A Critical Review of Recent Research on the Application of Nanofluids in Heat Exchanger

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Abstract Heat exchangers (HEs) are the devices that are used to transfer heat from one medium to another. Heat is not mixed together in this type of heat exchanger. A number of research studies have been conducted in order to improve heat transfer through HEs. Nanofluids are used as a coolant in HEs to improve their effectiveness. The nanofluids have been used in HEs recently in various HEs such as pipe-in-pipe heat exchangers, shell and tube HEs, plate heat exchangers and many other heat exchangers. However, several novel developments in the use of HEs and nano-fluids have been made.

Keywords Plate heat exchangers · Double-pipe heat exchangers · Shell and tube heat exchangers · Compact heat exchangers · Nanofluids

1 Introduction

Energy conservation is one of the most significant issues of the twenty-first century. It is one of the most significant issues of the 21st As a result; scientists, engineers, and researchers are working very hard to solve this important problem. Industrial equipment's usable life is further extended by the improvements in heat transfer and energy efficiency brought about by better heating or cooling. Saving energy is made possible by effective energy use. Conversion, conservation, and recovery of energy are a few strategies for energy conservation.

HEs have previously proven to be essential parts of thermal systems in a variety of industrial areas. In order to improve HE efficiency, nanofluids are currently being employed as coolants. Recent years have seen a tremendous increase in research on the unique characteristics of nanofluids. Recently, a number of studies and reports have focused on the use of nanofluids in heat exchangers, including those on plate heat exchangers, double-pipe heat exchangers (DPHE), shell and tube heat exchangers (STHE), and compact heat exchangers (CHE).

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Different types of HEs are used in a variety of manufacturing industries for the aforementioned purposes, including power plants, nuclear reactors, the petrochemical industry, refrigeration, air conditioning, process industries, solar water heaters, food engineering, and chemical reactors. Utilizing a range of techniques enhances the efficiency of HEs. Long-term efforts have been made to improve heat transfer in HEs reduce the time needed for heat to exchange, and eventually boost system efficiency. To improve the area for heat transmission, fins are frequently employed. But this approach leads to heavier and bigger HEs. As a result, widely used techniques like the use of fins have indeed been exhausted.

Convective heat transmission in HEs may be increased along with geometrical changes if the thermal characteristics of the heat transfer fluids are improved. The addition of additives to the working fluids to modify their thermophysical properties is an attractive technique for improving heat transfer. Nanotechnology's most recent developments have given rise to a remedy for this. S.U.S.C. [1] used the phrase "nano-fluid" for the first time in 1995 to refer to a fluid with improved capabilities for heat transport compared to common fluids. Regular fluids and solid nanoparticles are combined to form a nanofluid. Nanofluids, a new class of high performance heat transfer fluids, may overcome the shortcomings of traditional fluids' poor thermophysical characteristics, such as low thermal conductivity. Nanofluids are advantageous due to their excellent thermal conductivity and suitable stability, according to research [2, 3].

The use of nanofluids is one of the more promising ways to improve heat transfer in heat exchangers. For this, a number of researchers have used nanofluids. This review article attempts to summarise the developments in the application of nanofluids for heat exchangers while also highlighting shortcomings and issues. The review first focuses on research done on various heat exchanger types employing nanofluids as coolants before introducing and delving into some fascinating aspects of this topic.

2 Plate Heat Exchangers

The Plate Heat Exchanger (PHE), created in 1921 for use in dairy technology, is utilized extensively in a variety of industries. PHE comes with a set of thin plates and a frame to hold them. The working fluid is the fluid that is flowing within the void between adjacent plates. The heat transfer surface can be easily changed, as well as the heat transfer rate, by adding or moving plates. As the need for energy conservation grows, PHEs now play a vital role in several industries. Energy waste may be considerably decreased with an extremely efficient PHE. PHEs are available in many different designs, including chevron, herringbone, and washboard. The one of these types that is most usually used is the chevron PHE.

A chevron plate may frequently produce a lot of turbulence, which helps heat transfer effectively. The heat transfer coefficients provided by PHEs can be equivalent to those of pipes with several times higher Reynolds numbers, according to study by Morgan et al. [4]. As a result, several studies into PHEs with various geometries have been carried out.

Ghosh et al. [5] examined the heat transmission and pressure drop properties in a chevron-type corrugated PHE while using CeO_2/water nanofluid as the coolant. The experiments looked at how well heat transfer and pressure drop performed at various fluid flow rates (1–4 lpm) and operating temperatures across a wide concentration range (0.5–3 vol%). It was also determined at what CeO_2/water nanofluid concentration heat transmission above base fluid improved the most. It was discovered that at an ideal concentration of 0.75 vol%, the nanofluid in PHE has a heat transfer coefficient that is up to 39% greater than water's. Additionally, when the volume flow rate of the hot water and nanofluid increased and dropped as the temperature of the nanofluid climbed, the heat transfer coefficient increased.

The largest increase in heat transfer coefficient was 13% for a 4% concentration. Furthermore, when the Reynolds number increased, both the required pumping power and the pressure decreased. The greatest pressure drop increase over the base fluid was determined to be 45% at a concentration of 4%. The schematic of the used chevron plate and the corrugation proportions are shown in Fig. 1.

The flow and convective heat transfer characteristics of nanofluids inside a PHE were investigated by Peng et al. [7]. They used Cu, Fe_2O_3, and Al_2O_3 nanoparticles with a particle size of 50 nm. The outcomes showed that the inclusion of nanoparticles improves the total heat transfer coefficient and resistance coefficient. The convective heat transfer coefficient of the Cu-water nanofluid was the best because various nanoparticles had varied effects. The Cu-water nanofluid's maximum enhancement, which occurred at a concentration of 0.5%, was 34.55%.

For CeO_2-water, Al_2O_3-water, TiO_2-water, and SiO_2-water nanofluids, P. Ghosh et al. [8]'s optimization effort focused on the maximum heat transfer rate, convective heat transfer coefficient, total heat transfer coefficient, effectiveness, and performance index. Their work was unique in that it optimised the volume fraction of several

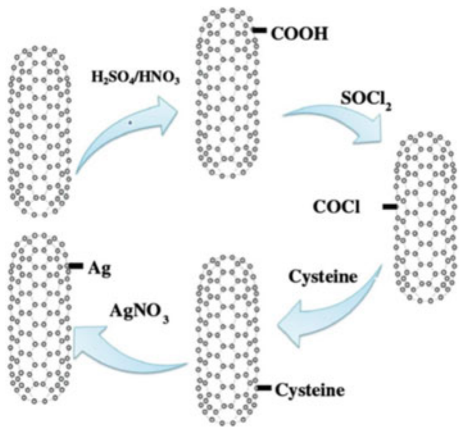

Fig. 1 Diagram of functionalization process of MWCNT with cysteine and Ag [6]

nanofluids using experiments in commercial PHE for a wide range of volume fractions. The findings show that various nanofluids function at various optimal concentrations for maximal augmentation of heat transfer properties. The ideal concentrations were 0.75%, 1%, 0.75%, and 1.25% for CeO_2-water, Al_2O_3-water, TiO_2-water, and SiO_2-water nanofluids, respectively. The relative maximum heat transfer improvements were approximately 35.9, 26.3, 24.1, and 13.9%.

SiO_2, TiO_2, and Al_2O_3 nanoparticle-containing nanofluids were used in a PHE by Sadeghipour et al. [9], and SiO_2, TiO_2, and Al_2O_3 nanoparticle-containing nanofluids were used in a PHE by Cengel et al. [10]. The results showed that the addition of nanoparticles increased the fluid's thermal conductivity, heat transfer coefficient, and heat transfer rate, and that TiO_2 and Al_2O_3 produced superior thermophysical qualities than SiO_2. The Al_2O_3 nanofluid had a total heat transfer coefficient of 308.69 W/m^2 K at a concentration of 0.2%, which was the highest ever recorded. Compared to SiO_2 nanofluid, the relevant heat transfer rate was increased by around 30%. SiO_2 demonstrated the lowest pressure drop when compared to TiO_2 and Al_2O_3, which was approximately 50% less.

The investigations mentioned above demonstrated that fouling may have a major impact on the properties of PHEs that function with nanofluids. However, there hasn't been much research done in this area, so much more research is needed to create applicable approaches to designing PHEs as effectively as possible.

There are two methodologies used in the literature for numerical studies on nanofluids: single-phase and two-phase. In the former, conservation equations are solved while taking into account the useful properties of nanofluids, and in the latter, solutions are applied to show how liquid and solid phases behave.

3 Shell and Tube Heat Exchangers

Shell-and-Tube Heat Exchangers have a wide range of uses in power plants, oil refineries, the food industry, and other industrial settings, making them one of the most widely used types of heat exchangers. Shell-and-tube heat exchangers account for more than 35–40% of all heat exchangers [11] due to their sturdy construction geometry, ease of maintenance, and upgradeability. Despite industrial developments in other types, these heat exchangers have continued to be engineers' first choice and are widely used as heat exchange devices because of their advantages.

Research on the forced convective heat transfer and flow properties of water-Al_2O_3 nanofluids flowing in a STHE under turbulence was published by Tayal et al. in [12]. The outcomes show that for the same mass flow rate and identical inlet, the nanofluid's heat transfer coefficient is marginally greater than that of the base liquid temperature. The nanofluid's heat transfer coefficient increased as the mass flow rate and concentration rose, but as the concentration rose, the viscosity and friction factor also rose. The total heat transfer coefficient of the nanofluid was 57% higher than that of plain water.

Abbassi et al. [13] studied Al_2O_3 nanofluid flow inside shell and helical tube heat exchangers for heat transfer. The findings showed that 0.2% and 0.3% volume concentration, respectively, increase the rate of heat transfer by approximately 14 and 18%. The outcomes also show that when concentration increases, so do the coil-side, shell-side, and total heat transfer coefficients. According to the data, the heat transfer rate of nanofluid improves considerably for the same mass flow rate compared to water and only a little with additional concentration increases. Additionally, it was discovered that increasing concentration, tube diameter, and coil diameter while reducing mass flow rate increases effectiveness.

Mahbubul et al. [14] evaluation of a nanofluid-operated STHE's performance. It was discovered that the convective heat transfer coefficient is 2–15% greater than that of water. Additionally, the nanofluid's energy effectiveness increased by roughly 23–52%. Maximum energy effectiveness was found for the ZnO-water nanofluid and the lowest one for the SiO_2-water nanofluid because the density and specific heat of the working fluids substantially rely on each other.

4 Compact Heat Exchangers

Although considerable research has been done on employing nanofluids in small heat exchangers, this application has received less attention than that of other heat exchangers even though it is widely used in a variety of thermal system applications. Common examples of ground equipment are automotive thermal fluid systems, vehicle radiators, HVAC evaporators and condensers, oil coolers, and inter coolers.

Krishna et al. [15] used the -NTU approach and an Al_2O_3/water nanofluid as coolant to examine the thermal design of a flat tube plain fin compact heat exchanger. It was discovered that the pressure drop of the 4% concentration nanofluid is nearly double that of the base fluid. The results of using nanofluids in vehicle radiators have been explored by several researchers. Car radiators are really thought of as little heat exchangers. A car's radiator is crucial in protecting the engine from overheating. A radiator with louvered fins has been constructed in order to transmit more heat from the surface area and disrupt the boundary layer that has developed nearby.

In an experiment conducted by Bakar et al. [16], TiO_2 and SiO_2 nanoparticles dispersed in water were used to study the enhancement of heat transfer in automobile radiators. The test setup was constructed using tubes and a container to resemble a vehicle radiator. The Reynolds number varied between 250 and 1750, and the volume fraction varied between 1.0 and 2.5%. The findings show that as volume percent increases, so does heat transmission. For TiO_2 and SiO_2 nanofluids, the enhancement values for the energy rate were 20 and 32%, and for effectiveness, they were 24 and 29.5%.

In a unique vehicle radiator, Saeed et al. [17] looked at the impact of nanofluid on pressure drop and friction factor at various concentrations. The base fluid was a 60:40 mixture of ethylene glycol and distilled water, and CuO nanoparticles were evenly scattered to create stable nanofluids. The findings showed that the presence of nanoparticles increases pressure loss, which was aggravated by raising concentration as well as lowering inlet fluid temperature. Additionally, an empirical equation was created to forecast the pressure decrease via the radiator. Additionally, when the flow rate climbed, the performance index did too, showing that using nanofluid at larger flow rates is affordable.

The flow and heat transmission of two different nanofluids, Al_2O_3 and CuO, in an ethylene glycol and water mixture flowing through the flat tubes of an automotive radiator were examined by Namburu et al. [18]. With the flow of the nanofluid along the flat tubes, the convective heat transfer coefficient significantly outperformed that of the base fluid in both the developing and developed zones. For a 10% Al_2O_3 nanofluid and a 6% CuO nanofluid, respectively, the percentage increase in the heat transfer coefficient over the base fluid at Reynolds number 2000 was 94% and 89%, respectively. The pressure loss rose as the concentration grew, but the necessary pumping power decreased since a smaller volumetric flow was needed for the same amount of heat transfer.

The effectiveness of ethylene glycol and water-based TiO_2 nanofluids as automotive radiator coolants was determined experimentally by Reddy et al. [19]. In each experiment, air moved at a constant speed in a transverse direction between the radiator tubes, and nanofluids were created to flow through them. The findings showed that while the fluid intake temperature to the radiator had minimal impact on heat transfer efficacy, increasing fluid circulation rate may have. When compared to base fluid, the heat transfer rate was increased by the nanofluids studied in the current work by up to 37% at low concentrations.

5 Conclusions

The current contribution made an effort to give a thorough analysis of studies done on the subject of using nanofluids in heat exchangers. Numerous studies have been conducted to examine the performance of nanofluids in heat exchangers due to the suitable features of nanofluids. According to the majority of experimental and computational studies, nanofluids have an enhanced rate of heat transfer, which is significantly boosted by raising concentration and Reynolds number. From this review, the following crucial directions for future study and difficulties may be learned:

1. The cost of synthesising nanofluids and the stability of nanoparticles are two crucial aspects to take into account in order to advance the usage of nanofluids in heat exchangers. In the future of research, it is crucial to pay more attention to the financial aspects of using nanofluids as coolants. The applicability of nanofluids may be constrained if trade-offs between nanofluid performance increase and cost cannot be thoroughly confirmed. Therefore, taking into account performance optimization and cost analysis at the same time is crucial. However, there are relatively few publications that have looked into both hydrothermal optimization and cost analysis in heat exchangers.

2. The absence of consistency among diverse assessments is one of the key issues observed in research studies on the application of nanofluids in heat exchangers. This may be the primary cause of the discrepancies in the findings reported by the relevant research.
3. The properties of nanofluid heat exchangers can be significantly impacted by fouling. To build appropriate solutions for heat exchanger design optimization, however, considerably more investigation is required as there hasn't been much study done in this field. Because research on double-pipe heat exchangers is dependent on the type of nanofluids used, the findings from this study cannot be applied to all nanofluids.
4. One of the crucial design factors that significantly affect performance in STHEs is the baffle. However, there hasn't been much investigation into how the baffle configuration affects the properties of STHEs that operate with nanofluids.
5. Future applications of hybrid nanofluids as potential nano-fluids for heat transfer enhancement in heat exchangers are possible. It may pave the way for heat exchanger performance to be improved.

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