Summary of Research and Studies on Heat Transfer Enhancements by Nanofluids

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Abstract— Need for the equipment and processes with low space and energy requirements is driving force towards innovative practices in chemical process engineering. Energy requirement is one of the major costs involved in the plants. Many plants depend on fossil fuel and conventional sources of fuel. Use of nanofluid with the water like liquid can be very effective in increasing thermal conductivity. A fluid containing nanometer-sized particles, called nanoparticles is nanofluid. These are colloidal suspensions of nanoparticles in a base fluid. Metals, oxides, carbides, or carbon nanotubes are used as nanoparticles. The nanoparticles suspended in base fluid increases thermal conductivity. Current review summarizes research and studies on application of nanofluids and nanoparticles for heat transfer enhancement with affecting parameters and results obtained in various investigations.

Keywords— Thermal conductivity, heat transfer coefficient, base fluid, Nusselt number.

I.INTRODUCTION

Process intensification has become most important study area for chemical and process engineers [1, 2]. Need for the equipment and processes with low space and energy requirements is driving force towards innovative practices in chemical process engineering [3, 4]. Many modifications in unit processes and operations and their combinations have yielded efficient results [5, 6, 7]. Energy requirement is one of the major costs involved in the plants. Many plants depend on fossil fuel and conventional sources of fuel. Biotechnology has helped in obtaining various products in energy efficient manner [8, 9, 10]. The biotechnological research indicates that use of low cost material for fuel synthesis is viable and cost effective alternative [11]. The initial high installation cost is limiting factors for this and many other non-conventional energy synthesis methods. The sources such as tidal and solar energy are being explored[12,13,14,15,16]. The regeneration, waste heat recovery and cogeneration are very effective methods to increase energy efficiency of the process [17, 18, 19, 20]. Use of Nanofluid with the water like liquid can be very effective in increasing thermal conductivity [21, 22, 23]. A fluid containing nanometer-sized particles, called nanoparticles is nanofluid. These are colloidal suspensions of nanoparticles in a base fluid. Metals, oxides, carbides, or carbon nanotubes are used as nanoparticles. The nanoparticles suspended in base fluid increases thermal conductivity. Many investigations are reported on use of nanoparticles and nanofluids for heat transfer enhancements Current review summarizes research and studies on application of nanofluids and nanoparticles for heat transfer enhancement with affecting parameters and results obtained in various investigations.

II. HEAT TRANSFER ENHANCEMENTS BY NANOFLUIDS

Maisuria et.al. carried out investigation on fin heat exchanger using nanofluids [24]. The nanofluids are fluids with higher thermal conductivity and better thermo-physical properties. They compared the nanofluids with base fluid containing water and ethylene glycol. They carried out theoretical analysis to investigate the variation in thermo-physical properties of base fluid. Sudarmadji et.al. carried out investigation on convective heat transfer and pressure drop of nanofluid[25]. In their investigation, they used alumina-water nanofluid under laminar flow regime. Nanofluid was used in tube side and water shell in side. They carried out experiments at nanoparticle volume concentration of 0.15%, 0.25% and 0.5%.They found that increase in nanoparticle concentration had positive impact on heat transfer. There was insignificant rise in pressure drop with concentration. Studies were carried out with ZnO Water nanofluid for concentric heat exchanger by Krishna [26]. According to him, low thermal conductivities of many utility fluids such as water, mineral oil, and ethylene glycol hampers the development of energy-efficient heat transfer in fluids. They synthesized nano-fluids using metal and metal oxide nanoparticles. Important steps in synthesis of nanomaterials were dissolving, preparation of solution, formation of gel, filtration and drying. They obtained 11 percent rise in heat transfer for 0.5 percent nanofluid. Rana and Bhargava carried out investigation on flow and heat transfer analysis of a nanofluid using Galerkin finite element method (FEM) for spherical shaped nanoparticles[27].They carried out experiments on vertical flat plate with non-uniform heating. They observed increase in heat transfer after nanoparticle addition. They also observed enhancement in skin-friction and Nusselt number. Smaller size nanoparticles resulted in higher Nusselt number than larger ones. Al_2O_3/water nanofluid was used by Mukeshkumar et.al. for increasing heat transfer[28].They carried out experimental study on parallel and counter flow configuration of a shell and helically coiled tube heat exchanger. They used X-ray diffraction (XRD) and scanning electron microscope (SEM) for characterization of nanofluids. They observed 4-8% higher heat transfer for counter flow than that of parallel flow at 0.4% nanofluid. They also found that heat transfer performance for 0.8% nanofluid was higher than 0.4% nanofluid. Ali and Al-Hattab carried out investigation on the transient 3-D fully developed forced convection in laminar flow [29]. They carried out thorough investigation with CuO/water and Al_2O_3 in horizontal triangular duct. They found that heat transfer rate became more remarkable after employing nanofluid. particle volume concentration increase had positive effect on heat transfer. Under same operating condition, CuO-water was better than Al_2O_3 in heat transformation process.

Shekarian et.al. carried out investigation on enhancement of thermal efficiency of shell and tube heat exchangers by using Al_2O_3/water nanofluid [30]. In their wok, they provided a combination of techniques such as adding nanoparticles to the hot or cold fluids, and/or using tube inserts as turbulators on tube side as well as changing baffles to a helical or twisted profile on the shell side to increase the impact of these improvements quantitatively. By using combined method, they were able to reduce heat transfer area by 10 percent. Abu-Nada and Chamkha carried out investigation on a CuO-EG-Water nanofluid in enclosures for natural convection studies[31]. Their focus was on effect of nanofluid variable properties.They also presented results from previous work for the streamline and isotherm contours as well as the local and average Nusselt numbers. According to them, the effects of the viscosity models were more predominant on the behavior of the average Nusselt number than the influence of the thermal conductivity models. Enclosure aspect ratio also had significant effect on Nusselt number. Arian et.al. used carbon nanoparticles with a diameter of 10-15 nm and a volume concentration of 0.2% (v/v) for studying performance heat transfer and overall heat transfer in a double pipe heat exchanger [32].They carried out studies on effect of parameters such as temperature, mass flow rate and concentration of nanoparticles on the overall heat transfer coefficient. They found that, with twisted tape and nanofluid, heat transfer coefficient was about 15 to 30 percent higher. Senthilkumar et.al. carried out investigation on copper nanofluid for increasing performance of heat pipes[33].They carried out experiments with copper nanofluid for examining the effect of filling ratio in heat pipe on the thermal performance. They found that maximum increase in heat pipe performance was observed at 100 mg/l of nanofluid. Cieslinski and Kaczmarczyk carried out an investigation on heat transfer during pool boiling of two nanofluids [34]. They carried out investigation with two nanofluids namely water-Al_2O_3 and water-Cu. In their investigation, they established the influence of nanofluids concentration as well as tube surface material on heat transfer characteristics at atmospheric pressure. They found that while boiling of water-Al_2O_3 or water-Cu nanofluids on smooth copper tube, concentration nanoparticle material (Al_2O_3 and Cu) has almost no influence on heat transfer coefficient.They obtained higher heat transfer coefficient for stainless steel tube than for copper tube for the same heat flux density. Wang et.al. carried out an investigation on effective thermal conductivity of mixtures of fluids and nanometer-size particle [35]. They carried out studies on Al_2O_3 and CuO, dispersed in water, vacuum pump fluid, engine oil, and ethylene glycol. They found that thermal conductivities of nanoparticle fluid mixtures were higher than base fluids. Their studies also indicated that with decreasing the particle size, there was increase in the thermal conductivity of nanoparticle-fluid mixtures. They also found that thermal conductivities computed by theoretical models were lower than the measured data. This was due to deficiencies in existing models in describing heat transfer at the nanometer scale in fluids.

Barber et.al. carried out review on boiling heat transfer enhancement with nanofluids[36]. They carried out studies on recent advances in both pool boiling and convective boiling applications in the last decade by researchers. They observed that there was conflicting data on the nanofluids boiling heat-transfer coefficient. Most significant common observation in all investigations was an enhancement in the critical heat flux during nanofluid boiling.Yu et.al. carried out investigation on single-phase convective heat transfer of nanofluids [37]. They observed different degrees of enhancement over the base fluids. They carried out investigation on convective flow boiling and two-phase flow for Al_2O_3–water nanofluids through a minichannel.Their investigation indicated that presence of nanoparticles delays onset of flow instabilities (OFI). Due to the nanoparticles, there was delay in onset of nucleate boiling, ONB and suppression of OFI. In nanofluid flow, this was attributed to available nucleation sites and surface wettability as well as thinning of thermal boundary layers. According to studies carried out by Mahrooghi and Moghiman, the overall heat transfer coefficient increases with nanoparticle volume concentrations in the heat exchangers [38]. They studied forced convection flow and heat transfer of a Al_2O_3/water nanofluid. They studied single and two phase (volume of fluid) models. They found that the particle volume concentration of 3% at the inner tube of concentric sinusoidal double tube heat exchanger resulted in 220% enhancement in overall heat transfer coefficient. Aghayari et.al. carried out investigation on the overall heat transfer coefficient of nanofluids in heat exchangers[39]. They also studied various factors affecting heat transfer. Their studies indicated remarkable 8%–10% rise in the mean HT and the OHTC. They also observed that, with an increase in the processing temperature and/or particle concentration, there was an increase in the OHTC. Kedzierski investigated the influence of copper (II) oxide (CuO) nanoparticle concentration on the boiling performance[40]. They carried out investigation on R134a/polyolester mixtures on a roughened, horizontal flat surface. They prepared two lubricating nanofluids using a synthetic polyolester and 30 nm diameter CuO particles. They observed 50 to 275 percent enhancement in heat transfer with a 0.5 % nanolubricant mass fraction with R134a.

Davarnejad and Ardehali carried out an investigation on effect of TiO_2-water nanofluid on heat transfer and pressure drop[41].They carried out work on turbulent heat transfer for the heat transfer coefficient (Nusselt number) and pressure drop of the nanofluid in a horizontal copper tube. They observed increase in Nusselt number with increasing the Reynolds number and nanoparticles volume fractions. With use of nanofluids, they also observed increase in the pressure drop. In their review, Wang and Mujumdar studied fluid flow and heat transfer characteristics of nanofluids in forced and free convection flows[42]. They also explored applications of nanofluids.They found that many interesting and complicated phenomena involving nanofluids have been observed by various investigators. Investigators had given more importance to the thermal conductivity than heat transfer coefficient earlier. According to them, there is lack of complete understanding of the process with nanoparticle. Also there are differences among the investigators about model fitting and agreement of model parameters with actual experimental data. They expressed need for further extensive research understand the heat transfer characteristics of nanofluids and identify new and unique applications. Qiang and Yimin carried out investigation on Cu-water nanofluid[43]. Their studies were concentrated on convective heat transfer and flow characteristics. They discussed effect of the volume fraction of suspended nanoparticles and the Reynolds number on the heat transfer and flow characteristics. Their investigation indicated increase in the convective heat transfer coefficient of the base fluid because of nanofluids.They also found that there was no significant change in the friction factor of the sample nanofluid with the low volume fraction of nanoparticles. With 2.0 vol% Cu nanoparticles at the same Reynolds number, they observed about 60% increases in convective heat transfer coefficient.

Vahidinia and Miri carried out an investigation on the effect of the Reynolds number on the thermal and hydrodynamic parameters of mixed convection heat transfer of the water-Al_2O_3 nanofluid turbulent flow[44]. They used an inclined circular channel as the subject of the investigation. They observed that with increasing Reynolds number, there was increase in the convective heat transfer coefficient and shear stress. Abdulwahab carried out an investigation on numerical investigation of turbulent magnetic nanofluid flow[45]. They investigated square straight channel flow. They used computational fluid dynamics method with a single-phase approach. In their work, they studied the effects of the concentration of nanoparticles and flow rate on the convective heat transfer and friction factor in turbulent regime. They observed increase in Nusselt number with volume fraction and Reynolds number. Also friction factor decreased with Reynolds number. Afshoon and Fakhar investigated heat transfer coefficient and friction factor of CuO water nanofluid [46].They observed that increase in the volume concentration and Reynolds number of nanofluid increase the local heat transfer coefficient, overall heat transfer coefficient and pressure drop of nanofluids. By using nanofluid, 32 percent enhancement was observed by them in heat transfer. An investigation carried out by SanthoshCibi et.al. suggested promising future for graphite nanofluids[47].They developed higher convective heat transfer behavior of graphite nanofluids through the shell and tube heat exchanger under laminar flow.They observed increase in the heat transfer with increase in graphite concentration. The increase in the thermal conductivity cause increase in heat transfer.They concluded that the effect of graphite on thermal conductivity of nanofluids is much more than heat transfer coefficient of nanofluids. An investigation carried out by Hasanuzzaman et.al. was focused on nanofluid driven effectiveness enhancement of heat exchanger[48]. For counter flow heat exchanger, they estimated convective heat transfer coefficient of water, Cu-water, Al-water, Al_2O_3-water and TiO_2-water of 2% nanoparticle concentration. They observed that convective heat transfer coefficients were 81%, 63%, 66% and 64% higher compared to pure water for Cu-water, Al-water, Al_2O_3water and TiO_2-water nanofluids respectively, whereas overall heat transfer coefficients were 23%, 20%, 21 % and 20% higher. Wen carried fundamental studies on the effect of nanoparticles on boiling heat transfer[49].They revealed the potential effect of nanoparticles on boiling heat transfer by performing two sets of experiments. In one set, they studied pool boiling of nanofluids on two well defined surfaces. In second set of experiments, they studied, bubble formation in a quiescent pool of nanofluids under adiabatic conditions. They found that the relative size between particles suspended in the liquid medium and the surface geometry influences the particle deposition effect. Also nanoparticles affect bubble dynamics by modifying pinning behaviour of the triple line. Mali et.al. reviewed research on flow boiling heat transfer enhancement with nanofluids[50]. In their review, they presented advances in the last decade in flow boiling and convective boiling applications.They focused on various aspects such as the preparation methods, stability of nanofluids, bubble dynamics in flow boiling. An investigation was carried out by Shareef et.al. with an Al_2O_3 -water based nanofluid as the working fluid for flat tube in plate type solar collector[51].They used di-ionized water as a base fluid.Then they used Al_2O_3 nanofluid of 0.5% volume fraction in base fluid. They found that the temperature difference increased with Al_2O_3-water nanofluid. They concluded that the nanofluids can be used as an appropriate heat transfer fluid for solar collectors.Yerrennagoudaru et.al. carried out studies on effect of nanofluids on heat transfer[52].They also summarized recent developments in research on nanofluids. In experimental work, they used four nanofluids namely Magnesium oxide-water, copper oxide-water, Titanium oxide-water, and Iron oxide-water. They also compared experimental results with cfd results.

In their investigation, Senthilraj et.al., carried out estimation of heat transfer coefficient of CuO/Water nanofluid in double pipe heat exchanger with or without electric field[53].The system consisted of a CuO/water nanofluid circulating inner tube and a hot air stream flowing through the outer tube.They reported that there was increase in convective heat transfer coefficient of the nanofluid up to 0.15% volume fraction. The high voltage supply to the electrode had positive effect on heat transfer.They concluded that with increasing the electric field intensity and nanofluid volume concentration, there was improvement in the convective heat transfer coefficient. Kadhim et.al. carried out an investigation on nanofluid (MGO) on heat transfer characteristics for integral finned tube heat exchanger[54]. As expected they found improvement in heat transfer with nanofluids. With 0.75 percent nanofluid, they obtained maximum 2.17 percent increase in thermal conductivity. With same concentration of nanofluid, they obtained maximum rise in heat dissipation rate. This maximum enhancement was 15.85%.They also observed 16.31 percent rise in air side Nusselt number. Aghayari et.al. carried out research on heat transfer in double pipe heat exchanger with nanofluid[55].They investigated the performance of the water/iron oxide nanofluid. A double pipe heat exchanger had perforated twisted tapes and was used in turbulent flow regime. They obtained 130 percent enhancement in heat transfer by reducing twist ratio and increasing the nanofluid concentration. Twist ratio of 2.5 and nanofluid concentration of 0.2 percent by volume yielded the best results. Kasaeian and Nasiri carried out studies on the effects of adding nanoparticles including TiO_2 to a fluid media[56].Their studies also emphasized the fact that adding nanoparticles to the fluid generally causes increment and development of heat transfer coefficient. In the modeling studies, they found that the Pakand viscosity model predicted a higher increase in viscosity. According to their studies, free convection heat transfer of nanofluids can be better explained by the Brinkman model, the Einstein model and the Brownian movement model.Chavda et.al. used aluminum oxide nanofluid in double pipe heat exchanger[57]. According to them, the factors such as type of nanoparticles, size of nanoparticles and concentration of nanoparticles in base fluid affects the heat transfer enhancement. Volume concentration of 0.008 % was found to be optimum for nanoparticles. Sharifi et.al. used numerical simulation and experimental investigation for studying laminar forced convective heat transfer of Al_2O_3/water nanofluid[58]. Experimental data and computer-aided simulation showed remarkable enhancement of convective heat transfer by adding small amounts of Al_2O_3 nanoparticles. They also observed decrease in heat transfer coefficient by increasing amount of ethylene glycol. In their investigation, Ferrouillat et.al. carried out investigation on influence of nanoparticle shape factor on convective heat transfer[59].They used ZnO aqueous colloidal suspensions of both polygonal and rod-like nanoparticles. They observed that pressure drop of nanofluid with polygonal particles was more than rod-like nanoparticles. Polygonal particles showed higher heat transfer augmentation. Higher dynamic viscosity can be reason for the same.

Sivashanmugam emphasized that enhancement of heating or cooling in an industrial process may create a saving in energy, reduce process time, raise thermal rating and lengthen the working life of equipment[60]. Increasing thermal conductivity is one of the way to increasing heat transfer coefficient. Addition of small solid particles can increase the conductivity appreciably. Nanoparticles, generally metal or metal oxides, greatly increase heat transfer. Studies were carried out by Cieliski and Krygie for augmentation of the critical heat flux(CHF) with nanofluids[61]. They carried out investigation with water-Al_2O_3, water-TiO_2 and water-Cu nanofluids. Their studies indicated that the CHF of water-Al_2O_3 water nanofluids - while boiling on a flat plate, was about 200% higher than that for pure water. They found that Enhancement factor for all tested nanofluids decreased with heat flux. Kumar and Pandey carried out review on heat transfer in nano-fluids flowing under laminar and turbulent flow regime[62]. According to them, for very low thermal conductivity of liquids such as water, air, engine oil, there is curb and hindrance in heat transfer rate. Combined properties of nanoparticles as well as base fluid resulted in advantage for heat transfer. The aspects like heat transfer and thermal performance of nano-fluid as coolant for industrial applications were discussed by them.Chavda et.al. used Aluminum oxide nanofluid for heat transfer enhancement[63]. The factors affecting nanofluid heat transfer are mainly type of nanoparticles, size of nanoparticles and concentration of nanoparticles in base fluid. In their work, they experimentally investigated the effect of various concentration of Al_2O_3 nano-dispersion mixed in water. As expected, they observed increase in friction factor and loss coefficient of different pipes and pipe fittings with increase in volume concentration of Al_2O_3 nano-dispersion. Kuppalapalle et.al. carried out investigation on the effects of the temperature dependent viscosity on the flow and heat transfer of a nanofluid[64]. They studied heat transfer over a flat surface in the presence of viscous dissipation. They transformed nonlinear partial differential equations into nonlinear ordinary differential equations. They also observed increase in heat transfer with increase in nanoparticle volume fraction. Ahmed and Mahdy investigated heat transfer through a truncated cone with magnetic field effect[65]. They investigated heat transfer enhancement by using water-based nanofluids containing Cu, Ag, CuO, Al_2O_3, and TiO_2.They found that as the solid volume fraction increases, the rate of heat transfer increases. Reverse trend was observed for skin fraction coefficients.

III. CONCLUSION

Nanoparticles, generally metal or metal oxides, greatly increase heat transfer. Metals, oxides, carbides, or carbon nanotubes are used as nanoparticles. Addition of small solid particles can increase the conductivity appreciably. The nanoparticles suspended in base fluid increases thermal conductivity. Many investigations are reported on use of nanoparticles and nanofluids for heat transfer enhancements. Current review summarizes research and studies on application of nanofluids and nanofluids for heat transfer enhancement, affecting parameters and results. Studies suggest that low thermal conductivities of many utility fluids such as water, mineral oil, and ethylene glycol hampers the development of energy-efficient heat transfer fluids. Dissolving, preparation of solution, formation of gel, filtration and drying are important steps in nanoparticle synthesis. The factors such as type of nanoparticles, size of nanoparticles and concentration of nanoparticles in base fluid affects the heat transfer enhancement. Most of the investigations reported significant rise in heat transfer with 0.2 to 0.5 percent volume by volume concentration of nanoparticles in base fluid.

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