Performance enhancement of heat exchanger using Nanofluids: A critical review

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***Abstract*: Heat exchanger is an important device which is used in thermal systems in many industrial fields. Nanofluids are recently employed as coolants to improve the efficacy of heat exchangers. Regarding unique characteristics of nanofluids, research studies in this area have witnessed a remarkable growth. Latest investigations conducted on use of nanofluids in heat exchangers including those carried out on plate heat exchangers, double pipe heat exchangers, shell and tube heat exchangers, and compact heat exchangers are reviews and summarized. Meanwhile, some very interesting aspects of nanofluids in combination with heat exchangers are presented. The challenges and prospects for future research are presented in this paper.**

***Keywords*: Nanoparticles, Fe_2O_3 Nanofluids, ZnO Nanofluids, SiO_2 Nanofluids, Ag Nanofluids, Heat exchanger.**

1. Introduction: New technologies are needed to fulfil the demand of high heat flow processes to enhance heat transfer requirement. Furthermore, there is growing interest in improving the efficiency of existing heat transfer processes. To enhancement heat transfer in the heat exchangers many active and passive techniques are used nowadays. Conventional heat transfer fluids such as water, air, lubricating oil, and ethylene glycol have very poor thermal conductivities compared with metal and metal oxides. Specific properties of conventional fluids can be improved by adding additives in liquid coolants to overcome this limitation. The heat transfer coefficient (heat transfer enhancement) can be improved via the addition of high thermal conductivity solid particles to the liquid coolant. To improve the heat transfer characteristics of conventional fluids thermal conductivity improvement is the key idea. Conventional fluids thermal conductivity enhancement by the suspension of solid particles, such as millimetre or micrometre sized particles, has been well known for more than 100 years. But, larger size particles cause many difficult problems such as agglomeration, clogging, erosion etc. In the flow path of devices. Modern material synthesis technologies and processes overlay the way for synthesize of different nanostructured material which possess quite different thermal, mechanical, electrical and optical properties from the analogous bulk materials. As the confluence of conventional modern nanotechnology and thermal science, for the achievement of enhanced thermal transport characteristics nanofluids have identified as progressive heat transfer fluids. Choi et al. **[1]** from Argonne national laboratory of United States America first developed the concept of nanofluids in the year 1995 and discovered its enhanced thermal characteristics. The present review gives a quick overview of important literature presented on the heat exchanger thermal performances and its application working on nanofluids.

2. Classification of nanoparticles: Nanoparticles are broadly classified into various groups depending on their size, chemical properties, thermal properties and morphology. Based on chemical and physical characteristics, some of the well-known groups of nanoparticles are given by Ibrahim khan et al. **[2]** shows below:

2.1 Carbon-based nanoparticles: Carbon nanotubes (CNTs) and Fullerenes represent two major groups of carbon-based nanoparticles. Nanomaterial contain by fullerenes are made of globular hollow cage such as allotropic forms of carbon. These materials have arranged hexagonal and pentagonal carbon units, in which each carbon hybridization is Sp2. The structure of carbon nanotubes is tubular, elongated of 1-2 nm in diameter. These can be projected as semiconducting or metallic contingent on their diameter telicity. On rolling upon graphite sheet itself these are structurally resembled. They named as single-walled (SWCNTs), double-walled (DWCNTs) or multi-walled carbon nanotubes (MWCNTs) because of single, double or many rolled sheets.

2.2 Metal nanoparticles: Metal nanoparticles are synthetized from purely metals predecessors. Because of localized Surface Plasmon Resonance characteristics, these nanoparticles possess unique opt electrical properties. Nanoparticles of the alkali and noble metals i.e. Cu, Ag and Au have a broad absorption band in the visible zone of the electromagnetic solar spectrum.

2.3 Ceramics nanoparticles: Ceramics nanoparticles are inorganic non-metallic solids, synthesized via heat and successive cooling. They can be found in amorphous, polycrystalline, dense, porous or hollow forms. Therefore, these nanoparticles are getting great attention of researchers due to their use in applications such as catalysis, photo catalysis, photo degradation of dyes, and imaging applications.

2.4 Semiconductor nanoparticles: Semiconductor materials possess properties between metals and non-metals and semiconductor nanoparticles possess wide bandgaps and therefore showed significant alteration in their properties with bandgap tuning. Therefore, they are very important materials in photo catalysis, photo optics and electronic devices.

2.5 Polymeric nanoparticles: These nanoparticles are synthesis from organic based materials and are mostly nano-spherical or non-capsular shaped. Matrix particles overall mass is generally solid and other molecules are adsorbed at the outer boundary of the spherical surface.

2.6 Lipid-based nanoparticles: These nanoparticles contain lipid moieties and effectively using in many biomedical applications. Generally, the shape of lipid nanoparticles is spherical with diameter ranging from 10 to 1000 nm. Like polymeric nanoparticles, lipid nanoparticles possess a solid core made of lipid and a matrix contains soluble lipophilic molecules. Lipid nanotechnology is a special field, which focus the designing and synthesis of lipid nanoparticles for various applications such as drug carriers and delivery and RNA release in cancer therapy.

3. Applications of nanofluid: Nanofluid can be used to cool Automobile Engine, Electronic component and Welding equipment and cool high heat flux device such as high power microwave tube and high power laser diode array. Nanofluid could flow through the tiny passage of equipment to improve the efficiency. B. Kirubadurai et al. **[3]** give an overview of some common applications of nanofluids that include; engine cooling, engine transmission oil, boiler exhaust flue gas recovery, cooling of electronic circuit, nuclear cooling system, solar water heating, refrigeration, defence and space application, thermal storage, bio-medical application, drilling and lubrication.

4. Literature Review

Mohammad Sikindar Baba et al. **[4]** This paper reports an experimental study of forced convective heat transfer in a double tube counter flow heat exchanger with multiple internal longitudinal fins using Fe_3O_4 /water nanofluid. Results indicates that the heat transfer rate is 80-90% more in finned tube heat exchanger compared to the plain tube heat exchanger for the higher volumetric concentration of nanofluid. The heat transfer rate in the finned tube heat exchanger is 90-98% higher than the heat transfer rate in plain tube heat exchanger for 0.4% Fe_3O_4-water nanofluid. The friction factor in finned tube is 3.75 times the plain tube friction factor for 0.4% Fe_3O_4-water nanofluid flowing at the rate of 2 LPM.
D Han et al. **[5]** This study aims at experimentally investigating the effect of Al_2O_3 /water nanofluids on the heat transfer enhancement inside the double tube heat exchanger at variable inlet temperature. Al_2O_3 nanoparticle with concentration of 0.25% and 0.5% by volume concentration has been used at different inlet temperature. Results from the study shows that the heat transfer increases with the increase in temperature and volume concentration of nano-particles. Significant improvement over the water is seen with maximum Nusselt number increase up to 24.5% at 50℃ inlet temperature. Maximum increase in convective heat transfer coefficient has been calculated of about 9.7% and 19.6% for 0.25% and 0.5% of volume concentration respectively. Maximum increase in convective heat transfer coefficient has been calculated of about 9.7% and 19.6% for 0.25% and 0.5% of volume concentration respectively. **Fig.1** show Schematic diagram of experimental appratus used.
K. Palanisamy et al. **[6]** This study investigates the heat transfer and the pressure drop of cone helically coiled tube heat exchanger using (Multi wall carbon nano tube) MWCNT/water nanofluids. The experiments results shown that 28%, 52% and 68% higher Nusselt number than water for the nanofluids volume concentration of 0.1%, 0.3% and 0.5% respectively. It is found that the pressure drop of 0.1%,0.3% and 0.5% nanofluids are found to be 16%, 30% and 42% respectively higher than water. The improved heat transfer coefficient is found to be 14%, 30% and 41% more than the water at 0.1%, 0.3% and 0.5% MWCNT/water nanofluid respectively. **Fig.2** shows Model used for numerical analysis.

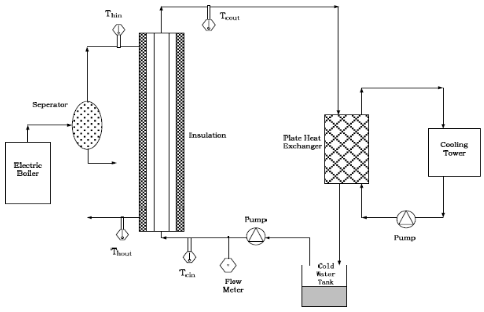

Fig.1: Schematic diagram of experimental Appratus.

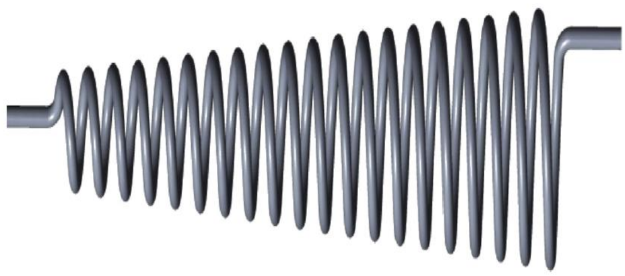

Fig.2 : Model used for numerical analysis.

P.C. Mukesh Kumar et al. **[7]** In this investigation, the heat transfers and pressure drop of the double helically coiled heat exchanger handling MWCNT/water nanofluids have been analyzed by the computational software ANSYS 14.5 version. The simulation data was compared with the experimental data. It is found that the Nusselt number of 0.6% MWCNT/water nanofluids is 30% higher than water at the Dean number value of 1400 and Pressure drop is 11%higher than water at the Dean number value of 2200. It is studied that the Nusselt number is 20%, 24%, and 30% higher than water at 0.2%, 0.4%, and 0.6% nanofluids respectively at the Dean number of 2000. Also found that the pressure drops are 4%, 6%and 10% for 0.2%, 0.4%, and 0.6% nanofluids respectively are higher than water. This is due to the effect of temperature on nanofluids viscosity. Finally, the CFD data were compared with experimental data and hold good agreement with the deviation of CFD Nusselt number and pressure drop are 7.2% and 8.75% with the experimental data.

Navid Bozorgan et al. **[8]** This paper focuses on the potential mass flow rate reduction in exchanger with a given heat exchange capacity using nanofluids. Al_2O_3 nanoparticles with diameters of 7 nm dispersed in water with volume concentrations up to 2% are selected as a coolant, and their performance in a horizontal double-tube counter flow heat exchanger under turbulent flow conditions is numerically studied. The mass flowrate of the nanofluid at a volume concentration of 2 vol.% is approximately 24.5% lower than that of pure water (base fluid) for given conditions. A further inspection shows that for a volume concentration of 2%, the heat transfer coefficient increases about 64.65%, while the increase of thermal conductivity is below 40%. For a concentration of 2 vol.%, the friction factor and pressure drop increase by 13.64% and 15.66%, respectively.

Rajput nitesh singh et al. **[9]** Nanofluid TiO_2/ water and CuO/water was used in a heat exchanger (double pipe) for the observation of behavior of heat transfer with flow rate and concentration of nanoparticles at ambient temperature. The results predict that CuO act as a better nanoparticle in comparison to TiO_2 due to high thermo-physical properties of the mixture, yield in the increase in heat transfer. Experimental results show that application of TiO_2/ water and CuO/water nanofluid enhances coefficient of heat transfer by 5 % and 8% at 0.3% concentration respectively.

Mohammad Hussein Bahmani et al. **[10]** In present study, heat transfer and turbulent flow of water/alumina nanofluid in a parallel as well as counter flow double pipe heat exchanger have been investigated. The governing equations have been solved using an in-house FORTRAN code, based on finite volume method. Single-phase and standard k- e models have been used for nanofluid and turbulent modeling, respectively. The results indicated that increasing the nanoparticles volume fraction or Reynolds number causes enhancement of Nusselt number and convection heat transfer coefficient. Maximum rate of average Nusselt number and thermal efficiency enhancement are 32.7% and 30%, respectively. Maximum thermal efficiency and average Nusselt number enhancement observed in counter flow regime which are equal to 30% and 32.7%, respectively.

Salman.K et al. **[11]** Titanium dioxide (TiO_2) is an excellent material for heat transfer boosting purpose due to its perfect physical and chemical properties. Thermal analysis of drafted geometry (double pipe heat exchanger) is studied by varying concentration of nanoparticle (0-3vol%) in coolant using 3-Dimensional simulations. It is observed that according to simulation results there is a 18% enhancement in heat transfer coefficient at 0.3% volume concentration of TiO_2 nanofluid. Nusselt number saw a significant increase when percentage of TiO_2 increased. The friction factor is increase is proportional with the increase of volume concentration and decrease with increase in velocity but it is inferred that the friction factor enhancement is less compared to the enhancement to the heat transfer for volume fraction considered in the analysis. **Fig.3** shows Model used for CFD analysis.

P.J. Fule et al. **[12]** The present work deals with the study of heat transfer enhancement using water based CuO nanofluids in the helical coil heat exchanger. Nanofluids with various volume percentage between 0 and 0.5 of CuO nanoparticles and their flow rate between 30 and 80 LPH (Reynolds number ranging from 812 to 1895, Laminar flow regime) were considered in the present study. In the present study, at 0.1 vol% concentration of CuO nanoparticles in nanofluid, enhancement in heat transfer coefficient was 37.3% as compared to base fluid while at 0.5 vol%, it is as high as 77.7%. At 0.1 vol% concentration of CuO nanoparticles in nanofluid, enhancement in heat transfer coefficient was 37.3% as compared to base fluid while at 0.5 vol%, it is as high as 77.7%. **Fig.4** shows **S**chematic diagram of experimenta set-up used for analysis.

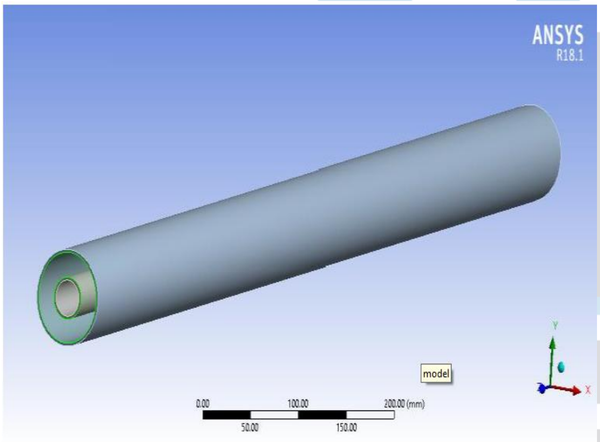

Fig.3 : Model used for CFD analysis.

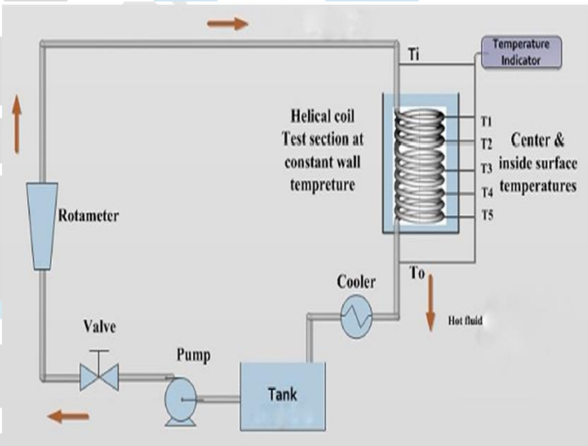

Fig.4 : Schematic diagram of experimental set-up.

Table 1: Some other nanofluids used in heat exchangers

S. N.	Researcher (s)	Year	Set-up	Nano-Partic-les	Base-Fluid	Work-Type	Flow-Regimes	Finding(s)
1	N.T. Ravi Kumar et al. **[13]**	2016	Double pipe U-bend heat exchanger	Fe_3O_4	Water	Num.	Turb.	1. Heat transfer enhancement of 34.93% is observed at 0.4% volume concentration. 2. There is a maximum friction penalty of 1.26 times at 0.4% volume concentration.
2	Dr. M Sakthivel et al. **[14]**	2018	Shell and Tube heat exchanger	Al_2O_3 SiO2	Water	Num.	Turb.	1. With the increase in Reynolds number and volume concentration of nanofluid thermal performance of heat exchanger is increased.
3	Bharat B. Bhosle et al. **[15]**	2017	Double pipe heat exchanger	Al_2O_3	Water	Num. and Exp.	Lam. and Turb.	1. For CFD analysis 11.5% enhancement in heat transfer rate observed at 0.1% concentration. 2. For Experimentally analysis 9.5% enhancement in heat transfer rate is observed at 0.1% concentration.
4	S. Nallusamy et al. **[16]**	2017	Shell and Tube Heat Exchange-r	Al_2O_3	Water	Exp.	Turb.	1. 10% enhancement in nusselt observed at 1.25% nanofluid concentration in counter flow arrangement of heat exchanger. 2. 8.9 % enhancement in nusselt observed at 1.25% nanofluid concentration in parallel flow arrangement of heat exchanger.
5	Ganesh Kumar Poongavanam et al. **[17]**	2019	Peened double pipe heat exchanger	carbon (AC) -	Solar Glycol	Num. and Exp.	Lam. and Turb.	1. 26.25%, 40.79%, and 57.06% enhancement of overall heat transfer coefficient is observed for 0.2, 0.4 and 0.6% volume concentrations nanofluid respectively.
6	Cong Qia et al. **[18]**	2019	Double-tube heat exchanger	TiO_2	Water	Exp.	Turb.	1. 10.8%, 13.4% and 14.8% improvement in heat transfer rate observed for 0.1%, 0.3% and 0.5% volume concentration of nanofluid respectively as compared with deionized water. 2. pressure drop of nanofluids increased by 2.77%, 4.38% and 6.5% for 0.1%, 0.3% and 0.5% volume concentration of nanofluid respectively.
7	N.T. Ravi et al. **[19]**	2018	Double pipe U-bend heat exchanger	fe3O4/	Water	Exp.	Turb.	1. The Nusselt number is enhanced to 14.76% (no insert) and it is further increased to 38.75% (with twisted tape inserts of H/D=10) at 0.06% volume concentration and at Reynolds number of 30000 compare to water. 2. The friction factor penalty of 1.092 times for no insert and penalty of 1.251-times for twist ratio of H/D=10 at 0.06% volume concentration of nanofluid and at Reynolds number of 30000 compared to water.
8	P. C. Mukesh et al. **[20]**	2015	Helically coiled heat exchanger	Al_2O_3	Water	Num.	Turb.	1. The coiled tube side Nusselt number (Nu) is found to be 30% higher with nanofluid compare to water. 2. The maximum pressure drop is found to be 9% higher with nanofluid compare to water.
9	Mojtaba Shirzad et al. **[21]**	2019	Pillow plate heat exchanger	Al_2O_3, CuO and TiO_2	Water	Num.	Lam. and Turb.	1. At 5% volume concentration the maximum and minimum thermal performance improvements in comparison with the water are belong to Al_2O_3(43.38%) and CuO (15.62%) respectively.

5. Conclusion: By studying the application of nanofluid in turbulent and laminar flows, it was found that thermal conductivity of nanofluids increases by adding nanoparticles into the base fluid. In general, the effects of nanoparticles on the heat transfer coefficient of homogeneous nanofluids are insignificant compared to the effects of thermos-physical properties of nanoparticles in the flow. Numerical studies of nanofluids within the heat exchangers are modeled in both single-phase and two-phase models. A single-phase model is considered without any slip between nanoparticles and fluids. However, in two-phase model, the particle slip and particle Brownian motion is considered. As literature shown that use of nanofluids in heat exchangers enhances its performance characteristics so it is very productive to use nanofluid instead of conventional fluid.

Abbreviations

Ag	Silver	Exp.	Experimental
Al_2O_3	Alumina	H_2O	Water
Au	Gold	Lmp	Litre per minutes
CFD	Computational fluid dynamics	MWCNTs	Multi walled carbon nano tubes
CNT	Carbon nano tubes	Num.	Numerical
Cu	Copper	SWCNTs	Single walled carbon nano tubes
CuO	Copper oxide	Theo.	Theoretical
De	Dean number	SiO_2	Silicon dioxide
DWCNTs	Double walled carbon nano tubes	TiO_2	Titanium dioxide
EG	Ethylene glycol	ZnO	Zinc oxide

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