Applications Of Nano-Materials In Heat Exchangers: Recent Advances & Prospects

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Abstract

Heat exchangers play an important role in various aspects of life, especially in industrial areas, including the oil and petrochemical industries, fertilizer production, industrial plants, reactors, and similar domains. In the industry, different heat exchanger configurations are used. Double pipe and shell and tube types are the most widely used. During the past few years, extensive research and studies have been underway to increase the efficiency of the heat transfer performance of this equipment. A remarkable research area is using nanomaterials to increase heat transport phenomena depending on the extraordinary thermal properties of nanomaterials and their structures. Oxides, nanoparticles, nanotubes, and carbide nanostructures such as (Al_2O_3, TiO_2, Cuo, SiC and CNT) are the commonly used nanomaterials. This paper reviews the application of different nanomaterials in heat exchangers as efficient nanofluids and the importance of these materials in improving the heat transfer performance compared to the heat exchangers' base fluids.

Keywords: *Heat Exchanger; Nanomaterials; Nanofluids; Titanium Dioxide; Titanium Nanotube; CNT; Al_2O_3; CuO; Thermal conductivity.*

1. Introduction

Heat exchangers are critical in several industries because they allow heat to transfer from colder to hotter streams. Their primary function is to enhance the rate of heat transfer to its maximum capacity. There are two methods to enhance heat transfer: optimizing the design of the heat exchanger and ensuring its optimal performance. Optimizing the operational parameters is crucial for enhancing the heat transfer rate after constructing a heat exchanger [1, 2]. design an effective configuration of tube bundles to handle the various types of shell and tube heat exchangers. The primary goal of a heat exchanger is to achieve optimal efficiency and cost-effectiveness. There are many types of heat exchanger used in industry; Figure (1-1) depicts the primary categories of heat exchangers that hold significant importance [3].

The development of various tube bundle designs aims to enhance the performance of heat exchangers. Regrettably, the occurrence of a high-performance design that is also modest in cost is rare. A study has determined that nanofluids exhibit superior heat transfer properties in comparison to base fluids. Increased heat transfer corresponds to a greater rate of heat transfer or a larger amount of heat transferred per unit area of the heat exchanger. An increased heat transfer rate would result in a reduced size of the heat exchanger, hence leading to lower costs. A higher heat transfer coefficient would result in a reduced flow rate of the heat transfer fluid, hence decreasing the amount of work required by the pump. A smaller heat exchanger requiring less pump work is a clear indication of an economically designed

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system. Utilizing nanofluids in shell and tube heat exchangers will increase design efficiency, making them more cost-effective.

Oil refineries and other large chemical processes predominantly use shell and tube heat exchangers. Applications requiring higher pressures specifically shape their design. The shell of this heat exchanger, a sizable pressure vessel, houses a bundle of tubes. A single fluid circulates inside the tubes, while another fluid passes over the tubes (via the shell) to facilitate heat transfer between the two fluids. We refer to the collection of tubes as a tube bundle, which can include a variety of tube types like plain tubes or longitudinally finned tubes.

Applications employ shell and tube heat exchangers across a broad spectrum of pressures and temperatures. Both fluids have the potential to exist as single-phase or two-phase substances, and they can flow in either the same direction or in a perpendicular direction to each other [4][5]. Despite being the most commonly utilized, shell and tube heat exchangers are somewhat less efficient. Researchers have made significant efforts to improve their efficiency.

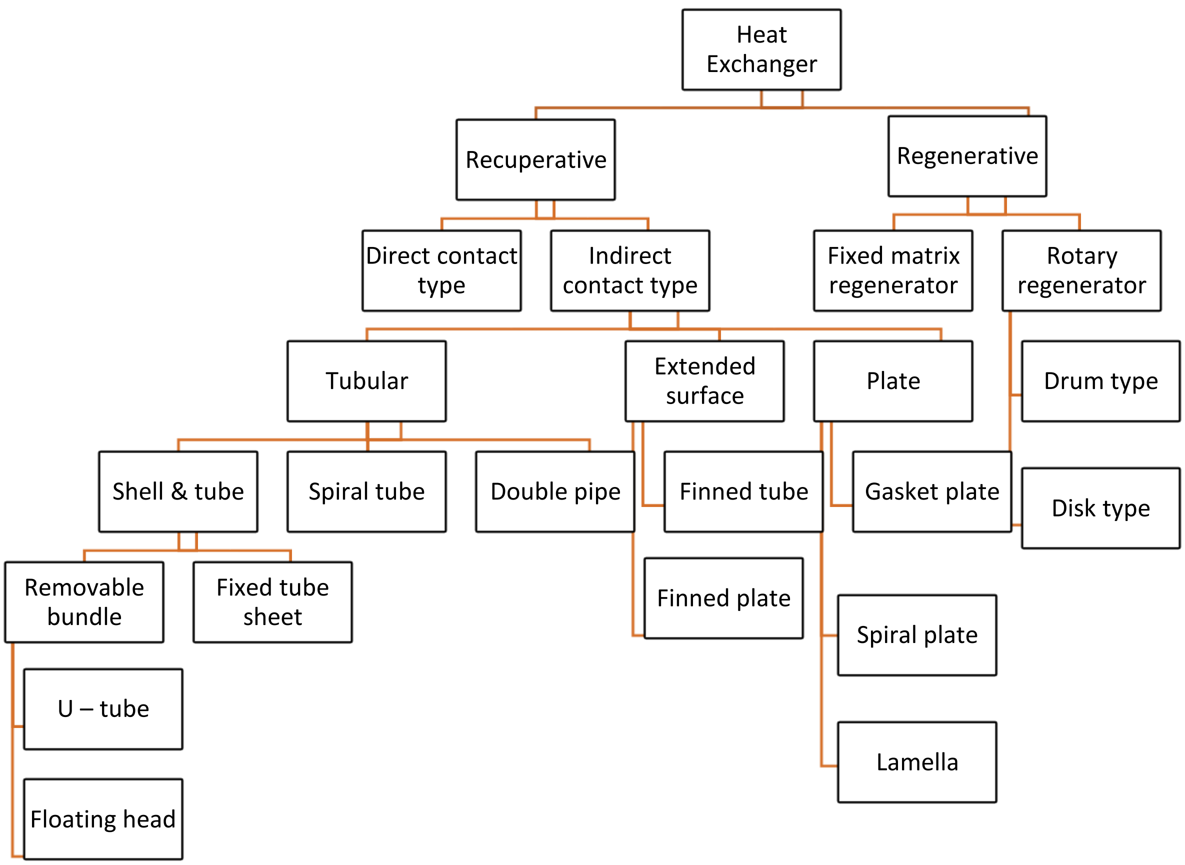

Fig. 1-1. Different Types of Heat Exchanger.[6]

Recent studies have revealed that nanofluids exhibit superior heat transfer properties in comparison to traditional heat transfer fluids. Extensive research was conducted to determine the viability of utilizing nanofluids in various heat transfer devices. Some studies are primarily focusing on the use of aqueous nanofluids and the uses of nanomaterials and novel nanofluids with high thermal properties. [7], [8]

2. Nanomaterials

Nanomaterials are materials with at least one external dimension on the nanometer scale or having special chemical, physical, or biological properties due to their nanostructure. Since the physical dimension of the nanomaterial is the same as the critical scale of the physical and chemical interaction, this unique nano-effect becomes a fundamental property of the nanomaterial, differing from the micro material. Nanomaterials have a large ratio of surface atoms to interior atoms and equal surface energy and interior energy, and thus the properties of nanomaterials are essentially determined by surfaces. The characteristics of nanomaterials improve with decreasing particle size; Figure (1-2) shows the different types of nanoparticles [9].

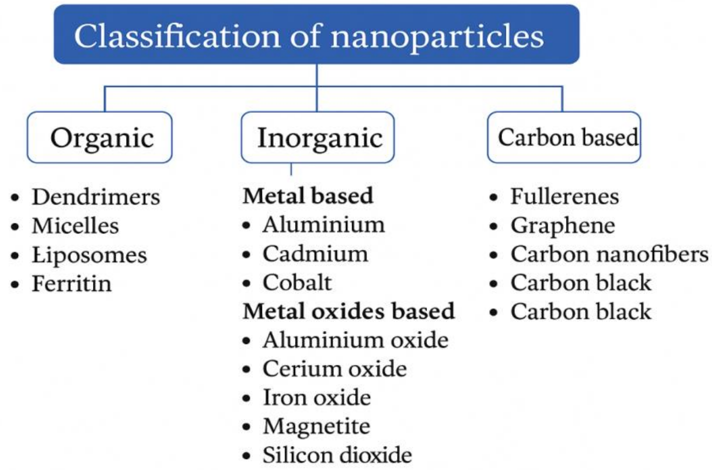

Fig. 1-2. Different Types of Nanoparticles[7]

Nanotubes are one of the most important nanostructures. They could be defined as a cylindrical structure with a diameter approximately in the range of 1-100 nm and a length-to-diameter ratio in the range of 13200. Nano-lube is similar to the composition of nanotubes, but their structure is much more complex than that of nanotubes. Nanotubes are found as single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs) [10]. The research for nanomaterials had been started by Sumio Lijima in 1991 through providing a structural model of multi-wall nanotubes (MWNTs), and it was the first way to synthesize nanotubes. It was scrutinized that at approximately 28000 K a hollow carbon structure known as a carbon selective area has been obtained during the arc discharge process between graphite electrodes [11]. After that, many other scientists worked on the production of nanotubes in different ways. Nanotubes have an extraordinary infrastructure and unordinary structure, because of which they have fantastic electrical and mechanical qualities. Nanotubes have an extraordinary thermal pasty than long-established thermal agents. There are two diameters of nanotubes known as inside wall diameter and outer wall diameter.

Titanium nanotubes (TiNTs) have emerged as a promising class of nanostructures due to their hollow cylindrical geometry and nanoscale dimensions. TiNTs show better thermal and physical properties, including high thermal conductivity, large surface area, and excellent chemical stability. These features make them an ideal additive to improve heat transfer performance in the heat exchanger system. Several recent studies have shown that incorporating TiNTs into cold liquids can significantly increase the total heat transfer rate, reduce thermal resistance, and increase the thermal efficiency of the system. This research direction not only paves the way for more effective thermal system design but also contributes to energy savings and environmental stability in different industrial applications [12,13].

2.1 Nano- Material And Nanofluids

Nanofluids are created using a wide variety of particle materials. The commonly employed nanoparticles are Al_2O_3, CuO, TiO_2, SiC, TiC, Ag, Au, Cu, and Fe. There are two primary methods for producing nanoparticles: physical and chemical. Yu et al. listed the common production strategies of nanofluids. The physical synthesis process involves converting a high-level description of a digital circuit into a physical layout suitable for fabrication on a semiconductor chip. Mechanical grinding and an inert gas condensation method are used in the process. Chemical synthesis methods include chemical precipitation, chemical vapor deposition, microemulsions, spray pyrolysis, and thermal spraying [8,14-15].

Carbon, titanium, and some other metallic oxide nanotubes are used due to their exceptional thermal conductivity in the longitudinal (axial) direction. The primary fluids commonly used in the nanofluid formulation are typical heat transfer working fluids, including water, ethylene glycol, and engine oil. The combination incorporates minute quantities of additives to enhance the stability of nanoparticles within the base fluid. The user's text needs to be completed and provide more information.

Nanomaterials have a larger surface area, leading to a higher heat transfer rate. The increased thermal conductivity of nanoparticles accelerates heat transfer. The decrease in particle size causes a decrease in pressure drop. This leads to a reduction in the size of the heat exchanger. Figure (1-4) shows the factors affecting on nanofluids in heat exchangers. [12-13]

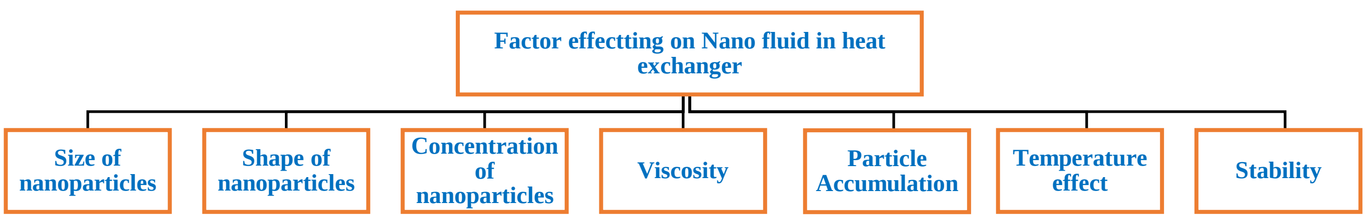

Fig. 1-4. Factors affecting on nanofluids in heat exchangers.[7]

2.2 Nanofluids Preparation

Nanofluids preparation includes two primary methods: the two-step method and the one-step technique. The two-step method involves two distinct processes: nanoparticle synthesis and nanoparticle dispersion in a base fluid. The two-step technique is beneficial for mass manufacturing of nanofluids, as it allows creating nanoparticles in large quantities using the inert gas condensation process[16]. One of the defects of the two-step process is that nanoparticles tend to stick together when nanofluid is made, making it harder for them to spread evenly in the base fluid. The one-step process integrates the synthesis and dispersion of nanoparticles in the base fluid, eliminating the need for multiple steps. There are several variations of this approach. A typical technique for generating nanofluids is the direct evaporation one-step approach. [14-15] This method involves solidifying gas-phase nanoparticles within the base fluid. Nanofluids created using one-step processes have superior dispersion characteristics than those produced using two-step approaches. One-step procedures have a significant limitation in that they are unsuitable for large manufacturing, hindering their commercialization. Figure (1-5) shows the different types of base fluid [7,11-16].

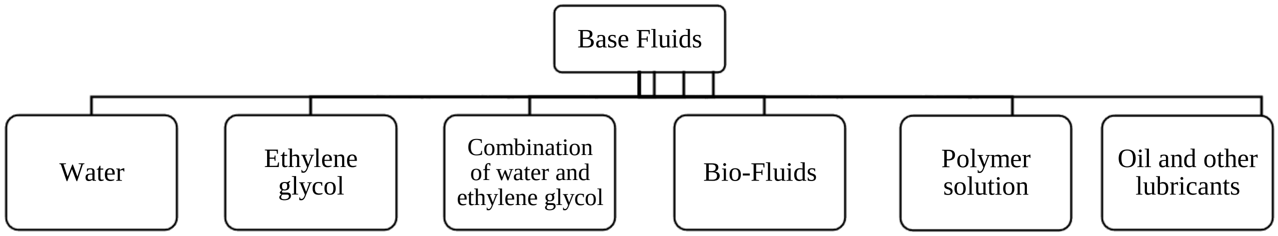

Figure (1-5) shows the different types of base fluid [7]

Enhancing the thermal conductivity of the working fluid improves the efficiency of the corresponding heat transfer process. Employing nanomaterials in heat exchanger working fluids increases the heat transfer coefficient, which increases the thermal conductivity of the nanofluid. Nanofluids' thermal conductivity has shown that using them can significantly improve thermal conductivity. With a particle volume fraction of less than 5%, nanofluids can increase thermal conductivity by more than 20%. These enhancement levels go beyond the predictions of theoretical models designed for suspensions containing larger particles [20]. Nevertheless, studies on nanofluid convective heat transfer have shown that the increase in heat transfer coefficient is more significant than the increase in thermal conductivity of nanofluids [8,17] Table 1 shows the thermophysical properties of different nanomaterials and base fluids.

Table 1. Thermo-physical properties of different nanomaterials and base fluids [7]**.**

Material	Thermal Conductivity (W/m. K)	Specific Heat (KJ/Kg.m)	Density (Kg/m^3)
Alumina (Al_2O_3)	40	0.773	3960
Alumina (Al_2)	237	0.903	2700
Alumina nitride (AIN)	285	0.74	3260
Carbone Nanotube (CNT)	2800-6000	-	1350
Copper (Cu)	401	0.385	8940
Copper Oxide (CuO)	33	0.551	6000
Diamond	2200	0.509	3530
Gold (Au)	317	0.129	19300
Graphite	120	0.701	2160
Silicon (Si)	148	0.714	2320
Silicon Carbide (SiC)	150	1.34	3370
Silver (Ag)	429	0.235	10490
Titanium Oxide (TiO_2)	8.4	0.692	4230
Zirconia	3	0.418	5680
Ethylene glycol	0.261	2664	1070
Water	0.67	4180	1000

3. Nanofluid Applications In Heat Exchangers

Nanomaterials such as aluminum oxide (Al_2O_3), copper oxide (CuO), silicon carbide (SiC) and titanium dioxide (TiO_2) are usually common spread materials in some base fluids such as water, ethylene glycol, oils, and some polymer solutions to prepare efficient nanofluids to improve the thermal and hydraulic performances of different types of heat exchangers. Herewith below are some of the extensively used nanomaterials for this purpose.

3.1 Metallic Oxide Nanoparticles

Some experimental work was conducted on a spiral-coil tube heat exchanger using aluminum dioxide (**Al_2O_3**) nanoparticles mixed with water used in cooling as the basic fluid to improve and increase the thermal performance factor (TPF) and blade number. Different volumetric concentrations of nanoparticles were used, from 0.0% to 0.75%, and after analysis. The experimental results showed a significant improvement in the heat transfer coefficient and text number and an 8.5% increase in the value of the performance evaluation criteria [22]. It is found that using nanoparticles is superior and more efficient than using conventional fluids, i.e., a 1% increase in nanoparticle volume resulted in a 17.62% increase in heat exchanger strength, a 1.473% increase in heat exchange efficacy, and a 10.8% increase in heat exchange [23] The thermal output in heat exchangers using aluminum oxide (**Al_2O_3**) and silver (Ag) at concentrations of 0.01%, 0.10%, and 0.25% improves irreversibility and thermal efficiency. Silver has superior thermal conductivity and efficiency compared to aluminum oxide. The large size of the nanoparticles significantly impacts the generation of low temperatures in the nanofluid within the tube. A higher thermal conductivity rating leads to an increase in thermal efficiency.

Agista *et al.* studied the influence of aluminum oxide nanoparticles in a shell-and-tube heat exchanger at different concentrations (0.5%, 1%, and 1.5%). The research findings revealed that a concentration of 1.5% achieved the highest effectiveness of 42%, while without using nanofluids, the effectiveness is only 17.7%. These results demonstrate that both the heat transfer and efficiency rate increase as the concentration of nanofluids rises. [24]. Based on Al_2O_3/water, when the nanofluid concentration and Reynolds number (Re) increased, the total heat transfer coefficient increased by 33% on the annular side for volume fractions ranging from 0.5% to 2% [13]

A numerical study using Ansys Fluent software to perform a computational analysis aimed at improving the heat transfer of a shell and tube heat exchanger (STHE) was investigated by Somasekhar *et al.* through substituting purified water with Al_2O_3/water nanofluid as a cooling medium with a volumetric concentration of 0.01%. The studied volumetric percentages are 0.3%, 0.5%, 0.75%, 1%, and 2%. The influence of the Peclet number, volumetric concentration of suspended nanoparticles, and particle morphology on heat transfer capabilities is also studied. The findings indicate that adding nanoparticles to distilled water's base liquid greatly enhances heat transmission capabilities. The most effective cooling method is to utilize an (STHE) using a combination of Al_2O_3 and water. Additionally, using nanofluid results in a more significant decrease in pressure on the tube's side compared to using pure water [25] The thermal efficiency of a horizontal STHE by using gamma Al_2O_3 nanofluid under turbulent flow conditions at ratios of 0.03%, 0.14%, and 0.3% has been considered, and results indicated that the percentages of (Nu) increased to 9.7%, 20.9%, and 29.8% when the nanofluid replaced the base fluid. Similarly, the percentages of overall heat transfer coefficient (U) were roughly 5.4%, 10.3%, and 19.1%, respectively [26]

An elliptical tube was equipped with two rotating ties made using a two-phase model of thermal and flow performance of nanofluids in an elliptical pipe heat exchanger was analyzed computationally. It was noted that the use of nanofluids, especially two-phase modeling methods, has given limited attention to the ties rotated inside the oval pipes. In order to increase the heat transfer, a combination of passive and active growth techniques was used. nanofluids containing Al_2O_3/water on different volume violations as well as with different tape rotation speeds and Recurrence Numbers (Re). The results show that the value of Re and band rotation has increased, which improves the (NU) between 6.1% and 19.4%, and pumping power increases from 59.2% to 280%. In addition, the increase in heat transfer was more noticeable when twisted ribbons were rotated than with stable tape or smooth pipes. The maximum FOM recorded was about 1.57, which corresponds to the highest tape rotation rate, the lowest Re, and a nanoparticle volume fraction of 1% [27].

The characteristics of Al_2O_3/water nanofluid in a shell and tube heat exchanger operating under laminar flow conditions with a concentration of 1% Al_2O_3 have been studied experimentally and theoretically [28]. The results of this study indicate that the Nusselt number (Nu) in the parallel flow heat exchanger is around 9.8%, but it is around 6% in the counterflow configuration. Determined the overall heat transfer coefficient (U) for Al_2O_3/water at Reynolds number 1200 to be 1.151% for uniform flow, 1.148% for counterflow, and 1.202% for STHE [29]. Analyzing the thermal performance of Al_2O_3 nanofluid in a heat exchanger consisting of concentric tubes for cooling has been done experimentally and theoretically [30]**.** Nanofluid concentrations of 0.002% and 0.004% with water have been conducted in this study. Results showed that the increase in the Nusselt number (Nu) reached 79.5%, and the overall heat transfer coefficients U were 23.6% and 34%, 4%, respectively, when using the 0.004% concentration of aluminum oxide (Al_2O_3) [31]. Thermal performance evaluation is focused on forced thermal transfer via the tube side of a heat exchanger, employing aluminum oxide nanoparticles at 1% and 2% ratios. found an increase in the heat transmission rate by 19.25% and 35.82% and an increase in the heat transfer coefficient (h) by 27.33% and 59.0%, respectively, compared to distilled water at a temperature of 30°C. An inverse relationship between the enthalpy (h) and the temperature of the liquid in this experimental setup was observed [30].

A numerical analysis to investigate the effects of **γ-**Al_2O_3 nanofluid on heat production and pressure drop in a single-tube heat exchanger (STHE). Various concentrations of γ-Al_2O_3 were employed. At a volume of 1%, the heat exchanger achieves the highest heat transfer efficiency. However, it is not recommended to use higher concentrations of nanoparticles. The permissible septum spacing, which accounted for 43.4% of the shell diameter, indicated high conformity with the Bell-Delaware method [32].

Employed thermal analysis and computational fluid dynamics (CFD) in Ansys to look into how nanofluid changed the heat transfer parameters of a Shell and Tube Heat Exchanger (STHE). Aluminum oxide nanoparticles at concentrations of 0.03%, 0.054%, 0.067%, and 0.135% in turbulent fluxes. Research reveals that an increase in nanofluid concentration results in a decrease in mass flow rate and heat transfer, accompanied by a proportional increase in the pressure droplet [33].

The study utilized the nanomaterial Al_2O_3 with water as the principal cooling fluid and employed various volumetric concentrations of the nanomaterial, ranging from 0.001% to 0.01%. The study showed that the total heat transfer coefficient increased as more Al_2O_3 nanomaterial was added to the base fluid (water). It was higher than the heat transfer coefficient when water alone was used as a cooling fluid. However, above a concentration of 0.008%, the heat transfer coefficient started to decline [34].

Published work on the pressure drop and convective heat transfer of an alumina-water nanofluid in laminar flow conditions, a continuous flow scenario, was carried out [35]. Within a double-pipe heat exchanger maintaining constant wall temperatures, the experiment used a test segment including a 1.1 m length and 5 mm inner diameter tube. Cold water flowed outside the tube, which housed the heated nanofluid. Different nanofluids with different concentrations of nanoparticles have been investigated. At various Reynolds numbers, the results demonstrated that convective heat transfer increased significantly as nanoparticle concentrations increased the number of ions at various Reynolds numbers. As the concentration of nanoparticles increased, the pressure drops of the nanofluid also increased marginally, and the Nusselt number increased by about 40.5%. However, there was no discernible change in pressure drop compared to water alone, suggesting that nanofluids had a negligible effect on this metric [35].

Aghayari *et al***.** [36] studied the enhancement of a nanofluid containing nanoparticles **(*γ*-Al_2O_3)** with a particle size of 20 nm and a volume fraction ranging from (0.1% to 0.3% V/V). A study on the heat transfer analysis using **Al_2O_3** as the medium in a heat exchanger, with a concentration range of 0.3% to 2% under turbulent flow conditions. The results indicated that when the concentration was 2%, the heat transfer coefficient (h) increased to (700.242 w/m^2), compared to pure water, which had a coefficient of (399.15 w/m^2). The Nusselt number (Nu) for the 2% concentration was 587, while for water it was 367.759. This resulted in an overall increase of 1.596% at a flow rate of (0.0125 l/sec). Furthermore, the Nusselt number for the nanofluid was 62.6% higher than that of the impact of the Reynolds number on the friction factor, which has reversed, indicating a decrease in the friction factor as the Reynolds number escalates [37].

A computational simulation using a nanofluid to enhance thermal transfer within the heat exchanger. utilized **Al_2O_3** at 1%, 2%, 3%, and 4%. At a Reynolds number (Re) of 7500 and a concentration of 4%, the simulation showed that the Nusselt number (N) and the heat transfer coefficient (h, nf) both went up by 13.5% and 9.5%, respectively. illustrate the correlation between convective heat transfer and Reynolds number for various concentrations. Dhaiban *et al.* conducted the study [38] In addition, a numerical simulation and experimental analysis were conducted using Al_2O_3 nanomaterial mixed with water as the working fluid [39]. The study revealed that increasing the volumetric flow rates of hot and cold water and the nanomaterial concentration improved heat transfer performance in the heat exchanger. Furthermore, Mehta *et al.* [40] compared the temperature of the used nanofluid to that of pure water. The thermal efficiency of a shell and tube heat exchanger using nanofluids. Adding 3% **Al_2O_3** nanoparticles to the water-based fluid was examined. The heat exchanger's effectiveness is significantly increased. Furthermore, with the addition of nanoparticles, the convective and overall heat transfer coefficients increased even more. [41].

An experimental comparative study on the effect of nanofluids on the heat transfer capabilities with those of pure fluids revealed that nanofluids have better thermal conductivity and heat transfer performance. This is especially true when the nanomaterial Al_2O_3 is used in a heat exchanger with laminar flow and a constant wall temperature. However, it is crucial to acknowledge that other factors also contribute to the enhanced heat transfer, not just the thermal conductivity of the nanofluid [41-45].

Analyzed the heat exchanger using computational and thermodynamic methods using CuO nanofluid at concentrations of 0.1%, 0.4%, and 0.8%, it is found that the nanofluid, specifically at a concentration of 0.8%, was the most optimal design for the state of the STHE [47]. Using distilled water as a medium resulted in a 30% increase in the heat transfer rate at Reynolds numbers ranging from 4000 to 20000. A stable nanofluid with CuO nanoparticles dispersed in an aqueous liquid and employed varying concentrations of nanoparticles (0.05%, 0.1%, and 0.3%) was studied by Said *et al* [48]. Based on the findings, when the mass flow rate and temperature of the liquid inlet were constant, there was a 7% rise in the (U) and an 11.39% increase in the (h, nf). Conducted a study and an experimental evaluation to investigate the impact of different concentrations of **CuO** nanoparticles mixed in water on the heat transfer characteristics of a double-pipe heat exchanger operating in parallel flow and counterflow arrangements. prepared the CuO nanofluid using a two-step method, with volume concentrations of 0.002%, 0.003%, and 0.004%. %. The study concluded that the overall heat transfer coefficient increases as the volume concentration of CuO nanoparticles increases, compared to Theoretical predictions, which also supported this conclusion [49].

To investigate the effect of using nickel oxide (NiO_2 into pure water in the STHE, various flow rates, including 0.45 liters per minute, 0.9 liters per minute, and 1.35 liters per minute were studied by Uspitasari *et al.*[50]. The study indicated that the NiO_2-sintering nanofluid exhibited the highest level of nanofluid efficiency. The specific heat fell by introducing nanoparticles into the working fluids, and the most significant thermal energy recorded was 48.30 J at a flow rate of 1.35 l/m.

Godson *et al.* [51] examined the utilization of Silver / water nanofluids in concentrations of 0.01%, 0.03%, and 0.04% in a double-pipe heat exchanger. Their results indicated that the heat transfer coefficient experienced a significant increase of 9.2%, 10.87%, and 12.4% for concentrations of 0.01%, 0.03%, and 0.04%, respectively, in addition to a 16.22% increase in pressure loss at a Reynolds number (Re) of 2500 [51].

Conducted an experiment using Fe_2O_3/water and Fe_2O_3/ethylene glycol at concentrations of 0.02%, 0.04%, 0.06%, and 0.08%, as well as varying flow rates, to examine the enhancement of heat transfer in shell and tube heat exchangers, and observed that the nanofluid's thermal conductivity increased with increasing temperature, surpassing that of the primary fluid. The results also showed that the pressure losses on the nanofluid side in the turbulent flow system were more considerable than those on the original fluid [52].

3.2 Silicon And Its Compounds Nanoparticles

An experimental work on a shell-and-tube heat exchanger, utilizing silicon nitride (SiNO3) nanomaterial at a volume concentration of 0.01%, is done to investigate the impact of this material's chemical characteristics on heat transfer and thermal conductivity. An increment in both the heat transfer rate and the Nusselt number has been observed as a result of utilizing this compound as a nanofluid materials [53]. The behavior of SiC/deionized water nanofluids under various pH conditions have done to determine the characteristics of these nanofluids by measuring the zeta potential values to examine the viscosity and thermal conductivity of SiC/DIW nanofluids relative to their volume fraction. This analysis aimed to evaluate the potential of these nanofluids to serve as more efficient working fluids in heat transfer applications [54].

Some heat transfer experiments were carried out for silicon carbide (SiC) water-based nanofluid. The experimental results expressed a promising economic utility for this nanofluid with a volume concentration of 3.7%. evaluated [55]. Furthermore, an experimental study on Silicon dioxide (SiO/water) nanofluid was conducted in both the tube heat exchanger and shell, utilizing ratios of 0.25%, 0.5%, 0.75%, and 1%. The results show that when the flow rate and volume percentage of nanofluids increase, it leads to a corresponding increase in both pressure loss and thermal performance and increased heat transfer efficiency by 19.8% [56]

The thermal properties of Silicone Carbone (SiC)/water nanofluids' and their fundamental macroscopic characteristics changed as a function of average particle size. The mean particle sizes were determined using the nanoparticles' specific surface area (d), which ranges from 16 to 90 nm. Compared to nanofluids with smaller particles, those with larger particles exhibiting the same material and volume concentration exhibited superior heat conductivity and reduced viscosity rises. The larger the particle, the smaller the contact area between the solid and the liquid. Additionally, demonstrated that, independent of thermal conductivity, water-based nanofluids may have their viscosity drastically reduced by adjusting the pH of the suspension. compared the results with those of base fluids and other fluids reported in the literature [57]

3.3 Aluminum Nitride Nanoparticles

The heat transfer of a fluid containing aluminum nitride (Al_2NO_3) nanoparticles with a diameter of around 20 nm. tested the fluid under turbulent flow conditions in a horizontal double-pipe counterflow heat exchanger, with a volume percentage **(Al_2NO_3)** ranging from 0.1 to 0.3 percent, has shown that the heat transmission of **Al_2NO_3/water** nanofluid is more than 9% higher than water-base fluid [58]

3.4 Graphene Nanoparticles

Nogueira *et al.* [59] investigated the heat transfer characteristics of an (STHE) using graphene nanofluid with a concentration level of 0.01%, 0.05%, 0.1%, and 0.2%. When utilizing a concentration of 0.2%, there was a significant enhancement of 29% in the heat transfer coefficient. In addition, using nanofluid (carbon nanotube CNT) resulted in a 7.3% increase in thermal efficiency in the cold (shell) side and a 24.4% increase in the hot (tube) side at a rate of 0.2%. At a concentration of 0.2%, the average thermal efficiency showed a maximum improvement of 13.7%. [60]. Another study conducted an exergy analysis of graphene oxide nanofluids in a shell and tube heat-exchanger, and the results indicated that increasing the concentration of graphene oxide led to an increase in the fluid flow's heat transfer coefficient [61]. It’s also examined how graphene oxide nanoparticles handled heat in the heat exchanger. Moreover, it is noted that increasing the temperature of the hot liquid intensified the energy reduction, primarily due to the temperature differential between the hot and cold liquids [61].

A study regarding the improvement of heat transfer using graphene nanofluids in shell and tube heat exchangers **is** conducted Ghozatloo *et al.* [11]. Specifically, this study focused on analyzing the viscosity of graphene nanofluids in laminar flow within these heat exchangers. results observation showed that adding graphene nanoparticles increased the heat transfer coefficient of water in laminar flow and the highest heat transfer coefficient at a temperature of 38°C was achieved [11]. The influence of carbon nanotubes in enhancing the heat transfer of both multi-walled carbon nanotubes (MWNT) and aqueous nanotubes solution was examined and results showed a higher thermal energy in the presence of multi-walled carbon nanotubes compared to the traditional fluid. [62].

Displayed an experimental examination on the impact of water-based nanofluids containing multi-walled carbon nanotubes (MWNTs) within a shell and tube heat exchanger to produce multi-walled carbon nanotubes using a chemical vapor deposition process, including steam evaporation and a Co-Mo/MgO catalyst. This nanostructured compound introduced carboxylic acid (COOH) functional groups, joining them with the nanotubes to enhance the stability of the nanofluid. Results indicated that utilizing multi-walled nanotubes will enhance the thermal conductivity of the horizontal shell and tube heat exchanger [63].

3.5 Titanium Dioxide Nanostructures

Due to its chemical and physical characteristics in improving heat transfer characteristics, nano-titanium dioxide (TiO_2) is extremely investigated. The effect of using TiO_2 nanoparticles in a double-pipe heat exchanger is conducted by varying the volume percentages of nano-titanium dioxide from 0% to 3% in a water-based nanofluid. Based on the modeling findings, when the volume concentration of TiO_2 nanofluid was 0.3%, there was a notable 18% increase in the heat transfer coefficient. The rise in the TiO_2 percentage resulted in a substantial increase in the Nusselt number values. An increase in velocity leads to a decrease in the friction factor, whereas an increase in volume concentration causes the friction factor to grow proportionally. However, the observed increase in the friction factor is not as significant as the increase in heat transfer for the studied volume fraction. The model was used to conduct computational fluid dynamics (CFD) experiments [9]. On the other hand, a 0.21% TiO_2 nanoparticles concentration resulted in a thermal performance factor of 1.18. Compared to the tube heat exchanger's base fluid (water), the TiO_2/water nanofluid achieved a thermal performance factor ranging from 1.7% to 4.5% [64].

Sahu and Dewangan [30] through a numerical analysis study on STHE using different concentrations of titanium oxide indicated that TiO_2/water nanofluids at a concentration of 1.5% had the highest logarithmic mean temperature difference (LMTD), while pure water had the lowest. The heat transfer rate at a concentration of 1.5% was higher compared to the use of TiO_2/water at a concentration of 1%. and the overall heat transfer coefficient is increased by 6% when (TiO_2/water) is used with water as the base fluid in a corrugated plate heat exchanger [65]. The experimental investigation of utilized CuO and TiO_2 nanoparticles to enhance thermal conductivity and improve heat transfer by convection conducted at flow rates ranging from 0.02% to 0.06 has been established by Xuan *et al.* [66]. It found that TiO_2- CuO nanofluids exhibited a significant increase in thermal performance with average enhancement values ranging from 3% to 25% for copper and aqueous nanofluids [67].

The effect of the thermal properties of nanofluid on Nusselt number is increased by volume concentration increases, as studied by Arulprakasajothi *et al* [68]. It is seen that adding TiO_2 nanoparticles increased the Nusselt number by 13.2% compared to the base fluid at a maximum volume concentration of 0.75%. It was also found that the increase in thermal conductivity of TiO_2/water nanofluids depends on several things, including the particle volume fraction, pH value, Brownian motion, specific surface area, nanolayer, nanocluster, thermophoresis, and the size and shape of the particles that are suspended [68]. However, volume concentrations of 0.02%, 0.04%, and 0.06% (at a flow rate of

3 liters per minute) give an increase in the heat transfer coefficient in CuO and TiO_2 with 12%, 17%, and 27% for CuO and 10%, 14%, and 17% for TiO_2, respectively, at a temperature of 50 °C. Additionally, the Nusselt number increases by 13%, 18%, and 29% for CuO and by 11%, 15%, and 19% for TiO_2, respectively, at a temperature of 80 °C [66]

3.6 Nanoparticles Mixture And Nano Composites

Hybrid nanofluids were used to evaluate the effectiveness and thermal performance of the heat exchanger. Tareq Salameh *et al.* used concentric tube heat exchangers and different nanoparticles such as Al_2O_3, CuO, and TiO_2 for the purpose of increasing the thermal performance of various types of heat exchangers. An experimental study was conducted on the effect of GO- and Al_2O_3 water-based nanofluid in a double-tube heat exchanger to determine the improvement of heat transfer and the efficiency of the studied heat exchangers. In one case study, nanofluid flow rates were varied according to the Reynolds number, and the volumetric concentrations of the different nanomaterials were 0.15%, 0.1%, and 0.05%, respectively. The results obtained showed that the Nusselt number increased by 29.24% and the thermal performance factor increased by 1.32%. [69]. The thermal behavior of nanomaterials used in a double-tube heat exchanger was the subject of the researcher's investigation. An improvement in the heat exchanger's power efficiency and coefficient of heat transfer was seen when alumina nanoparticles were added to the basic fluid (water). Another experimental study on the performance of a new porous heat exchanger, the heat exchanger contained 5% TiO_2, 1% Al_2O_3, and 0.03% MWCNT nanoparticles, with water as the base fluid when results showed that the presence of TiO_2 in the nanofluid led to improved cooling efficiency, mainly when the heat exchanger had rectangular or square cross-sections at the inlets. This finding was consistent with previous studies by Zing *et al*.[70]

The performance of the hybrid nanofluid in a heat exchanger with a single-pass shell and tube configuration and utilizing different amounts of Al_2O_3/water in combination with Cu/water has been studied. The hybrid nanofluid significantly increased the heat transfer coefficient by 139%, whereas the Cu/water nanofluid only showed a 25% increase. The Nusselt number (NTU) increase between water and hybrid nanofluids is approximately 75% compared to the nanofluid Al_2O_3/water. Multi-nanofluid systems yield the highest productivity, leading to a 90% increase in the Nusselt number (Nu) for the hybrid nanofluid. Consequently, the hybrid nanofluid enhances effectiveness by approximately 124%. [71]

The SnO_2/water and Ag/water nanofluids are used to enhance the heat transfer capabilities of the heat exchanger. The nanofluid concentrations employed were 0.05%, 0.1%, and 0.15% of SnO_2 and Ag nanoparticles, which significantly increased nanofluids thermal conductivity (K) by 29% and 39%, respectively, while a 23% and 41% increase in the thermal heat transfer coefficient has been achieved. Sridhar *et al.* [72] utilized aluminum and magnesium nanoparticles, with concentrations ranging from 5% to 25%. The mass flow rates employed are 0.2 kg/s, 0.3 kg/s, and the results indicate that adding nanofluids to the base liquid (purified water) improves a heat exchanger's thermal efficiency by increasing its thermal conductivity. Increasing the concentration of nanofluids significantly reduces the temperature difference. The results also demonstrate an improvement in the heat transfer rate when the volume fraction of nanofluids increases and when two different nanofluids are combined.

Arsan *et al.* [73] conducted a numerical investigation to study the turbulent flow of nanofluids in a shell and tubes, double pipe heat exchangers. Their findings indicate that representing the nanofluids as a single phase aligns with the experimental data. Furthermore, they revealed that augmenting the nanoparticle volume fractions and Reynolds number enhances the heat transfer rate. Moreover, the pressure drop escalates as the volume fractions of nanoparticles [74]. Considered the efficacy of the STHE running at a concentration of 0.03% for various nanofluids. The results indicate that the Al_2O_3/water mixture has the highest heat transfer coefficient, measuring 12.06%, while the CuO/water mixture has the lowest heat transfer coefficient, measuring 8.6%. The heat exchanger increased energy efficiency, reaching 43.73% for ZnO/water and a minimum of 31.29% for Al_2O_3/water at a fixed flow rate of 50 kg/min. 5.

Changing the flow rate within the tubes decreased the results; however, increasing the flow rate within the shell to 70 kg/min led to significant improvements in the operations. Furthermore, there has been an increase in thermal conductivity [75]. A study to analyze heat transmission in a Shell and Tube Heat Exchanger (STHE) using a nanofluid of Al_2O_3/SiC nanoparticles, indicated that Al_2O_3 has superior thermophysical characteristics compared to SiC nanofluid [76].

A comparative research work has been done on different nano-oxides/water nanofluids, i.e. (ZnO/water, Fe_3O_4/water, Al_2O_3/water, CuO/water, TiO_2/water, and SiO_2/water) in different concentrations (0.01% to 0.04%) [35]. The ZnO/water nanofluid demonstrated the highest efficacy, whereas the SiO_2/water nanofluid showed the lowest. The density and specific heat of the operating fluids influence the energy efficiency, causing this discrepancy in effectiveness. determined the thermal conductivity of the nanofluids to range from 8.79–36.31%, 8.69–35.94%, 8.38–34.70%, 8.10–33.39%, 6.84%, 28.05%, and 2.12–8.46% at concentrations of 0.01%–0.04%, respectively, sing the following combinations of nanomaterials: Al_2O_3/water, Fe_3O_4/water, CuO/water, ZnO/water, TiO_2/water, and SiO_2/water with the same volume fractions. The percentage improvement of heat transfer coefficients was 7.10–14.29% for Al_2O_3/water, 6.76–12.89% for Fe_3O_4/water, 5.99–10.10% for CuO/water, 5.95–9.86% for ZnO/water, 5.91–9.76% for TiO2/water, and 3.85–2.18% for SiO_2/water [77].

The thermal conduction of nanofluids in a shell and tube heat exchanger was examined using two types of nanofluids, one composed of water and TiO_2 and the other composed of water and Al_2O_3. The findings demonstrated that incorporating nanoparticles into the base fluid results in a significant improvement in conductive heat transfer characteristics, and the heat transfer properties of water- TiO_2 nanofluids outperform those of water-Al_2O_3 nanowires when comparing the thermal behavior of two nanostructures under optimized volume conditions. However, at higher volume percentages, water- Al_2O_3 nanofluids exhibit better heat transfer [78]. The heat transfer properties of nanofluids, including -Al_2O_3/water and TiO_2/water in a shell and tube heat exchanger exhibiting rough flow behavior, demonstrated considerably enhancement the heat transfer performance. At the optimal nanoparticle concentration, the TiO_2/water nanofluid outperformed the Al_2O_3/water nanofluid in terms of heat transmission at a certain Peclet number. Nevertheless, as the concentration of nanoparticles increased, the heat transfer behavior of the Al_2O_3/water nanofluid improved. focal points [79]

4. Conclusion

In engineering and many heat removals processes, heat transmission from one medium to another medium is essential. This heat transfer process becomes easy when the temperature difference is greater. Not only the greater temperature differences but also the rate of heat transfers, condition, and type of heat exchangers also play a major role in the heat exchange process. There are many types of heat exchangers, and these are round tube exchangers, shell and tube exchangers, double pipe exchangers, fin exchangers, etc. Heat exchanger (DPHE) is one of the most popular types, which are used in many applications. Between the two fluids inside and outside the pipes, the heat transfers by convection mechanism and in the counter direction. A thorough review of past research on the use of different nanofluids in heat exchangers, such as shell-and-tube and double-tube exchangers, is presented in this article. These experiments reveal that heat exchangers of any type can benefit from using nanofluids to enhance heat transfer and thermal performance. different. The use of nanomaterials in heat exchangers has been the subject of over a hundred prior studies, with experimental investigations accounting for 60% and numerical and analytical investigations accounting for the remaining 40%. Half of them dealt with heat exchangers with two tubes, a third with those with a shell and tube, and the remaining 10% with various other types of heat exchangers. In this nanofluid research, water is one of the most significant basic fluids, followed by ethylene glycol (10%) and other liquids. The vast majority of these substances are liquids. Adding nanoparticles to the basic cooling liquid improved heat transfer performance and the heat transfer coefficient (h), according to these researchers. The Nusselt number and Reynolds number also increased. As a result, we think that researchers should look into the link between the Nusselt number, the Reynolds number, and the amount to which various nanoparticles' shapes affect heat transfer and pumping power in future studies. Different types of nanoparticles affected the flow of nanofluids in a shell-and-tube heat exchanger with angled baffles, showing that cylindrical nanoparticles have superior performance in terms of heat transfer coefficient and heat transfer velocity compared to other forms of baffles with varying angles, particularly when segmental baffles. They demonstrated that a cylindrical shape of the nanoparticles and angular-segmented baffles increase the heat transfer rate. r-segmented-segmented. Additionally, an increase in the nanoparticles leads to an increase; it was found that varying the nanoparticle concentration at different angles increases overall entropy production. Concentration varies at various angles.

Significant published studies regarding improving convection heat transfer using nanofluids. Have concisely summarized Over the past 10-20 years. Research workers have extensively investigated the behavior of compounds composed of minuscule particles. Nanotechnology is a field of study and application that focuses on manipulating and working with materials and structures at the nanometer scale, where individual particles range in size from 1 to 100 nm. Visualizing the scale of nanoparticles might be challenging, but it is worth noting that there are approximately (2.54) nanometers in an inch. Nanofluids, with a diameter of less than a micron (about 10–9 times smaller), are highly reactive and efficient materials that can enhance factors such as heat transfer rate and thermal conductivity of metals or other materials. They possess significant reactivity and strength. The material's thermal conductivity increases as it decreases, and the material's thermal conductivity increases. As thermal conductivity increases, so does the rate of heat transmission.

5. Conflict of Interest

The authors declare that they have no conflict of interest.

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