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Heat Exchangers Using Multi Types of Nanofluids: A Review

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Abstract

A heat exchanger, which may be found in cooling systems, refineries, power plants, and other facilities, is one of the frequently utilized devices in the application heat transfer process. Water, mineral oil, and ethylene glycol—which has poor heat transfer characteristics—were the typical fluids utilized in heat exchangers. Hence, nanofluid was employed to enhance the fluid's ability to transport heat in heat exchangers. The issue of enhancing heat transmission in heat exchangers with nanofluid was researched experimentally, theoretically, and experimentally. Some of the research done in this area is as follows.

Keywords: Base Fluids, Nanofluids, Nanoparticles, Heat Transfer Coefficient, Heat Exchangers, Effectiveness, Thermophysical Properties, Temperature.

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Introduction

A heat exchanger is used to transfer thermal energy between two or more fluids, a solid surface and a fluid, or between solid particles and a fluid when they are in thermal contact and are at different temperatures. Normally, heat at exchangers does not interact with heat from the outside or with work. **[1].** Applications involving the management of evaporation or condensation in single or multiple-component fluid streams commonly necessitate the utilization of heating or cooling mechanisms within the fluid stream. In alternative scenarios, the objectives may encompass the recuperation or disposal of a process fluid, as well as tasks such as heat sterilization, pasteurization, fractionation, distillation, concentration, or crystallization. The majority of heat exchangers employ a partitioning wall or a combination of inner and outer walls to facilitate the transient transfer of heat between these fluid streams. A heat transfer surface is employed within numerous heat exchangers to maintain separation between the fluids, thus preventing mixing or leakage. These categories of exchangers can be classified as direct transfer units, where heat exchange occurs with the intent of immediate interaction, or recovery-based units. In contrast, there exist indirect transfer configurations, often referred to as regenerators, wherein intermittent heat exchange between the hot and cold fluids is facilitated through thermal energy storage and subsequent release via the exchanger's surface or matrix. **[2]**. The use of nanoparticles in the fluids produced enhanced fluid heat transfer qualities. This is due to the fact that nanoparticles are often used at nanometer diameters and very low concentrations. These characteristics stop the passage of sediment that could choke the channel. **[3]**. A two-phase mixture known as a "Nano fluid" is often made up of a continuous liquid phase and distributed nanoparticles in suspension (i.e., extremely fine metallic particles of size below 50 nm). Engineering-related nanoparticle dispersions are easily accessible from a variety of commercial sources. It is commonly known that base fluid thermal conductivities are significantly lower than those of nano fluids, which is fascinating. **[4]**. The most important stage in using nanoparticles to increase fluids' thermal conductivity is the creation of nanofluids. Two different types of procedures have been used to create nanofluids. One involves a single step, whereas the other involves two steps. **[5]**.

Literature Review

Studies in this field have increased in the recent period due to the importance of the subject in many applications and because of the multiplicity of types heat exchangers, and types of nanofluids. In this paper, we review many of the works of researchers in this field.

Experimental Investigations

Fotukian and **Nasr**,**[6]** have been examined experimentally how well an extremely diluted (less than 0.24% volume) CuO/water nanofluid would perform in terms of turbulent convective heat transfer and pressure drop. A considerable an increase in heat transfer coefficients was achieved with the addition of small concentrations of nanosized CuO particles to the base fluid. An average increment of 25% was observed in the coefficient of heat transfer in addition to a penalty of 20% in pressure drop for (φ=0.015-0.236% & 5440< Re <31110). The reported enhancement ratio did not show considerable variation in terms of the concentration of CuO in a nanofluid. Compared to base fluid, a substantial increase in flow resistance was obtained. This increase was also seen at extremely low CuO concentrations.. **Jwoa et al. [7]** have been conducted research to create alumina/water-based nanofluids (Al_2O_3/water) using a direct synthesis method. Various concentrations (0, 0.5, and 1.0 wt.%) of nanofluids were used as well as various values of flow rates (0.032 kg/s at φ=1.0 wt%) of the inlet water temperatures were adopted. The Heat exchanger with multiple channels (MCHE) experiment in the experimental program used created nanofluid as the operational fluid. The practicality of its performance was evaluated by simulation of its application in the cooling system of an electronic chips. The highest nanoparticle concentrations produce a greater overall heat transfer coefficient ratio, as shown by the data.

Meibodi et al. [8] investigation using experiment the influence of friction factor and coefficient of convection on the characteristics of basic fluids as well as nanofluids. In their work, Al_2O_3/water was selected using a shell and tube heat exchanger. Similar velocity profile was recorded for both nanofluid and its base fluid. It was found that the only parameter that causes the unexpected Changes in the temperature profile are the result of the convective heat transfer coefficient of nanofluids. for nanofluids when compared with the base fluids**. Mansour et al. [9]** investigated experimentally the mixed convection of Al_2O_3 water nanofluid inside of a copper tube that is inclined and exposed to a consistent wall heat flux at its exterior (between 190Wand 420W) The influence of various concentrations of nanoscale particles as well as the power supply on the development of the thermal field were explored for laminar flow condition. A slight reduction in as the particle volume concentration was increased from 0 to 4%, a heat transmission coefficient was noted.

Two novel correlations were proposed to determine the Nusselt number for the horizontal and vertical tubes in the fully formed region. They were for the volume concentrations, Rayleigh number 5×10^5 to 9.6×10^5, Reynolds number from 350 to 900 and the volume concentrations of the particle were up to 4%.

Zamzamian et al. **[10]** investigated experimentally the Nanofluid in the word used to describe a suspension of solid particles smaller than a nanometer in regular fluids; by far notable characteristics among these fluids are improved attributes of heat, such as the convective heat transfer coefficient, when compared without the basic fluid significant changes in chemical and physical characteristics. In their investigation, copper oxide and aluminum oxide nanofluids were made separately in ethylene glycol. Using plate and double pipe heat exchangers, the coefficient of forced convection heat transfer in turbulent flow was estimated. The results indicated considerable enhancement in the convective heat transfer coefficient of the nanofluids as compared to the base fluid, ranging from 2% to 50%. **Hojjat et al**. **[11]** experimented with creating three different types of nanofluids employing g-Al_2O_3, CuO, and TiO_2 nanoparticles (with φ=0.1-1.5%). These nanoscale particles were dispersed in an aqueous carboxymethyl cellulose solution (CMC). These nanofluids underwent turbulent flow conditions forced convective heat transfer through a circular tube that was uniformly heated. in an aqueous carboxymethyl cellulose solution (CMC). These nanofluids underwent turbulent flow conditions convective heat transfer under force through a circular tube that was uniformly heated. (2800<Re<800). A pseudo plastic (shear-thinning) rheology behavior was obtained for all fluids (base fluid and nanofluids). It was found that, nanofluids have larger local and average heat transfer coefficients than the base fluid. An increment in with an increase in nanoparticle concentration, heat transfer enhancement of nanofluids was undertaken. A same pattern was seen for the Nusselt number of nanofluids. The local heat transfer coefficients of base fluid and nanofluids were shown to decrease with axial distance from the tube entrance for a given concentration of nanoparticles and Peclet number. In order to properly anticipate the Reynolds and Prandtl numbers as a function of the Nusselt number of non-Newtonian nanofluids., a new correlation has been proposed.

Sajadi and **Kazemi [12]** investigated experimentally the behavior of turbulent heat transfer in the circular pipe for titanium dioxide/water nanofluid. Less than 0.25 percent of the base fluid's volume was made up of nanoparticles. For various volumetric concentrations, the experimental program was run in the fully developed turbulent regime. According to one study, small amounts of nanoscale particles added to the base fluid greatly increased heat transmission. The increment in the volume fraction of nanoparticles has no much influence on the enhancement of the heat transfer. Additionally, it was demonstrated that the drop of the pressure of nanofluid was observed to be slightly higher than of the base fluid and it was increased with the increment in the volume concentration. Their research's findings were compared to the correlations already in place for the nanofluid convective heat transfer coefficient in turbulent regimes. Additionally, using the findings of the study and for water containing titanium dioxide nanoparticles, a new correlation of the Nusselt number was investigated. **Vishwanadula** and **Emmanuel [13]** studied experimentally the flow of nanofluid and heat transfer in circular conduits. The experimental program was carried out for various flow features of nanofluid in the system. It was recorded that the rate of heat transfer for the flow of the base fluid is lower than the nanofluid. It was pointed out that the demonstrated relationship between the molecular diffusivity of momentum and the molecular diffusivity of thermal energy at the macroscale may differ from that at the nanoscale. The investigation yielded correlations for turbulent forced convection heat transfer in circular pipes, employing Nusselt number, Reynolds number, and Prandtl number as key parameters to establish these heat transfer relationships. **Murugesan** and **Tamilkolundu [14]** investigated experimentally the fully developed laminar and turbulent flow convective heat transfer properties of an Al_2O_3/water nanofluid passing through a horizontal tube that has been uniformly heated with and without wire coil inserts. Al_2O_3 nanoparticles measuring 43 nm in size were created for this project, characterized, and dispersed in distilled water to create an Al_2O_3/water nanofluid with concentrations of 0.1, 0.15, and 0.2%. There were two stainless steel wire coil inserts with pitch ratios of 2 and 3. The findings offer experimental proof that the thermophoresis mechanism is essential to explaining the heat transfer enhancement seen with nanofluids.

Heyhat et al. [15] investigated experimentally the friction factor and convective heat transport of nanofluids in a circular tube. Under turbulent flow conditions, the wall temperature remained constant. Al_2O_3 nanoparticles, measuring 40 nm in diameter, were used to make the test fluid and were dispersed in distilled water at varying volume percentages between 0.1% and 2%. Analyses of the Al_2O_3-water nanofluids' physical characteristics were conducted. To conduct the pressure, drop and the coefficient of convective heat transfer, such qualities are necessary. It was shown that nanofluids have a higher coefficient of heat transfer than the basic fluid. The convective heat transfer coefficient rises as particle concentrations do as well. Additionally, it was shown that the Reynolds number had a minor impact on improving heat transmission.

Darzi et al. [16] The experimental study focused on investigating the thermal characteristics, pressure drop, and heat transfer behavior of a twin-tube heat exchanger utilizing an Al2O3 nanofluid with an average nanoparticle diameter of 20 nm. The research encompassed an examination of the effective viscosity of the nanofluid within the temperature range of 27 to 55 °C. A comprehensive range of Reynolds numbers, spanning from approximately 5000 to 20,000, was employed, along with nanoparticle concentrations reaching up to 1% by volume. The findings of the study indicate that the incorporation of nanoparticles within the investigated parameters, where there is no substantial increase in pressure drop, holds substantial potential for enhancing the thermal efficiency of heat exchangers. Using the Reynolds number and the concentration of nanoparticles as a starting point, an empirical correlation for Nusselt number fluctuation was developed.

Albadr et al. **[17]** investigated experimentally Using a horizontal shell and tube heat exchanger with a maximum delivery rate of 18.3 L/min., the forced convective heat transfer and flow characteristics of a nanofluid consisting of water and various volume concentrations of Al_2O_3nanofluid (0.3-2) % are investigated. The Al_2O_3 nanoparticles utilized in this work have a diameter of roughly 30 nm. The findings demonstrate that for the same mass flow rate and inlet temperature, the convective heat transfer coefficient of the nanofluid is marginally higher than that of the base liquid. With an increase in mass flow rate, the nanofluid's heat transfer coefficient rises. Additionally, as the volume of the Al_2O_3 nanofluid's concentration increases, the coefficient of heat transmission increases as well.

Aghayari et al. [18] explored experimentally the improvement of the Nusselt number and coefficient of heat transfer of a nanofluid containing nanoparticles (ɣ-Al_2O_3) with a volume fraction of (0.1-0.3) % and particle size of 20 nm. This study delves into the impact of temperature and nanoparticle concentration on the variability of Nusselt numbers and heat transfer coefficients within a counter-turbulent flow arrangement of a twin-pipe heat exchanger. A comparative analysis between experimental outcomes and established theoretical values derived from semi-empirical equations reveals a noteworthy level of agreement. Specifically, at a nanoparticle concentration of 0.3% and a Reynolds number of 26500, experimental results showcase a substantial enhancement in the heat transfer coefficient and Nusselt number by approximately 19% and 24%, respectively. Furthermore, the investigation highlights that the heat transfer coefficient displays an upward trend in tandem with both operating temperature and nanoparticle concentration**. Chavda et al. [19]** experimentally investigated the impact of different Al_2O_3 Nano dispersion concentrations mixed with water as the base fluid on the heat transfer properties of double pipe heat exchangers for both parallel flow and counter flow configurations. Al_2O_3 Nano fluid is generated at volume values ranging from 0.001% to 0.01%. According to the study's findings, up to a volume concentration of 0.008% for Al_2O_3 Nano dispersion in comparison to water, the overall heat transfer coefficient increases before decreasing. **Hasan et al. [20]** studied experimentally Two different types of Nano fluids are used as a cooling medium in a double pipe heat exchanger with laminar counter and parallel flows.

Al2O3 and TiO2 nanoparticles were introduced into the base fluid, which is deionized water, resulting in the formation of nanofluids. Both types of nanoparticles possess a typical particle diameter of approximately 20 nm. The manipulation of both the base fluid and nanofluid flow rates, ranging from 0.5 to 2 L/min, was undertaken, along with variations in the volume concentrations of the nanofluid, spanning from 0.05% to 0.3%. The heat exchanger configuration entailed the utilization of an inner tube containing a hot fluid (water) characterized by a consistent inlet temperature. Simultaneously, an outer tube was employed to accommodate the cold fluid (nanofluid), which also exhibited a constant inlet temperature. A comparative analysis against the performance of the base fluid (deionized water) was conducted. The findings of the study showcased discernible improvements in heat transfer attributed to the presence of Al2O3 and TiO2 nanoparticles within the nanofluid. This enhancement is explicitly manifested by the elevation in both the inner and outer heat transfer coefficients, subsequently augmenting the overall heat transfer coefficient. Notably, the percentage increase in the heat transfer coefficient of the nanofluid relative to the base fluid was determined to be 18.25% for Al2O3 and 15.5% for TiO2 nanoparticles. **Ghalib et al. [21]** carried on an experimental study examines the properties of heat transmission in a twin pipe heat exchanger utilizing various fluid types. Zirconia was added to the deionized water and ethylene glycol base fluid to create the nano fluid. The base and nano fluid flow rates were altered with a range of 1.5, 1.8, and 2.1 L/min, while the concentration of the nano fluid was varied with a range of 0.2, 0.7, and 1.2%. According to the findings, among the working fluids, ethylene glycol has the greatest Nusselt number (40.70) at input temperature (70 ºC) and flow rate (2.1 L/min). The Nusselt number for the ethylene glycol and water mixture is lower than it is for Reynolds number and number at (φ =1.2%, temperature=70 ºC, and flow rate=2.1L/min). It is evident from the experimental results that as concentration and flow rate rise, so does the Nusselt number of Nano fluid. The number (24.2) of Nusselt 3679 was discovered. Ethylene glycol has a maximum heat transfer enhancement of 1.50 at an intake temperature of 70 ºC and a minimum enhancement of 0.16 at a temperature of 40 ºC.). **Peker et al. [22]** have been Studied experimentally To improve a plate heat exchanger's thermal efficiency, a novel design has been created. In the formulated design, springs are meticulously positioned at a 45°C inclination upon the heat exchanger plates. This study incorporates the integration of nanoparticles to heighten the heat transfer coefficient within the heat transfer fluid, thereby pursuing an enhanced heat transmission through intensified turbulence. Specifically, Al2O3 and CuO nanoparticles, varying in three distinct densities, have been harnessed for this purpose. The experimental investigations encompassed the evaluation of system performance factors by subjecting these fluids, with differing nanoparticle concentrations, to six discrete inflow velocities upon entry into the heat exchanger. Notably, the most favorable outcome was achieved with a 1% mass ratio of Al2O3 nanoparticles, yielding the highest performance factor of 1.33. Concurrently, CuO nanoparticles, the alternate nanoparticle variant employed, exhibited a maximum performance factor of 1.27. Evidently, the most substantial enhancements in heat transfer were recorded with Al2O3 and CuO nanoparticles, displaying remarkable increments of 60.7% and 56.5%, respectively**. H M Shankara and Ramakrishna.[23]** This experimental study systematically investigates the collective influence of the Propeller Turbulator (PT) insert, water-based graphene oxide (GO), and Al2O3 nanofluids on the enhancement of thermal efficiency within a counter-flow double tube heat exchanger configuration. The research protocol encompassed a range of experimental scenarios involving the passage of hot water through the inner tube at a Reynolds number of 2500, featuring the presence of a propeller insert (with three different propeller counts: 6, 8, and 10). Concurrently, the annulus was subjected to the flow of water-based GO and Al2O3 nanofluids at varying flow rates ($500 \leq Re \leq 5000$) and nanoparticle volume concentrations (0.05%, 0.1%, 0.15%). Based on the empirical findings, a notable increase in the Nusselt number, by a magnitude of 29.43%, was observed when the tube incorporated 10 propellers in conjunction with a 0.15% volume fraction of Al2O3 nanofluid. Furthermore, the Thermal Performance Factor (TPF) demonstrated an enhancement of 1.32 times under these conditions. It was discerned that while a marginal increase in the friction factor was evident, the pronounced augmentation was particularly prominent when a higher propeller-to-Al2O3 nanofluid ratio was implemented. In order to encapsulate the relationship between the Nusselt number and the friction factor, correlations were established, indicating an anticipated accuracy within the range of -14% to +10% and -10% to +5%, respectively.

Theoretical Investigations

Fard et al. [24] studied heat transfer numerically using a CFD method. Two models were used in order to predict the temperature, flow field, and calculation of the heat transfer coefficient. The models were single-phase and two-phase models. The influence of various parameters on heat transfer rate was explored. These parameters are sources of nanoparticle volume fraction and nanofluid Peclet number. A comparison was made using the results of the CFD simulation of the two-phase model with other models such as the single-phase model, theoretical models and experimental data. An increment in the coefficient of heat transfer coefficient was recorded with the increment in the concentration of particles. Moreover, the enhancement in the heat transfer was observed to increase as the Peclet number increased. The best agreement between models and experimental measurements was recorded for the two-phase model. In the case of Cu/Water nanofluid with 0.2% concentration, the average relative error between experimental data and CFD outcomes was 16% and 8% for the single-phase model and two-phase model respectively. Depending on findings from the simulation, the two-phase model provided a better prediction of heat transfer rate than the single-phase model.

Bianco et al. [25] investigated and analyzed numerically the turbulent forced convection flow of a water-nanofluid in a circular tube subjected to a constant and uniform temperature at the wall. The nanofluid convection was simulated using a two-phase mixture model with a consideration of the thermophysical properties. Particles are assumed spherical with 38 nm in diameter. A higher convective heat transfer coefficient for nanofluids was recorded when compared with base liquid. The enhancement of heat transfer was observed to increase with the volume concentration of particles and Reynolds number. A comparison was made with correlations reported by other researchers. A very good agreement was demonstrated with other researchers. In terms of the friction factor, a good agreement was achieved with the conventional correlation used for normal fluid, such as the Blasius formula. **Bianco et al. [26]** investigated and analyzed numerically the turbulent forced convection flow of water Al_2O_3 nanofluid (at $10000<Re<100000$) in a circular tube under a constant and uniform heat flux at the wall (500000 w/m^2). Two different methods were considered. These were single and two-phase models. The particle was 38 nm in diameter. Higher coefficient of convective heat transfer was recorded for nanofluids in comparison with base fluid. The enhancement of heat transfer enhancement was observed to increase with the particle volume concentration and Reynolds number. Depending on the comparison made with correlations from previous work, a very good agreement was achieved.

Demir et al. [27] investigated numerically the forced convection flows of nanofluids in a horizontal tube with constant wall temperature. The nanofluids were prepared from TiO2 and Al_2O_3 nanoparticles that dispersed in water. A CFD program was used to model the horizontal test section. In order to conduct the nanofluid properties, the correlations of other researchers were utilized. To comprehensively examine the hydrodynamics and thermal dynamics characterizing nanofluid flow, a two-dimensional single-phase model was employed, encompassing both constant and temperature-dependent material properties. As a specific illustrative instance, the numerical analysis was undertaken using an unvarying Al2O3 particle size. This choice was validated by establishing the model's efficacy through its congruence with experimental data involving TiO2 nanoparticles, as conducted by other researchers. The numerical findings unequivocally demonstrated that the heightened heat transfer performance observed was inherently attributed to the nanoparticles' presence within the fluid. This outcome aligns seamlessly with the outcomes of the experimental investigation, which served as a benchmark for validating the accuracy of the numerical model. **Akbari et al. [28]** investigated numerically The CFD predictions of single-phase and three alternative two-phase models (fluid volume, mixture, and Eulerian) for laminar mixed convection of Al_2O_3 water nanofluids were examined. The finite volume method is used to numerically solve the elliptical, coupled, steady-state, three-dimensional partial differential equations for laminar mixed convection in a horizontal tube with uniform heat flux. It was discovered that while single-phase and two-phase models predicted substantially different thermal fields, nearly identical hydrodynamic ones. The three two-phase models all make substantially the same predictions. The outcomes were for three nanoparticle volume concentrations (2%) and two Reynolds numbers (1050 and 1600). This study marked the inaugural comprehensive juxtaposition of single-phase and two-phase model predictions within the context of laminar mixed convection flow. The investigation encompassed a meticulous consideration of both hydrodynamic attributes and the ramifications of temperature-dependent properties. Notably, while the utilization of single-phase and two-phase models in analyzing mixed convection of nanofluids has been previously documented, this research represented a novel effort in systematically comparing their predictive capabilities. **Gabriela** and **Angel [29]** studied and analyzed numerically the properties of nanofluid heat transfer in double-tube helical heat exchangers operating in laminar flow. Water was employed as the working fluid after CuO and TiO_2 nanoparticles with a 24 nm diameter were scattered in it. The volume concentrations ranged from 0.5 to 3 vol%. In the scenario involving water infused with 2% CuO nanoparticles at equivalent mass flow rates within both the inner tube and annulus, the heat transfer rate exhibited an approximate enhancement of 14% compared to that of pure water. Moreover, when juxtaposed with the configuration where water exclusively flows through both the inner and outer tubes, the heat transfer rate exhibited an increase of approximately 19% when water from the annular region was directed through the inner tube containing nanofluids.

Moraveji et al. [30] investigated numerically the influence of convective heat transfer on the flow of nanofluid using computational fluid dynamics (CFD) in the developing region of a tube with constant heat flux. In their study, Al_2O_3 with water formed the single phase nanofluid. Four particle concentrations (1, 2, 4, and 6 wt%) were utilized with two average particle sizes (45 and 150 nm). For various axial locations of the tube, the effect of particle size on the coefficient of convective heat transfer was investigated at different Reynolds numbers (500–Re–2500). The outcomes of the modelling lead to obtaining an equation for the prediction of Nusselt number using the dimensionless numbers. A very good agreement was achieved between the predicted data with experimental data from literature. Only 10% was reported as maximum error. **Ahmed et al. [31]** investigated numerically the characteristics of heat transfer and pressure drop of copper–water nanofluid flow using isothermally heated corrugated channel. In their study, a numerical simulation using the Finite Difference (FD) method was employed by resolving the fundamental continuity, momentum, and energy equations for curvilinear laminar flow. The nanoparticle volume fraction ranged from 0-0.05 and the Reynolds number ranged from 100-1000. The impact of utilizing the nanofluid on the pressure drop and heat transmission inside the channel was investigated. According to a report, while there is a modest rise in pressure drop, the augmentation of heat transfer increases with an increase in the nanoparticle volume fraction and Reynolds number. Comparisons between their findings and those reported in the literature were made and discussed. **Tahir** and **Mital [32]** investigated numerically the developed laminar forced convection flow of alumina /water nanofluid in a circular tube under a uniform wall heat flux and (Re=250,750 &1250, φ=1,2.5&4%). In their study the impact of various parameters on the average heat transfer coefficient was explored. Such parameters include diameter of the particle, Reynolds number and particles volume fraction. A discrete phase modeling (DPM) in which it is a Euler Lagrangin approach was employed in this study. The fluid was treated as continuous media. Additionally, Navier-Stokes equations were used to solve the flow field. In a Lagrangian reference frame, nanoparticles were individually tracked. Particle force balance was used to conduct their trajectories. It was found that the application of this approach leads to a good match between their numerical model and the outcomes of the experiments reported by another researcher.

Corcione et al. [33] studied theoretically the heat transfer of nanoparticle suspensions in turbulent pipe flow. Their work is based on the idea that the behavior of nanofluids is more like single-phase fluids than conventional solid-liquid mixtures. The novelty of this study was the evaluation bases of nanofluids merits with respect to the corresponding base liquid. Such evaluation was based on global energetic performance rather than the common point of view of the heat transfer enhancement. It was discovered that as the bulk temperature of the nanofluid rises (303-343 k), so does the ideal concentration of suspended nanoparticles. The pipe's length to diameter ratio decreases while the base fluid's Reynolds number (2300 Re $5*10^6$) increases. **Moraveji et al. [34]** investigated numerically by using computational fluid dynamics (CFD). Non-Newtonian nanofluid flow in the horizontal tube with continuous heat flux and convective heat transfer. They employed an Al_2O_3 and Xanthan aqueous solution as a liquid single phase non-Newtonian nanofluid in their research. The particle diameters were 45 and 150 nm on average. The usage of different particle concentrations (1, 2, 4, and 6 wt%) was made. Two concentrations of the Xanthan aqueous solutions (0.6, 1.0 wt%) were utilized. Particle size and Xanthan solution concentration effects on convective heat transfer coefficients were investigated for varied Reynolds numbers (500–Re–2500) and axial tube placements. An increment was recorded for both the heat transfer coefficient and Nu number of non-Newtonian nanofluid. The such increment was observed when the concentration of Xanthan solution was increased. The findings of the modelling lead to conduct an equation for the prediction of the Nusselt number prediction using the dimensionless numbers. A very good agreement was demonstrated between the correlated data and predicted data. A round 5 % was recorded as maximum error.

Elias et al. **[35]** Conducted within this study was a comprehensive analytical exploration into the impact of distinct nanoparticle geometries (including cylindrical, brick-shaped, blade-like, platelet-like, and spherical configurations) on the operational efficiency of a shell and tube heat exchanger operating with a nanofluid medium. This nanofluid was synthesized by dispersing varying shapes of Boehmite alumina (γ-AlOOH) nanoparticles within a composite blend of water and ethylene glycol. The central objective of the research entailed the evaluation of the thermodynamic performance exhibited by the shell and tube heat exchanger, as integrated within a waste heat recovery system. The analysis was carried out in regard to heat transfer rate and entropy generation. An increment was recorded for heat transfer and thermodynamic performance of the system. **Hussein et al**. **[36]** studied numerically the thermal properties of three types of nanoparticles (Al_2O_3, TiO_2, and SiO_2) mixed with water to form the base fluid. A numerical simulation was conducted to investigate turbulent forced convection heat transfer within a heated flat tube configuration. The heat flux applied to the flat tube was set at 5000 W/m^2, while the Reynolds number ranged from 5000 to 50000. The simulation outcomes indicated a direct correlation between volume concentration and elevated friction factors and Nusselt numbers. In contrast to circular tubes, the implementation of flat tubes demonstrated a notable enhancement in heat transfer efficiency, accompanied by a reduction in pressure loss by 6% and 4%, respectively. Subsequent comparison of the numerical analysis with experimental findings showcased a high level of agreement, with a maximum deviation of 2%.

Khairul et al. [37] This study offers a comprehensive examination of a helical coil heat exchanger through the lens of the second law of thermodynamics, encompassing the utilization of three distinct nanofluid compositions, namely CuO/water, Al2O3/water, and ZnO/water. The analytical assessment focused on the heat transfer coefficient and entropy generation rate inherent to the helical coil heat exchanger configuration. Pertinent considerations comprised variations in nanofluid volume fractions spanning 1% to 4%, as well as volume flow rates ranging from 3 to 6 L/min. Particle volume concentration, heat exchanger duty parameter, coil to tube diameter ratio, and Dean number were the four parameters used to express the entropy generation rate during the analyses. CuO/water nanofluid, out of the three nanofluids, had the greatest improvement in heat transfer and the lowest rate of entropy production, at 7.14 and 6.14%, respectively. Additionally, as the volume concentration and flow velocity of nanoparticles increased, the heat transfer coefficient improved while the rate of entropy formation decreased. **Haddad et al**. **[38]** presented summery of the methods used by other researchers to prepare nanofluid in order to conclude appropriate method to produce stable nanofluids. Based on material type, nanofluids were classified as metallic and nonmetallic nanoscale particles due to the fact that various nanoparticles required their own stability method. Different kinds of nanoscale particles (CNTs, CuO, SiO_2, Al_2O_3, TiO_2, Fe_3O_4…. etc) with various base fluids (DI-water, Pure water, EG, EG/W, CMC solution in deionized water……etc) were used. Additionally, a discussion was carried out to cover the available data for the zeta potential as a function of pH. **Ch. Venkata et al. [39]** carried on simulation study. CFD simulations are done for three Al_2O_3-water Nano fluid concentrations of 0.1%, 0.2%, and 0.3% by volume. Analysis using ANSYS Computational Fluid Dynamics (CFD) has been completed on a double pipe heat exchanger. The findings indicate that as nanofluid concentration rises, so does the system's overall effectiveness. The imposition of an input temperature for the outer fluid pipes leads to an elevated temperature distribution across these pipes. Consequently, the concentration of micro fluids within the system experiences an increase, culminating in a heightened overall efficiency. This improvement stems from the enhanced capability of Heat Exchanger devices to facilitate the transfer of greater amounts of heat to adjacent pipes. Notably, the temperature distribution across the outer pipes becomes more pronounced with the provision of input temperatures for these outer fluid pipes. **Ankit et al. [40]** reviewed Reviews and summaries of the most recent studies on the use of nanofluids in heat exchangers, including those done on plate heat exchangers, double pipe heat exchangers, shell and tube heat exchangers, and compact heat exchangers. Meanwhile, some fascinating features of using heat exchangers and nanofluids are presented. **Kafel et al. [41]** Studied numerically the rate of heat transfer and pressure drop in a tube with turbulent flow. The Reynolds number range and the concentration of nanoparticles are, respectively, (5000-30000) and 1% to 4%. The finite volume method, which uses ANSYS software for simulation, has been used to solve the governing equations. With the use of the SIMPLE method, the boundary conditions are the inlet velocity, outlet pressure, and constant inlet temperature. The findings show that the Al_2O_3/Water nanofluid can improve the thermal properties of the base fluid by 20%. In addition, the nanofluid has a better heat transfer rate than water while having a slightly higher friction factor than pure water.

Sirine et al. [42] Utilizing the computational fluid dynamics approach, this investigation delves into the thermal attributes of a nanofluid as it traverses a plate heat exchanger featuring fractal Y-shaped obstructions. Employing numerical simulation and assessment techniques, the study centers on nanofluids characterized by Fe3O4 particles suspended in water. These nanoparticles maintain a consistent diameter of 30 nm, encompassing volume concentrations spanning from φ= 0.2% to 1%. Additionally, the analysis spans a Reynolds number range extending from 400 to 1400. An independent meshing investigation has been done to confirm the accuracy of the numerical method. In order to increase the method's dependability, the numerical results have undergone experimental validation. These simulations made use of the SST k-ω turbulence model. The major goal of this research is to use nanofluid to investigate and analyze temperature distributions, heat transfer rates, and fluid flow characteristics. With a new PHE design, the convective heat transfer coefficient h and the pressure drop ΔP are maximized by 5.85 and 2.36 times, respectively, when compared to the conventional fluid. **Ban and Zena [43]** investigated numerically utilizing the finite volume approach and CFD package in the ANSYS 20.R1 software. Cold water runs through the outer tube at 25°C while hot water at 60°C flows through the inner tube. Five mass flow rates from 0.012 kg/s to 0.02 kg/s for the hot side and 0.01 kg/s to 0.03 kg/s for the cold side are present in the laminar flow. Al_2O_3 and SiO_2 are two different types of nanoparticles that have been combined to create four different concentrations of nanofluids that act as heat transfer fluid in the exterior channel (cold fluid flow). The heat transfer rate increased as the concentration of Nanofluids did, according to the results. At 1% concentration, the maximum heat transfer coefficient belonged to Al_2O_3/water nanofluid, which had a 22.3% improvement over distilled water, while SiO2/water nanofluid had a 19% improvement over distilled water. Both nanofluids exhibit greater pressure drops when compared to distilled water; the SiO_2/water nanofluid has a greater drop (33.2%) while the Al_2O_3/water nanofluid exhibits a smaller drop (32.1%).

Experimental and Theoretical Investigations

Sultan [44] investigated theoretically and experimentally the flow of nanofluids and the heat transfer via a circular tube that is heated axially and uniformly. Laminar flow and full thermal and hydrodynamic development were present during the study's execution. Al (25nm) - distilled water, Al_2O_3 (30nm) - distilled water, and CuO (50nm) - distilled water were the three different types of nanofluids used in this study. The results showed an increase in the Nusselt number values as the heat flux increased and as the angle of inclination moved from a vertical to a horizontal position, which was based on the observation that the secondary flow produced by natural convection had significant effects on the heat transfer process. Construction of an experimental test rig made of 4 mm Pyrex tubes was part of the experimental study. It was fixed horizontally and heated by tungsten wire. There was a tank for collection of the nanofluid, a pump, pressure gauges, a flow meter and thermocouples. The range of Reynolds number chosen was (100 – 900), heat flux range was between (588– 7910W/m^2) to cover a range of Rayleigh number between (1×10^3–4×10^6) and concentrations from (0.25–2.5) %. **Akbaridoust et al**. **[45]** investigated experimentally and numerically the uniform wall temperature and laminar, steady state flow in helically coiled tubes. For nanofluids, both pressure drop and behavior of convective heat transfer were explored. An experimental design was carried out for the heat exchanger. Such design was able to supply constant wall temperature for coils with various curvature and torsion ratio in order to facilitate the assembly. Measurements of the pressure drop as well as the calculations of the coefficient of the average convective heat transfer were obtained. Numerically, finite difference method with projection algorithm using FORTRAN programming language were employed to solve the three-dimensional governing equations. **Tareq et al. [46]** investigated experimentally and numerically, inside a concentric tube heat exchanger, three different CuO and TiO_2 based nanofluid options were researched. Different mass flow rates (0.05 kg/sec and 0.25 kg/sec) and volume fractions (0.05% and 0.2%) were examined. All variants of nanofluids were subjected to comprehensive three-dimensional numerical simulation employing computational fluid dynamics (CFD), each at an identical volume fraction of 0.2%. The experimental findings revealed augmentation ratios of 48% and 50% for TiO2 and CuO, respectively, when the volume fraction was set at 0.05%. Furthermore, at a volume fraction of 0.2%, these ratios escalated to 30% and 62% for TiO2 and CuO, respectively. Conversely, the numerical outcomes indicated that the CuO nanofluid exhibited the most substantial enhancement in heat transfer ratio among the three considered types.

Mawj et al. [47] Studied experimentally and numerically the improvement of the thermal characteristics of the water-based base fluid in a twin pipe heat exchanger with the addition of Al_2O_3-Fe_2O_3 nanoparticles. Water/Al_2O_3/Fe_2O_3 hybrid While hot water was running in the center tube of a twin pipe counter heat exchanger at a temperature of 60°C and a flow rate ranging from (3 to 5) Lpm, nanofluid was running at varied flow rates in an external tube at a temperature of 25°C. Additionally, experimental and computational evidence was provided to support the impact of different concentrations of Al_2O_3-Fe_2O_3 nanoparticles dispersed in water (0.05, 0.1, 0.15, 0.2, 0.25, and 0.3%) on the rate of heat transfer and friction coefficient. Al_2O_3 and Fe_2O_3 have a 0.5:0.5 ratio. The results of the experimental and numerical study showed that as the concentration of suspended nanoparticles in the base fluid increases, the rate of heat transfer also increases. On the other hand, however, the pressure drop and skin friction coefficient also increase as the concentration of nanoparticles rises. Al_2O_3-Fe_2O_3 has a maximum improvement in heat transmission of about 6%. The experimental study's findings mostly agreed with the numerical findings. **Faraz et al. [48]** investigated experimentally and numerically in order to determine the effects of utilizing TiO_2-Al_2O_3/water hybrid nanofluid in different plate heat exchangers, analyses have been carried out. The obtained results demonstrated the effective use of TiO_2-Al_2O_3/water nanofluid. Based on the results, using both types of nanofluids resulted in a greater increment when the heat exchanger's number of plates was increased.

Conclusions

In this review, the previous works of practical studies, theoretical studies, and studies that are theoretical and practical were studied.

According to this study, one of the key elements influencing performance enhancement in various applications is the thermal conductivity of nanofluids. Theoretical studies and actual research indicate that nanoparticles improve the fluid system's laminar flow heat transfer coefficient, but the increase is considerably smaller than that anticipated by the current correlation based on static thermal conductivity data. In turbulent flow conditions, the friction factor rises along with the particle volume concentration, leading to an increase in pressure loss. The average Nusselt number grew as Reynolds number and volume concentration increased. The Nusselt number is slightly influenced by the nanoparticle diameter. Using nanofluids, the heat exchanger's heat transfer rate has been increased at the expense of pumping power. The high cost of production and lower stability of nanofluids are major barriers to their commercialization. Nanofluids are expected to have a significant influence as coolants in heat-exchanging devices by resolving these encounters.

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