Application of Nanofluids in enhancing the Thermal Conductivity of Heat Exchangers- A Review

Maria Terese*

* Services and Digitalization Division, Siemens Ltd

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Abstract- The demand for energy has risen so much over the years because of the exponential increase in population and urbanization. Thus there is an immediate need for improving the efficiency of the heat transfer devices used in power generation. However, a major challenge to increasing the capacity of power plants is the accompanied increment in pressure drop which has to be balanced economically by the heat transfer efficiency. From ongoing studies, it was found that the heat transfer characteristics and thus the efficiency of heat exchangers can be greatly improved by using nanofluids. This paper explores previous studies on the enhancement of thermal conductivity of heat exchangers using nanofluids in them. The purpose of the paper is to prepare a review of the most recent innovations in heat exchangers using nanofluids as their working medium. It was concluded that in the majority of the situations, the use of nanofluids improves the rate of heat transfer. This in turn reduces the size of heat exchangers and saves energy, cost, reduces water usage and waste.

Index Terms- efficiency,heat transfer,heat exchanger,nanofluid, thermal conductivity

I. Introduction

Heat exchangers are components used to transfer heat between different fluids where the fluids may or may not be in direct contact. They are used in power plants, refrigerators, sewage plants, and air conditioners to name a few. Heat exchangers are classified according to flow arrangement in three ways, parallel, counter, and cross flow. Nanofluids are suspensions of nanoparticles in a base fluid which have novel properties like enhanced thermal conductivity and the convective heat transfer coefficient compared to the base fluid that makes them useful in many applications in heat transfer including heat exchangers. This paper intends to explore and review the latest innovations and breakthroughs in the usage of nanofluids in augmenting the thermal conductivity of heat exchangers.The review was conducted for nanofluids of different types such as organic, inorganic, hybrid and carbon based. The effects of external factors like tubes, inserts and turbulators were also reviewed. The main parameters taken into consideration regarding the heat transfer enhancement are Nusselt number, Prandtil number, effectiveness and volume percentage of nanofluid.

II. RESEARCH ELABORATIONS

Bahmani et al. [1] focused on the turbulent flow and heat transfer mechanisms of water/alumina nanofluid in both parallel and counter flow double pipe heat exchanger using single-phase models for the nanofluid. There was an improvement in the Nusselt number (30%) and thermal efficiency (32.7%) by enhancing either the Reynolds number or the nanoparticles volume fraction. Another useful observation was that adding nanoparticles at higher Reynolds numbers had more effect on increasing convection heat transfer coefficient and Nusselt number. The maximum thermal efficiency enhancement of the heat exchanger occurred at a nanoparticles volume fraction of 5% and a further increase in volume fraction resulted in reduced efficiency of the heat exchanger.

Rezaei et al. [2] used water-Al_2O_3 nanoparticles to study the heat transfer inside a micro channel with a triangular section by analyzing the effect of varying volume fractions of the nanofluid through numerical simulation. The micro channel walls were attached with semi-truncated and semi-attached ribs for increasing the heat transfer and their effects were studied. It was observed that due to the colliding of the flow with the ribs, flow twisted which caused an increase in the turbulence of flow and increase of fluid mixing resulting in an enhancement of heat transfer. Also, by increasing the volume fraction of nanoparticles in all geometrical conditions and Reynolds numbers, the Performance Evaluation Criterion enhances which shows that the increase of applied pressure to the system by adding nanoparticles was reasonable compared to the increase of heat transfer. The addition of nanoparticles had a greater influence on the flow with higher Reynolds numbers. The maximum performance operation was found to be in a micro channel with five ribs and with the volume fraction of nanoparticles 4% in the base fluid.

Kim et al. [3] studied the flow and heat transfer characteristics of a nanofluid confined in a circular pipe using numerical and experimental methods. The nanofluid consists of distilled water and Al_2O_3 nanoparticles in the concentrations 0.25, 0.5, and 1 wt%. It was observed that the heat transfer coefficient and Nusselt number rise with increasing the Reynolds number which enhances the heat transfer characteristics and it is also seen that the Prandtl number reduces when the concentration of nanofluids increase. It was observed that as the concentration of alumina in the nanofluid increased the thermal conductivity and heat transfer coefficient tended to increase. An empirical correlation was derived for each concentration of nanofluids using a curve fit for the heat transfer coefficient at different Reynolds numbers. A similar curve fit was created for the Nusselt number and Prandtl number at different Reynolds numbers at different nanofluid concentrations.

Karimi et al. [4] conducted a numerical study of the efficiency of the horizontal and vertical radiator under external flow with air as an external fluid and water and MgO-MWCNTs/EG (Multi walled Carbon nanotube/ Expanded Graphene) hybrid nanofluid as radiator fluid. The study explored the effect of various types of tube sections on inlet temperatures and concentrations of nanofluid for different Reynolds numbers to analyse the effect on heat transfer enhancement. The radiators with horizontal tubes were observed to have better thermal efficiency than vertical tubes. It was observed that heat exchangers with circular pipes have 25% lower pressure drop and those with elliptical tubes had 10% higher Nusselt number which indicates a higher rate of convection heat transfer. An increase in Nusselt number and pressure drop was also brought by an increase in the nanofluid concentration. It was also observed that the cooling fluid inlet temperature only had a negligible effect on pressure drop and heat transfer.

Using a simple and economical method Pourhoseini et al. [5] synthesized silver-water nanofluid and studied the effect on the overall heat transfer coefficient of a CR14-45 COMER plate heat exchanger (PHE) by changing the nanofluid volume flow rate and concentration. The results indicated that both the nanofluid concentration and volume flow rate enhance the overall heat transfer coefficient of PHE. However, the volume flow rate has a greater effect than nanofluid concentration does. It was found that as the concentration of silver nanoparticles in water increases, thermal conductivity initially rises to a maximum at a concentration of about 2.5 mg/L but on the further increase due to aggregation phenomenon and a smaller area-to-volume fraction the effective thermal conductivity decreases.

Bahiraei et al. [6] analyzed the thermal and hydraulic attributes of a counter-current spiral heat exchanger which used eco-friendly graphene nanofluid as the working medium. The results indicate that there is an improvement in the performance index of the heat exchanger by increasing either the Reynolds number or concentration of nanofluid. Performance index is the ratio between heat transfer rate and pressure drop. While the heat transfer rate and overall heat transfer coefficient are enhanced by increasing either Reynolds number or nanofluid concentration, the effect of increasing concentration becomes more prominent at higher Reynolds numbers. On the other hand the effectiveness and number of transfer units decrease. Also, at high Reynolds numbers, higher heat transfer occurs in the end sections of the heat exchanger whereas, at a low Reynolds number, the major heat exchange happens at the initial sections.

Using a rectangular channel, Parsaiemehr et al. [7] simulated the turbulent flow of a water-Al_2O_3 nanofluid in it to observe the effect of attack angle of inclined rectangular rib, Reynolds number, and volume fraction of nanoparticles on heat transfer enhancement. Using Reynolds numbers ranging from 15000 to 30000 and volume fractions of nanoparticles from 0 to 4% and the change in attack angle of ribs ranging from 0° to 180° the turbulent flow of nanofluid was simulated. By influencing the shape of the created vortexes behind the ribs, the attack angle of the rib affects the flow pattern and fluid mixing which enhances the heat transfer. The results indicate that using ribs inside the channel enhances heat transfer more than adding nanoparticles. The maximum Nusselt number has been obtained in attack angles of 60 degrees and 120 degrees as the largest vortex is created in this range.The maximum amount of performance evaluation criterion has been obtained in attack angle of 60 degree, higher Reynolds numbers and 4% volume fraction of nanoparticles in the base fluid.

Sheikholeslami et al. [8] numerically investigated the entropy generation and flow characteristics by using a turbulator in a circular heat exchanger with CuO-water nanofluid as the working medium. The parameters whose effects are taken into consideration are revolution angle (β) and inlet velocity. It was found that as the inlet velocity rises, there was a corresponding reduction in the thermal boundary layer thickness and thus a stronger convective flow. As β increases, secondary flow increases leading to better nanofluid mixing and in turn enhanced convective heat transfer. β has a higher effect at lower inlet velocities because the boundary layer thickness is higher at lower Reynolds number. Since viscous entropy generation augments with an increase of pressure drop, it is directly related to augmentation of inlet velocity and revolution angle. Results also demonstrated that Bejan number (ratio between irreversibility due to heat transfer and total irreversibility due to heat transfer and fluid friction) reduces with intensification of inlet velocity and revolution angle.

Purbia et al. [9] conducted an investigative comparison between graphene oxide nanoparticles and conventional nanoparticles like Al_2O_3 and TiO_2. The two-dimensional, steady-state model was simulated using water as base fluid and at various nanoparticle concentrations (0.025%, 0.05%, 0.075%, and 0.1%). It was observed that the usage of graphene-water nanofluids resulted in better thermal performance of the heat exchangers compared to other nanofluids while maintaining a similar pressure drop which reduces the operating cost significantly. This was attributed mainly to the similarity in thermal and physical properties of graphene nanoparticles and the base fluid. While the pressure energy factor which represents the ratio of the pressure drop associated with nanofluid to that with base fluid was more dominating at higher concentrations, the overall increase in thermal performance in these conditions is higher than the base fluid. After doing the cost analysis in terms of both fixed and cold utility operating cost, it was concluded that graphene oxide nanofluid will not only be beneficial in terms of cost but also lead to the development of more efficient and compact heat exchanger equipment.

Alsarraf et al. [10] used a horizontal double-pipe heat exchanger to study the fluid flow characteristics of boehmite alumina nanofluid by varying the nanoparticle shape. Various nanoparticle shapes such as cylindrical, brick, blade, platelet, and spherical were investigated. Flows ranging from turbulent to highly turbulent were studied using nanoparticle concentrations varying from 0.5–2%. The results indicated that the spherical shape led to the highest performance index of the heat exchanger while the platelet shape led to the lowest. Also, it was found that the nanofluid containing platelet shape led to the maximum heat transfer rate, overall heat transfer coefficient, pressure drop, effectiveness, viscosity, and pumping power while the lowest occurs for spherical shape nanoparticles.

Using a two-phase mixture model, Karimi et al. [11] studied the performance of the double tube heat exchanger using alumina/water nanofluid and pure water as working mediums. Variations in the roughness of twisted tape and its consecutive effect on heat transfer and pressure drop in the heat exchanger were also observed. The results showed that the use of twisted tape improved the Nusselt number and thus heat transfer up to 22%. At the same time, usage of alumina water nanofluid augmented heat transfer rate up to 30% and pressure drop up to 40% in comparison to water as the working fluid. Additionally, it was found that by increasing the roughness of tapes the heat transfer rate increased up to 16%, whereas the friction factor increased up to 21%.

Maddah et al. [12] studied the increase in thermal performance of a heat pipe using Ethylene glycol – nickel oxide nanofluid. It was observed that the thermal conductivity of the base fluid increases and the temperature gradient reduces by using the nanofluid. This contributes to higher thermal power for the heat pipe and lesser thermal resistance. It was also seen that initially there was a reduction in thermal resistance and an increase thereafter by increasing evaporation Filling ratio (volume of charged fluid to the total volume of the evaporating region.). Using the experimental data, the heat conductivity resistance equation was derived. A model of neural networks was built which could predict thermal performance, Filling Ratio, the nanofluid concentration, and input power.

Shirzad et al. [13] investigated the effect of using three different nanofluids (Al_2O_3, CuO, and TiO_2) as a coolant fluid on the thermal performance of Pillow plate heat exchanger (PPHE) for Reynolds number in the range of 1000 to 8000. The results showed that by increasing the nanoparticle volume concentration (φ) in the range of 2 to 5%, the heat transfer coefficient is improved significantly at low Reynolds number. It was also observed that the Al_2O_3-water with φ=2% at all Reynolds numbers and the TiO_2-water with φ=5% at higher Reynolds numbers have better performance compared to other nanofluids.

Malekan et al. [14] numerically investigated the effect of using Fe_3O_4-water nanofluid as the secondary fluid under magnetic field in a double pipe heat exchanger. In the adiabatic compressed air energy storage (CAES) system, the air is heated by the secondary fluid and is stored in a cavern. This air then expands in the turbine. It was found that the temperature of cavern was reduced when the mass flow rate of secondary fluid increased. Also, using ferrofluid as the secondary fluid in the heat exchanger increased the outlet temperature compared to the base fluid (water). Increasing the volume fraction of nanoparticles in the base fluid increased the convective heat transfer in the heat exchanger but also increased the pressure drop as well as the friction factor.

Anitha et al. [15] used a single pass shell and tube heat exchanger to analyze the effect of nanoparticle volume concentration and heat transfer performance (HTP) by using Al_2O_3–Cu/water hybrid nanofluid with a three-dimensional multi phase model. It was observed that the optimization of nanoparticle volume concentration served as the deciding factor in the HTP of the heat exchanger. There is a significant increase in heat transfer coefficient of hybrid nanofluid when compared to water (139%) and Cu-water nanofluid (25%). At a higher Reynolds number, the increment in the Number of Transfer Units (NTU) between water and hybrid nanofluid is close to 75%. Maximum enhancement in Nusselt number for hybrid nanofluid exceeds 90% when compared to Al_2O_3/Water nanofluid. Consequently, the highest heat transfer performance was obtained for hybrid nanofluid systems. The effectiveness of heat exchanger increases almost to 124% when hybrid nanofluid is employed which is higher than water as well as conventional nanofluids.

Deymi-Dashtebayaz et al. [16] used dimpled heat exchangers to analyse the effect of using CuO/water nanofluid and its consequent effect on the thermal and hydraulic parameters. The parameters taken into evaluation include entropy generation number, Bejan number and irreversibility distribution ratio under varying conditions of Reynolds number, flow temperature and nanofluid concentration and pitch ratio of the heat exchanger. The results showed that the flow temperature had the highest effect on entropy generation while pitch ratio has the lowest effect on the same. The optimum values of Reynolds number, dimensionless average flow temperature, nanofluid concentration and pitch ratio were also determined through this experiment.

Abdelrazek et al. [17] conducted the thermo-hydraulic analysis of flow through single-pipe heat exchangers having circular and square cross-sectional configurations both numerically and experimentally. The thermal performance of two metallic oxides (Al_2O_3-water and SiO_2-water) and two carbon-based nano structure nanofluids (KRG and GNP) in comparison with distilled water (DW) were evaluated. The test conditions considered were as follows: fully developed turbulent flow subjected to uniform heat flux, with varying flow rates (Reynolds number from 6000 to 11,000) and nanofluid concentration varying from 0.025–0.1 mass %. It was observed that the fluid which had the highest performance index and the lowest concentration was Distilled water except for KRG/DW. Owing to a very low performance index, non-covalent graphene was judged to be not suitable for heat transfer applications.

Du et al. [18] investigated the effect of the thermal performance of CuO-water nanofluid on the energy efficiency of geothermal heat exchanger (GHE) both experimentally and using a three-dimensional discrete phase model. The usage of nanofluid augmented the heat transfer rate and pumping power consumption of the GHE system by 39.84% and 16.75%. Moreover, the ratio between heat load and pumping power had an enhancement of 20.2%. While earlier studies showed that the nanofluids, which had a significant effect on the heat transfer of other types of heat exchangers, had very little effect on the energy efficiency of GHEs, the simulation result was able to show that the special structure of traditional GHEs may have been the main reason for the lower possibility of collision between nanoparticles and thus the insignificant effect of nanofluid on its heat transfer enhancement. Therefore, it could be concluded that the length of every straight tube segment should be restricted to achieve the better thermal performance of GHEs using nanofluids. Also, usage of elbows, which can disturb fluid, should be incorporated into the GHEs for the higher possibility of collision between the nanoparticles and therefore, the higher heat transfer rate of nanofluid.

Manh et al. [19] studied the use of tapes inside heat exchangers to augment pressure drop and heat rate in the presence of H_2O-CuO nanofluid using a three-dimensional model of the twisted tape with a focus on the effect of significant parameters such as pitching ratio, height ratio, and inlet velocity. Results indicate that as the Reynolds number increases in the tube, the efficiency of the H_2O-CuO nanofluid considerably increases. Also, the rate of exergy declines by more than 35% as the height ratio increases from 0.3 to 0.5. The variation of the exergy at the tip of the turbulator blade is higher than in other sections. Also, the high exergy region occurs in the vicinity of the tube which is close to the blade of the turbulator.

Abhilash et al. [20] investigated the heat transfer characteristics of a hairpin exchanger when using two different nanofluids namely, Aluminium Oxide and Titanium Carbide in proportions of 0.6 and 0.7 volume %. Using nanoparticles in the base fluid was found to improve the thermal conductivity and heat transfer rate of the system. The most suitable nanofluid for maximum heat transfer rate in the heat exchanger was found to be Titanium carbide (0.6 vol %)

Ahmed et al. [21] studied the effect of using ZnO-Distilled water (DW) based nanofluids in a square heat exchanger in improving its heat transfer characteristics. The ZnO nanoparticles were prepared using single-pot sonochemical techniques in different concentrations (0.1, 0.075, 0.05 and 0.025 mass %). Thermal conductivity was recorded highest (52%) at 0.1 mass% concentrations of ZnO-DW based nanofluids and the highest enhancement in Nusselt number was found to be 47% at the same concentration recorded at the end of the square pipe. This was higher than the reference case of distilled water as a working medium.

The use of magnetic induced nanofluid (Fe_3O_4-water) and rotary tube in a compact heat exchanger and its consequent effects on exergetic and energetic performance criteria was investigated Bezaatpour et al. [22] utilising a two-phase Eulerian model. The study was conducted at different Reynolds numbers, magnetic field intensities and tubes angular velocities. The application of magnetic field and rotational tubes caused an increased circulation of nanofluid in the heat exchanger as vortexes and swirling flow formation enhanced heat transfer augmentation. The highest heat transfer rate was recorded at 62.8%. In addition, at lower Reynolds numbers, usage of high-speed rotary tubes and high intensity magnetic field at lower Reynolds number flows minimized the entropy generation and at the same time enhanced the exergy efficiency in the heat exchanger.

Maghrabie et al. [23] experimentally studied the heat transfer characteristics and pressure drop of the shell and helically coiled tube heat exchanger (SHCT-HE) using base water, Al_2O_3/water and SiO_2/water nanofluids as working medium. The experiments were conducted at different inclination angles (θ-0◦, 30◦, 60◦, and 90◦), flow rates using Reynolds number ranging from 6000 to 15000. It was observed that the Nusselt number and the effectiveness of the heat exchanger enhances as the inclination angle (θ) increases while the coil pressure drop decreases. At Reynolds number (Re) of 15000, there is an improvement in Nusselt number by 11% (water), 8.3% (Al_2O_3-water), and 7.5% (SiO_2-water) all at 0.1 vol% by changing the orientation of the SHCT-HE from the horizontal to the vertical. Furthermore there was a significant improvement in Nusselt number and effectiveness of heat exchanger when it was in vertical orientation, Reynolds number at 6000 and when utilizing Al_2O_3/water nanofluid (0.1 vol %) nanofluid. This was better than base water working fluid performance by 35.7% (Nusselt number) and 35.5% (effectiveness). Using multiple regression analysis, empirical correlations are proposed to estimate the coil Nusselt number for water, Al_2O_3-water, and SiO_2-water nanofluids as a function of Re, θ, and volume flow rate of nanoparticles.

Plant et al. [24] numerically and experimentally investigated the effect on the thermal performance of a heat exchanger employing aluminum oxide nanofluid and porous aluminum foam for both a two-channel and three-channel model. The experimental work was carried out at varying heat fluxes, flow rates and nanofluid concentration (1% vol and 2% vol) and Nusselt number was taken as the parameter to quantify heat transfer rates. There was a 15.6% decrease in average Nusselt number for the 2% vol alumina nanofluid compared to that of 1% vol nanofluid. The lower heat transfer rate for the 2% vol nanofluid can be attributed to the higher pressure drop which leads to additional pumping power.

Sriharan et al. [25] studied the thermal performance of the mini hexagonal tube heat sink (MHTHS) using nanofluids (Al_2O_3, CuO, and SiO_2) and deionized water (DIW) as working medium. Nanofluids were made to flow through the hexagonal tube side and DIW were made to flow through the mini-passage side. The tests were conducted at flow rates of deionized water varying from 15-50 Litre/hour and flow rates of nanofluids constant at 30 litre/hour. The experiment shows that there is an enhancement in both the heat transfer rates and the effectiveness in the case where Al_2O_3–DIW nanofluid nanofluid is used. It was also concluded that thermal performance of MHTHS was further improved by increasing the volume flow rates of nanofluids in the heat sink.

Dalkılıç et al. [26] found out the number, geometry and dimensions of the fins in a double pipe heat exchanger using previously available literature. The optimization and cost analysis of the optimal operating condition was also conducted accompanied by a study on the effects of the different working fluids (Ti, TiO_2, Cu, CuO, Al and Al_2O_3 nanoparticles, multi-wall carbon nanotubes and graphene nanosheet) in fouled and clean cases to evaluate its effect on heat transfer enhancement, performance, lifetime and cost issues. It is observed that as the number of fins increases the pumping power and pressure drop increases while the cleanliness factor decreases because of fouling. The number of tubes also decreases in the finned case. The nanofluid containing graphene or Carbon nanotube (CNT) exhibit the optimal cost and heat transfer characteristics while Ti and TiO_2 show the least performance owing to their low thermal conductivity and high costs. This study also compiles the data for the total tube number, the pumping power and the surface area for a specific nanofluid for a fixed heat duty.

Using a circular finned double pipe heat exchanger Mozafarie et al. [27] studied the effect of using Al_2O_3 nanofluid (1-2% vol) and fin configuration on its thermo-hydraulic characteristics. The numerical study was conducted at different flow rates (Re numbers from 5000–100,000), fin heights (1, 2 and 3 mm) and fin pitches (80, 160 and 320 mm) and for both Newtonian and non Newtonian fluids. The results showed that there was a significant enhancement in the heat transfer rates of both Newtonian (36%) and non-Newtonian (30%) fluids by using circular fins and Al_2O_3 nanofluids. Using a thermal performance criterion the correlation between heat transfer and pressure drop was studied. It was observed that while the thermal performance of Newtonian fluids was increased by using both fins and nanoparticles, the non-Newtonian fluids witnessed a decrease in thermal performance due to an increase in pressure drop.

Ajarostaghi et al. [28] numerically investigated the heat transfer and flow characteristics of hybrid nanofluids (Ag/HEG and MWCNT–Fe_3O_4/water) in a pipe equipped with a vortex generator (18 blades). The study is divided into two parts; the first part evaluates the effect of the type of working fluid on the heat transfer, and second part evaluates the effect of the selected nanofluid volume concentration (φ) on the thermal performance of the vortex generator equipped heat exchanger. It was noted that there was an overall heat transfer enhancement while using hybrid nanofluid and the vortex generator. It is important to note that MWCNT–Fe_3O_4/water hybrid nanofluid has better thermal performance than the other nanofluid. At a low Reynolds number, the maximum thermal performance (11%) was achieved at φ=1% while at φ=5% has the lowest enhancement in heat transfer. At higher Reynolds number, the highest and lowest heat transfer enhancements belong to cases at φ=3% and φ=7%.

III. CONCLUSION

In general, the results indicate that the additions of nanoparticles are instrumental in improving the Nusselt number and convection heat transfer coefficient. It is important to note that the effect of addition of nanoparticles is more visible at higher flow rates. Also at higher volume fractions of the nanoparticle, the thermal performance reduces due to agglomeration effect.

Unlike conventional nanofluids, it was found that using carbon based nanofluids like graphene water nanofluids result in better thermal performance and compact design of the heat exchanger with the same pressure drop.

Another important observation was that the combination of nanoparticle working medium with ribs, rotary tubes, fins and inserts placed in the flow path was more efficient in heat transfer enhancement due to the creation of secondary flows. However, there is an accompanying increase in pressure drop and so an optimum volume concentration of nanofluid and number of inserts should be decided accordingly. In some studies the use of twisted tapes with increasing roughness was also shown to have positive effects on heat transfer with a penalty in friction factor.

The shape of nanoparticles also has an effect on thermal performance. It is also noted that using hybrid nanofluids and nanofluids impregnated with porous metal foam will provide a better heat transfer performance for the heat exchangers than conventional nanofluids. The same effect was observed when using magnetic field induced nanofluids.

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AUTHORS

First Author – Maria Terese, Service engineer,Siemens Ltd, mariateresejos@gmail.com
Correspondence Author – Maria Terese, mariateresejos@gmail.com, +91 8882390781