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Convective Heat Transfer in Heat Exchanger Using Nanofluids -A Review

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Abstract: In the recent scenario, nanofluids play a major role in the heat transfer enhancement of heat exchangers due to their fascinating thermophysical properties and other potential benefits. The heat transfer characteristics of nanofluids were improved by incorporating a very small quantity of nanoparticles in the base fluid. A new correlation has been proposed for the selected nanofluids with performance analysis. The parameters like volume concentration, particle size, and base fluid properties are analyzed in the compact heat exchanger. Instead of using the helical coil heat exchanger instead of the straight tube type leads to an enhancement in the Nusselt number. Most of the researchers reported that the pumping power decreases by increasing the concentration at a constant mass flow rate. This paper, discussed the numerical and experimental investigations of heat transfer using nanofluids in heat exchanger applications. The latest works of literature on nanofluids have been presented in this paper. Moreover, as summarized nanotechnology is a promising field in sustainable energy to reduce energy consumption for the optimum design of heat exchangers.

Keywords: Nanoparticle, Heat Exchanger, Nanofluid, Heat transfer

Introduction

The Heat exchanger plays a major role in heat transfer applications, research efforts from various sources shows nanofluids a better convective heat transfer than the base fluid such as water and ethylene glycol. In general, water has the advantage of high specific heat capacity and availability. Due to the advantages of water, it is popular in industrial heat transfer applications. The well-dispersed nanoparticle in base fluid induced to increase in conduction and convection coefficient and enhance the heat transfer capacity of nanofluids used in heat exchangers. The main aim of the review is to summarize the results published in the articles related to the convection of heat transfer in a heat exchanger using nanofluids.

Plate Heat Exchanger

In the heat transfer application, the plate heat exchanger (PHE) is one of the most efficient and compact designed heat exchangers in various process industries. In the plate heat exchanger, the plates and gaskets are used to separate the flow. The Major advantage of the plate heat exchanger is the larger surface area because of its peculiar design such as fluids being spread over the plates. (Çuhadaroğlu & Hacisalihoğlu, 2022), conducted experiments to study the performance of the plate heat exchanger with water in the cooling circuit and water-based CuO nanofluids in the heating circuit. Experiments were carried out with four different nanofluid volume fractions from 0.27 to 1.1 at different flow rates.

The parameters considered for the study were pumping power, pressure drop, effectiveness, heat conduction coefficient, and Nusselt number. They obtained 96% effectiveness and observed an increase in the heat transfer coefficient with the increase in the nanoparticle volume fraction. Also, a new Nusselt number correlation for CuO nanofluid system was proposed relating volume fraction, Reynolds number, and Prandtl number. (Singh Sokhal, Singh Dhindsa, Jakhar, Singh Malhi, & Tonk, 2022), experimentally investigated the plate heat exchanger using Al_2O_3 and CuO hybrid nanofluid as working fluids.

The performance of the PHE was tested at various Reynolds numbers for the nanoparticle concentration (0.1% to 0.5%) within the temperature range of 60°C to 80°C. They observed an increase in heat transfer with the increase in nanoparticle concentration along with the increase in the pressure drop, but the augmentation of the heat transfer is higher compared to that of the pressure drop. (Singh & Ghosh, 2022), performed a numerical and experimental study on the 30° and 60° chevron PHE with multi-walled carbon nanotubes (MWCNT)/distilled water nanofluid as the working fluid. Experiments were carried out by maintaining a fixed flow rate on the hot side and varying flow rates on the cold side with distilled water and MWCNT/distilled water nanofluid.

The numerical study of the exact geometry used for the experimental study was performed in the Fluent solver (Ansys 15.0). The authors proposed a correlation for Nusselt number and friction factor with a 0.996-0.998 coefficient of determination. The maximum heat transfer enhancement for 30° and 60° chevron PHE was found to be 13.64% and 17.27% respectively for 1 vol% nanofluid concentration. (Goltaş et al., 2022), conducted a thermohydraulic performance numerical study on the PHE with fish gill shapes in the plate surface with the Cu-water and Al_2O_3- water nanofluid systems as working fluids on the hot and cold side of the PHE. The nanoparticle volume concentration of 0.5 vol% and 1 vol% of both Cu and Al_2O_3 were tested at similar conditions.

The fish gill shape PHE compared to conventional Chevron type PHE resulted in a 17.5% and 41% improvement in the heat transfer for water and 0.5 vol% of Cu-water nanofluid respectively. (Sundar, Punnaiah, Sharma, Chamkha, & Sousa, 2021), conducted experiments on the PHE with the nanodiamond/water nanofluid as a working fluid and analyzed the thermal entropy and exergy efficiency of the PHE system. They studied the PHE system with the nanodiamond volume concentration of 0 to 1 vol%, between Reynolds number: 140 to 610, mass flow rate: 0.05 to 0.183 kg/s and Peclet number 895.78 to 3882.72. For 1 vol% of nanodiamond/water nanofluid in the PHE compared to the water at Re=526.37, the enhancement was found to be 32.5% in overall heat transfer coefficient, 55.47% in heat transfer coefficient, 35.11% in Nusselt number, 22.8% in pressure drop and 18.93% in pumping power, 14.41% in effectiveness, 32.81% in NTU and 19.72% in exergy efficiency. Also, they proposed a new correlation between the Nusselt number and the friction factor. (Ray, Das, & Vajjha, 2014), compared the performance of a compact mini channel plate heat exchanger using three types of nanoparticles such as aluminum oxide, copper oxide, and silicon dioxide in an ethylene glycol and water mixture.

The selected volumetric concentration of 1% shows better improvements in performance over the base fluid. The result obtained is an increase in convective heat transfer coefficient, a reduction in the volumetric flow rate, and a reduction in the pumping power requirement is the remarkable dynamic performance of nanofluids in compact heat exchangers. (Zheng, Wang, Chen, Baleta, & Sundén, 2020), investigated the heat transfer and fluid flow characteristics of various nanofluids using a corrugated plate heat exchanger in solar energy systems by adding various nanoparticles (Al_2O_3 -30 nm, SiC-40 nm, CuO-30 nm, and Fe_3O_4 -25 nm) in the base fluid. The nanoparticle concentrations (0.05 wt.%, 0.1 wt.%, 0.5 wt.%, and 1.0 wt.%) and flow rates in the range of 3–9 L/min are notable. While compared to the base fluid, both heat transfer enhancement and pressure drop are increased significantly. In particular, the Fe_3O_4 shows better performance and CuO-water nanofluids show worst performance in the plate.

Table 1. Summary of Plate Heat Exchanger

Author	Nanofluid	Observation
Çuhadaroglu et al (2022)	CuO nanofluids	Obtained 96% effectiveness and observed an increase in the heat transfer coefficient with the increase in the nanoparticle volume fraction
Singh Sokhal et al (2022)	Al_2O_3 and CuO hybrid nanofluid	They observed an increase in heat transfer with the increase in nanoparticle concentration along with the increase in the pressure drop, but the augmentation of the heat transfer is higher compared to that of the pressure drop
Singh et al (2022)	MWCNT nanofluid	The maximum heat transfer enhancement for 30° and 60° chevron PHE was found to be 13.64% and 17.27% respectively for 1 vol% nanofluid concentration
Goltaş et al (2022)	Cu & Al_2O_3-nanofluid	This resulted in a 17.5% and 41% improvement in the heat transfer for water and 0.5 vol% of Cu-water nanofluid respectively
Sundar et al (2022)	Diamond nanofluid	Enhancement was found to be 32.5% in overall heat transfer coefficient, 55.47% in heat transfer coefficient, 35.11% in Nusselt number, 22.8% in pressure drop, and 18.93% in pumping power, 14.41% in effectiveness, 32.81% in NTU and 19.72% in exergy efficiency
Ray et al (2014)	Aluminum oxide, copper oxide, and silicon nanofluid	The result obtained is an increase in convective heat transfer coefficient, a reduction in the volumetric flow rate, and a reduction in the pumping power requirement is the remarkable dynamic performance of nanofluids in compact heat exchangers.
Zheng et al (202)	Al_2O_3, SiC, CuO and Fe_3O_4 nanofluid	In particular, the Fe_3O_4 shows better performance and CuO-water nanofluids show worst performance.

Helical Coil Heat Exchanger

In general, to transfer heat from one fluid to another fluid the Helical Coil Heat Exchangers (HCHE) is played a better role as engineering equipment. This type of heat exchangers is widely used in various industries such as refrigeration and air-conditioning systems, power plants, nuclear reactors, petrochemical, etc. A (Sheeba, Abhijith, & Jose Prakash, 2019), studied through experiment and numerical investigations on a helical coil double pipe heat exchanger to determine its heat transfer and flow characteristics using Dean number and torsion.

The numerical analysis was verified with the experimental results which showed the use of helical coil heat exchangers has an enhancement in the Nusselt number compared to straight piped heat exchangers. During the study, they found that the friction factor was comparatively high in helical coil-type heat exchangers. The Nusselt number of the inner tube and annulus increased with Dean number and the effect of Dean number on Nusselt number was found to be more significant in the annulus. (Srinivas & Venu Vinod, 2016), studied the heat transfer intensification determining the performance of a shell and helical coil heat exchanger through experimentally investigation using three water-based nanofluids (Al_2O_3, CuO and TiO_2). Their studies were carried out at different concentrations of nanofluid at 0.3%, 0.6%, 1%, 1.5%, and 2% by weight, varying the nanofluid temperatures, stirrer speeds, and coil-side fluid flow rates. Nanofluid was used as a heating medium circulated at the shell-side fluid and water was used on the coil-side fluid.

The result they found to have an increased rate of heat transfer with an increase in nanofluid concentration, increased stirrer speed, and higher shell-side fluid temperature resulting in an increase of 30.37%, 32.7%, and 26.8% in the effectiveness of the heat exchanger while using Al_2O_3, CuO and TiO_2 nanofluids respectively, when compared to water on the coil-side fluid, indicating intensification of heat transfer. (Mirgolbabaei, 2018), studied the thermal performance in a vertical helical coiled tube heat exchanger, at different shell-side mass flow rates, varying the coil-to-tube diameter ratios, and varying the dimensionless coil pitches. He studied a conjugate thermal boundary condition for the tube wall fluid-to-fluid heat transfer mechanism and investigated the thermal performance using a numerical solution based on the control volume method. It has been discovered that increasing the shell-side fluid mass velocity reduces the heat exchanger's effectiveness. (Khairul et al., 2013), analyzed the thermodynamic second law in a helical coil heat exchanger using three different types of nanofluids (e.g. CuO/water, Al_2O_3/water, and ZnO/water). Also, analytically investigated the nanofluid volume fraction and flow rates in the range of 1–4% and 3–6 L/min, respectively. During the analysis, the heat transfer enhancement and reduction of entropy generation rate were obtained at about 7.14% and 6.14% respectively. Moreover, the heat transfer coefficient was improved with the increase of nanoparticles volume concentration and volume flow rate, while the entropy generation rate went down.

Table: 2. Summary of Helical Coil Heat Exchanger

Author	Heat Transfer Fluid	Observation
Sheeba et al (2019)	Water	showed the use of helical coil heat exchangers has an enhancement in the Nusselt number compared to straight piped heat exchangers
Srinivas et al (2016)	Al2O3, CuO and TiO2	The result the found to have an increased rate of heat transfer with an increase in nanofluid concentration, increased stirrer speed, and higher shell-side fluid temperature resulting in an increase of 30.37%, 32.7%, and 26.8% in the effectiveness of the heat exchanger while using Al2O3, CuO and TiO2 nanofluids respectively,
Mirgolbabaei, (2018)	Water	It has been discovered that increasing the shell-side fluid mass velocity reduces the heat exchanger's effectiveness
Khairul et al., 2013	CuO, Al2O3 and ZnO	The heat transfer coefficient was improved with the increase of nanoparticles volume concentration and volume flow rate, while the entropy generation rate went down.

Spiral Heat Exchanger

The Spiral heat exchangers are coming under the compact type of heat exchanger because of their compactness and high heat transfer area. It consists of circular units containing two concentric spiral flow channels for each circulating fluid in counter-current flow directions. The arrangement is made such as one fluid entering the center of the unit and exit flows through the periphery and another fluid enters the unit at the periphery and moves towards the center. (Khorshidi & Heidari, 2016), studied the distribution of temperature and Nusselt Number of

Spiral Plate Heat Exchanger through Fluent software, which showed a high rate of heat transfer behavior. Their study also showed that the spiral-shaped heat exchanges had fluid had flowed in all directions leading to well mixed and forced to turbulent flow.

The Velocity, Nusselt, and temperature distribution predictions were experimentally varied. These two Galvanized Iron sheets were rolled together around a central core in, two separated channels to form a spiral plate heat exchanger. The researchers concluded that these types of heat exchangers were economical and had high heat transfer rates. (Nguyen & San, 2015), investigated the effect of radial and spiral-direction heat conduction in the solid partition on the surface of both fluid streams on the effectiveness of a spiral heat exchanger which had Archimedes spirals. Their study revealed that maximum effectiveness was originate with larger NTU and NTU value maximum effectiveness increases with a number of turns. They also found that the spiral-direction heat conduction decreases the effectiveness as the Biot number (Bi) based on the partition's thermal conductivity decreases, while the radial-direction heat conduction increases the effectiveness. (Vivekanandan, Saravanan, Vijayan, Gopalakrishnan, & Krishna, 2021) investigated the thermal, hydraulic, and thermodynamic performances of heat exchangers with spiral coils cascading on the cylindrical-shaped shell inside the heat exchanger.

Tube side pressure drop and exergy efficiency are considered hydraulic and thermos-hydraulic performance which was varied from 2 to 6 lpm at the tube side and 4 lpm and 10 lpm flow rates at the shell side. The overall heat transfer coefficient (U) and effectiveness are considered as thermal performance. Experiment was conducted at different flow conditions to find the best flow rate inside the spiral heat exchanger. From the experiment results effectiveness, Nusselt number, Prandtl number, heat transfer rate, overall heat transfer coefficient and exergy efficiency, to validate the outlet temperature CFD analysis were performed on various flow rates. The research concluded that the experimental results agreed with CFD results and at sell-side flow rate of 10 lpm gives higher efficiency for the different flow rates of the tube side from 2 to 6 lpm. (Varvani & Al-Obaidi, 2020), analyzed the effect of spiral heat exchanger performance using CFD.

The effect of a number of variable parameters such as inlet and outlet pressures for both hot and cold were The results showed the pressure drop reduces when there is an increase in cold input pressure from 480 kPa to 510 kPa while decreasing the hot input pressure from 520 kPa to 490 kPa based on the range of data. The research concluded that the pressure drop becomes better only in the hotter fluid region by 99.4 % while for the colder region it reduces by 50%. (Bahiraei & Ahmadi, 2018), studied the thermohydraulic performance of a spiral heat exchanger operated with the water–alumina nanofluid under a turbulent flow regime. The effects of various parameters such as Reynolds number, mass flow rate, nanoparticle concentration, and the gap between the plates on the convective heat transfer coefficient, pumping power, overall heat transfer coefficient as well as the effectiveness of the heat exchanger are evaluated. The average heat flux enhances with the increase of concentration and Reynolds number, while reduces by increasing the gap magnitude. The convective heat transfer coefficient and overall heat transfer coefficient enhance with increasing Reynolds number and concentration, the pumping power intensifies by decreasing the gap, and this augmentation is more significant at higher concentrations.

Table: 3. Summary of Spiral heat exchangers

Author	Heat Transfer Fluid	Observation
Khorshidi & Heidari, (2016)	Water	The researchers concluded that these types of heat exchangers were economical and had high heat transfer rates

Nguyen & San, (2015)	Water	They found that the spiral-direction heat conduction decreases the effectiveness as the Biot number (Bi) based on the partition's thermal conductivity decreases, while the radial-direction heat conduction increases the effectiveness
Vivekanandan (2021)	Water	The research concluded that the experimental results agreed with CFD results and at sell-side flow rate of 10 lpm gives higher efficiency for the different flow rates of the tube side from 2 to 6 lpm
Varvani & Al-Obaidi, (2020)	Water	The research concluded that the pressure drop becomes better only in the hotter fluid region by 99.4 % while for the colder region it reduces by 50%
Bahiraei & Ahmadi, (2018)	Alumina nanofluid	The convective heat transfer coefficient and overall heat transfer coefficient enhance with increasing Reynolds number and concentration, the pumping power intensifies by decreasing the gap, and this augmentation is more significant at higher concentrations

Conclusions

This paper preferred the heat transfer characteristics of various nanofluids and various types of heat exchangers to provide a comprehensive review. Most of the nanofluids have shown an enhanced thermodynamic performance on the thermal convection side. Researchers have shown that nanofluids have good suspension stability. One of the researchers concluded that the pressure drop becomes better only in the hotter fluid region by 99.4 % while for the colder region it reduces by 50%. It is expected that these findings will provide better insights for future investigations. The effect of nano particles such as copper oxide, aluminium oxide, silver oxide, titanium oxide, gold, cerium oxide, zinc oxide, brass, carbon nano tubes dispersed with 0.5%, 1%, 1.5%, etc. by volume fractions in the basefluid has the biggest impact on nanofluid thermal conductivity and the nanofluid shows great potential in enhancing the heat transfer process.

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