JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. **16** No 6, 06020(4pp) (2024)

ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том **16** № 6, 06020(4cc) (2024)

OPEN ACCESS

REGULAR ARTICLE

A Critical Analysis of Nanofluid Usage in Shell and Tube Heat Transfer Systems

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(Received 25 August 2024; revised manuscript received 12 December 2024; published online 23 December 2024)

Nanofluid technology combines nanoscience, nanotechnology, and thermal science enhancing the heat transfer capacity of base fluids like water or oil. Researchers have put their effort into transforming these base fluids by adding nanomaterials to them, resulting in improved thermophysical properties of the coolant. Studies reveal that nanofluids with different nanomaterials suspended in them exhibit different thermophysical properties like density, viscosity, diffusivity, and thermal conductivity, unlike conventional fluids. Under the same boundary condition, nanofluids are capable of transferring more heat in different types of heat exchangers. However, several disadvantages like accumulation, long-term stability, sedimentation, and higher costs are associated with it. This paper summarizes the various aspects of the application of nanofluids in shell and tube heat exchangers. The purpose of the paper is not only to examine previous studies related to this but also to discuss the recent developments in the heat transfer process using nanofluids in shell and tube heat exchangers. Challenges remain in optimizing nanoparticle size, concentration, and synthesis techniques. Further research should address these gaps so that nanofluids can be implemented as coolants in shell and tube heat exchangers.

Keywords: Nanofluids, Shell and tube heat exchangers, Heat transfer, Thermal conductivity, Nanoparticles, Viscosity, Pumping power.

DOI: 10.21272/jnep.16(6).06020 PACS numbers: 44.30. + v 66.20. – d

1. INTRODUCTION

Nanofluids, which consist of small amounts of metallic and non-metallic nanoparticles dispersed in base fluids, offer great promise for enhancing heat transfer in various applications. They have the potential to improve thermal conductivity, rheological properties, and wettability, leading to increased heat transfer rates, reduced energy consumption, and overall improvements in efficiency [1, 2]. Further research has also shown that nanofluids can exhibit long-term stability, negligible erosion rates, and controlled surface wettability, making them suitable for next-generation heat transfer applications [3]. With their ability to intensify heat transfer rates and improve energy efficiency, nanofluids are indeed a promising candidate for a wide range of industrial and technological processes.

Multiple approaches have hence been explored to develop advanced HTFs with higher thermal conductivities by incorporating solid-fluid dispersions [4-5]. A nanofluid is a homogeneous suspension of nano-sized particles dispersed in a base fluid. By suspending metallic [6] or non-metallic nanometer-scale solid particles in conventional heat transfer fluids, nanofluids can substantially increase the thermal conductivity and convective heat transfer performance compared to the base fluid alone. This makes nanofluids well-suited as advanced heat transfer fluids in thermal processing equipment to improve energy efficiency and process productivity [7-9].

In recent years industries have relied on heat exchangers to overcome thermal energy shortage. Among all heat exchangers, the shell and tube heat exchangers gained popularity because of their simple design and resistance to temperature and pressure. To enhance the efficiency of the heat exchangers different cooling technology has been adopted. Heat transfer enhancement techniques can be categorized as either active or passive methods [10]. Passive approaches rely on fluid additives or specialized surface geometries to increase heat transfer without external energy input. In contrast, active methods apply external forces to the fluid or surfaces, such as acoustics, vibration, or electric fields, to change the boundary layer and increase turbulence and mixing. While passive techniques are simple and incur lower operational costs, active techniques can offer superior heat transfer augmentation but require additional equipment and energy input. The choice depends on parameters such as the allowable pressure drop, pumping power, cost constraints, and required heat transfer for the specific application. In the hybrid method, both processes are applied. The key components of a shell and tube heat exchanger are tubes, shell, front head, back head, and baffles [11]. The tube material should have high thermal conductivity. Within the shell, baffles redirect the shell-side fluid flow across the tubes multiple times, creating turbulent cross-flow as shown in Fig. 1. This increases contact with the tube surfaces, improving heat transfer performance. Maximizing the heat transfer coefficient allows heat exchangers to have smaller sizes, higher thermodynamic efficiency, and lower pumping power

Cite this article as: B. Monalisha et al., *J. Nano- Electron. Phys.* 16 No 6, 06020 (2024) https://doi.org/10.21272/jnep.16(6).06020

requirements for a given task. Optimizing baffle configuration and tube layout are critical design factors. The shell-side fluid flow pattern governs the rate of heat transfer from the tubes. Controlling the flow to maximize tube surface and turbulence is key to superior thermal performance. Proper heat exchanger design ensures high productivity for industrial processes while minimizing associated costs.

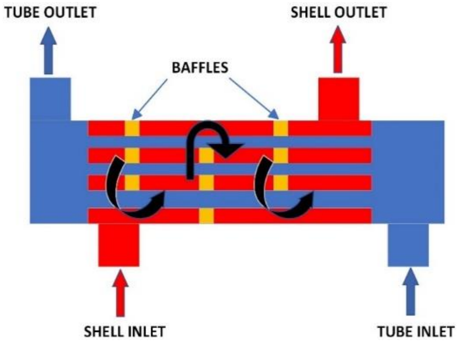

Fig. 1 – Schematic representation of Shell and tube heat exchanger

Most heat transfer enhancement techniques surveyed focus on modifying equipment design features. Examples include adding heating surface area with vanes, oscillating heating surfaces, injecting fluid, and applying electrical or magnetic fields. However, these methods alone may not satisfy the increasing demands for high-performance heat transfer systems. Several studies have experimentally demonstrated that nanofluids with tiny nanoparticles dispersed in a base fluid can enhance heat transfer and thermal conductivity compared to the base fluid alone in a heat exchanger. Common nanoparticles used include alumina, titanium oxide, and carbon nanotubes. Nanofluids show significant potential as enhanced coolants in situations where heat transfer performance is critical, despite higher pumping power requirements. Hence, further research is still needed to optimize nanoparticle materials, concentrations, and configurations.

The present paper's objective is to provide a comprehensive overview of recent research and advances using nanofluids as heat transfer fluids in shell and tube exchangers specifically. This would analyze numerical and experimental results across different nanofluid types, nanoparticle materials, concentrations, and flow conditions in shell and tube heat exchangers. It also highlights the key opportunities and challenges associated with adopting nanofluids in shell and tube exchanger systems on an industrial scale.

2. METHODOLOGY AND OBSERVATION

Scopus, a database owned by Elsevier B.V., and Web of Science are two premier sources for systematic and scientific literature. Both databases were utilized extensively in this study to compile basic bibliographic records for the literature review. Specifically, a search has been done in Scopus using the keyword "nanofluids in heat exchangers" in publications worldwide from 1997 through 2023. The search spanned several fields related to nanofluids including chemical engineering, biomedical engineering, mechanical engineering, solar energy, wastewater treatment, transportation, and industrial cooling applications. By searching Scopus across these disciplines, analysis has been done on nanofluid use in heat exchangers over the past few decades and is represented in Fig. 2. From Fig. 2, it is evident that nanofluid in heat exchangers has been an area of interest for many researchers over the years.

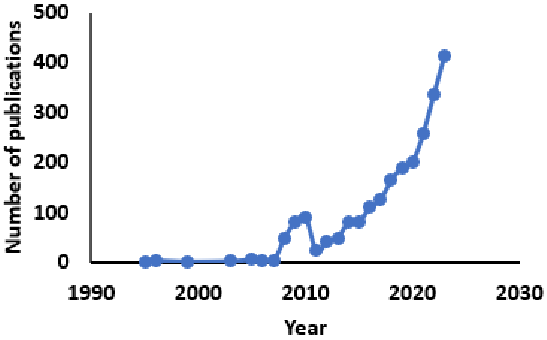

Fig. 2 – Number of articles published per year and number of citations in Scopus database

3. THERMAL PERFORMANCE OF NANOFLUIDS IN HEAT EXCHANGERS

Among all thermal energy-saving processes, heat exchanger is the most effective way of heat transfer. Nanofluid has prominent potential to increase the efficiency of the operating fluids enhancing the heat transfer rate & and efficiency of the heat transfer fluid [12]. The heat transfer coefficient of nanofluids is enhanced with increasing particle volume fraction. However, higher nanofluid pumping pressures and subsequently, greater pumping power requirements have been reported with rising Reynolds numbers compared to conventional fluids.

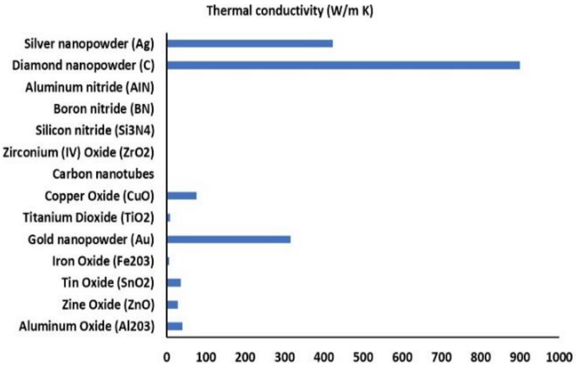

Fig. 3 – Thermal conductivity of different nanoparticles

Koo-Kleinstreuer model [13] was used to find corrections for computing key thermophysical properties like thermal conductivity, nanoparticle diameter, temperature, volume fraction, base fluid properties, and brownian motion of suspended nanoparticles. The thermal conductivity of different nanoparticles is shown in Fig. 3. Another vital parameter of nanofluid i.e. viscosity, is impacted by the base fluid viscosity, particle volume fraction, and nanoparticle density [10]. Nanofluid viscosity governs pivotal performance metrics including flow resistance, pumping power needs, and viability. Governing dimensionless numbers for heat transfer like Nusselt and Reynolds numbers share direct relationships with nanofluid viscosity.

While optimizing these parameters, factors like particle agglomeration, sedimentation, and clogging affect nanofluid stability over prolonged utilization. Adopting customized nanoparticle surface modifications, surfactant additions, and sonication are constructive to obtain stable, homogeneous nanofluids with lower viscosities and better heat transfer capacities. Furthermore, implementing nanofluid property models that holistically account for temporal changes can aid sustainable design. A wide range of nanoparticles have been used to make nanofluid for different applications. Some of them are mentioned in Table 1.

Table 1 – Principal list of nanoparticles used in heat exchangers

Nanoparticle category	Name of Nanoparticle
Carbon Nanoparticles	MWCNT, SWCNT, Gn, GO, diamond and fullerene
Metal Nanoparticles	Ag, Al, Au, Co, Cu, Fe
Metal oxide Nanoparticles	Al_2O_3, CeO_2, CuO, Fe_3O_4, TiO_2, ZnO
Others	Si, AIN-C, $CoFe_2O_4$, SiC, $ZnBr_2$, SiO_2 etc

Several studies have investigated the thermal performance of nanofluids in shell and tube heat exchangers. Shahrul et al. [14] analytically studied heat exchangers using four types of nanoparticle nanofluids – Fe_3O_4, ZnO, TiO_2, CuO, and Al_2O_3 – finding that Al_2O_3/water nanofluids achieved the maximum heat transfer coefficient. Another study [15] compared turbulent heat transfer of Al_2O_3 and TiO_2 nanofluids with water, demonstrating superior heat transfer with TiO_2. Lotfi et al. [16] experimentally tested multi-walled carbon nanotube (MWNT)/water nanofluid in a horizontal shell and tube heat exchanger, showing enhanced overall heat transfer versus water. Albadr et al. [17] studied varying concentrations of Al_2O_3/water nanofluid in a horizontal heat exchanger, finding slightly improved heat transfer coefficients. Ghozatloo et al. [18] investigated laminar convective heat transfer of graphene/water nanofluids in a shell and tube heat exchanger, determining 0.1 wt % graphene nanofluid increased heat transfer by 35.6 % over base fluid. Exergy analysis was performed by researchers using graphene oxide nanofluid as coolant in shell and tube heat exchangers where they found nanofluid is improving heat transfer in both laminar and turbulent flows. In summary, multiple studies have shown nanofluids can enhance shell and tube heat exchanger performance. Graphene /water nanofluids in a vertical shell and tube heat exchanger was studied by F. Mohammad et al. [19] using a 0.2 wt % nanofluid concentration on the tube side. Compared to water base fluid, the 0.2 wt % graphene nanofluid increased the heat transfer coefficient by up to 29 %.

4. FLOW CHARACTERISTICS OF NANO FLUIDS

The flow behavior of nanofluids plays a crucial role in determining their heat transfer performance. This behavior is primarily influenced by factors such as viscosity and density. Experimental studies have shown that the viscosity of nanofluids is affected by various factors including particle size and shape, type of nanoparticles, choice of base fluid, volume fraction of nanoparticles, and temperature [12]. To further enhance the heat transfer performance of nanofluids, it is important to consider and optimize their flow behavior, which is influenced by factors like viscosity, density, particle size/shape, type of nanoparticles, base fluid selection, volume fraction of nanoparticles, and temperature. Viscosity impacts critical parameters like pressure drop and pumping power [19].

Metal oxides, including Al_2O_3, TiO_2, ZnO and CuO, have shown significant promise as thermal additives in nanofluids [20]. These metal oxide nanoparticles have excellent properties such as high thermal conductivity, electrical insulation, compatibility with base fluids, and cost-effectiveness. Their incorporation into nanofluids has led to enhanced heat transfer performance, making them attractive for various heat transfer applications. The use of hybrid Nano fluids offers enhanced heat transfer performance exhibiting better thermo physical properties that may be used in heat transfer systems. The use of hybrid Nano fluids offers enhanced heat transfer performance exhibiting better thermo physical properties that may be used in heat transfer systems.

1. CHALLENGES AND MITIGATION STRATEGIES

Nanofluids comprise nanoscale particles (below 100 nm) suspended in base fluids like water, oils, or alcohols. Multiple interparticle forces exist in nanofluids, including van der Waals attractive forces, gravity, electrostatic repulsion, and buoyancy [14]. The complex interaction of these forces can trigger nanoparticle destabilization and sedimentation, posing a major technological barrier to nanofluid functionality and performance. Ensuring the dispersed nanoparticles remain kinetically stable without aggregation is imperative, else particle settlement degrades key thermophysical properties.

Nanoparticles tend to aggregate over time which disrupts thermal performance [17]. The use of optimal surfactants can improve particle dispersion stability. High velocity nanofluid flow causes surface erosion especially around tube inlets. Material selection as titanium, nickel alloys can help to overcome this problem. Tube inlet design modifications can also have positive impact. Complex nanofluid flow in narrow shell side passage leads to larger pressure losses. Baffle and tube layout design optimizations can reduce the pressure drop.

5. FUTURE SCOPE

Many efforts should be carried out to develop cost-effective and efficient nanofluids as the preparation of the nanofluid is costly. More extensive and systematic research should be performed on Graphene-based nanoparticles which show promising results on the application of heat transfer. Further studies on nanofluid heat transfer correlation are needed to develop accurate Nusselt number correction equations for use in numerical models. Reliable and validated heat transfer correlations for different nanofluids that appropriately capture the multiscale effects will enable more precise numerical predictions. Further research is required to understand the effects of metallic nanoparticle oxidation in phase change material nanofluids on the thermal performance of latent heat storage systems.

6. CONCLUSIONS

The integration of nanofluids in shell and tube heat exchanger systems has emerged as a promising approach to meet rising heat transfer needs in industries, due to the heat transfer enhancement achieved by these advanced fluids. This critical review assimilates recent research on developments in nanofluid applications for shell and tube heat exchangers concerning multiple aspects – thermophysical properties, flow characteristics, stability issues, economic impacts, and mitigation of operational challenges. The analysis indicates that properties like thermal conductivity and heat transfer coefficients see significant improvements with nanofluids containing metals and metal oxides like Cu, CuO, Al_2O_3 as well as some carbon-based particles. These effects get amplified with properties such as smaller size, higher concentrations, and aspect ratios of suspended nanoparticles. However, problems with settling, clogging, erosion, high pressure drops and pumping power present barriers to reliable long-term utilization.

REFERENCES

1. D.S. Rakshe, P. William, M.A. Jawale, A.B. Pawar, S.K. Korde, N. Deshpande, *J. Nano- Electron. Phys.* **15** No 3, 03020 (2023).
2. H.V. Mhetre, Y.K. Kanse, *J. Nano- Electron. Phys.* **14** No 3, 03017 (2022).
3. K. Dubyk, L. Chepela, S. Alekseev, A. Kuzmich, B. Zousman, O. Levinson, A. Rozhin, A. Geloen, M. Isaiev, V. Lysenko, *J. Nano- Electron. Phys.* **12** No 4, 04033 (2020).
4. I. Tlili, *Math. Sci.* (2021).
5. V.V. Wanatasanapan, M.Z. Abdullah, P. Gunnasegaran, *J. Mater. Res. Technol.* **9** No 6, 13781 (2020).
6. A.V. Korotun, N.A. Smirnova, G.V. Moroz, G.M. Shilo, *J. Nano- Electron. Phys.* **15** No 6, 06025 (2023).
7. P.P. Gohain, N.R. Medikondu, V.V. Kamesh, M.G. Choudhury, K. Chakraborty, P. Samrat, *J. Nano- Electron. Phys.* **15** No 6, 06031 (2023).
8. M.M. Zahornyi, O.M. Lavrynenko, O.F. Kolomys, V.V. Strelchuk, N.I. Tyschenko, O.A. Korniienko, A.I. Ievtushenko, *J. Nano- Electron. Phys.* **15** No 4, 04001 (2023).
9. A. Mishra, M.K. Nigam, *J. Nano- Electron. Phys.* **15** No 4, 04020 (2023).
10. A. Shahsavar Goldanlou, M. Sepehrirad, M. Papi, A.K. Hussein, M. Afrand, S. Rostami, *J. Therm. Anal. Calorim.* **143**, 1689 (2021).
11. M. Bahiraei, M. Naseri, A. Monavari, *Powder Technology*, **395**, 348 (2022).
12. P. Kanti, K.V. Sharma, C.G. Ramachandra, B. Panitapu, *Heat Transfer* **49** No 8, 4722 (2020).
13. H.W. Xian, N.A. Sidik, R. Saidur, *Int. Commun. Heat Mass Transf.* **110**, 104389 (2020).
14. I.M. Shahrul, I.M. Mahbubul, R. Saidur, S.S. Khaleduzzaman, M.F.M. Sabri, M.M. Rahman, *Numer. Heat Transf., Part A: Appl.* **65** No 7, 699 (2014).
15. B. Farajollahi, S.G. Etemad, M. Hojjat, *Int. J. Heat Mass Transf.* **53** No 1-3, 12 (2010).
16. R. Lotfi, A.M. Rashidi, A. Amrollahi, *Int. Commun. Heat Mass Transf.* **39** No 1, 108 (2012).
17. J. Albadr, S. Tayal, M. Alasadi, *Case Studies in Thermal Engineering Commun.* **1** No 1, 38 (2013).
18. A. Ghozatloo, A. Rashidi, M. Shariaty-Niassar, *Exp. Therm. Fluid Sci.* **53**, 136 (2014).
19. M. Fares, A.M. Mohammad, A.S. Mohammed, *Case Studies in Thermal Engineering Commun.* **18**, 100584 (2020).
20. D. Zhu, L. Wang, W. Yu, H. Xie, *Sci. Rep.* **8** No 1, 5282 (2018).

Критичний аналіз використання нанофлюїдів у оболонкових і трубчастих системах теплопередачі

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Технологія нанофлюїдів поєднує в собі нанонауку, нанотехнологію та теплову науку, підвищуючи теплообмінну здатність базових рідин, таких як вода чи нафта. Дослідники доклали зусиль для перетворення цих базових рідин шляхом додавання до них наноматеріалів, що призвело до покращення теплофізичних властивостей теплоносія. Дослідження показують, що нанофлюїди з різними наноматеріалами, суспендованими в них, демонструють різні теплофізичні властивості, такі як щільність, в’язкість, коефіцієнт дифузії та теплопровідність, на відміну від звичайних рідин. За однакових граничних умов нанофлюїди здатні передавати більше тепла в різних типах теплообмінників. Однак з цим пов’язано кілька недоліків, таких як накопичення, довгострокова стабільність, осадження та більш висока вартість. У цьому документі узагальнено різні аспекти застосування нанофлюїдів у кожухотрубних теплообмінниках. Метою статті є не тільки вивчити попередні дослідження, пов’язані з цим, але й обговорити останні розробки в процесі теплопередачі з використанням нанофлюїдів у кожухотрубних теплообмінниках. Проблеми залишаються в оптимізації розміру наночастинок, концентрації та методів синтезу. Подальші дослідження мають усунути ці прогалини, щоб нанофлюїди можна було використовувати як теплоносії в кожухотрубних теплообмінниках.

Ключові слова: Нанофлюїди, Кожухотрубні теплообмінники, Теплопередача, Теплопровідність, Наночастинки, В'язкість, Потужність накачування.