Nanofluids for Heat Transfer Augmentation in Heat Exchangers—An Overview of Current Research

P. Adarsh Varma, Ch. SatyaPriya, M. Prashanth, P. Mukesh, B. Sai Sri Nandan, G. Srinivas, M. Sandeep Kumar, and T. Srinivas

Abstract In the heat exchanger system, nanofluids are used to improve the effectiveness of passive heat transfer methods. Many researchers have demonstrated the wide range of engineering applications for nanofluids. In this study, heat transfer in heat exchangers is enhanced by the use of nanofluids. Nanofluids have a better thermal conductivity in heat exchangers than conventional fluids. When compared to pure liquids, the mixing stream had superior heat transfer properties because of the nanosized particles in nanofluids. Despite the fact that many heat exchangers outperform others, nanofluids are the only ones that do so due to their thermal conductivity and faster heat transfer rates. This review paper looks at and discusses the findings and observations of various research groups on nanofluids as an employed way. Furthermore, the conclusions of various authors are evaluated, and points of argument are discussed. As a result, using nanofluid in a heat exchange system is likely to improve thermal transmission performance.

Keywords Base fluid · Nanoparticles · Nanofluid · Thermal conductivity · Heat transfer rate

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P. Adarsh Varma · Ch. SatyaPriya · M. Prashanth · P. Mukesh · B. Sai Sri Nandan · G. Srinivas · T. Srinivas (✉)
Chemical Engineering Department, B V Raju Institute of Technology, Narsapur, Medak, Telangana State 502313, India
e-mail: dr.t.srinivas85@gmail.com

M. Sandeep Kumar
Mechanical Engineering Department, B V Raju Institute of Technology, Narsapur, Medak, Telangana State 502313, India

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1 Introduction

Heat exchangers, also known as heat transferring equipment, allow thermal energy to flow among two or additional liquids that are at various temperatures. There are many industries that use heat transfer devices, including power generation, food, process, and chemical, as well as manufacturing, electronics, air-conditioning, space, and refrigeration applications. In terms of global economics, energy, materials, and space, saving energy prompted an increase in efforts to develop more cost-effective heat exchange equipment. As a result of these efforts, the fundamental dimensions of heat exchange device for a certain thermal capability has been reduced [1]. Therefore, the more effective heat purposes in a heat exchanger are to reduce the heat exchanger's size, which is necessary for thermal efficiency (capacity), to improve the capability and function of an current heat exchanger, or to diminish pumping power. In addition to improving heat transfer in heat transfer fluids and heat exchangers, many investigations have been carried out [2].

A device that enables the transfer of heat from one liquid to another is a heat exchanger. Heat exchangers can also be utilized for heating as well as cooling. To prevent cross-contamination, the liquids could be detached by a solid object, or maybe they're in touch directly. In chemical plants, petrochemical plants, electricity generation and distribution, petroleum refineries and petroleum plants, natural gas processing, and sewage treatment, they are widely used [3].

A variety of heat exchanger issues can lead to poor productivity or, in certain situations, the complete shutdown of the industrial heat exchanger. The researchers use a variety of approaches to elucidate them. Because the most recent research supports utilizing nanofluids in heat exchangers, the work in question is taken into account. Other methods to avoid vibration problems, heat exchanger secretion, enhanced heat exchanger power usage, aisle separation (thermal leakage), and contamination should be considered in other articles [4].

But there is a quick brief of the difficulties that can happen in heat exchangers and why nano is a good idea. Contemplating the foregoing, the accessibility of superior-effectiveness heat exchangers is one of the most basic requirements in many businesses and research. As a result, the researchers suggested new approaches. The purpose of passive heat transfer mechanisms and variations in the rheological properties of fluids are being researched to find solutions to these problems. These techniques work by reducing the formation of a laminar sublayer, improving the number of interruptions, improving the efficient heat transfer surface, creating secondary flows or vortices, and improving fluid blending [5]. Many methods for increasing the heat transfer level in these methods have been proposed because heat exchangers show such a significant function in various electronics, transportation, manufacturing processes, including heat sources, and industrial processes. Most of these procedures rely on structural changes, such as increased thermal exteriors (fins), thermal exterior pulsation, and fluorescence. Heat transmission and compression in high-energy process equipment will be a challenge for these techniques to meet [6].

2 Improved Heat Transfer in Nanofluids Heat Exchangers

Plate type heat exchangers, double pipe heat exchangers, shell and tube heat exchangers, shell and helical coil heat exchangers, and fin type heat exchangers are just a few examples of the many types of heat exchangers available. In the tables below, we summarized heat transfer development using nanomaterials in different heat exchangers (Tables 1, 2, 3, 4 and 5).

Table 1 An overview of experimental work on a double pipe heat exchanger with nanofluids

Refs.	Investigator	Nanomaterial—fluid	Remarks
[7]	Bahiraei and Hangi (2013)	Mn–Zn ferrite magnetic—water-based nanofluid	They studied how pressure drop and heat transfer were affected by magnetic fields and nanofluids. For maximum heat transfer and little pressure drop, they reported the ideal conditions
[8]	C.S. Reddy and V.V. Rao (2014)	TiO_2—ethylene glycol water based	They discovered that when 0.02% nanofluid is added to reference fluid, the heat transfer coefficient and friction factor increase with 10.69 and 13.85%, respectively
[9]	Marjan et al. (2016)	Graphene with nitrogen-doped water-based nanofluids	They reported that for a given pumping energy, heat withdrawal, heat transfer rate and the power usage for nanofluids were significantly higher than that for liquid throughout all studies reported. They also demonstrated a nearly 16.2% increase in heat transfer coefficient on average
[10]	Ravi Kumar et al. (2017)	Fe_3O_4/water	They found that, in comparison to water data, the *Nu* improvement for the nanofluid's 0.06% volume fraction is 14.7%, and it increases to 41.29% when combined with the longitudinal tape spacer

(continued)

Table 1 (continued)

Refs.	Investigator	Nanomaterial—fluid	Remarks
[11]	Hussein (2017)	Aluminum nitride—EG	In comparison to conventional fluids, he claimed that the use of hybrid nanofluids with low volume parts increased the heat transfer efficiency by 160%
[12]	Milani Shirvan et al. (2017)	Al_2O_3—water	They observed that the mean Nusselt number increased by 57.70% when combined with the nanoparticle concentration and Reynolds number
[13]	Maddah et al. (2018)	Al_2O_3–TiO_2/water	If used as a fluid for heat transfer instead of ordinary water, they made the discovery that the utilization of twisted tapes and nanostructured materials results in an increase in exergy competence
[14]	Bahmanu et al. (2018)	Alumina/water	They discovered that when the Reynolds number and the volume fraction of nanoparticles were combined, the Nusselt number and the convection heat transfer coefficient increased by 32.7 and 30%, respectively
[15]	V Nageswarw et al./2019	CuO/water	When related to base fluid, augmentation in the *Nu* was about 18.6% at 0.06% volume concentration
[16]	Sumit Kr. Singh et al./2020	Al_2O_3_MgO hybrid nanofluid	In this study, it was determined that a hybrid nanofluid and tapered wire coil arrangement was a viable choice for enhancing a double pipe heat exchanger's hydrothermal properties

Table 2 Experimental studies on the efficiency of a Shell and tube heat exchanger employing various nanofluids are summarized

Refs.	Author/year	Nanoparticle/base fluid	Observations
[17]	Kanjirakat Anoop et al./2013	Water—SiO_2	Heat transfer coefficient of nanofluids enhanced with nanoparticles intensity in heat exchangers, according to experimental results
[18]	K.V. Sharma et al./ 2014	TiO_2 and SiO_2/ water	Heat transfer coefficients increased by 26% with 1.0% TiO_2 nanofluid concentration and 33% with 3.0% SiO_2 nanofluid concentration

(continued)

Table 2 (continued)

Refs.	Author/year	Nanoparticle/base fluid	Observations
[19]	Nishant Kumar/ 2016	Fe_2O_3/water Fe_2O_3/ ethylene glycol	They discovered that as nanoparticle content rises, thermal conductivity and overall heat transfer improved due to particle interaction. The thermal conductivity of the conventional fluids improved with temperature
[20]	Milad Rabbani Esfahani, et al./2017	Graphene oxide/DI water	With both turbulent and laminar flow conditions, graphene oxide nanofluids were found to be more effective as the hot fluid
[21]	Ramtin Barzegarian, et al./2017	Al_2O_3/water	Because of this, nanofluids outperformed base fluids in heat transfer, increasing the Nusselt number from 9.7 to 20.9 to 29.8% while also improving overall heat transfer by 5.4 to 11.0% (and the Nusselt number from 9.7 to 19.9 to 29.8%)
[22]	V. Rambabu et al./ 2017	TiO_2/water	The introduction of Nano particles at different volume concentrations (0.05, 0.1, 0.15, and 0.2%) and flow rates results in a significant improvement in heat transfer characteristics
[23]	S. Anitha et al./ 2019	Al_2O_3-Cu /water	They found that hybrid nanofluid heat transfer coefficient has a 139% greater than pure water and a 25% greater heat transfer coefficient than water-Cu nanofluid. Furthermore, the significant increase in Nusselt number exceeds 90% for hybrid nanofluids
[24]	Z. Said et al./2019	CuO/water	They discovered using the Al_2O_3 at a volume concentration of 0.3% improved thermodynamic efficiency by 24.21%
[25]	Mohammad Fares, et al./2020	Graphene /water	They discovered that at 0.2 wt%, the heat transfer coefficient was 29%, and the mean thermal efficiency was 13.7%
[26]	Aysan Shahsavar G et al./2021	Fe_3O_4-CNT/water	They discovered that increasing hybrid nanofluid concentration and Re improved heat transfer in heat exchangers

Table 3 On the effectiveness of a Shell and Helical heat exchanger with various nanofluids, experimental studies are summarized here

Refs.	Author/year	Nanoparticles/base fluid	Observations
[27]	Vinod Kumar /2015	Al_2O_3/water	He indicated that higher the mass flow rate and the Reynolds number led to an increase in the amount of heat that could be transferred by convection. He used 0.2 vol%
[28]	Khoshvaght, et al./2016	Cu/water	They showed that changing the pressure drop increased the heat transfer enhancement caused by copper nanoparticle suspension in water and that the enhancement was amplified by boosting the nanoparticle intensity
[29]	T. Srinivas, et al./2016	TiO_2	They found that when TiO_2/water nanofluids were compared to water, the heat exchanger's effectiveness increased by 26.8%, indicating that heat transfer was intensified
[30]	P.J. Fule, et al./2017	CuO/water	At 0.1 and 0.5 vol%, respectively, the heat transfer coefficient is found to be 37.3 and 77.74% greater than the base fluid
[31]	Amol F. Niwalker et al./2018	SiO_2/water	This fluid has a 29% higher heat transfer coefficient than the base fluid. Furthermore, friction and pressure drop are improved by 52.61 and 62.60%, respectively, when related to the base fluid

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Table 3 (continued)

Refs.	Author/year	Nanoparticles/base fluid	Observations
[32]	K. Palanisamy, et al./2019	Water/MWCNT	At 0.1, 0.3, and 0.5% volume intensity, the Nusselt number is 28, 52%, and the pressure drop is 16, 30, and 42% higher than the base fluid
[33]	Neeraj R. Koshta, et al./2019	Graphene oxide-TiO_2/water	The percent heat transfer coefficient improvement for a 0.25% volumetric intensity of the rGO/TiO_2 nanocomposite in the base liquid was 35.7%
[34]	Kriti Singh, et al./2020	CNT/water	At Reynolds number 5000, CNT nanofluid has a 62.62% higher overall heat transfer coefficient than water
[35]	Abhishek Lanjewar, et al./2020	CuO-Polyaniline/water	When 0.2% vol. 1 wt% CuO—PANI nanocomposite was added to a base fluid, the heat transfer coefficient increased 37%
[36]	D. Saratha Chandra, et al./2021	Cu–Ni/water	Because of its consistency in maintaining a constant temperature, 0.04% volumetric Cu–Ni/H_2O with 12 rings appears to be more dominant in food processing applications

Table 4 Experimental investigations on the efficiency of plate type heat exchangers using various nanofluids are summarized

Refs.	Author/year	Nanoparticle/base fluid	Observations
[37]	Pantzali et al./2017	CuO	They discovered that the heat exchanger operates in laminar conditions, making nanofluids an effective option
[38]	Shalkevich et al./2018	Gold nanoparticle	All of the experimental tests were repeated twice, and the thermal conductivity of gold nanoparticles was improved using a plate type heat exchanger
[39]	Sözen A et al./2019	Kaolin—deionized water	The use of kaolin—deionized water nanofluid as a working fluid improved the mean heat transfer coefficient by 9.3%, according to the authors
[40]	Bhattad A et al./2019	Al_2O_3—MWCNT hybrid nanofluid	They observed a negligible increase of 0.08% in pump work and a 12.46% increase in the performance index for Al_2O_3—MWCNT (4:1) hybrid nanofluid heat transfer coefficient
[41]	Talari VK et al./2019	Al_2O_3/water	They claimed that using nanofluids in heat exchangers could increase heat transfer efficiency
[42]	Behrangzade et al. / 2019	Ag/Water	When water contains 100 parts per million of silver nanoparticles, the overall heat transfer coefficient of the plate heat exchanger increases by 17%
[43]	Khanlari A et al. / 2019	TiO_2/DI water and Kaolin/DI water	The heat transfer rate of TiO_2/deionized water was 12%, while kaolin/deionized water was 18%
[44]	Kumar SD, et al./2019	CNT, Al_2O_3, surfactant with deionized water	They showed that nanofluids can replace conventional fluids in heat transfer applications where large volumes of conventional fluids are required
[45]	Mehrali et al./2020	Graphene nanoplatelet (GNP)	GNP nanofluids with 300, 500, and 750 m^2/g particular surface areas have thermal efficiency considerations of 1.51, 1.74, and 1.89, respectively
[46]	Hussein M Maghrabiea, et al./2021	CeO_2/Water	With a CeO_2/water concentration of 0.75 vol.%, the best performance was achieved, with a 16% increase in the performance index

Table 5 Experimental investigations on the effectiveness of a Finned tube heat exchanger using numerous nanofluids are summarized

Refs.	Author/year	Nanoparticle/base fluid	Observations
[47]	Y. Vermahmoudi, et al./2014	Fe_2O_3/water	The heat transfer rate and total heat transfer coefficient increase by 13 and 11.5%, respectively, when associated with the base fluid (DI water), at an intensity of 0.65 vol.%
[48]	Dr. Qasimb S. Mahdi, et al./ 2016	Al_2O_3/water	It was discovered that as the concentration of nanoparticles increased, H.T. increased as well, reaching a maximum of 12.4% at 0.8 vol%. In addition, improving the intensity of nanoparticles to a maximum of 19.22% at 0.8 vol% increased inner-side heat transfer
[49]	DR. Zena K. Kadhim, et al./ 2016	MGO/water	The airside heat transfer coefficient increases with nanoparticle concentration. At 0.75% concentration, the increase over the base fluid was 15.85%
[50]	Mohammad. SikindarBaba, et al./2017	Fe_3O_4 /water	They noticed that the heat transfer rate in three tubes is 70–80% higher than any other type when particle Reynolds number and concentration are considered
[51]	Behrouz Raei, et al./2018	Gamma alumina/water	When 0.2 wt% alumina nanoparticles are added to water, the heat transfer coefficient and friction factor increased by 5 and 20% correspondingly
[52]	Hassan Hajabdollahi, et al./ 2020	Al_2O_3, CuO—water	They discovered that at 0.025, 0.05, and 0.075 vol concentrations, a Reynolds number of 3000 increased 1.92, 15.08, and 22.46% for Al_2O_3 and 10.98, 35.30, and 46.11% for CuO
[53]	Budi Kristiawan, et al./2020	TiO_2/water	Their findings add to our knowledge of how helical micro fins inside tubes and nanofluids can improve heat transfer

3 Conclusions

This paper reviews all the important papers on heat exchangers and nanofluids that have been published in the last few years (HEs). This comprehensive review looked at the outcomes of nanofluid on heat transfer in five various kinds of heat exchangers. The key findings are summarized below:

- The use of nanofluid in all five heat exchangers has increased in the last decade as a result of its promise and a significant growth in thermal conductivity over the pure fluid.
- The optimum volumetric concentration of nanofluid is a point at which the heat transfer rate increases as the volume concentration of nanoparticles rises.
- It also increases viscosity and friction, lowering pumping energy. Almost all studies found that the desired thermal performance, heat transfer augmentation, entropy generation decline, and exergy destruction reduction were all better than the base fluids. Nanofluids for industrial use, on the other hand, necessitate high concentrations and kilos of nanoparticles, which have yet to be proven cost-effective.
- It was also discovered that the working nanofluids temperature has a significant impact on heat exchanger efficiency improvement.

4 Recommendations for Future Work

- The most research is required to ascertain how a nanofluid mixture affects a heat exchanger's convective heat transfer coefficients, containing nanoparticle size, shape, pH variation, surfactant addition, sonication time, and agglomeration.
- The heat transfer performance of a variety of hybrid nanofluids can be improved by changing the statistical constraints, such as plate thickness, plate pitch, corrugation pattern, and corrugation angle.
- The effects of different surfactants on the thermal stability and properties of nanofluid mixtures.

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