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Nanocolloids as Heat Transfer Fluids: Advantages, Limitations, and Protocol Considerations

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Extended Abstract

Nanocolloids—suspensions of nanoparticles dispersed in conventional fluids—have emerged as promising alternatives to traditional coolants such as water, ethylene glycol, or oils. By improving thermal conductivity and heat transport properties, they open the way toward more compact, efficient, and sustainable thermal systems.

Over the past two decades, numerous studies have demonstrated the ability of nanocolloids to enhance heat transfer in both single-phase and phase-change applications. Yet, their large-scale adoption remains constrained by several critical challenges. Stability is among the most pressing [1], as nanoparticle agglomeration and sedimentation reduce long-term performance. Similarly, the viscosity increase at higher particle concentrations can offset thermal benefits by raising pumping power demands and reducing overall system efficiency.

Recent developments in nanoparticle surface functionalization, hybrid nanostructures, and environmentally friendly synthesis methods have significantly improved stability and tunability. Applications in renewable energy, microelectronics cooling, and advanced manufacturing highlight their growing relevance in future energy technologies [2].

Despite these advances, important limitations persist. A major challenge is the lack of consistent evidence supporting synergies between different base fluids and nanoparticles. The unique behavior of each fluid–nanoparticle system makes many numerical studies of limited value in the absence of robust experimental validation [3]. Furthermore, the absence of standardized protocols for nanocolloid preparation, stabilization, and thermophysical property measurements hinders comparability and reproducibility across studies.

For nanocolloids to transition from laboratory research to industrial practice, coordinated multidisciplinary efforts are essential. Standardized testing methodologies, scalable production processes, and comprehensive safety and life-cycle assessments will be critical for demonstrating reliability in real-world systems.

This work aims to highlight several research questions shaped by over 15 years of experimental and numerical experience [1], while also drawing attention to the urgent need for coordinated international efforts. In particular, the integration of artificial intelligence tools could facilitate the development of robust experimental databases, enabling predictive modelling and informed design of nanocolloid systems. More exactly, experimental tests on several base fluids and nanoparticles will be discussed, together with insights into surfactants advantages and drawbacks in an attempt to propose a protocol for nanocolloids preparation and stabilization.

In conclusion, nanocolloids show great potential as next-generation heat transfer fluids, provided that issues of stability, energy trade-offs, and standardized design protocols are addressed [1]. With sustained progress and application-oriented research, they may become vital enablers of energy-efficient and sustainable thermal management solutions. Not at last, a new project proposed at COST will consider AI tools in predicting nanocolloids properties.

References

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