solar receiver using synthetic oil–Al_2O_3 nanofluid. Figure 3 shows that porous structure was found to reduce the maximum temperatures of absorber tube. The authors believed that the reduction was attributed to the increase in conduction heat transfer mechanism through the bulk of heat transfer fluid, while the forced convection became weaker.

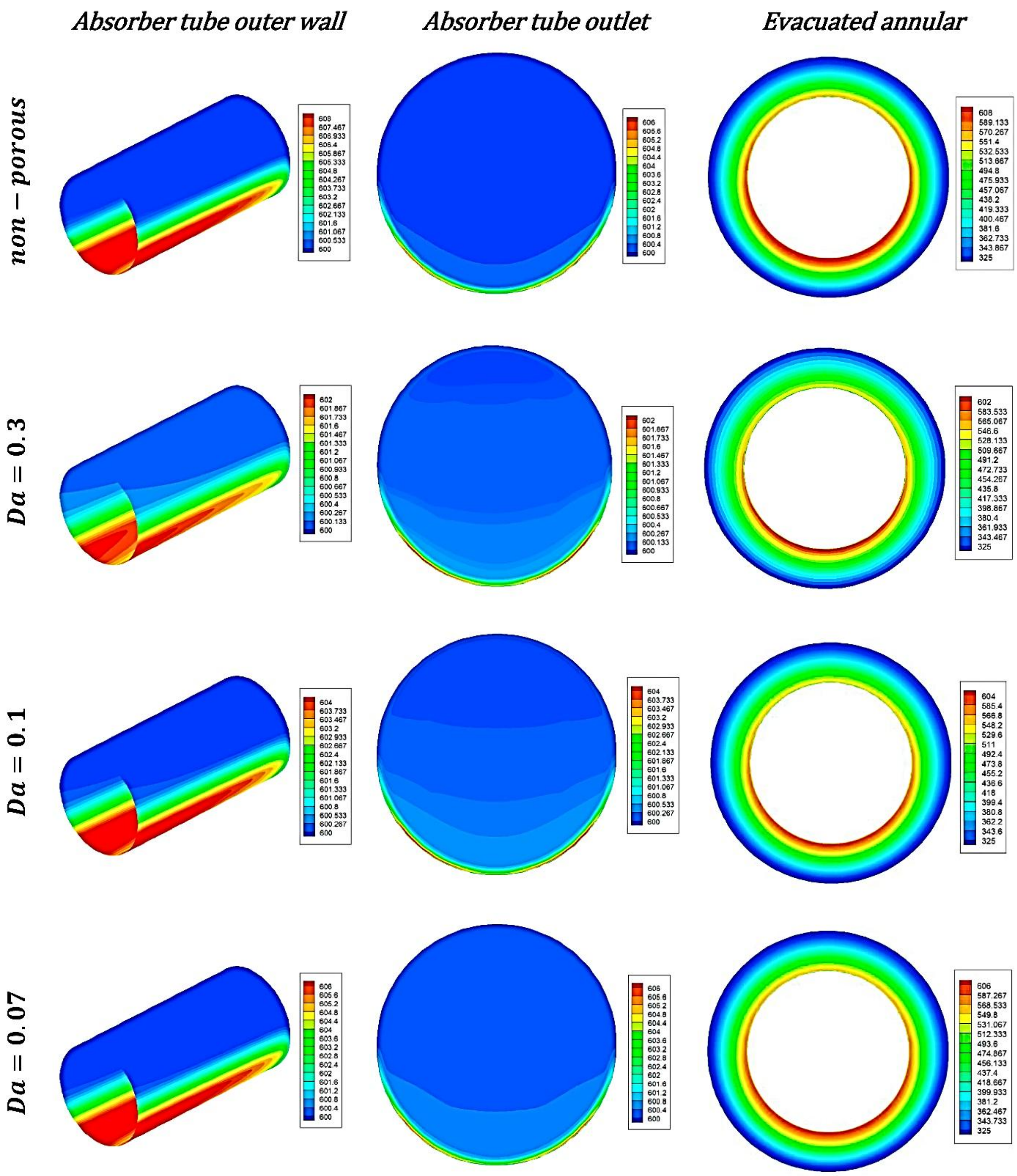


Figure 3. Temperature distributions with nanoparticle volume fraction of 0.03, inlet temperature of 600 K and Reynolds number of 15 x 10^5, reproduced from [5].

Rapid IT progress, such as the Internet, need PC performance capable of processing more data at a faster rate. PC-based high-performance devices have been developed to fulfil this need. Particularly, CPU exhibits a shift toward becoming more compact and thinner, as well as the production of faster and more powerful devices to compete with them. This causes an increase in heat density and heat dissipation, which raises the CPU's temperature, shortens its lifespan, and causes it to malfunction or fail. CPU cooling has been given significant attention.

Due to the use of cutting-edge technology and an increase in processor frequency, personal computers (PCs) are becoming increasingly efficient and fast each year. Due to increased heat output and increased electric power consumption, the CPU's life cycle may be shortened or destroyed [6]. Electronic components, especially the CPU, have strict requirements for high efficient heat dissipation due to their small size and high power density. The tremendous heat dissipation of electronic components makes it impossible for mediums of conventional heat transfer like water, air, and ethylene glycol to meet their needs. High thermal conductivity heat transfer media are a necessity for electronic components [7].

2.Nanofluids Heat Transfer for CPU Cooling

In general, the use of nanofluid has shown better cooling performance compared to the pure water. Izadi et al. [8] investigated Magnetohydrodynamic (MHD) enhanced convection of Water-alumina nanofluid facilitated heat transfer for CPU cooling in porous metal as shown in Figure 4. At high aspect ratio, the results suggest that the rise of Darcy number on the heat transfer became weak, while the rise of Eckert number or aspect ratio affected heat transfer negatively. It was also found that viscous dissipation had significant influence on temperature distribution and heat transfer.

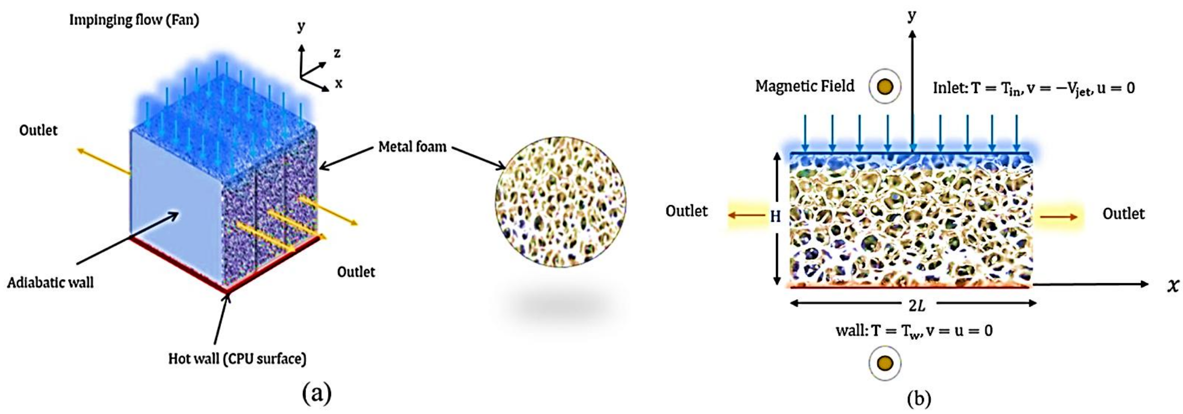


Figure 4. Schematic of the CPU cooler's porous metal: (a) the 3-D view; (b) the 2-D view with its boundary conditions, reproduced from [8].

Qi et al. [9] examined the impacts of half spherical bulges on thermo-hydraulic performances of CPU using nanofluids and found that TiO_2-water nanofluids could successfully reduce the CPU temperature. Using Cu-water and $A1_2O_3$-water nanofluids, Sun and Liu [10] were able to decrease the CPU surface temperature by 4–18 °C compared to the deionized water. Qi et al. [9] investigated the thermo-hydraulic performances of CPU cooled by Al_2O_3-water and TiO_2-water nanofluids. Compared to water, results showed that both nanofluids could decrease the CPU temperature by 23.2% and 14.9% respectively. For the best heat transfer performance, this study also suggests that there seems to be a critical mass fraction of nanoparticle, reporting that the nanofluids with the highest mass fraction of nanoparticle did not give the best performance of heat transfer.

Qi et al. [11] studied the thermo-hydraulic characteristics of magnetic nanofluids focusing on rotation angle and the magnetic field intensity. Overall, magnetic field could effectively reduce the CPU surface temperature by just over 30%. It was also found that the magnetic field with an angle $\alpha = 60°$ gave the best cooling performance with nanofluids having $\omega = 0.3\%$ gave the lowest generation of entropy. Under magnetic field, Qi et al. [12] examined the impact of both magnetic nanofluids and squid fin bionic surface. With the increasing magnetic induction intensity, wave frequency and nanofluids mass fraction, the magnetic nanofluids cooling capacity was found to increase with higher wave frequency and stronger magnetic field showing better comprehensive performance.

Utilising rectangular grooves and cylindrical bugles characterised by exergy efficiency, Zhao et al. [13] examined the thermo-hydraulic performance of TiO_2-water nanofluids in CPU heat sink. It was found that compared to water, CPU temperature decreased by 5.76 °C (12.4%) with exergy efficiency being susceptible to significant aligned arrangement and depth groove. The same authors [14] investigated the effects of cylindrical grooves on thermal efficiency, exergy efficiency and entropy generation using the same TiO_2-water nanofluids. Compared to deionized water, a reduction of CPU temperature by roughly 3.3 °C (8.2%) was reported. Nusselt number increased by 30.9% and 31.3% for staggered and aligned arrangement with the later showing enhanced performance of entropy generation.

Neyestani et al. [15] used a novel porous heat sink and Al_2O_3/water nanofluids (40 nm) and found that the heat sink geometry had a crucial impact on the system thermal performance. The heat transfer rate of in the novel porous heat sink was larger compared to the other cases. Also, by using nanofluids, the Nusselt number in the porous heat sink was 2.2 times larger compared to the inline pattern heat sink. Sarafraz et al. [16] comparatively examined the thermal performance of liquid gallium with CuO/water nanofluid. Gallium was found to provide more excellent thermal performance, but CuO/water nanofluid gave sufficient thermal performance at low heat flux situation.

Using biologically synthesised water-Ag nanofluid, Shahsavar et al. [17] performed a numerical investigation of a novel heatsink utilising helical microchannels. Results showed that the best hydrothermal performance took place at $\varphi = 1\%$ and $Re = 1500$. Chen et al. [18] found that 9% TiO_2-water nanofluids could decrease the CPU average temperature by 4.54 °C. Compared to at both two sides, CPU with inlet and outlet at top decreased the average temperature by 8.49 °C. Bahiraei and Heshmatian [19] applied novel distributor liquid block using a nanofluid having graphene decorated with Ag nanoparticles. It was found that the use of nanofluid in the liquid blocks gave superior results compared to pure water. Novel liquid block was also reported to have an excellent efficacy and lower irreversibility with exceptionally low possibility of hot spot formation on the surface of CPU surface.

Bazkhane and Zahmatkesh [20] analyse how did alumina–water nanofluids and porous substrates in a microchannel heat sink (MCHS) change the system performance. Results showed that the material of the MCHS and the porous substrates led to the highest CPU mean temperature surface. Al-Rashed et al. [21] performed a numerical evaluation of biological water-silver nanofluid in a wavy microchannel heat sink. By improving the Reynolds number and nanofluid fraction, more intensified heat sink performance was observed as a result of higher convective heat transfer coefficient, thus decreasing the temperature of CPU surface. Consequently, the uniformity of CPU surface temperature could be achieved. Wang et al. [22] examined the impacts of the inlet and outlet location in the heat sink of pin fin CPU and found that the heat sink with four outlets and centre vertical jet had the best comprehensive performance.

Al-Rashed et al. [23] numerically investigated non-Newtonian CuO nanofluid flow in an offset strip-fin MHS. Solution of 0.5% Carboxymethyl Cellulose in water was used as the base fluid. By employing the nanofluid, the optimal results indicated that the highest ratio (2.29) of heat transfer enhancement to pressure drop increment could be achieved. Utilising a structural stability approach, Moradikazerouni et al. [24] examined CPU heat sink under laminar forced convection and found that convection-radiation heat transfer had more heat transfer by 1.66% compared to pure convection. Yang et al. [25] investigated the use of Ag-water nanofluid flow in two novel microchannel heatsinks and found that from the perspective of the first and second laws of thermodynamics, the heatsink having more path changes was more efficient. Using connecting holes for a MHS cooled with silver/water nanofluid, Shahsavar et al. [26] found that reduced and uniform CPU temperature were observed as a result of higher Re and φ. Sajid et al. [27] used TiO_2–water nanofluid for wavy MHS and observed that the use of 0.012% TiO_2 nanofluids could reach the minimum wall base temperature of 33.85 °C and obtain the highest enhancement Nusselt number of 40.57%.

3. Discussion: Nanofluids and CPU Cooling

Most published works agree that nanofluid show better cooling performance compared to the pure water. Copper oxide, highly ionic metal oxides nanoparticle, has attracted considerable attention owing to its beneficial physical properties, including high temperature superconductivity, spin dynamics and electron correlation effects. It is considered as the simplest member of copper compounds, which is relatively stable from the standpoint of chemical and physical properties. CuO is also relatively affordable and easy to be mixed with polymers and polarised liquids such as water.

Note that from the heat transfer perspective, the use of twisted tape and nanoparticles appear to be satisfactory owing to the improvement in heat transfer. From the hydrodynamic perspective, however, they may lead to the increase in pressure drop. Hence, the non-dimensional performance evaluation criteria (PEC) play an important role here as it examines both thermal performance and hydrodynamics. The geometry would be accepted in terms of the economic and engineering viewpoint if the value of PEC is more than 1. When the value is less than 1, which may be caused by the increase in pressure drop, this is where adding nanoparticles into the base fluid would be able to raise the PEC to a value above 1 depending upon the nanoparticles volume fraction and Reynolds number. The fact that the PEC will improve by rising the nanoparticles volume fraction implies that the concurrent utilisation of nanofluid and twisted tape is satisfactory from the viewpoint of engineering and economic.

Table 1 summarizes the comparative performance of different nanofluids for CPU cooling, emphasizing optimal nanoparticle concentrations and temperature reductions. Most effective cooling was achieved at concentrations below 1%, indicating that moderate nanoparticle loading improves heat transfer while maintaining fluid stability.

Table 1. Comparative summary of nanofluids for CPU cooling applications

Nanofluid Type	Base Fluid	Optimal Concentration	Temperature Reduction / Performance	Key Observation	Reference
CuO–Water	Water	1.0 vol%	Reduced CPU surface temp. by 18 °C	Enhanced heat transfer; stable at low loading	Sun and Liu [10]

Nanofluid Type	Base Fluid	Optimal Concentration	Temperature Reduction / Performance	Key Observation	Reference
Al_2O_3–Water	Water	0.5 vol%	Decreased CPU temperature by 23%	Optimal PEC achieved at $\varphi < 1\%$	Qi et al. [9]
TiO_2–Water	Water	0.012 vol%	Base wall temperature reduced to 33.85 °C	Highest Nusselt number of 40.57% enhancement	Sajid et al. [27]
Ag–Water	Water	1.0 vol%	5–8 °C temperature drop	Uniform cooling with low entropy generation	Shahsavar et al. [26]
Magnetic CuO–Water	Water	0.3 wt%	30% reduction in CPU surface temperature	Best performance at magnetic field $\alpha = 60°$	Qi et al. [11]
Al_2O_3–Synthetic Oil	Synthetic oil	0.03 vol%	Lowered absorber wall temperature	Enhanced conduction through porous medium	Bozorg et al. [5]
Graphene–Ag Hybrid	Water	0.5 wt%	Average temperature reduction of 4.5 °C	Excellent exergy efficiency, minimized hot spots	Bahiraei and Heshmatian [19]
Porous Al_2O_3–Water	Water	1.0 vol%	2.2× higher Nusselt number	Porous geometry significantly improves heat transfer	Neyestani et al. [15]

4. Conclusion, Practical Implications, and Recommendations

4.1. Conclusion

The mixture of nanofluids and heat sinks of porous metal is incredibly attractive for high-performance CPU cooling. Nevertheless, the complex relations of nanofluids-porous metal foams have hindered the development and progress for superior thermal performance. Therefore, a number of possible future works on nanofluid heat transfer in porous metals are apparent. This includes the utilisation of Magnetohydrodynamic (MHD) as a promising field modulation technique to strengthen thermal performance of porous media nanofluids such as metal heat sinks.

Nanofluids have been successfully applied for heat transfer enhancement such as CPU cooling. However, one point worth noting here is that adding nanoparticles into water as the base fluid may exhibit negative effect. This opens prospect for other liquids such as synthetic oil.

4.2. Practical Implications for Industry and Future Nanofluid Design

The growing demand for high-performance computing and compact electronic devices highlights the importance of efficient thermal management systems. Nanofluid-based cooling technologies offer a promising solution for industries developing next-generation CPUs, GPUs, and power electronics. The findings in this review suggest that optimizing nanoparticle type, size, and concentration can significantly enhance heat transfer while maintaining system stability and economic feasibility. Future nanofluid design should prioritize stable dispersion, corrosion resistance, and compatibility with microchannel heat sinks and porous metal structures. Integrating these characteristics into industrial cooling systems can lead to more reliable, energy-efficient, and longer-lasting electronic components.

4.3 Recommendations for Future Experimental and Numerical Work

1. Establish standard CPU cooling benchmarks and repeatable test rigs that report geometry, roughness, Reynolds number, particle size, concentration, inlet temperature, and pressure drop for fair comparison
2. Map optimal concentration and size windows for each nanofluid under realistic heat flux and pulsating loads while tracking long term stability, agglomeration, and fouling
3. Quantify the tradeoff between heat transfer gain and hydraulic penalty using nondimensional PEC and include uncertainty bands from repeated trials
4. Test hybrid nanofluids and eco friendly dispersants that improve stability without excessive viscosity rise and validate compatibility with seals, pumps, and common heat sink alloys
5. Conduct durability studies under power cycling and thermal shocks to assess corrosion, erosion, and deposition in microchannel and porous metal heat sinks
6. Explore active field modulation such as magnetohydrodynamic control and acoustic agitation and couple experiments with high fidelity CFD to resolve near wall transport
7. Optimize heat sink topology using multi objective design linking temperature uniformity, maximum junction temperature, pressure drop, and cost with Pareto fronts
8. Build reduced order or machine learning surrogate models trained on CFD and experiments to enable fast design screening across fluid and geometry spaces
9. Include full uncertainty quantification and sensitivity analysis to identify dominant parameters such as particle size, volume fraction, and surface energy
10. Validate models with transient workloads that mimic real processors and characterize hotspot suppression, temperature uniformity, and recovery time
11. Extend studies to alternative base fluids and dielectric coolants for immersion and two phase concepts while monitoring stability and safety
12. Perform life cycle and techno economic assessments that couple performance, pumping power, and maintenance with environmental and cost metrics for data center scale adoption
13. Integrate sensors for inline monitoring of viscosity, particle stability, and fouling and develop control strategies for adaptive flow rate and real time health tracking
14. Report open datasets with raw measurements and metadata to accelerate cross group validation and meta analysis

Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

CRediT Authorship Contribution Statement

All authors contributed equally to the conception, analysis, writing, and final approval of the manuscript. Each author has read and agreed to the published version.

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