بسم الله الرحمن الرحيم

“Heat transfer augmentation in engineering thermal devices by incorporating nanofluid as heat transfer medium: An extensive review study’’

A thesis submitted to the department of Mechanical and chemical Engineering (MCE), Islamic University of Technology (IUT), in the partial fulfillment of the requirement for B.Sc. degree in Mechanical Engineering.

Prepared By:

NAJEEB ULLAH (141464)

JAVAID AHMAD (141461)

Supervised By: Dr. Arafat Ahmed Bhuiyan

(Assistant professor MCE department)

Department of Mechanical and Chemical Engineering

Islamic University of Technology

CERTIFICATE OF RESEARCH:

The thesis title “Heat transfer augmentation in engineering thermal devices by incorporating nanofluid as heat transfer medium: An extensive review study” submitted by NAJEEB ULLAH (141464), JAVAID AHMAD (141461), has been accepted as satisfactory in partial fulfillment of the requirement for the Degree of B.Sc. in Mechanical and Chemical Engineering in Nov, 2018.

Signature of the Supervisor

____

Dr. Arafat Ahmed Bhuiyan

(Assistant Professor MCE Department)

Department of Mechanical and Chemical Engineering.

CANDIDATE'S DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma

Signatures of the Candidates.

______________________   ______________________

Najeeb Ullah

Student ID: 141464

Javaid Ahmad

Student ID: 141461

____

Department of Mechanical & Chemical Engineering (MCE)

Islamic University of Technology (IUT), OIC

Board Bazar, Gazipur Bangladesh.

Signature of the Supervisor

____

Dr. Arafat Ahmed Bhuiyan

(Assistant Professor MCE department)

Department of Mechanical & Chemical Engineering (MCE)

Islamic University of Technology (IUT), OIC

Board Bazar, Gazipur Bangladesh.

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We seek excuse for any errors that might be in this report despite of our best efforts.

CONTENTS:

ABSTRACT:

To acknowledge the prominent significance of new generation heat transfer medium (Nanofluid) in current engineering era, we have demonstrated the extensive literature study to shed light on its every crucial aspect. Heat transfer enhancement in engineering thermal devices is carried out by incorporating Active and Passive techniques. Passive techniques such as modifying heat transfer surfaces, inclusion of obstacles, replacement of base fluid with various nanofluids etc. impart substantial role in augmentation of heat transfer performance. We have extensively elaborated the noteworthy impact of nanofluids on thermal performance of heat exchangers, automotive radiators, refrigeration and air-conditioning system, and solar thermal convection. Furthermore, downsides of nanofluid have also been elucidated while evaluating the various parameters such as increment of nanoparticles, geometric-size and shape of solid particles etc. on pressure drop and pumping power. To conclude, this thesis will impart noteworthy role in designing and availing desired heat transfer and pressure drop requirements in heat transfer devices.

CHAPTER ONE

INTRODUCTION:

Nanofluids:

Nanofluids are colloidal suspensions which contain a nanometer-sized particles, called nano particles and tends to have higher thermal conductivity then the base fluids. The nanoparticles are typically made of metals, oxides, carbides etc. to be mixed with common base fluids including water, ethylene glycol and oil. Nanoparticles collides with the molecules of the base fluid by means of Brownian motion, so when they collide the solid-solid heat transfer mode increases the overall thermal conductivity of the nanofluid.

$$D = \frac{k_B T}{3\Pi \eta d}$$

The effect of Brownian motion is a diffusive process with diffusion constant D, so higher the temperature higher the diffusivity and thus higher the thermal conductivity [62].

The low thermal conductivity of conventional fluids has a serious drawback for improving the performance and reducing the size of engineering equipment. It all began with millimeter-to-micrometer sized particles in the late 19th century and lay the foundation for much smaller particles called nanoparticles which the concept and design are proposed by Choi in the early 1990s. In 1991 Choi develops a microchannel heat exchanger for the advanced photon source.

Nanofluids are a new class of nanotechnology by stably suspending nanoparticles with size ranging from 1-100 nm in base fluid. In the last decade scientists have found that a very small amount of the particles (less than 1% vol.) can impressively enhance the thermal properties of the base fluids.

From historical evidence the use of nanofluids are not really new, back in the medieval ages artisans used to suspend gold nanoparticles to give red color for their cathedral windows, and also in the 15^{th} century potters in Italy used metallic nanoparticles to make luster pottery [63].

In 1857 Michael Faraday first studied on the synthesis and colors of colloidal gold but experimental work was not possible at that time, but after the development of the nanotechnologies in the last decade one can put it into practice [64].

Higher heat conduction:

Nanoparticles have large surface area to volume ratio which means that the atoms present at the surface of a material are often more reactive then the ones in between or at the center which allows for more heat transfer e.g. particles finer than 20nm carry about 20% of their atoms at the surface which is available at any instant for thermal interaction. Another advantage is the mobility of the particles due to the tiny size of the particles which may bring about micro convention of the fluid and so increase the transfer of heat. The micro convection of the fluid and the enhance heat transfer of the fluid increases the dispersion of heat in the fluid very quickly and it is already been found that the thermal conductivity of nanofluids increases with the increase in temperature [65].

Nanofluids is nanophase powders and a base liquid, it is a two phase system with solid phase in liquid phase. For two Phase system we have to face some important issues like stability of nanofluids which has remained a challenge to get a desired nanofluids stability, some other Challenges like low thermal conductivity of fluids, high compactness and effectiveness of heat Exchangers [66]. These challenges are need to be solved. A variety of techniques is applied for understanding the enhancement of heat transfer, adding different types of powders metallic, non-metallic into the fluids to form a semi-liquid mixture, the thermal conductivity of the fluids is expected higher than that of the normal fluids. It have been found that by increasing the thermal conductivity of the working fluids will improve the heat transfer efficiency. Commonly used fluids such as water, ethylene glycol and oil which has low thermal conductivities as compared to the thermal conductivity of solids [67].

Stability:

One of the major drawbacks of the suspension is sedimentation and because of the very small size of the nanoparticles and less weight it overcomes that problem of settling the particles and make the nanofluid more stable [65]. A homogeneous solution is difficult to prepare because of strong van der Waal interactions between the nanoparticles tends to form a loosely compact structure, however we can improve the stability by treating them physically or chemically by the addition of surfactant to lower the surface tension between the solid and liquid. And in aqueous suspension the surfactant can improve the stability of nanofluid because of the hydrophobic (nonpolar) surfaces are modified to become hydrophilic (makes bond with water) and vice versa for other non-aqueous liquids. Though for non-aqueous solutions of nanofluid depends on the electro kinetic properties through which a high surface charge density, and strong repulsive forces can stabilize a much altered suspension [68].

Heat Exchanger:

Heat exchanger is a device used to transfer thermal energy (heat) from one fluid to another, between solid surface and liquid, or especially in nanofluids from solid particles to liquid with different temperatures and in contact. Common heat exchangers are shell-and-tube exchangers, automobile radiators, condensers, evaporators, cooling towers, and air preheaters. When there is no phase change in heat exchanger then it is called sensible heat exchanger. There may be an internal thermal energy sources and sometimes a chemical reaction can also take place in a heat exchanger. Usually there is no rotating parts in the heat exchanger except in the rotary regenerative exchanger in which there is a mechanically driven matrix at a design speed. The heat exchanger are classified in number of ways, depending on their construction and the way how the fluids flows relatively to each other through the device. A double pipe heat exchanger with two pipes or tubes, the flow is like one fluid (warmer) flows through the inner pipe and the other flows in annulus making a temperature difference which is the reason for heat transfer. The flow of fluids may be parallel flow or it may be opposite in direction to each other [69]. There are two types of heat exchangers in terms of transfer processes which are direct and in-direct contact types.

1) Indirect contact heat exchangers:

In this type the fluids are not in direct contact so the transfer of heat occurs through a dividing wall so there in no direct contact between the thermally interacting fluids, and this type of heat exchangers is called surface heat exchanger.

2) Direct transfer type exchangers:

In direct contact heat exchanger the fluids come into direct contact and exchange heat and then separated. Common application involving mass transfer in addition to heat transfer.

1) Construction.

2) No real pollution problem.

There are some advantages of direct heat exchanger over indirect heat exchanger which are these:

3) We can achieve a very high heat transfer rate.

4) Inexpensive

CHAPTER TWO

Applications of Nanofluids:

Due to the development in technology the demand for higher heat transfer is never been so high as of now for designing a device which is more compact, to increase the performance and heat transfer. Today industries like micro-electronics, manufacturing, and metrology are facing a major technical problem in the department of cooling due to the need of high end tech devices by the world more than ever, and they need ultrahigh-performance cooling system. They frequently used slurries but due to the dire problems caused by large particles in those slurries or suspensions is the brisk settling of the millimeter or micrometer sized particles. And also increases pressure drop and clogging, peculiarly in small thermal control systems. So the use of nanofluids becomes more common and efficient in modern world applications e.g. micro devices, heat exchangers, military equipment's, space technology, nuclear reactors, medicines, and cooling of electronics. Experiments shows that a small amount of nanoparticles in basic fluids shows substantial changes in thermal properties. Experimental study was investigated to show that the thermal performance of the heat pipes can be enhanced by using water based nanofluids with 17nm of gold particles in it in a disk shaped miniature heat pipe. The results show a 40% decrease in thermal resistance compare to that of water [1].

In ref [2] according to international technology road map for semiconductors the heat flux generation is increased from 330 W/cm^2 in 2007 to 520 W/cm^2 in 2011 as the performance of the chip proliferates. For this the cooling capacity of nanofluids can also be increased upto 6.7% at a flow rate of 60L/min. and is related to the dynamic interaction of the flow field and nanopowder. Nanopowder is capable of absorbing fluctuations of the turbulent kinetic energy results a better heat transfer characteristics which leads to better system performance.

In ref [3] an experimental study was investigated about heat transfer enhancement of an Al_2O_3/water nanofluid for cooling of micro-electronic components and found that with the addition of the nanoparticles in distilled water increases the heat transfer For a 6.8 vol. % concentration the heat transfer coefficient has been found to increase about 40% compared to that of base fluid.

The loss of coolant component accident or (LOCA) is a failure in a nuclear reactor and can damage the reactor core if not managed properly, it occurs during a break in reactor coolant system (RCS) pipeline. Each nuclear power plant has a specific emergency core cooling system only to deal with the LOCA. It occurs when the temperature of the nuclear fuel rods increases due to lake of coolant in RCS. Hence the nanofluids showed a remarkable performance of thermal properties like increase in thermal conductivity, single phase heat transfer coefficient, critical heat flux and quenching efficiency [19].

In ref [10] an experimental study was investigated to acknowledge the application of Al_2O_3 and aluminum nitride (AlN) nanoparticles in transformer oil. The thermal conductivity of the (AlN) nanoparticles at a volume friction of 0.5% increases by 8% and the overall heat transfer coefficient by 20%. Also by adding nanofluids such as (Fe_3O_4) to the transformer oil can increase the dielectric properties and can strengthen insulation [11].

Many viable applications of nanofluids have been studied to utilize the properties of nanofluids in transportation, and the result would be very large indeed. Another potential application of nanofluid is that it is used in nuclear reactor safety affair, for the removal of waste heat from the systems and the Emergency Core Cooling System (ECCS) ascribed to the boiling critical heat flux can be increased upto 50% from the base fluid [12].

Some special kind of nanoparticles exhibits antibacterial activities so the fluid which contain that particular type of nanoparticles will have some significant properties. In high pressures and temperatures the stability of organic antibacterial materials is low which leads to the use of inorganic materials e.g. metals and metal oxides to endure the severe circumstances. By increasing the nanoparticles concentration and decreasing its size results with the increase in antibacterial activities. Nanoparticles can also be used in optical applications to make optical filters such as ferrofluid optical filter for the selection of different wavelengths of light [16].

Application in refrigeration and air conditioning technologies:

Also there are some applications for enhancing the heat transfer in refrigerators. Nanoparticles can be used in domestic refrigerators to increase the performance of the refrigerant, thermo physical properties, heat transfer characteristics, thermal conductivity and also reduce energy consumption

[26]. For example, in ref [4] experimental study was conducted on TiO_2-R600a nano-refrigerants on a domestic refrigerator without redesigning of the system and investigating the performance of the nano-refrigerant using energy consumption and freeze capacity test leads to the refrigerant which works fine in the refrigerator and the performance was better than the original R600a system, with 9.6% less energy used with 0.5 g/L TiO_2-R600a nano-refrigerant. Also the use of TiO_2 nanoparticles as additives can increase the solubility of mineral oil in hydrofluorocarbon (HFC) refrigerant [2].

In ref [20] researchers used R113 refrigerant and CuO nanoparticles in an experimental study and found out that the heat transfer is enhanced upto 29.7% by using refrigerant based nanofluids as compared to the pure refrigerant.

In ref [5] investigating the effect of Al_2O_3 nano-refrigerants in a domestic refrigerator, the nano-refrigerant works normally in refrigeration system and the results that the freezing capacity increases and the power consumption reduces by 11.5% when polyolester oil is replaced by a mixture of mineral oil and aluminum oxide nanoparticles.

In ref. [24] an experimental study was examined on the performance and reliability of a domestic refrigerator by adding nanoparticles to the base fluid. Instead of polyol-ester (POE) oil as a lubricant a mixture of mineral oil with TiO2 nanoparticles were used in 1, 1, 1, 2-Tetrafluoroethane (HFC134a) refrigerator. The performance of the refrigerator was tested using energy consumption and freeze capacity tests and found out that at 0.1% volume concentration of TiO2 consumes 26.1% less energy compared to the HFC134a and POE oil system. In ref. [25] an experimental study was acknowledged to enhance the COP of the refrigeration system using R12 as the working fluid by adding low concentration of TiO2 nanoparticles to the mineral oil based lubricant. The experimental observations shows an increase in viscosity occurs, and the friction coefficient decreases with an increase in mass fraction of the nanoparticles, at 0.01% mass friction the average heat transfer rate is increased about 3.6% and the compressor work is reduced about 11% which leads to an overall increase of 17% in the COP.

In ref. [23] an experimental study was performed on predicting the thermal conductivities of CNT nanorefrigerants by using R113 as the base refrigerant and tested the effect of CNT diameters and aspect ratios on nanorefrigerants thermal conductivity. Study showed that the thermal conductivity of CNT nanorefrigerants is higher than that of CNT-water nanofluids or spherical-nanoparticle-

R113 nanorefrigerants with the same nanoparticle volume concentration, and predicted data on four kinds of CNT-R113 nanorefrigerants, at 0.1% volume friction of CNT the thermal conductivities of all four CNT-R113 nanorefrigerants are measured and found the increase upto 104%. The smaller diameter and large aspect ratio can lead to higher thermal conductivity of CNT-R113 nanorefrigerant.

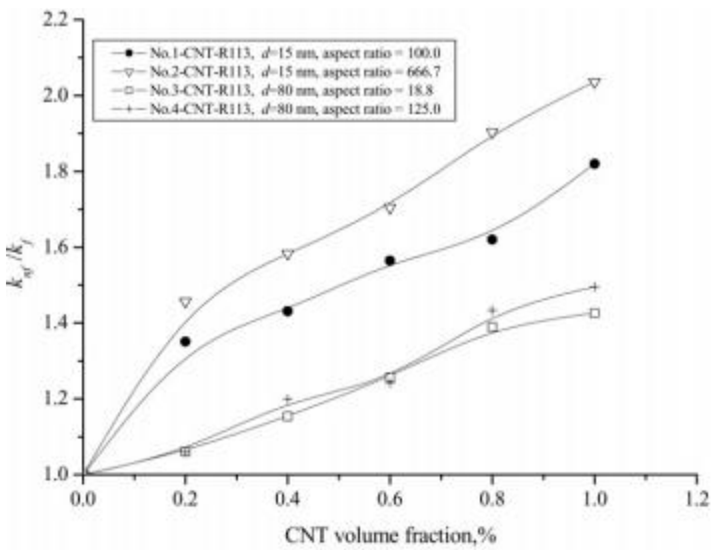

Fig. 1. k_{nf} /k_f of four kinds of CNT-R113 nanorefrigerants.

Application in automotive radiators:

Also there are some applications of the nanofluid as a coolant in a car radiator to increase the dissipation of heat out of the system this overall increase the performance and life span of the engine as compared to the traditional water and ethylene glycol coolants. Nanoparticles use is not limited to coolants but can also be used in transmission fluids, gear oils, and many different types of fluids and lubricants. In ref [6] application of the copper based nanofluid in ethylene glycol is numerically investigated in a car radiator and found out that 3.8% of heat transfer is enhanced by the addition of 2% of copper particles in ethylene glycol as base fluid with Reynolds number of 5000 and 6000 for coolant and air respectively.

In ref [7] Al2O3 water nanofluid effect on the car radiator compared to the water was experimentally investigated. Five different concentration of Al2O3 nanoparticles ranges from 0-1% been added into the water and the flow rate was also being changed in the range of 3-8 l/min for fully turbulent regime and results come out that the heat transfer can be enhanced upto 40-45% as compare to pure water which can be easily implemented to reduce the size of the radiator. Hybrid nanofluids are equitably new type of nanofluids and their applications are almost in all the fields of heat transfer. Although study revealed that the thermal conductivity of hybrid nanofluid may be appreciably higher than that of mono ones ascribed to synergistic effect [8]. However, research work is needed to test the stability and other thermophysical properties of hybrid nanofluids to discover its functionality in applied applications.

In the (MIT) Nuclear Science and Engineering Department revealed a study to estimate the practicality of nanofluids in nuclear applications including pressurized water reactor (PWR), standby safety systems, accelerator targets, plasma divertors. Engineers are constantly in a struggle for to improve the aerodynamics of the vehicles, and they must come up with the idea of reducing the drag caused by the wind on the vehicle which is due to the large radiator put in the front of the vehicle to cool down the engine by maximizing the effect of oncoming air. For example in trucks approximately 65% of the total energy produced by the engine is lost to overcoming the aerodynamic drag. The use of the nanofluid will reduce the amount of fluid in the radiator due to higher efficiency and thus reduce the size of the coolant pumps used and shrunk the overall size of the radiator and allow the engine to operate at higher temperatures and produce more horsepower [13].

In an annual report, Argonne National Laboratory they examined that by adding high thermal nano fluids in car radiators can reduce the size of the radiator upto 10% which leads to the reduction of fuel usage by 5%. It can also work as a lubricant for the radiator and will reduce wear which can be credible for even greater development of savings in the near future [14]. When diesel fuel is mixed with aluminum nanofluid it increases the total combustion by oxidation of the Al which allow better decomposition of hydrogen from water during combustion leads to the reduction of smoke and nitrous oxide during the emission from diesel engine [15].

In ref. [21] an experimental study was carried out to enhance the heat transfer performance of a car radiator using different volumetric concentrations of ZnO nanoparticles e.g. (0.01%, 0.08%, 0.2% and 0.3%) into the base fluid. The flow rate was in the range of 7-11 LPM and Reynolds number was varied from 17,500 to 27,600. At 0.2% upto 46% increase was found in the heat transfer performance as compared to base fluid, an increase or decrease in concentration level shows decrease in heat transfer. Also a 4% increase in heat transfer rate was noted by changing the fluid inlet temperature from 45^{o}C to 55^{o}C.

In ref. [22] a study on car radiators was performed experimentally by using Al2O3 nanoparticles, but before adding nanoparticles a test on pure water and pure ethylene glycol was performed to check the reliability of the experimental setup, then different amounts of the Al2O3 nanoparticles has been added to these base fluids by keeping the flow rate in the range of 2-6 LPM and the fluid inlet temperature has been changed for every experiment. A substantial increase of 40% in the heat transfer rate was found compared to the base fluids.

Nanofluids has great friction reduction properties and often work as a lubricant attributed to form a protective layer with low hardness and elastic modulus on the worn out surface and provide an excellent lubricating properties for better engine performance and in other transportation applications [9].

Application in heat exchangers:

In ref. [27] a numerical study has been investigated on natural heat transfer and fluid flow inside a wavy enclosure filled with Al2O3-water nanofluid using ANSYS-FLUENT for different concentrations of Al2O3 nanoparticles in water. It has been concluded that the heat transfer rate inside the enclosure has a negligible effect by changing the surface waviness and volume friction at low Rayleigh number, but increasing the Rayleigh number ($Ra \geq 10^5$) heat transfer rate increases to higher values and also the effect of changing the aspect ratio is more evident. In light of this study the geometrical parameters can be arranged in such a way to help us improve the heat transfer for solar collectors, electronic cooling, and food processing industries.

In ref. [28] analytical investigation has been performed on a helical coil heat exchanger using three different types of nanofluids (e.g. CuO/water, Al2O3/water and ZnO/water) by considering the nanofluid volume fractions 1-4% and volume flow rates ranges from 1-4% and 3-6 LPM. The CuO water nanofluid among the three enhances the heat transfer rate about 7.14% and reduces the entropy generation rate about 6.14%, also by increasing the volume concentration of the nanoparticles and flow rate the heat transfer rate increases and decreases the entropy generation. It has been concluded that the performance of the heat exchanger can be improved by adding nanofluids to the working fluid and on the basis of this study , CuO/water nanofluids is a good option.

In ref. [29] the effect of nanofluids on helically coiled tube heat exchanger are numerically investigated by taking four types of nanoparticles (Al_2O_3, SiO_2, CuO, ZnO) with volume concentration 1-4% and particle dia. 25-80 nm with base fluid of (water, ethylene glycol, engine oil). The results shows that when the concentration of the nanoparticles increases from 2% the convective heat transfer tends to worsen due to the increase in pressure drop for CuO-water nanofluid. On the other hand, it is found that SiO_2 had the highest pressure drop followed by Al_2O_3, ZnO and CuO due to different densities, also by increasing the particles concentration and reducing its diameter tends to increase the pressure drop due to higher viscosity. Engine oil had the highest pressure drop compared to ethylene glycol and water due to larger viscosity. However rotation can cause additional pressure drop in case of HCTHE.

In ref. [30] a numerical study has been examined by taking elliptical tube to enhance the heat transfer rate with a minimum increase in pressure drop. Four different volume friction of TiO_2 ranges from 0.25%-1% with different nanoparticle diameters varying from 27nm to 50nm scattered in water by keeping the Reynolds number in between 10000 to 100000. The results obtained through CFD shows that the elliptical tube enhances the heat transfer and friction factor by approx. 9% and 6% then the circular tube.

In ref. [31] an experiment was conducted for heat transfer characteristics of different nanofluids in plate heat exchangers, by using CeO_2-water nanofluids with different volume frictions ranges from 0% to 3.0%. The result showed that the maximum overall heat transfer coefficient of 28% occurred at 0.75% volume concentration with a volume flow rate of 3 LPM.

In an experimental study plate heat exchanger and shell-and-tube heat exchanger was incorporated in a single setup and was designed to carry out the experiment in both of the heat exchangers by changing the control valves. The result showed that the overall heat transfer coefficient was improved by the addition of the nanoparticles. However at low mass flow rate the max rise in OHTC was 5% at 2 wt. %. In a corrugated plate heat exchanger heat transfer coefficient increased upto 13% by using Al_2O_3-water nanofluid with a volume concentration of 4% in a laminar flow.

An experimental and numerical investigations was carried out on compact minichannel-plate heat exchanger about the performance of nanofluids, three types of nanofluids (aluminum oxide, copper oxide and silicon oxide nanoparticles) in water and ethylene glycol mixture were used. The comparisons were on the basis of equal mass flow rate, equal heat transfer and equal pumping power. The result showed that HTC was enhanced about 11% and OHTC by 4.85%, and by reducing the surface area of the heat exchanger by 2% the pumping power could be reduced by 5.65% for 0.5% of Al2O3 nanofluid. An equal mass flow rate of 0.2kg/s on the hot side of PHE aluminum oxide showed 4.75% and copper oxide showed 4.78% increase in the convective HTC and a decrease of 1.73% in a volumetric flow rates and pumping power respectively compared to the base fluid [32].

In ref. [33] a numerical study was performed on the enhancement of heat transfer and pumping power through a semicircular corrugated pipe by using Al2O3-water nanofluid and CuO-water nanofluid with a volume concentration of 1 % - 5 %. Due to corrugation the heat transfer performance was found to increase as the flow pattern and mixing behavior changes as compared to the plain circular pipe. The heat transfer was enhanced upto 26.39% and 24.27% at a highest volume concentration of Al2O3 and CuO (i.e. 5%) than water at Reynolds number of 20,000.

In ref. [34] heat transfer enhancement for a turbulent flow and pumping power required for Reynolds number 4000 to 20,000 has been studied numerically by the use of V-shaped corrugated tube. The result obtained shows that the increase in heat transfer rate occurs by sacrificing the pumping power in plain circular pipe at a volume friction of 5%, but by introducing corrugation to the pipe the pumping power requirement is much lower than that of water at 5% Al2O3-water nanofluid.

Application in solar-thermal conversion:

There are some applications of the nanofluids in the field of solar energy because it’s renewable and green and is used to generate electricity, thermal heating and chemical processing. Solar collectors uses solar radiation and converts it to internal energy. These are a specific type of heat exchangers which absorbs incoming solar radiations and converts it to heat which is transmitted to a fluid basically air, water or oil flowing in the collectors, the heat energy collected than transfers to hot water. Theoretical and numerical investigations demonstrates that the presence of nanoparticles increases the absorption of incoming radiations by approximately nine times as of pure water the results of this investigation shows that the use of nanofluid as a working fluid the efficiency of direct absorption solar collector is higher than the flat-plate collector. Solar water heaters are popular devices studied in terms of efficiency, economic and environmental perspective [17-18]. Solar collector is the main part of solar water heating system which generates heat by absorbing solar radiation. The generated amount of heat is then used for the heating of fluid (water, non-freezing liquid, or air) directly by passing through the collector or indirectly heating the domestic water by passing through heat exchanger. The heat transfer fluid is circulated either by natural convection or by forced convection which uses fans or pumps [35].

In ref. [36] an experimental and numerical study was performed on solar system heat exchangers in order to increase the efficiency using TiO2/water nanofluid flowing through a uniformly heated circular tube, the study revealed that an average of 21% of heat transfer coefficient is enhanced by using TiO2 water nanofluid instead of water. And this enhancement is largely due to the Reynolds number, particles concentration and nanoparticle thermal conductivity, however particle diameter had a negative impact on the heat transfer coefficient. For designing a solar thermal system the bigger and substantial solar collector has a huge surface area of heat transfer that can increase the output temperature which in turn will increase the cost of manufacturing and transportation. Study shows that by using nanoparticles as working fluid we can reduce the size of the solar collectors and can achieve a desired output temperature e.g. by using CuO, SiO2, TiO2 and Al2O3 the area of the solar collectors can be reduced upto 25.6%, 21.6%, 22.1% and 21.5% correspondingly and can reduce the cost of manufacturing the collectors [37].

In ref. [38] an experimental study was executed to investigate the effects of water based Single Walled Carbon Nanotubes (SWCNTs) nanofluids compared to water on the Evacuated Tube Solar Collector (ETCS) with a volume concentrations of 0.05, 0.1 and 0.2% using flow rates of 0.008, 0.017 and 0.025 kg/s. The results shows that the thermal efficiency of the ETCS was 74.84% higher than that of water as working fluid due to the enriched thermal properties of SWCNTs nanofluids, and was found that upto 93.43% of thermal efficiency was increased for a volume concentration of 0.2% and mass flow rate of 0.025 kg/s. And by increasing the volume friction and flow rate the thermal efficiency also increases and for the same mass flow rate the efficiency of the collector on cloudy days is better than that of water on sunny days using 0.2 vol.% of SWCTNs nanofluids. In ref. [39] the effects of AL2O3-water nanofluids was tested experimentally on a flat plate solar collector having different volume frictions of the nanoparticles i.e. 0.1% and 0.3% using 13nm diameter of nanoparticles. The results obtained on the energy and exergy efficiencies using water and nanofluids as working fluid was compared and discovered that the energy efficiency was enhanced 83.5% for 0.3 vol.% and a mass flow rate of 1.5 kg/min as well as the exergy efficiency was increased upto 20.3% for 0.1 vol.% with a mass flow rate of 1kg/min. The use of AL2O3-water nanofluids is found to be superior then water as a working fluid for a flat plate water heater.

The possible challenges and future prospects of nanofluids are discussed as follows: -

Researchers have made many developments in the field of thermal conductivity and received maximum deliberations in the field of nanofluids applications. It appears promising but the development is stalled by: **i)** Disagreement on the results obtained by different researchers **ii)** Poor classification of suspensions **iii)** Misunderstandings of the theoretical mechanisms responsible for changes in properties. The various significant factors like thermal conductivity, the Brownian motion of particles, particle migration, and thermo physical properties including changes with temperature must be cautiously considered with connective heat transfer in nanofluids in order to receive better consideration in the future. In all the past studies involves inclusion of oxide nanoparticles in high concentrations has increased the viscosity and pumping power of the base fluid. While on the other hand the corresponding thermal conductivity of the metallic particles is 100 times more than that of the oxide nanoparticles. The main challenges of the nanofluids are high production cost, low specific heat, pressure drop, and irregular high thermal conductivity. Also, the preparation of the homogeneous suspensions of the nanofluids always remained a technical challenge attributed to very strong Van Der Waals interactions nevertheless a stable homogeneous suspension can be obtained by applying various procedures such as addition of surfactant or modifying the surface and applying strong force on the clusters of the suspended particles [49-47-50]. Also, the dispersion stability of nanoparticles has a direct relation with the heat transfer enhancement as the nanofluid becomes stable the better will be the thermal conductivity. The two important phenomena for the stability of the nanofluid is aggregation and sedimentation [41-50]. The dispersion of the nanoparticles plays a major role in thermal conductivity of the nanofluids**.** For example, ethylene glycol based nanofluid containing 0.3% of copper nanoparticles thermal conductivity is acknowledged within first 2 days and after 2 months and found that in the fresh nanofluids the heat transfer is slightly higher than that of the old one due to the low dispersion stability after the passage of time results shows that nanoparticles can settle down and decrease the dispersion during the passage of time [42-43]. Another experimental study showed the settlement of Al_2O_3 nanoparticles after 30 days in the base fluid [49]. The possible challenge for nanofluids is the stability of nanofluids with respect to length of time, in most of the experimental studies did not contemplate the fleeting response of nanofluid wields within solar thermal collector. The stability of nanofluids affects the thermal properties of nanofluids and also its optical properties [44]. Strong van der Waals forces between nanoparticles have introduced a challenge for preparing a homogenous suspension. This challenge need to be studied to be a major concern for using a nanofluids as a coolant for heat exchanger. To obtain stability in nanofluids, some physical and chemical treatment have been suggested, they can be either surface modification of nanofluids, using of surfactants, or applying high forces on the collected nanoparticle. The researchers have also suggested that with the addition of surfactant and ultrasonic vibration of nanofluids an enhancement in stability of nanofluid is occurred. Four types of surfactants have been used according to the composition of the head; i.e. non-ionic surfactants with no charge on its head (e.g. alcohols, polyethylene oxide, and polar groups), anionic surfactants with negative charge head (e.g. alkyl sulphates phosphates, fatty-acid, sulfonates, and sulfosuccinates), cationic surfactants with positively charge head, and zwitterionic head group with amphoteric surfactants [61].

The viscosity of the nanoparticle-water suspensions increases with increasing the nanoparticles concentration in the suspension so the mass fraction of the particles cannot have increased unconstrained [59]. By adding nanoparticles to the base fluid, the viscosity of the nanofluids increases which is a strong function of temperature and volumetric concentration, although studies on viscosity of nanofluids are very limited and is a challenge for the researchers, as the viscosity increases gives rise to the pressure drop e.g. an experimental study shows that an increase of 40% pumping power arises after the addition of nanoparticles to the base fluid (water) [48]. To overcome the pressure, drop of the nanofluid will require more power to operate especially in domestic devices such as refrigerators, vehicles radiators etc. attributed to bigger size pumps and energy consumption on a large industrial scale is costly. There are some incentives of using nanofluid but one just cannot ignore the drawbacks which needs to be considered as well for example, in ref [51] an experimental study shows that by increasing the concentration of the TiO_2 nanoparticles in water increases the pressure drop considering a turbulent flow regime. In ref [52] another experiment shows pressure drop by dispersion of CuO nanoparticles in base oil considering the laminar flow regime. In ref [45] nanoparticles may create non-Newtonian fluid effect and the research available on this is limited so it's a challenge to obtain accurate heat transfer and two-phase flow result for the refrigerant base nanofluids**.** This study revealed that surfactant is used to stabilize the nanofluid but it effects the physical properties like surface tension and viscosity of the fluid even though the added amount of surfactant is small (ppm level). And without a surfactant the odds of stable nanofluid is slim [46].

The cost of the nanofluids is much higher as they are prepared either by one step or two step method and both processes requires technologically advance equipment's [47]. Thus, the use of nanofluids in thermal engineering systems like heat exchangers is considered as a deterrent. Also, nanofluids can lead to corrosion and erosion of thermal devices though it will take a long time. Experimental research shows that TiO_2, Al_2O_3, SiC, ZrO_2 nanoparticles in base fluid like water flows in three different materials of pipes i.e. aluminum, stainless steel and copper the highest erosion occurred by using ZrO_2 and TiO_2 nanoparticles while the SiC shows the least [53]. Nanofluid, high production cost is one of the reason which prevent the application of nanofluids in industry, nanofluids can be produced by one or two step method, however in each method high sophisticated and unconventional equipment are required.in ref [56] an experimental study was conducted which hassled that the high cost among one of the drawbacks of the nanofluids applications.

In these days, many industries experiencing thermal challenges and have a need of ultrahigh cooling systems. Although, a suspended particle used in the liquid suspension in industries but they are not worthy for heat transfer application. The particles were first too large due to severe problems caused by large particles in those slurries. The major problem was the particles is the rapid settling of these particles. If the fluids were kept flowing to prevent settling, then the walls of the pipes would damage and make them thin, some other problems like pressure drop. Some properties which could affect the coolant pressure drop i.e. density, flow rate, viscosity, it is projected that the coolant with higher viscosity and density know-how higher pressure drop [54]. Most of the studies, indicated that with the addition of nanoparticles increases the thermal performance of nanofluid operated in solar collector. However, few studies have shown inconsistent result among the researchers that the thermal performance of nanofluid deteriorates when definite particles loading is exceeded. In ref [57] an experimental study was conducted to examine the thermal efficiency of nanofluid MWCT, the result indicated that using 0.2wt% MWCT nanofluid without surfactant decrease in efficiency occurred, while with surfactant an obvious increase was observed. The increase in efficiency depends upon the temperature differences parameters. However, by using 0.4wt% MWCT without surfactant an increase in efficiency was observed with small value change (reduced) in temperature differences parameters. The efficiency increased with the increase in mass flow rate and get reversed beyond these small values.

Design of solar collector is one of the possible challenge of nanofluids in solar thermal collector. The particles sedimentation is affected by the design of the solar collector. In ref [59] an experimental study was conducted, this study identified that the particles sedimentation can be addled by maintaining a constant mass flow rate of the fluid. Water-AL2O3 have been contemplated with different volumetric values to avoid sedimentation and improve the efficiency in the flat-plate solar collectors. A modification is required in design of solar collector, so these authors came up with in new design but still a more comprehensive study is needed in this area.

In ref [55] a numerical study was conducted to examine the specific heat, from the previous researches, it is acknowledged that the specific heat of the nanofluids is lower than that of basefluid, A nanofluids like AL_2O_3/ethylene glycol nanofluids, CuO/ethylene glycol nanofluids, and SiO_2/ethylene glycol exhibit lower specific heat than that of the base fluid. For ideal coolants it should possess higher specific heat value which enable high removal rate of heat. One of the major challenge and future research needs on single–phase liquid flow is roughness effects. Using numerical techniques in the literature the effects of two dimensional and three dimensional roughness elements on heat transfer and friction factor have been studied. Since the effect of recirculation and eddies created behind the roughness structure are not listed for correction in numerical schemes, an experimental validation of the numerical results is required and developing a theoretical models for these effects, especially on heat transfer, heat transfer in some important area. Such models are anticipated to provide information for a desired mechanism which can help in designing surface with higher heat transfer enhancement than related increase in pressure drop **[60]**.

CHAPTER THREE

CONCLUSIONS:

An extensive literature review study has been demonstrated to acknowledge the significant influence of nanofluids on various engineering thermal devices such as automotive radiators, refrigerators and air conditioning system, solar thermal convection, and heat exchangers. The noticeable key conclusions are summarized as follows,

- Nanofluid play crucial role in augmenting heat transfer performance of various heat exchangers due to inclusion of solid particles with higher thermal conductivity and specific heat capacity.
- Base fluid provided comparatively lower thermal performance in solar collectors and car radiators than nanofluid. However, various nanofluids possess different effect on heat transfer rate.
- Nano-refrigerant in refrigerants and air-conditioning system tends to impart significant role in yielding desired cooling rate.
- The increment in nanoparticles concentration and size yield higher pressure drop and hence higher pumping power. Which entails the prominent importance for selection of optimal parameters of solid particles.
- Fouling rate on heat transfer surfaces tends to rises with prolonged duration as the volume fraction of particles increases.

Augmentation of thermal characteristics and pressure drop performance of engineering thermal devices is depiction of proper selection of various nanofluids while thoroughly evaluating the thermophysical properties and their impact on important parameters. To acquire greater heat transfer rate in the penalty of low pressure drop optimal selection of nanoparticles tends to impart noteworthy role.

REFERENCES:

[1] NANOFLUIDS Science and Technology by Sarit K. Das, Stephen U. S. Choi, Wenhua Yu, T. Pradeep.

[2] A review on applications and challenges of nanofluids by R. Saidur, K.Y. Leong, H.A. Mohammad.

[3] Cooling performance investigation of electronics cooling system using Al2O3–H2O nanofluid by M.R. Sohel, R. Saidur, S.S. Khaleduzzaman, Talaat A. Ibrahim.

[4] Performance of a domestic refrigerator using TiO2-R600a nano-refrigerant as working fluid by Shengshan Bi, Kai Guo, Zhigang Liu, Jiangtao Wu.

[5] Heat transfer enhancement in domestic refrigerator using R600a/mineral oil/nano-Al2O3 as working fluid, R. Reji Kumar, K. Sridhar, M.Narasimha.

[6] Performance investigation of an automotive car radiator operated with nanofluid-based coolants (nanofluid as a coolant in a radiator) by K.Y. Leong, R. Saidur, S.N. Kazi, and A.H. Mamun.

[7] Performance Investigation of an Automotive Car Radiator Operated With Nanofluid as a Coolant by Durgeshkumar Chavan, Ashok T. Pise.

[8] A review on hybrid nanofluids: Recent research, development and applications by Jahar Sarkar, Pradyumna Ghosh, Arjumand Adil.

[9] A Review on Nanofluids: Preparation, Stability Mechanisms, and Applications by Wei Yu, and Huaqing Xie.

[10] Preparation and heat transfer properties of nanoparticle-in-transformer oil dispersions as advanced energy-efficient coolants C. Choi, H.S. Yoo, J.M. Oh.

[11] AC (60 Hz) impulse breakdown strength of a colloidal fluid based on transformer oil and magnetite nanoparticles by V. Segal, A. Hjortsberg, A. Rabinovich, D. Nattrass, and F. Dreparation.

[12] Small particles, big impacts: A review of the diverse applications of nanofluids by Robert Taylor, Sylvain Coulombe, Todd Otanicar, Patrick Phelan, Andrey Gunawan, Wei Lv, Gary Rosengarten, Ravi Prasher, and Himanshu Tyagi.

[13] Applications of Nanofluids: Current and Future by Kaufui V. Wong and Omar De Leon.

[14] Annual Report, Argonne National Laboratory, 2006. "Heavy vehicle systems optimization merit review and peer evaluation" by D. Singh, J. Toutbort, G. Chen, et al.

[15] An overview of Nanofluids: A new media towards green environment by Gupta H.K, Agrawal G.D, Mathur J.

[16] A review on preparation, characterization, properties and applications of nanofluids by Dhinesh Kumar Devendiran n, Valan Arasu Amirtham.

[17] A review of the applications of nanofluids in solar energy by Omid Mahian, Ali Kianifar, Soteris A. Kalogirou, Ioan Pop, Somchai Wongwises.

[18] Predicted Efficiency of a Low-Temperature Nanofluid Based Direct Absorption Solar Collector by Himanshu Tyagi, Patrick Phelan, and Ravi Prasher.

[19] Review of applications of Nano Fluids for heat transfer &efficiency of Safety Systems in Nuclear Power Plants by Deepak Awasthi, Ashutosh Tiwari.

[20] Heat transfer characteristics of refrigerant-based nanofluid flow boiling inside a horizontal smooth tube by Hao Penga, Guoliang Dinga, Weiting Jianga, Haitao Hua, Yifeng Gaob.

[21] Experimental investigation of convective heat transfer augmentation for car radiator using ZnOewater nanofluids by Hafiz Muhammad Ali, Hassan Ali, Hassan Liaquat, Hafiz Talha Bin Maqsood, Malik Ahmed Nadir.

[22] Experimental study of heat transfer enhancement using water/ethylene glycol based nanofluids as a new coolant for car radiators by S.M. Peyghambarzadeh, S.H. Hashemabadi, S.M. Hoseini, M. Seifi Jamnani.

[23] Measurement and model on thermal conductivities of carbon nanotube nanorefrigerants by Weiting Jiang, Guoliang Ding, Hao Peng.

[24] Application of nanoparticles in domestic refrigerators by Sheng-shan Bi, Lin Shi, Li-li Zhang.

[25] Application of TiO2 nanoparticles as a lubricant-additive for vapor compression refrigeration systems - An experimental investigation by R. Krishna Sabareesh, N. Gobinath, V. Sajith, Sumitesh Das, C.B. Sobhan.

[26] Performance Analysis of a Refrigeration System Using Nano Fluid by T. Coumaressin and K. Palaniradja.

[27] Natural Convection of Al2O3-Water Nanofluid in a Wavy Enclosure by Mitchell Leonard, Aloke K. Mozumder, Shohel Mahmud, Prodip K. Das.

[28] Heat transfer and thermodynamic analyses of a helically coiled heat exchanger using different types of nanofluids by M.A. Khairul, R. Saidur, M.M. Rahman, M.A. Alim, A. Hossain, Z. Abdin.

[29] Influence of nanofluids and rotation on helically coiled tube heat exchanger performance by K. Narrein, H.A. Mohammed.

[30] HEAT TRANSFER ENHANCEMENT WITH ELLIPTICAL TUBE UNDER TURBULENT FLOW TiO2-WATER NANOFLUID by Adnan M. HUSSEIN , Rosli Abu BAKAR , Kumaran KADIRGAMA , and Karada Viswanatha SHARMA.

[31] Heat transfer and pressure drop characteristics of CeO2/water nanofluid in plate heat exchanger by Tiwari AK, Ghosh P, and Sarkar J.

[33] Performance Evaluation of Nanofluid for Heat Transfer Enhancement and Pumping Power Reduction through a Semicircular Corrugated Pipe by M Salehin, M M Ehsan and A.K.M. Sadrul Islam.

[34] Heat Transfer and Pumping Power Using Nanofluid in a Corrugated Tube by Shafi Noor, M. M. Ehsan, Sayedus Salehin and A.K.M. Sadrul Islam.

[35] Solar thermal collectors and applications by Soteris A. Kalogirou.

[36] Experimental and numerical investigation of nanofluids heat transfer characteristics for application in solar heat exchangers by Ehsan Ebrahimnia-Bajestan, Mohammad Charjouei Moghadam, Hamid Niazmand, Weerapun Daungthongsuk, and Somchai Wongwises.

[37] Energy, economic and environmental analysis of metal oxides nanofluid for flat-plate solar collector by M. Faizal, R. Saidur, S. Mekhilef, and M.A. Alim.

[38] Energy performance of an evacuated tube solar collector using single walled carbon nanotubes nanofluids by M.A. Sabiha, R. Saidur, S. Hassani, Z. Said, Saad Mekhilef.

[39] Energy and exergy efficiency of a flat plate solar collector using pH treated Al2O3 nanofluid by Z. Said, R. Saidur, M.A. Sabiha, A. Hepbasli, N.A. Rahim.

[40] A review on preparation methods and challenges of nanofluids by Nor Azwadi Che Sidik , H.A. Mohammed, Omer A. Alawi, S. Samion.

[41] A review of nanofluid heat transfer and critical heat flux enhancement—Research gap to engineering application by J.M. Wu and Zhao Jiyun.

[42] Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles by J.A. Eastman, S.U.S. Choi, S. Li, W. Yu, L.J.

[43] Assessment of the effectiveness of nanofluids for single-phase and two-phase heat transfer in micro-channels by Jaeseon Lee, Issam Mudawar.

[44] An overview on current application of nanofluids in solar thermal collector and its challenges by K.Y. Leong ,n, Hwai Chyuan Ong , N.H. Amer , M.J. Norazrina , M.S. Risby , K.Z. Ku Ahmad.

[45] Boiling and two-phase flow phenomena of refrigerant-based nanofluids: Fundamentals, applications and challenges by Lixin Cheng, Lei Liu.

[46] Boiling phenomena with surfactants and polymeric additives: a state-of-the-art review by Cheng, L., Mewes, D., Luke, A., 2007.

[47] An overview of Nanofluids: A new media towards green environment by Gupta H.K, Agrawal G.D, Mathur J.

[48] Nanofluids: From vision to reality through research, Journal of Heat Transfer by Stephen U S Choi. (2009).

[49] Application of metallic nanoparticle suspensions in advanced cooling systems by Lee S & Choi S U S., (1996).

[50] A review on preparation, characterization, properties and applications of nanofluids by Dhinesh Kumar Devendiran, Valan Arasu Amirtham.

[51] An experimental study on the heat transfer performance and pressure drop of TiO2–water nanofluids flowing under a turbulent flow regime by W. Duangthongsuk, S. Wongwises.

[52] Pressure drop and thermal characteristics of CuO–base oil nanofluid laminar flow in flattened tubes under constant heat flux by Pooyan Razi, M.A. Akhavan-Behabadi, M. Saeedinia.

[53] A review of the applications of nanofluids in solar energy by Omid Mahian, Ali Kianifar, Soteris A. Kalogirou, Ioan Pop, Somchai Wongwises.

[54] Improved efficiency of nanocoolants by Ankit Jain, Devender Pratap, Satyapal Yadav.

[55] Numerical study of turbulent flow and heat transfer characteristics of nanofluids considering variable properties by Praveen K. Namburu, Debendra K. Das ∗, Krishna M. Tanguturi, Ravikanth S. Vajjha.

[56] Assessment of the effectiveness of nanofluids for single-phase and two-phase heat transfer in micro-channels by Jaeseon Lee, Issam Mudawar.

[57] An experimental investigation on the effect of MWCT-H2O nanofluid on the efficiency of flat-plate solar collectors by Tooraj Yousefi, Farzad Veisy, Ehsan Shojaeizadeh, Sirus Zinadini.

[58] A new solution for reduced sedimentation flat panel solar thermal collector using nanofluids by Gianpiero Colangelo, Ernani Favale, Arturo de Risi, Domenico Laforgia.

[59] A review on application and challenges of Nano-fluids as coolant in automobile radiator by Rahul A. Bhogare B. S. Kothawale.

[60] History,Advances, and Challenges in liquid flow and flow boiling heat transfer in microchannels: A critical review by Satish G. Kandlika

[61] The potential of using nanofluids in PEM fuel cell cooling systems: A review by M.R. Islam n, B. Shabani, G. Rosengarten, J. Andrews.

[62] Book of Heat Transfer enhancement with nanofluids by Vincenzo Bianco, Oronzio Manca, Sergio Nardini and Kambiz Vafai.

[63] Nanofluids: From Vision to Reality through Research by Stephen U. S. Choi.

[64] Thermal Conductivity of Nanofluids by A. K. Singh.

[65] Heat Transfer in Nanofluids—A Review by Sarit Kumar Das, Stephen U.S. Choi, Harishikesh E. Patel.

[66] A Review on Nanofluids: Preparation, Stability Mechanisms,

and Applications by Wei Yu and Huaqing Xie.

[67] Heat transfer enhancement of nanofluids by Yimin Xuan and Qiang Li.

[68] A review of nanofluid stability properties and characterization in stationary conditions by A. Ghadimi, R. Saidur, H.S.C. Metselaar.

[69] ENGINEERING HEAT TRANSFER Second Edition by Dr. William S.Janna, Ph.D.