Paramertic Study of Effect on Heat Transfer Using Various Nanofluids in Tube in Tube Heat Exchanger

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Paramertic Study of Effect on Heat Transfer Using Various Nanofluids in Tube in Tube Heat Exchanger

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(Thermal Engineering)

By

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Declaration

This is to certify that

1. The thesis comprises of my original work towards the degree of Master of Technology in Thermal Engineering at Nirma University and has not been submitted elsewhere for a degree or diploma.

2. Due acknowledgment has been made in the text to all other material used.

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I, Brahmarshi Bhatt, Roll. No. 16MMET30, give undertaking that the Major Project entitled "Parametric Study on Effects of Heat Transfer Using Variuos Nanofluids in Tube iin Tube Heat Exchanger" submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in Mechanical Engineering (Thermal Engineering) of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere, it will result in severe disciplinary action.

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Abstract

There are many methods of enhancement of heat transfer coefficient including active and passive methods. Nanofluid is the passive method to increase the heat transfer. The present work deals with experimental investigation to enhance the heat transfer coefficient using nanofluid. Experiments are performed varying Reynolds number of hot water and flow rates of the base fluid. To know the effect of change of Prandtl number on heat transfer coefficient experiments are performed using three different base fluid by Distilled water. Experiments have been carried out experiments with Al_2O_3, CuO and SiO_2 nanofluid. The average size of Al_2O_3, CuO and SiO_2 nanoparticles used in this work was 40 nm with a rage of 30-100 nm . Experiment was carried out with 0.05%, 0.1%, 0.25%, 0.5%, 1% w/w concentrations of Al_2O_3, CuO and SiO_2 nanoparticles in distilled water, for five Reynolds number in turbulant region. To avoid agglomeration of Nano particles in nanofluid a special treatment is required. For this SDBS(sodium dodecyl benzonyl sulphate) is selected for Al_2O_3, CuO and SiO_2 type of nanofluid. Based on the present experimental investigation it is found that heat transfer coefficient increases with increase in Reynolds number for any type of fluid. The stability of nanouids was checked using Malvern Zetasizer and it was found that it was stable for 6 to 7 hours after synthesis. The experimental results shows that there were increament in the overall heat transfer coefficient. It was found that the nanofluids CuO, Al_2O_3 and SiO_2have maximum of 40%, 30% and 23% higher heat transfer coefficient compared to base fluid at mass fraction of 1% concentration, respectively. The measurements also showed that the pressure drop of nanofluids was higher than that of the base fluid. The use of nanofluids CuO, Al_2O_3 and SiO_2 increased the friction factor by 21%, 26% and 31% in comparison with pure water, respectively .As a result, the CuO nanofluid performed the best amongst the three metal oxide nanofluids at a given particle size, concentration, and temperature. According to the results, this nanofluids can be a good alternative in similar applications such as heat exchangers.

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Nomenclatures

d_i	Inner diameter of tube
d_o	Outer diameter of tube
f	Friction factor
$\bar{f}$	Ratio of friction factor
h	Convective heat transfer co-efficient
h_i	Inner convective heat transfer co-efficient
h_o	Outer convective heat transfer co-efficient
m_h	Mass flowrate hot fluid
m_c	Mass flowrate cold fluid
w/v	Weight by volume percentage
A	Surface Area
A_c	Cross-section Area
C_p	Specific heat
C_{bf}	Specific heat of base fluid
C_{nf}	Specific heat of Nano-particles
D_e	Equivalent Diameter
D_h	Hydraulic Diameter
D_i	Annulus inner diameter
D_o	Annulus outer diameter
K	Thermal Conductivity
K_{eff}	Effective Thermal Conductivity of Solid-Liquid mixture
K_m	Thermal Conductivity of Base Fluid
K_2	Thermal Conductivity of Particles
L	Length of pipe
L_c	Characteristic Length
Nu	Nusselt number
$\bar{N}u$	Ratio of Nusselt number
$\triangle P$	Pressure loss
P_w	Wetted perimeter
Pr	Prandtl number
Q	Net Heat Transfer
Re	Reynold number
Re_c	Reynold number of cold fluid
Re_h	Reynold number of hot fluid
R_{wall}	Wall resistance
R_{fi}	Inner fouling resistance
R_{fo}	Outer fouling resistance

d_i	Inner diameter of tube
d_o	Outer diameter of tube
f	Friction factor
$\triangle T$	Temperature difference
$\triangle T_{LM}$	Logarithmic mean temperature
T_{ci}	Nano-fluid inlet temperature
T_{co}	Nano-fluid outlet temperature
T_{hi}	Hot fluid inlet temperature
T_{ho}	Hot fluid outlet temperature
T_s	Surface temperature
U	Overall heat transfer co-efficient
V	Velocity of fluid
Φ	Volume Fraction of Nanofluid at different concentrations
Greek symbols	
ρ	Density
μ	Dynamic viscosity
ν	Kinematic viscosity
ϕ	Volume Fraction of Nanofluid at different concentrations
Abbreviations	
SWNTs	single-walled nanotubes
MWNTs	multi-walled nanotubes
SDBS	Sodium Dodecyle Benzoic Sulphonate
SDS	Sodium Dodecyle Sulphonate
CTAB	Cetyle Tri-methail Ammonium Bromide

Subscripts

nf	Nanofluid
bf	Base fluid
np	Nanoparticles
eff	Effective
m	Mean
LM	Logarithmic mean
h	Hot
2	outlet

Chapter 1

Introduction

Numerous applications that generate the heat flux have a requirement of heat exchanger that can help to cool at a faster rate and can take the maximum amount of heat. For the cooling applications in electronics field, heat exchanger is required. This chapter deals with various methods to enhance the heat transfer rate and also discusses one of the passive method of the same by use of Nanofluid and details of the Nanofluid.

1.1 General

Thermal properties of liquids play a major role in heating as well as cooling applications in industrial processes. Thermal conductivity of a liquid is an important physical property that decides its heat transfer performance. Conventional heat transfer fluids have poor thermal conductivity which makes them inadequate for ultra high cooling applications. Scientists have tried to enhance the inherently poor thermal conductivity of these conventional heat transfer fluids using solid additives following the classical effective medium theory for effective properties of mixtures. Fine tuning of the dimensions of these solid suspensions to millimeter and micrometer ranges for getting better heat transfer performance have failed because of the drawbacks such as still low thermal conductivity, particle sedimentation, corrosion of components of machines, particle clogging, excessive pressure drop etc. Downscaling of particle sizes continued in the search for new types of fluid suspensions having enhanced thermal properties as well as heat transfer performance.

Numerous applications which generate the heat flux have a requirement of heat exchanger that can help to cool at a faster rate and can take the maximum amount of the heat. For expansion of heat move in such application, Nanofluid - an aloof technique to build the heat exchange coefficient - has as of late been presented. Choi [1] made the Nanofluid innovation. Some variation in heating or cooling in any of the industrial process may help in the saving of some amount of energy, may reduce the process time, it may raise the thermal rating and might increase the age of the equipment. The heat transfer up to some extent there are some processes in industry which are affected qualitatively. For the cooling applications in electronics field miniaturization of heat exchanger is required.

All physical mechanisms have a critical scale below which the properties of a material changes totally. Modern nanotechnology offers physical and chemical routes to prepare nanometer sized particles or nanostructured materials engineered on the atomic or molecular scales with enhanced thermo-physical properties compared to their respective bulk forms. To explain the above reason the new high thermal conductivity liquids known as "Nanofluids" have proposed by the analysts [1]. Nanofluids are termed as a suspended nanoparticle in the old conventional fluids. Nano particles of metals, metal oxides or any ceramic particles are suspended in the base fluids such as water, ethylene glycol etc. the intensification of thermal conductivity of the base fluids using a few nano particles was astonishing and cannot be predicted using the theories existed.

Nanofluids are engineered by dispersion of fine metallic and non metallic particles of nano-meter dimension in traditional host liquids which include water, ethylene glycol, propylene glycol, oil etc. Use of such nanoparticles in the base fluids increase their thermal conductivity and heat transfer performance of nanofluids. Nanofluids are new generation heat transfer fluids and can be used for heat transfer augmentations. Nanofluids have high heat transport capability and can replace traditional thermo fluids normally used for heat transfer applications in heat exchangers, chemical process plants, manufacturing processes, automotives and cooling of electronic components. Nanofluids are used in micro channel cooling without any clogging and sedimentation problems. The nanofluids can also be employed in high heat flux applications where single phase pure fluids are not capable of transferring the heat at desired rate.

Heat transfer augmentation using nanofluids is one of the emerging areas of research. Generally conventional single phase fluids have low thermal conductivities when compared to metals and their oxides. The fluids with suspended particles of metals and metal oxides are supposed to exhibit better heat transfer properties than the conventional fluids without solid particles. Particles clogging, sedimentation and erosion are some of the common problems associated with the use of micro or millimeter sized solid particles when suspended in the host fluids. Such problems can be minimized by replacing micrometer sized particles by nano sized particles.

Many heat transfer augmentation techniques are reported in literature. Heat transfer enhancement in fluids can be effected primarily by two techniques viz. passive heat transfer technique and active heat transfer technique. Passive heat transfer techniques can be employed by provision of rough and extended surfaces tubes and creation of swirl in the flow using inserts of certain geometrical shape. Active heat transfer techniques include applying of electric/magnetic fields, inducing vibrations in the heated surface, injection and jet impingement of fluids etc. The above techniques can hardly meet the requirements of high heat transfer performance desired by present day modern heat exchanger. Compact heat exchangers with higher performance demand fluids having better heat transfer capabilities. Such devices results in material saving, energy conservation and hence low cost of heat exchangers. Nanofluids improve thermal conductivity of host fluids and now become important area of research attracting the attention of many researchers across the world. The nanofluids will quench the thirst of investigators who are in quest to engineer better heat transfer fluids [2].

Heat transfer coefficient and friction factor are two important parameters associated with thermo fluids. Many experimental as well as theoretical investigations have been carried out to study heat transfer and pressure drop characteristics of pure fluids. The investigation results on nanofluids indicated that heat transfer coefficient increases with the increase of nanoparticle concentration in the base fluid. Most of the research works done so far on nanofluids are experimental studies and confined either to laminar or turbulent flow conditions. The host or base fluid is water in majority of the cases. In severe cold climatic conditions glycols are added to water in different proportions to reduce the freezing point of heat transfer liquids. Glycol based fluids are used in base board heaters, automobile radiators and process plants particularly in cold countries where the ambient temperatures are below zero degree Celsius.

1.2 Basic hypothesis of Nanofluid

Nanofluids are the new invention for the heat transfer medium which containing up to 100nm size small particles, which are stable and mixture with the base fluids.fig.1.1 . These conveyed nano particles, for the most part a metal or metal oxide extraordinarily upgrade the thermal conductivity of the nanofluid, builds conduction and convection coefficient, taking into consideration more heat exchange.

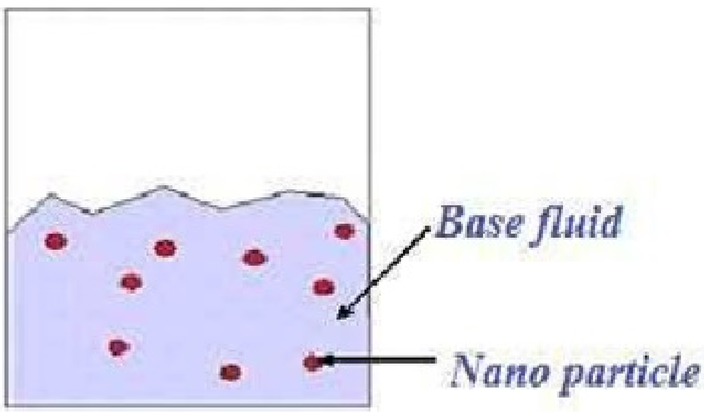

Figure 1.1: Physical structure of Nanofluid[3]

Nano-fluid has been considered for applications as innovative heat exchange liquids for nearly two decades. Nevertheless, because of the wide assortment and the intricacy of the nanofluid frameworks, no understanding has been accomplished on the greatness of potential advantages of utilizing nanofluid for heat exchanger applications. Contrasted with customary solid– fluid suspensions for heat exchange intensifications, nanofluid having legitimately scattered nano particles have the accompanying focal points:

High particular surface range and in this manner more heat exchange surface amongst particles and liquids.

High scattering strength with transcendent particles' Brownian movement.

Reduced molecule obstructing when contrasted with traditional slurries, accordingly advancing framework scaling down.

Basic base liquids incorporate water, natural fluids (e.g. ethylene, tri-ethylene-glycols, refrigerants, and so forth.), oils and greases, bio-liquids, polymeric arrangements and other regular fluids. Materials generally utilized as nanoparticles incorporate artificially stable metals (e.g. gold, copper), oxide ceramic (e.g. Al_2O_3, CuO), metal carbides (e.g. SiC), carbon in different structures (e.g., precious stone, graphite, carbon nano-tubes, fullerene), metal oxides (e.g., alumina, silica, zirconia, titania) and functionalized nanoparticles.

1.3 Heat Transfer Enhancement Techniques

1. Active method : External power required for enhancement
2. Passive method: No External power required for enhancement
3. Compound method : Combination of Active or Passive method.

The active method includes the external stimuli like electric field, vibration or acoustic media for the enhancement of heat transfer. On the other side, passive methods are those in which the internal characteristics of fluids are changed or else the geometry of the heat exchangers is changed. Some researcher have also use the combined techniques for the increase heat transfer coefficient thats called as a compound method. In this report, we would be focusing on the passive methods and that too basically fluid additives.

1.4 Types of Nanofluid

There are a wide range of helpful combinations of the different base liquids and nanoparticle. Nanofluid can be sorted by the diverse kind of molecule in four unique gatherings: Ceramic, pure metallic, composite, and carbon-based nanofluid. Diverse mixes of the particles said above and distinctive base liquids and give distinctive nanofluid.

1.4.1 Ceramic Nanofluid

As ceramic particles were easy to synthesize and were chemically stable in the solution they were the first particles which were used for the nanofluid. This ceramic was further categorized into three different groups: like oxides made of alumina and zirconium, non-oxides like carbides. Nitrides, and silicates, and composites made up of the combinations of oxides and non-oxides. As above mentioned classes each contribute and develop separate material properties. From the different types of ceramics, maximum effort has been shown on the nanofluid made from the oxides. There was the rise of 30% in the thermal conductivity with the addition of only 4.3 vol. % of Al_2O_3 nano particles, this data was first by Masuda et al. [4] .

1.4.2 Pure Metallic Nanofluid

In spite of the fact that fewer investigations of nanofluid containing metal nano particles have been directed when compared with those containing oxide nano particles, the outcomes have been comparatively higher. A high thermal conductivity is being observed and exhibited for a nanofluid containing metal as a nanoparticle rather than the nanofluid containing the similar volume fraction of the oxide of that metal.

1.4.3 Alloy Nanofluid

New material with different properties and better heat transfer qualities, when compared to their parent metal can be synthesized by alloying all such different metals. The physical properties of the nano particles made up from alloy showed a difference in the properties which were shown by the bulk sample. There are mainly two processes in which the alloy nanofluid can be prepared they are 1) mechanical alloying and 2) condensation process.

1.4.4 Carbon Based Nanofluid

Due to the presence of high thermal conductivity in some of the nanostructure made of carbon-based conceivably appealing for utilizing as a part of nanofluid. The densities of the carbon-based nanostructure are lesser than metal nanostructure. Some of the best examples of carbon-based nanofluid are carbon single-walled nanotubes (SWNTs), fullerenes, carbon multi-walled nanotubes (MWNTs), and ultra-dispersed diamond in different fluids. The value of thermal conductivity of carbon nanotubes is higher than the metal or metal oxide material. The thermal conductivity value of SWNT is 6000 W/mK, of MWNT is 3000 W/mK and of a double-walled carbon nanotube is 3986 W/mK respectively. The experiment performed by Choi et al.[1] which reported the thermal conductivity value of 1.0 vol. % MWNTs which were dispersed in synthetic poly (a-olefin) oil and an increase of 160% of thermal conductivity was noted. The value of thermal conductivity of Carbon nanotube (CNT) is almost same as that of graphite approaches or even surpasses that of natural diamond, the best room-temperature thermal conductor.

1.5 Potential and highlights of nanofluids

The accompanying highlights for various nano-liquids have been watched reliably by various specialists at different associations:

1. It may be noted that particle size is an important physical parameter in nanofluids because it can be used to find the nanofluid thermal properties as well as the suspension stability of nanoparticles. Researchers in nanofluids have been trying to exploit the unique properties of nano particles to develop stable as well as highly conducting heat transfer fluids. [5, 9] .

2. The viscosity o nanofluids is comparatively higher than respective base fluids. [6].

3. The nanoparticles stay suspended for a longer duration in base fluids as compared with other micro sized particles.

4. Micro scale channel cooling with no clogging impacts. Nano-fluids alongside being better medium for exchange of heat they are additionally perfect for smaller scale channel applications where large conducting liquids and high heat loads. Micro scale channels and nano-fluids together will give greater heat exchange region. This can't be accomplished with micro-or smaller scale particles as they clogging up miniaturized scale channels. Nanoparticles have higher small-scale channels compared to order of particles. They are just a couple of hundreds or thousands of molecules long [5].

5. Erosion has less in these channels. Nanoparticles are significantly littler, and the force they can confer to a solid wall is considerably smaller. These decreases the erosion of segment, for example, pipelines, heat exchangers and pumps. [6].

6. Decrements in the pumping power. To increase the heat exchange of base liquids by two factor, pumping power should for the most part be improved by a factor of ten. It can be exhibited that one can multiply the conductivity by a factor of three, the move of heat in a similar devices are double. Subsequently, a radical investment funds in pumping force can be accomplished if a thermal conductivity rise can be realized with a particles small amount of volume fractions. [7, 8, 9].

7. Reduce coefficient of friction. Nano-liquids could adequately decrements in friction [7, 8].

8. Save the energy and cost. Successful organizations of nano-liquids will give significant in save energy and saving in costs because the heat exchanger can be made smaller in size and lighter in weight. [6].

1.6 Surfactant

To avoid agglomeration of nano particles in nanofluid a special treatment is required. Surfactants are compounds that lower the surface tension (or interfacial tension) between two liquids, between a gas and a liquid, or between a liquid and a solid. Surfactants may act as detergents, wetting agents, emulsifiers, foaming agents, and dispersants. The graphical presentation of the surfactant is in fig. 1.2The Surfactants are used to reduce the agglomeration and provide coating on the particles. For that purpose the 3 different surfactants used for the reduce the agglomeration. Proper ratio of surfactant is taken, so mixture is done properly and no settling of Nano particle is done. Surfactant will attract the Nano particle boundary layer to prevent settlement. Distilled water + Surfactant Proper stirring is done by vertical or homogeneous method.

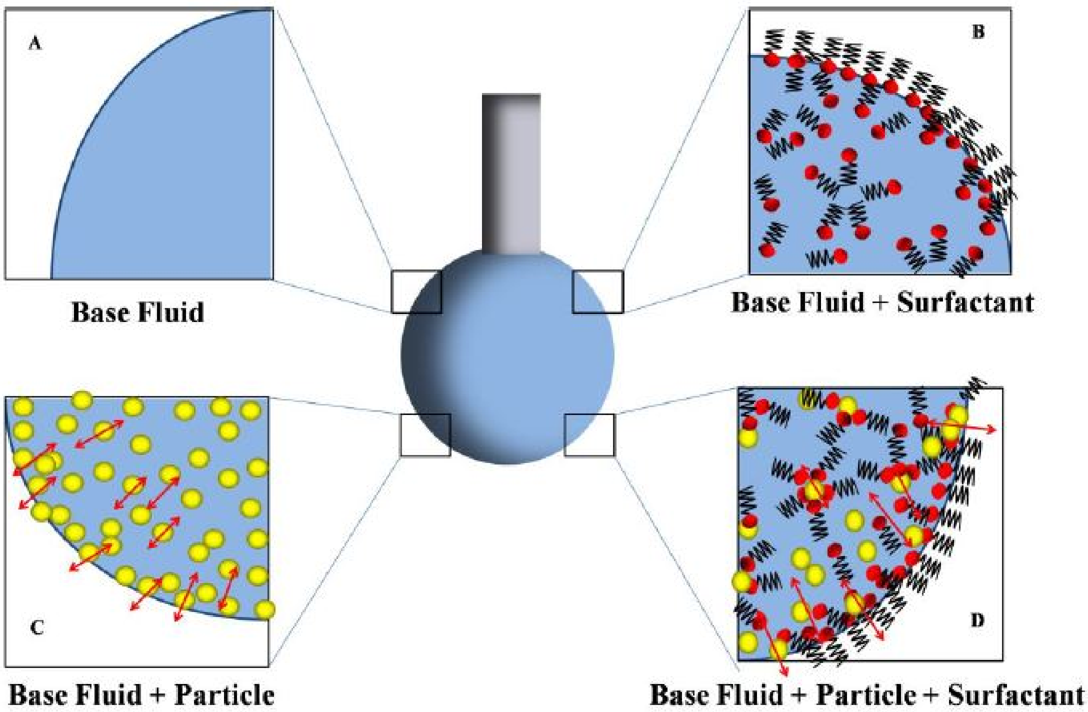

Figure 1.2: Graphical presentation of Surfactant[10]

Agglomeration is greatly reduced by adding the surfactant. Surfactants used in nanofluids are also called dispersants. Dispersants can markedly affect the surface characteristics of a system in small quantity. Dispersants consists of a hydrophobic tail portion, usually a long-chain hydrocarbon, and a hydrophilic polar head group1.3. Dispersants are employed to increase the contact of two materials, sometimes known as wettability.There are generally three types of surfactant. Anionic, Cataoinic and Non-ionic.

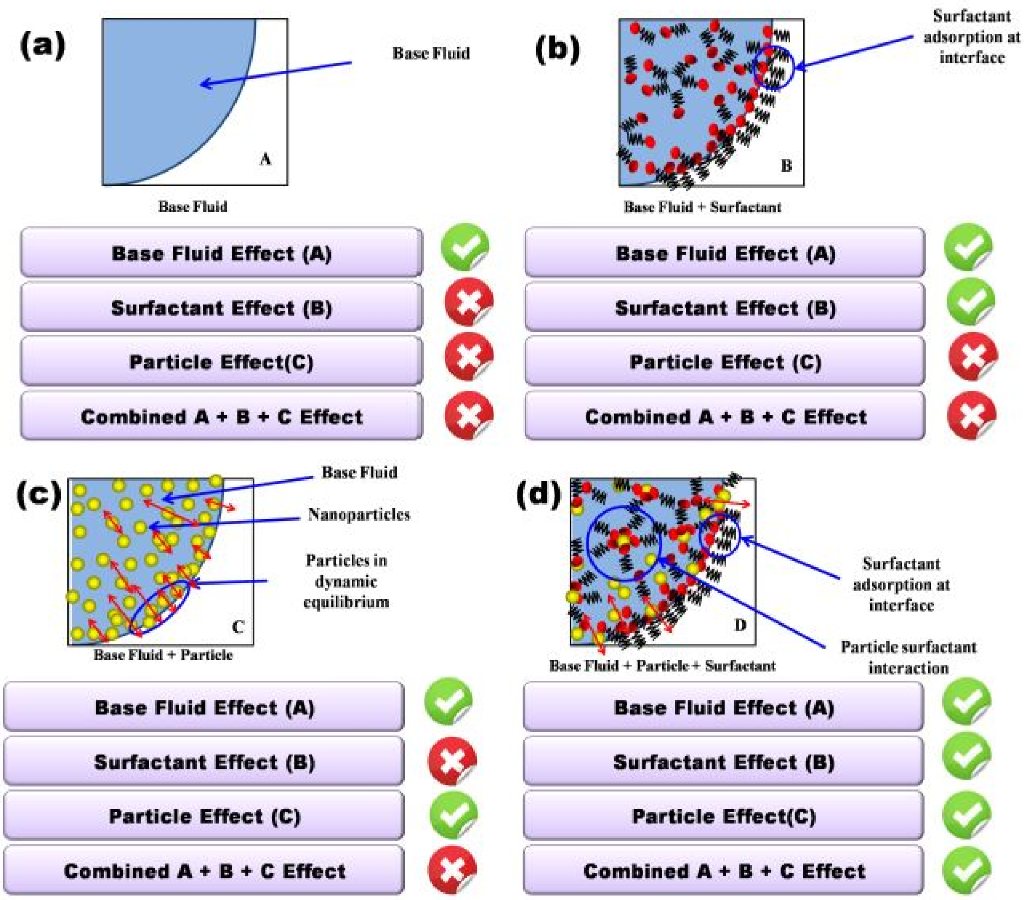

Figure 1.3: Schematic of different experiments to segregate the effect the contributing effects present in each of the protocols.(a) experiments with only base fluid (b) surface tension studies with only particles (c) surface tension experiments on nanofluids with only surfactants and (d) surface tension studies on nanofluids prepared with particle and surfactants[10]

1.7 Organization of the Thesis

Chapter 1 deals with the introduction part. It deals with basic theories regarding methods of increasing the heat transfer co efficient and also basic theories of nanofluids.

Chapter 2 It combines all the literature studied and reviewed related to the topic and the conclusion drawn from the same. It also gives the objectives, motivation and future scope of the present work.

Chapter 3 describes the experimental setup of the heat exchanger and different parameters of the set up used for the experiments. It suggests the modification or requirements pertaining to the setup. It gives the methodology to calculate the heat transfer coefficient from the known temperatures of the inlet and outlet of the nanofluid and hot water.

Chapter 4 includes the observations taken by performing the experiments on the experimental setup and shows a different comparison of the parameters graphically. It gives the pictorial study of the enhancement of heat transfer coefficient by different base fluid used for nano fluids.

Chapter 5 concludes the study and determines the future which needed to be carried out.

Chapter 2

Literature Review

This chapter includes the literature survey carried out to understand the various aspects of properties, application and methods of synthesis of nanofluids and elaborated thermal conductivity studies. Factors affecting the properties and the reasoning behind it. It also includes basic correlations and the past studies done by researchers. This review is the foundation for the experimental work carried out ahead.

There are many different parameteres which can be varied to enhance the heat transfer coefficient such as different concentrations of nanofluids, variation in the heat exchanger by providing baffles,etc. Many researchers have worked on these different parameters to study the increment in the heat transfer coefficient. Some of the studies by different researchers with their results, is described below:

2.1 Literature review for synthesis of nanofluids

Table 2.1: Synthasis of nanofluids

Sr. No.	Author	Nano-particles	Base fluids	Particle Size	Volume Concentra-tion	Surfactant	Sonication Time	Ref. No
1	Khairul et al.	Al_2O_3 CuO	Water	10nm 10nm	0.20, 0.30, 0.50	SDBS SDBS	6H	[32]
2	Kwek et al.	Al_2O_3	Water	30nm	0.25, 0.5	CTAB	7H	[48]
3	Shanker et al.	Al_2O_3	EG	50nm	0.20, 0.25, 0.5	SDBS	8H	[49]
4	Agarwal et al.	Al_2O_3	Kerosene	20nm	0.5, 1, 1.5	Oleic Acid	3H	[50]
5	Tang et al.	Al_2O_3	R141b	<100nm	0.001, 0.01, 0.1	SDBS	8H	[51]
6	Kathiravan et al.	CuO	Water	10nm	0.25, 0.5, 1	SDS	10H	[52]
7	Huang	Al_2O_3 CuO	Water	30nm	0.5, 1, and 2	SDBS SDBS	5H	[53]
8	Zhu et al.	Al_2O_3	Water	20nm	0.1, 0.3	SDBS	6H	[54]
9	Michael & Iniyan	CuO	Water	75nm	0.05	SDBS	1H	[55]
10	Sarafraz & Hormozi	CuO	Water	50nm	0.1- 0.4	SDBS Trion X-100	8H	[56]
11	Chang et al.	CuO	Water	20-30nm	0.01 to 0.1	NaHMP	6H	[57]

In the 'one step method' of synthesis of nanofluid, the nano particles are prepared by different processes such as vapor condensation, mechanical comminuting, chemical reaction or decomposition of organic complex. This one step method is followed by the 'two step method' in which the nano particles produced, are homogenously dispersed into the heat transfer fluids with help of mechanical agitation or ultra-sonication. Even though solid nanostructures are finely immersed in the liquid the stable dispersion is not formed. When surfactants are mixed in the base fluid, it creates a film on the surface of nanoparticles. The surfactant molecules prevent the nano particles from agglomeration and it gives stability of the suspension of particles in base fluid. Metal oxide nano particles are first used to synthesis nanofluid as they were easy to manuufacture and can easily disperse into the water as it has surface hydrophilicity.

From literature study it ia observed that many reaserchers have used SDBS as a surfactant, but few of them [48, 50] suggested CTAB and Oliac acid as a surfactant for the Al_2O_3 nano-particle. Many reaserchers [32, 49, 53, 54] Suggested that SDBS is preferable for Al_2O_3 nanoparticles for the better stability. SDBS surfactant was also preferable for the CuO particles to enhance suspension stability[55, 56]. The SDS, NaHMP were also suggested by some reaserchers for the stability of the nanofluids[52, 57].

2.2 Literature review for the Nusselt Number

Table 2.2: Summary of Nusselt number

Sr. No.	Author	Nano-Particle	Base fluid	Particle size	Volume Concentration	Flow Regime	Results and Remarks	Ref. No
1	Hamid et al.	TiO_2	Water-EG	20nm	0.5,0.7,1.0,1.3,1.5	3000 to 24,000	The nusselt number of TiO_2 nanofluids shows enhancements up to 1.30% with an increase in concentration and an increase in temperature.	[11]
2	Sonawane et al.	Al_2O_3	Water	20nm	2.0 and 3.0	500-4000	For same range of Re, addition of nano particles to the base fluid enhances the heat transfer performance and Nusselt number was 1.14% times higher than base fluid.	[13]
3	Azmi et al.	Al_2O_3 TiO_2	Water-EG	50nm	0.5, 0.7 and 1.0	3000 to 24,000	The maximum enhancements in Nusselt number were 1.32% and 1.28% were observed for TiO_2 and Al_2O_3 nanofluids.	[20]

Sr. No.	Author	Nano-Particle	Base fluid	Particle size	Volume Concentration	Flow Regime	Results and Remarks	Ref. No
4	Khedkar et al.	TiO_2	Water	30nm	2.0 to 3.0	500-4000	The enhancement in heat transfer performance and Nusselt number was 1.40% times higher than base fluid	[15]
5	Aghayari et al.	Al_2O_3	Water	20nm	0.1-0.3	15000-28000	When Reynold number increases the increament was seen in the Nusselt up to 1.28 times more.	[21]
6	Rebientaj et al.	Al_2O_3	Water	20nm	0.25,0.5,1	5000 to 20000	By increasing the concentration of nanofluid, the Nusselt number is also increases up to 1.20 than that of base fluids	[14]
7	Xuan and Li	Cu	Water	26nm	0.5, 1, 1.5, 2	1000–4000	Nusselt number increases 1.39% with increase in concentration and flow velocity	[17]
8	Mohammat Himmat	Ag	Water	30-50 nm	0.125, 0.25, 0.5, 0.75, and 1	3000-32000	As increamement in the Reynold number the Nusselt number is also increasing up to 1.12 times.	[18]
9	Siavashi & Jumali	TiO_2	Water	21nm	0, 2 and 4	5000-25000	The Nusselt number is increasing up to 1.5% with increasing in the volume concentration	[22]

Sr. No.	Author	Nano-Particle	Base fluid	Particle size	Volume Concentration	Flow Regime	Results and Remarks	Ref. No
10	Wu et al.	Al_2O_3	Water	40nm	0.78, 2.18, 3.89, 5.68 and 7.04	2000-10000	As the Heat transfer increases the increament in Nusselt number is 1.26%.	[23]
11	Heris et al.	CuO Al_2O_3	Water	20nm 50-60nm	0.2-3	650-2050	For both nanofluid systems, Nusselt number increasing with increasing in nanoparticles concentrations, But the Al_2O_3/water nanofluids show more enhancement compared with CuO/water and it was 1.29 times and 1.23 times more than base fluids	[27]
12	Jumpholkul et al.	SiO_2	Water	7nm	0.5, 1, and 2	4000-13000	The enhancement in the heat transfer leads to enhace in the Nusselt number up to 1.4% compared with Base fluid.	[34]
13	Bahmani et al.	Al_2O_3	Water	30nm	2.5 to 10	10000-100000	The Nusselt number is increases 1.4 times more than that of base fluid	[35]
14	Yanjun et al.	ZnO	Water-EG	35nm	0 to 5	1500-6000	Negligible heat transfer enhacement shown in the Nusselt number and that is 1.065%	[42]

Sr. No.	Author	Nano-Particle	Base fluid	Particle size	Volume Concentration	Flow Regime	Results and Remarks	Ref. No
15	Sahin et al.	Al_2O_3	Water	30nm	0.5, 1, 2 and 4	4000-20000	The use of Al2O3/water nanofluid increases Nusselt number up to 1.14 times as of base fluid for volume concentration 0.5 wt % to 4.00 wt %.	[46]
16	Naik et al.	CuO	Water	40nm	0.1 and 0.3	4000-20000	The convective heat transfer co-efficient increases with an increasing Re and an increasing mass flow rate of the heating fluid, and increaseing in Nusselt number to 1.36%	[45]
17	Suresh et al.	CuO Al_2O_3	Water	15nm	0.1	800-2400	The experimental results of hybrid nanofluid for laminar flow showed maximum enhancement of 1.14 times more Nu at a Re of 1730 when compared to pure water	[26]
18	Fotukian & Esfahany	Al_2O_3	Water	20nm	0.2, 0.5, 1, 1.5, 2, 2.5	700–2050	Nusselt number ratio increases 1.4 times with volume concentration increaese	[24]

Sr. No.	Author	Nano-Particle	Base fluid	Particle size	Volume Concentration	Flow Regime	Results and Remarks	Ref. No
19	Albadr et al.	Al_2O_3	Water	30nm	0.3, 0.5, 0.7, 1 and 2	5000-9000	Nusselt number of nanofluids increased up to 1.68 times more with increasing Renolds number and the volume concentration	[12]
20	Azmi et al.	SiO_2	Water	22 nm	1,2,3,4	5000–27,000	The enhancement in Nusselt number at 3.0% volume concentration in the Re range is 1.33 times higher	[16]
21	Fotukian & Esfahany	CuO Diamond	Water	30-50nm 2-10nm	Up to 0.3	6000 and 31,000	Increasing the nanoparticles concentration showed much effect on heat transfer enhancement in turbulent regime and Nusselt number ratio is 1.22 that of base fluid.	[25]
22	Shuichi Torii	Al_2O_3 CuO	Water	33nm 47nm	Different concentration	3000-10000	The nano fluids Nusselt number increases with an increase in concentration of nanoparticles and for that the Al2O3 seems the maximum Nusselt nuumber 1.42 times higher than base fluids	[37]

Sr. No.	Author	Nano-Particle	Base fluid	Particle size	Volume Concentration	Flow Regime	Results and Remarks	Ref. No
23	Sohel et al.	Al_2O_3	Water	13nm	0.10 to 0.25	395-998	Nusselt number enhancement of 1.19 times when Volume concentration of 0.25%	[38]
24	Barzegarian et al.	CuO	Water	30-50nm	Up to 0.3	8000-30000	The ratio of Nusselt number is 1.3 times higher and the wall temperature of the test tube decreased when the nano-fluid flowed into the tube.	[47]

For the heat transfer into the heat exchanger the heat transfer co-efficient plays a major role. For that Nusselt number of the nanofluids get effect. The observed results from the prior work done on the convective heat transfer performance of nanofluids clearly shows, that the suspended particles increase the heat transfer performance of the base-fluid; and the nanofluids have higher heat transfer coefficients than those of the base-fluids at the same Reynolds number. High aspect ratio nanoparticles such as carbon nanotubes resulted in greater enhancement in thermal conductivity and the heat transfer coefficient, compared to spherical and low aspect ratio nanoparticles. It has been shown in many references that the heat transfer behavior of nanofluids and the application of nanofluids for heat transfer enhancement, are influenced by the effective thermo-physical properties of nanofluids and many other factors such as particle size, shape and distribution.

The Nusselt number of TiO_2 nanofluids shows enhancements up to 1.30 with an increase in concentration and an increase in temperature[11]. For same range of Re, addition of nano particles to the base fluid enhances the heat transfer performance and Nusselt number was 1.14 times higher than base fluid[13].As the compare of $Al_2O_3$with CuO nanofluid the maximum enhancements in Nusselt number were 1.32 and 1.28 were observed for TiO_2 and Al_2O_3 nanofluids[20].When Reynold number increases the increament was seen in the Nusselt up to 1.28, 1.20 and 1.29 compare with base fluids[14, 15, 21].Nusselt number increases 1.39, 1.12, 1.5 with increase in concentration and flow velocity[17, 18, 22]. The convective heat transfer co-efficient increases with an increasing Re and an increasing mass flow rate of the heating fluid, and increaseing in Nusselt number to 1.36, 1.29 and 1.33,1.41,1.40 [23, 34, 35, 27]. The enhancement in the heat transfer leads to enhace in the Nusselt number up to 1.4, 1.36, 1.14 compared with Base fluid[42, 45, 46]. Nusselt number of nanofluids increased up to 1.68, 1.4, 1.14 times more with increasing Renolds number and the volume concentration[12, 24, 26]. The ratio of Nusselt number is 1.3 times higher and the wall temperature of the test tube decreased when the nano-fluid flowed into the tube[47]. Nusselt number enhancement of 1.19 times when Volume concentration of 0.25%[38]. The nano fluids Nusselt number increases with an increase in concentration of nanoparticles of Al_2O_3, Diamond and CuO and for that the Al_2O_3 seems the maximum Nusselt nuumber 1.42 times higher than base fluids[37].

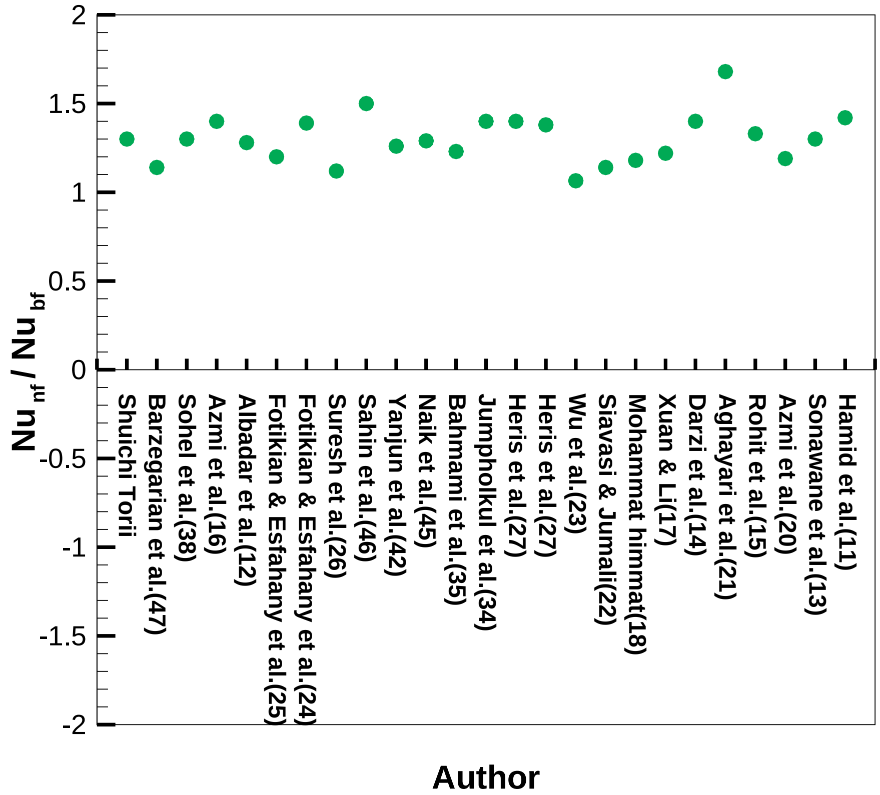

Figure 2.1: Experimental investigations in Nusselt number of nanofluids

2.3 Summary of experimental investigations in friction factor of nanofluids

Table 2.4: Summary of experimental investigations in friction factor of nanofluids

Sr. No.	Author	Nano-Particle	Base fluid	Particle size	Volume Concentration	Flow Regime	Results and Remarks	Ref. No
1	Hamid et al.	TiO_2	Water-EG	20nm	0.5,0.7,1.0,1.5	3000 to 24,000	The friction factor of TiO_2 nanofluid increases with an increasing in concentration is 1.1 times more than that of base fluid	[11]
2	Rebientaj et al.	Al_2O_3	Water	20nm	0.25,0.5,	15000 to 20000	By increasing the concentration of nanofluid, the friction factor is also increases up to 1.08 than that of base fluids	[14]
3	Wu et al.	Al_2O_3	Water	40nm	0.78, 2.18, 3.89, 5.68 and 7.04	2000-10000	As the pumping power increases the increament in friction factor is 1.56 times higher.	[23]
4	Jumpholkul et al.	SiO2	Water	7nm	0.5, 1, and 2	4000-13000	The enhancement in the heat transfer leads to enhace in the friction factor 1.3 more compared with Base fluid.	[34]

Sr. No.	Author	Nano-Particle	Base fluid	Particle size	Volume Concentration	Flow Regime	Results and Remarks	Ref. No
5	Naik et al.	CuO	Water	40nm	0.1 and 0.3	4000-20000	The convective heat transfer co-efficient increases with an increasing Re and an increasing mass flow rate of the heating fluid, and increaseing in ratio of friction factor to 1.5	[45]
6	Yanjun et al.	ZnO	Water-EG	35nm	0 to 5	1500-6000	Negligible heat transfer enhacement shown in the Nusselt number and that is 1.065 and ratio of friction factor is increases up to 1.125.	[42]
7	Sahin et al.	Al_2O_3	Water	30nm	0.5, 1, 2 and 4	4000-20000	The use of Al2O3/water nanofluid increases friction factor up to 1.14 times as of base fluid for volume concentration 0.5 wt % to 4 wt %.	[46]

Sr. No.	Author	Nano-Particle	Base fluid	Particle size	Volume Concentration	Flow Regime	Results and Remarks	Ref. No
8	Suresh et al.	CuO Al_2O_3	Water	15nm	0.1	800-2400	The experimental results of hybrid nanofluid for laminar flow showed friction factor higher up to 1.25 at a Re of 1730 when compared to pure water.	[26]
9	Albadr et al.	Al_2O_3	Water	30nm	0.3, 0.5, 0.7, 1 and 2	5000-9000	Friction factor of nanofluids increased up to 1.83 times more with increasing pressure drop and the volume concentration	[12]
10	Azmi et al.	SiO_2	Water	22 nm	1,2,3,4	5000–27,000	The enhancement in pumping power at 3.0% volume concentration in the Re range is 1.42 times higher.	[16]
11	Barzegarian et al.	CuO	Water	30-50nm	Up to 0.3	8000-30000	The ratio of friction factor is 1.6 times higher and the wall temperature of the test tube decreased when the nano-fluid flowed into the tube	[47]

Sr. No.	Author	Nano-Particle	Base fluid	Particle size	Volume Concentration	Flow Regime	Results and Remarks	Ref. No
12	Kumarsan et al.	CNT	Water-EG	30-50 nm	0.15,0.30,0.45	2200-11000	The friction factor is higher for 11000 Reynold number at all particle concentration compared to the base fluid and is 1.34	[40]
13	Ramin et al.	graphene oxide	Water	-	0, 0.05, 0.1, 0.2	4000-22000	The use of nanofluid increased the friction factor by 1.2 times more comparison with pure water	[41]
14	Khahirul et al.	CuO Al_2O_3	Water	10nm	0.2, 0.3 and 0.5	600-4600	The friction factor of nanofluid flow increased with increasing volume fraction of nanofluid in all internal Reynolds numbers	[32]
15	Jung et al.	Al_2O_3	Water	10nm	0.5–1.8	5 to 300	Convective heat transfer coefficient increased by 32% for volume concentration of 1.8% and friction factor of 1.6	[39]

Sr. No.	Author	Nano-Particle	Base fluid	Particle size	Volume Concentration	Flow Regime	Results and Remarks	Ref. No
16	Duangthongsuk and Wongwises	TiO_2	Water	21nm	0.2	5000-18000	The friction factor increasing up to 1.2 times when increasing mass flow rate of the heating fluid	[29]

Friction factor of the nanofluids depends on the volume fraction of the particles, temperature of the nanofluid and pumping power. In which pumping power is main source for the increament in the friction factor. The friction factor is always higher than that of the base fluids.

Various researchers [11, 14, 23, 34] have suggested that when the particles concentrations increases that increases in the friction factor compare to the base fluids. Many researchers [35, 42, 46] have suggested that when the pumping power increases that increases in the friction factor up to 1.4 times higher than that of base fluids. When the pressure drop increaese the friction factor is also increases [12, 16, 26]. The ratio of friction factor is 1.6 times higher and the wall temperature of the test tube decreased when the nano-fluid flowed into the tube[47]. Various reaserchers [32, 40, 41] have proved that the friction factor is higher for higher Reynold number at all particle concentration compared to the base fluid. Many reaserchers [29, 32, 39] have suggested that higher concentration of the nano particles leads to high friction factor of the nanofluids.

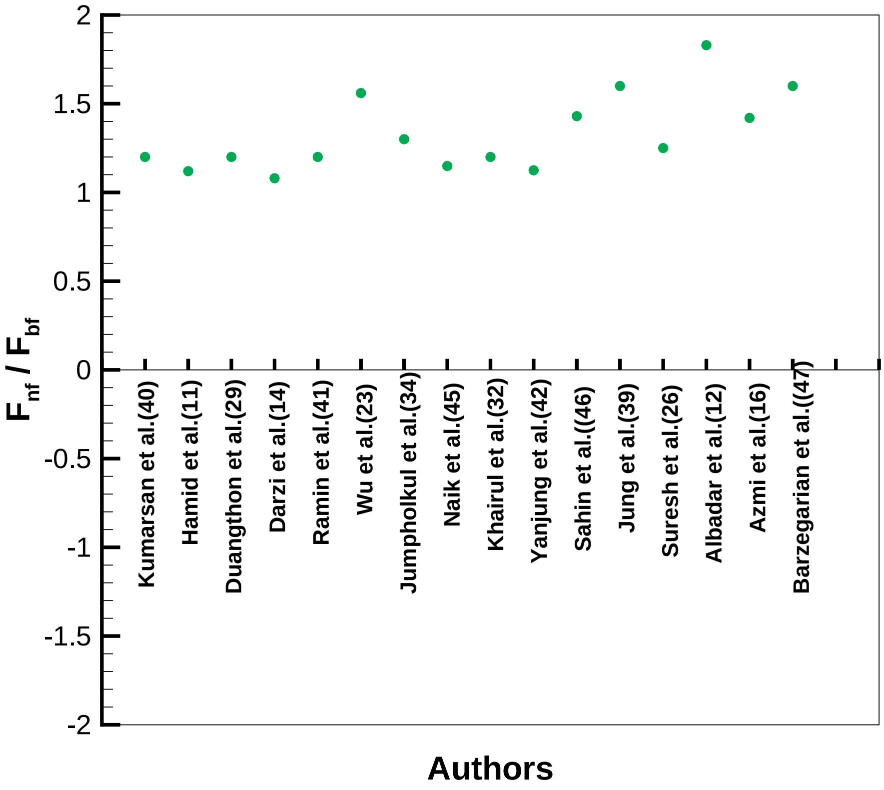

Figure 2.2: Experimental investigations in Friction factor of nanofluids

2.4 Summary of experimental investigations in pressure drop of nanofluids

Table 2.6: Summary of experimental investigations in pressure drop of nanofluids

Sr. No.	Author	Nano-Particle	Base fluid	Particle size	Volume Concentration	Flow Regime	Results and Remarks	Ref. No.
1	Hamid et al.	TiO_2	Water-EG	20nm	0.5,0.7,1.0,1.5	3000 to 24,000	The pumping power of TiO_2 nanofluids shows increament in pressure drop up to 1.35 with an increase in concentration and an increase in temperature.	[11]
2	Rebientaj et al.	Al_2O_3	Water	20nm	0.25,0.5,1	5000 to 20000	By increasing the concentration of nanofluid, the pressure drop is also increases up to 1.85 than that of base fluids	[14]
3	Mohammat Himmat	Ag	Water	30-50nm	0.125, 0.25, 0.5, 0.75, and 1	3000-32000	There is an increase in relative pressure drop with the rise of volume fraction up to 1.2 times.	[18]
4	Jumpholkul et al.	SiO_2	Water	7nm	0.5, 1, and 2	4000-13000	When the inlet temperature decreases, the pressure drop increases slightly 1.3 compared with Base fluid.	[34]
5	Yanjun et al.	ZnO	Water-EG	35nm	0 to 5	1500-6000	Negligible heat transfer enhacement shown in the pressure drop and that is 1.18 higher than base fluid	[42]
6	Fotukian	Al_2O_3	Water	20nm	0.2 to	700–2050	The pressure	[24]

The pumping power of TiO_2 nanofluids shows increament in pressure drop up to 1.35 with an increase in concentration and an increase in temperature[11]. By increasing the concentration of nanofluid, the pressure drop is also increases up to 1.85 than that of base fluids[14]. Many researchers [18, 24, 42] have suggested that when the pumping power increases the pressure drop ratio increases compare to the base fluids.Some reaserchers [16, 24] have seen that the pressure drop of the nanofluid increases with particle concentration is higher compare to the base fluids

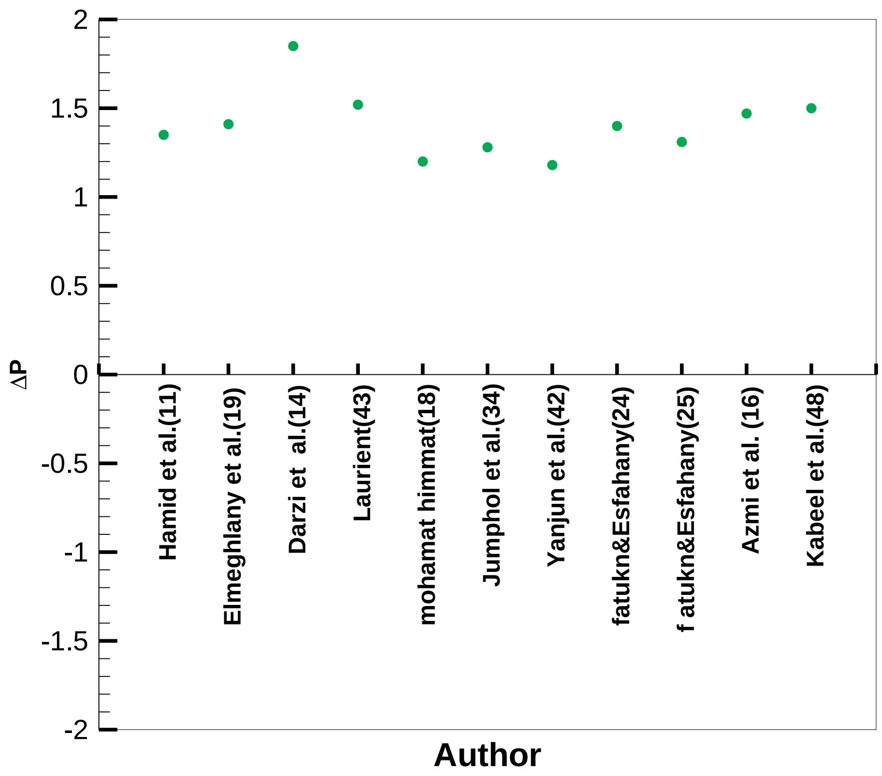

Figure 2.3: Experimental investigations in pressure drop of nanofluids

2.5 Preparation of Nanofluid

2.5.1 One Step Method

To minimize the agglomeration of nano particles, a method was developed by Eastman et al [5]. which was one-step physical vapor condensation method used to prepare nanofluid of Cu nano particles and ethylene glycol as base fluids. The one-step process comprises of synthesis of nano particles and then dispersing the particles in base fluid simultaneously. As this process avoids different stages such as drying, storage, transportation, and dispersion of nano particles so the agglomeration of the nano particles is decreased and hence the stability of the fluids is increased. The one-step processes help in synthesis of uniformly dispersed nano particles which can be stably suspended in the base fluid. The submerged arc nanoparticle synthesis system (SANSS) is another productive method to prepare nanofluid with the use of different dielectric liquids and different morphologies are influenced using various thermal conductivity properties of different dielectric liquids. The nano particles prepared show different shapes such as square, needle-like, polygonal and circular morphological shapes.

As the one-step physical method is not able to synthesize nanofluid in large scale because the cost is high. A novel one-step method was presented by Zhu et al. [31] for preparing the nanofluid of copper by reducing the copper sulphate pentahydrate ($CuSO_4$ 5 H_2O) with sodium hypophosphite ($NaH_2PO_2.H_2O$) in ethylene glycol under microwave irradiation. Hence well suspended and stable copper Nanofluid were synthesized.

2.5.2 Two Step Method

The two-stage technique is the most common method for synthesis of nanofluid. Nano particles, nanofibers, nanotubes, or other nanomaterials which are used in this method are first prepared in dry powders by any chemical or physical methods. Then with help of different processes such as ultrasonic agitation, intensive magnetic force agitation, high-shear mixing, homogenizing, and ball milling this nano-sized powder will be dispersed into a fluid which is the second step. As the techniques of the synthesis of nano powder have been scaled up to industrial production level therefore the two-step method is the most efficient method. The nano particles have a high surface area as well as high surface activity due to which it shows the tendency of aggregation. With the use of surfactants, the stability of nano particles in the fluid can be enhanced. In any case, the usefulness of the surfactants under high temperature is likewise a major concern, particularly for high-temperature applications.

In the first step of the synthesis of nanofluid, the nano particles are prepared by different processes such as vapor condensation, mechanical comminuting, chemical reaction or decomposition of organic complex. This first step is followed by the second step in which the nano particles produced are homogenously dispersed into the heat transfer fluids with help of mechanical agitation or ultra-sonication. Even though solid nanostructures are finely immersed in the liquid the stable dispersion is not formed. A Large of particles aggregates together to form clusters. But these particles can again re-disperse in the base fluids with the help of mechanical dispersion but they clump together which settles down of the suspension quickly. When surfactants are absorbed on the surfaces of the solid particle, the surfactant molecules prevent the nano particles from aggregation and it gives solubility to particles in base fluids to gain the stability. Metal oxide nano particles are first used as nanofluid as they were easy to produce and easily disperse into the water as it has surface hydrophilicity.

2.6 The Ways to Enhance the Stability of Nanofluids

2.6.1 Surfactants Used in Nanofluids

Surfactants used in nanofluids are also called dispersants. Adding dispersants in the two-phase systems is an easy and economic method to enhance the stability of nanofluids. Dispersants can markedly affect the surface characteristics of a system in small quantity. Dispersants consists of a hydrophobic tail portion, usually a long-chain hydrocarbon, and a hydrophilic polar head group. Dispersants are employed to increase the contact of two materials, sometimes known as wettability. In a two-phase system, a dispersant tends to locate at the interface of the two phases, where it introduces a degree of continuity between the nanoparticles and fluids. According to the composition of the head, surfactants are divided into four classes: nonionic surfactants without charge groups in its head (include polyethylene oxide, alcohols, and other polar groups), anionic surfactants with negatively charged head groups (anionic head groups include long-chain fatty acids, sulfosuccinates, alkyl sulfates, phosphates, and sulfonates), cationic surfactants with positively charged head groups (cationic surfactants may be protonated long-chain amines and long-chain quaternary ammonium compounds), and amphoteric surfactants with zwitterionic head groups (charge depends on pH).

How to select suitable dispersants is a key issue. In general, when the base fluid of nanofluids is polar solvent, we should select water-soluble surfactants; otherwise, we will select oil-soluble ones.Although surfactant addition is an effective way to enhance the dispersibility of nanoparticles, surfactants might cause several problems [32] . For example, the addition of surfactants may contaminate the heat transfer media. Surfactants may produce foams when heating, while heating and cooling are routine processes in heat exchange systems. Furthermore, surfactant molecules attaching on the surfaces of nanoparticles may enlarge the thermal resistance between the nanoparticles and the base fluid, which may limit the enhancement of the effective thermal conductivity [33].

2.6.2 Surface Modification Techniques: Surfactant-Free Method

Use of functionalized nanoparticles is a promising approach to achieve long-term stability of nanofluid. It represents the surfactant-free technique. Yang and Liu presented a work on the synthesis of functionalized silica (SiO_2) nanoparticles by grafting silanes directly to the surface of silica nanoparticles in original nanoparticle solutions.One of the unique characteristics of the nanofluids was that no deposition layer formed on the heated surface after a pool boiling process. With no contamination to medium, good fluidity, low viscosity, high stability, and high thermal conductivity, would have potential applications as coolants in advanced thermal systems. A wet mechanochemical reaction was applied to prepare surfactant-free nanofluids containing double- and single-walled CNTs.

2.7 Conclusion from literature

Enormous studies have been done in the fields of nano fuids particularly to check the heat enhancement characteristics. Also several methods to synthesize nano fluids, to keep them stable are developed. That includes one step, two step and other methods. Still till date no such method is developed in which agglomeration is negligible for very long duration. But this area still lacks in the systematic approach. Most of the researchers have taken cheaply available nanoparticles. Also the variation in size of particles is not seen to a larger extent.

All researchers have showed thermal conductivity enhancement using nano fluids. They have discussed various properties that a fect the thermal characteristics of nano fluids. Many theories have been proposed in order to explain the behavior of thermal properties of nano fluids.

One of the applications of nano fluid is in heat exchangers. Researchers have studied their effects on plate, compact, shell and tube, tube in tube type heat exchangers. This field is an upcoming field which has the potential to solve cooling related problems of high heat flux in industries. Analytical models to calculate the properties of nano fluids are not general, they are applicable for a small set of conditions only. A more rigorous and systematic study is required in this field to develop the general idea for all sets of nano fluids available.

2.8 Motivation and Objective of the Present Work

The requirement of enhancement of heat transfer leads to the motivation of this study despite having some restrictions. Using nanofluid in the circulation will increase the heat transfer coefficient as reviewed in the literature. Also, the main objective is to perform the experiments to show the increase in the heat transfer coefficient and make a setup to perform the same. Since Nano particles are costly it cannot be thrown away in a single pass and hence it should be recirculated. And for that, a refrigeration system is required to cool the nanofluid coming out from the heat exchanger and making the inlet temperature of working fluid constant. A whole experimental set up is modified to meet the needs of the experiments which are to be performed.

2.9 Scope of Present Work

From the above studies by researchers, it is observed that there is a wide scope of increasing the heat transfer coefficient by varying different parameters. The study can be done by varying concentration of nanofluid and comparing the heat transfer coefficient. We can also compare same by taking different nanofluids. By changing the configurations of the heat exchanger i.e. parallel or counter flow, the change in the heat transfer coefficient can be studied. Also baffles can be introduced inside the heat exchanger to increase the turbulence and same can be studied. Above study of baffles can be done by varying the helix angle of baffles and study the change in heat transfer coefficient.

In the present work, we have performed the experiments by taking base fluid Water. For better results and drawing a good conclusion, different experiments can be performed by taking different Reynolds no. and also different higher concentrations of the nano particles in all three base fluids. And also heat transfer coefficients can be compared by taking different Nano particles like CuO, SiO_2, Al_2O_3. Also, different parameters can be added in the heat exchanger like an introduction of the baffles and create turbulence in the heat exchanger to increase the heat transfer rate.

2.10 Closure

This chapter It combines all the literature studied and reviewed related to the topic and the conclusion drawn from the same. It also gives the objectives, motivation and future scope of the present work.

Chapter 3

Experimental Setup & Methodology

For performing the experiments to study the enhancement in heat transfer coefficient by adding nano particles, a setup of the tube in tube heat exchanger is made along with a new refrigeration system to cool the nanofluid coming out from the heat exchanger. This chapter deals with the whole experimental setup along with the methodology to calculate the required heat transfer coefficient.

3.1 Introduction

Experiment setup is already prepared where wsater was taken as the base fluid. The pump provided which will pump the nanofluids in the inlet of the inner tube the flow rate was controlled using flow meters and temperature was desired. The other fluid passes from the annulus side that gives heat to the fluid which in the region of turbulence. The nanofluid in the tube should enter at desired temperature and for maintaining the temperature the refrigeration chamber is there for the cooling the nanofluid in the tube in that chamber.

3.2 Synthesis of nano fluids

Nano fluids CuO, Al_2O_3 and SiO_2were prepared using nanopowder purchased from NanoShell LLC (product number: 44898, Lot: D28X017) having size of 40-100 nm with an average size of 40nm. SDBS was used at a surfactant in the ratio of 1:4 of the weight of nanoparticles. 2.5 liter of distilled water was taken and surfactant was added to it and the solution was stirred at 800 rpm for 15 mins. Then nanopowder was added in the required weight and the mixture was stirred for 1.5 hours at 800 rpm and then sonicated for 8 hours at 300 watts. Total nano fluids were prepared before experimentation using different concentration. 0.05% to 1%, 0.05%, 0.1%, 0.25% and 0.5% and 1% w/w of all nanoparticles in Distilled water were prepared. For instance to make 1% weight by volume nano fluid, 25 gms of nanopowder was added to previously mixed solution of 6.25 gms of SDBS in 2.5 liter of water. The aqueous dispersion of nanoparticles in water with surfactant was stirred for 1.5 hour with mechanical motor based REMI LAB stirrer at 800 rpm. Then the mixture was sonicated for 8 hours using probe sonicator at 300 watts by VIBRONICS ULTRA PROBE SONICATOR. The solution was taken to Institute of Pharmarcy, Nirma University for particle analysis using MALVERN ZATASIZER ZS90, based on differential light scattering. The result show no agglomeration for 1% wt by volume, for 8 hrs. Visible visualization shows that the solution is stable for two days that is there was no settlement seen on the bottom of bottle for two days. As the experimentation lasts for 5 hours, the above method of synthesis was used.

3.3 Description of experimental setup

Experimental setup was arranged to find out the heat transfer co-efficient, Nu number, friction factor etc. Therefore, for that purpose fluids was water base for the considerations. There was a pump to pumping the base fluids and the annulus side the water was fixed to examine. The water was enter at desired temperature and the main fluids in outer tube temperature was 55°c. Constant in to the system. It was planned to variation in the Re number of base fluids to show the effect on the Nu, friction factor, Nu/f ratio. In the apparatus hot fluids were fixed and it was tap water. The cold water was in the tube side and hot fluids on the annulus side. There were different pump for the hot and cold-water tank. The two rotameters measures the flow rate of the both fluids. In the hot water tank a heater was provided for the controlling the annulus fluids temperature and Refrigeration system for the cold water temperature control. The test section length is 2m. Here the outer pipe is made of stainless steels and the inner pipe with the smooth copper tube. Here the diameters of the inner tube are 0.0095 m OD and 0.0075 m ID while outer diameters of the tube were 0.032 m OD and 0.028 m ID. The external surface was isolated thermally using by wrapping the thick layer of the glass wool and asbestos rope. There is a manometer placed at channel and outlet area to measure the pressure drop. By this, the friction factor of the heat exchanger will be finding.

To quantify the cold fluid temperature there were RTD sensors placed at the outlet and the inlet of the both tubes. One of the sensors is placed to measure the hot water tank temperature and the controller to control the heater temperature. Other two sensors attached at inlet of hot and cold side and other two sensors at the exit. The least count of temperature sensors is 0.1 °C. The schematic diagram is as shown in fig. 3.1 . There were a refrigeration system to cool the cooling fluid turning out from the exchanger. It incorporates the entire plan of refrigeration frame and gives the details of all the segments like evaporator in the fig. 3.2 and condenser, compressor an fan engine in the fig.3.4

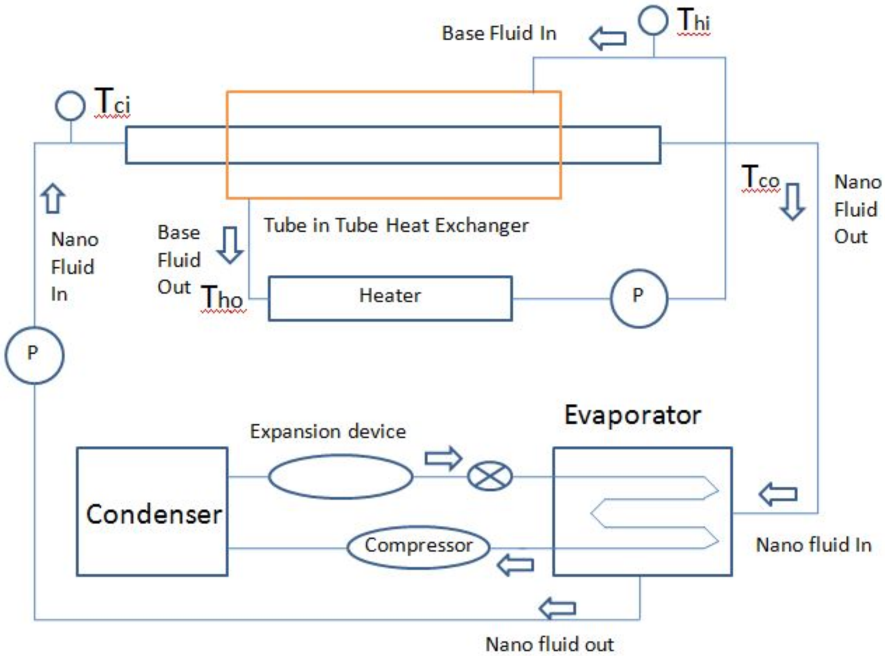

Figure 3.1: Schematic diagram of the experimental set up including tube in tube heat exchanger

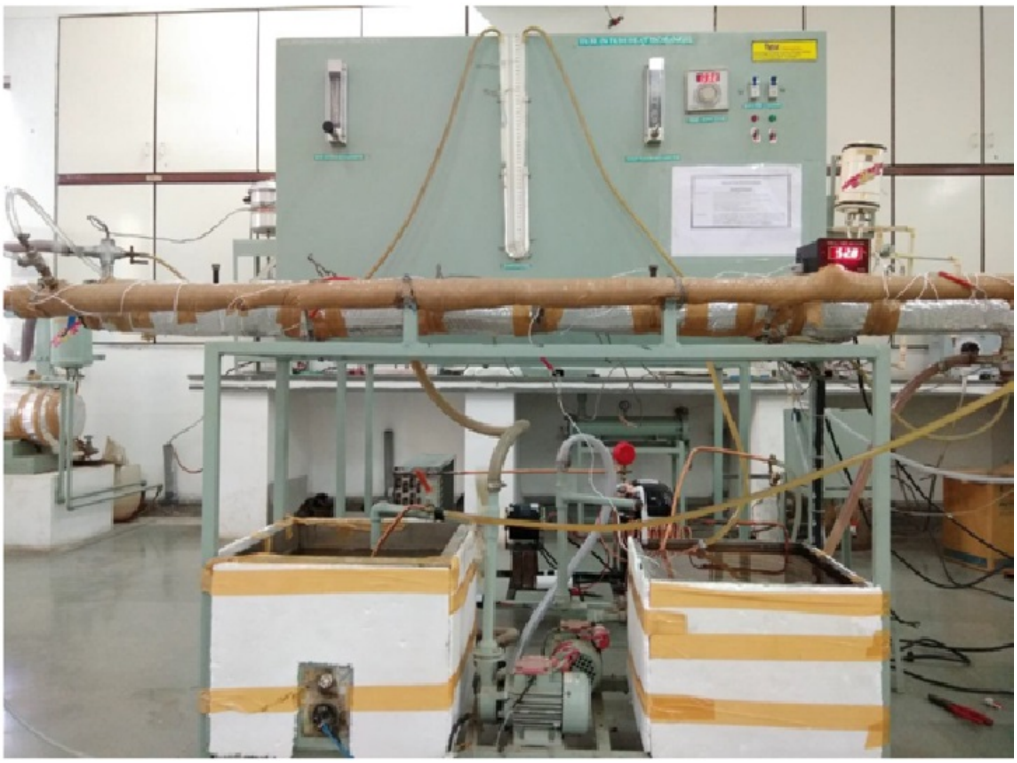

Figure 3.2: Experimental Setup showing tube in tube heat exchanger with both tanks

Figure 3.3: 3.2Evaporator to cool the Nanofluid

Figure 3.4: Refrigeration System showing compressor, coming from heat exchanger. capillary tube, condenser and condenser fan.

3.4 Component Lists

COMPONENT	SPECIFICATIONS	QTY.
Outer annulus pipe	Material : SS, ID : 28 mm, OD : 32 mm, L : 2 m	1
Inner pipe	Material : Cu, ID : 7.5 mm, OD : 9.5 mm, L : 2 m	1
Hot water tank	Material : SS, Capacity : 20 liters	1
Heater	Capacity : 2000W	1
Cold water tank	Material : SS, Capacity : 20 liters	1
Refrigeration system	Copper tube coil, Condenser (18 x 16 x 4 Rows), Motor (1/5 HP), Hermetically Sealed Compressor (1.5 Tonne) Air Cooled, Refrigerant : R22	1
Chilling storage tank	Capacity : 20 liters installed with 20 m of Cu tube (3/8 inch OD)	1
RTD sensors	Least Count : 0.1°C	6
Flow meter	Capacity : 10 liters/min. Least count : 0.1 liters/min	2
Pumps	Hot water pump : Capacity : 1/2 HP, Cold water pump:	2
	Capacity :1/4 HP	
Insulation	Asbestos rope winding 4 mm thick, Glass wool wrapping 1 inch thick, Brown tape coating	-

Table 3.1: Component list

3.5 Properties of Nanofluids

The properties of nanofluid are calculated which can be used to reduce the parameters determined from the experiments and are given as under. The density of the nanofluid is calculated using Pak and Cho's [28] equation,

$$\rho_{nf} = (1 - \phi)\,\rho_{bf} + \phi\rho_{np} \tag{3.1}$$

By the pak and choi's[28] equation for specific heat,

$$Cp_{nf} = (1 - \phi)\,Cp_{bf} + \phi Cp_{np} \tag{3.2}$$

Einstein equation, To find out the viscosity of the fluid, Drew and passman [2] gave,
This equation is as follows

$$\mu_{nf} = (1 + 2.5\phi)\,\mu_{bf} \tag{3.3}$$

The thermal conductivity of the fluid was found out by using Maxwell[6] model and it follows:

$$\frac{K_{eff}}{K_m} = 1 + \frac{3\,(\alpha - 1)\,\phi}{(\alpha + 2) - (\alpha - 1)\,\phi} \tag{3.4}$$

$$\alpha = \frac{K_2}{K_m}$$

In our present work, to calculate Nusselt number of nanofluid flowing in the heat exchanger only Maxwell equation to measure thermal conductivity of nanofluid at different concentrations is used as shown in equation no. 4.

3.6 Plan of the Experiments

The experiments were performed by keeping the Reynolds number of the hot fluid same and varying the Reynolds number of base fluid and repeat the same by varying the Reynolds numbers of hot fluid and also repeating the above steps by different Reynolds number of cold fluid at different flows rate and calculating heat transfer coefficient of above readings and comparing the same with reference to water to water heat transfer coefficient. Firstly, readings are taken by keeping flow rate of hot water as 3 LPM and by varying flow rates of working fluid i.e. water or nanofluid from 1 to 3 LPM in the intervals of 0.5 LPM. Then flow rate of hot water 5 LPM and above steps were repeated.

3.7 Methodology

Different parameters measured from the experimental setup, which is given below;

1) Nanofluid Inlet and Outlet Temperatures
2) Hot water inlet and outlet temperatures
3) Mass flow rates of both hot water and nanofluid
4) Pressure drop between inlet and outlet of nanofluid

From above parameters, different properties are calculated because of temperatures obtained from the experiments. Based on mass flow rate, an inlet and outlet temperature of hot water heat transfer in the heat exchanger calculated as under.

$$Q = mC_p \bigtriangleup T \tag{3.5}$$

$$m_h C_p (T_{hi} - T_{ho}) = m_c C_p (T_{co} - T_{ci}) \tag{3.6}$$

The overall heat transfer coefficient is calculated using the heat transfer rate, area of the heat exchanger and LMTD calculated above.

$$U = \frac{Q}{A \triangle T_{LM}} \tag{3.7}$$

LMTD i.e. Logarithmic Mean Temperature Difference is calculated using eq. no. 6 with the help of inlet and outlet temperatures of hot water and nanofluid.

$$\triangle T_{LM} = \frac{((T_{hi} - T_{co}) - (T_{ho} - T_{ci}))}{\ln \frac{(T_{hi} - T_{co})}{(T_{ho} - T_{ci})}} \tag{3.8}$$

$$A = \pi d_o l \tag{3.9}$$

Calculation of Heat Transfer Coefficient of Annulus (Hot Water):

First bulk mean temperature is calculated using hot inlet and outlet temperature of fluid in annulus side. All properties related to heat transfer is taken from property table at bulk mean temperature.
Reynolds Number calculated using the velocity of fluid, hydraulic diameter of the pipe and kinematic viscosity. Here, velocity was calculated from the mass flow rate of hot fluid and cross section area of the annulus. Hydraulic Diameter is calculated using c/s area and wetted perimeter of the annulus.

$$Re = \frac{\rho V D_h}{\mu} \tag{3.10}$$

$$D_h = \frac{4A}{P_w} \tag{3.11}$$

$$A_c = \frac{\pi \left(D_i^2 - d_o^2\right)}{4} \tag{3.12}$$

Friction factor of hot fluid is calculated using an empirical formula shown in equation and also it is calculated based upon Reynolds number only as shown in equation.

$$f = (1.58 \ln Re - 3.28)^{-2} \tag{3.13}$$

Nusselt number of hot fluid is estimated using empirical formula shown in equation which depends upon friction factor, Reynolds number and Prandtl number.

$$Nu = \frac{\left(\frac{f}{2}\right)(Re - 1000)\,Pr}{1 + 12.7\left(\frac{f}{2}\right)^{\frac{1}{2}}\left(Pr^{\frac{2}{3}} - 1\right)} \tag{3.14}$$

Heat transfer co-efficient of the annulus side is calculated using this Nusselt number, equivalent diameter and thermal conductivity of fluid.

$$h_o = \frac{Nuk}{d_o} \tag{3.15}$$

Inner heat transfer co-efficient of nanofluid is estimated using formula of overall heat transfer co-efficient. In this equation, all factor like copper-tube resistance, fouling factor, inner and outer convective heat transfer are considered.

$$h_i = \frac{1}{\frac{A_{in}}{A_{out}}\frac{1}{U_o} + R_{fi} + \frac{A_{in}}{A_{out}}R_{wall} + \frac{A_{in}}{A_{out}}R_{fo} + \frac{A_{in}}{A_{out}}\frac{1}{h_o}} \tag{3.16}$$

Nusselt number of nanofluid is calculated using inner heat transfer co-efficient of nanofluid and thermal conductivity which was calculated using empirical equation.

$$Nu = \frac{h_i d_i}{k} \tag{3.17}$$

Friction factor of copper tube of inner nanofluid is calculated using Darcy Weisbach equation. Pressure drop is measured using water-mercury manometer between two end points of inner tube.

$$f = \frac{2\triangle P d_o}{\rho V^2 l} \tag{3.18}$$

3.8 Reduction of parameters

From the calculated parameters from experimental setup and different basefluid, the nusselt number is calculated based on the calculation of inner heat transfer coefficient of water/ethylene glycol/water + ethylene glycol at different Reynold number of cold fluid . Also from pressure drop calculated by attaching Manometer between inlet and outlet of nanofluid, friction loss i.e. friction coefficient (f) is calculated from Darcy Weisbach equation. Now from the Nusselt number of the nanofluid and friction coefficient, different graphs are plotted as under:

1) Nu vs Re of base fluid at different Reynolds number of cold fluid and different plots were plotted of Distilled water.

2) f vs Re of base fluid at different Reynolds number of hot fluid and different plots are plotted of Distilled water. Now at a particular Reynolds number, both heat transfer coefficient and pressure drop across heat exchanger increases for base fluid, which shows the increment in pumping power of base fluid. Hence, to compare whether heat transfer is dominating or pressure drop is dominating, the graph plotted between (Nu/f) vs Re of working fluid at different Reynolds number of hot fluid. Then to compare the above results with water, we calculated the ratio of the Nusselt number of Distilled water and also ratio of Friction coefficient calculated from Weisbach equation of Distilled water.

3.9 Closure

This chapter describes the experimental setup of the heat exchanger and different parameters of the set up used for the experiments. It suggests the modification or requirements pertaining to the setup. It gives the methodology to calculate the heat transfer coefficient from the known temperatures of the inlet and outlet of the nanofluid and hot water.

Chapter 4

Results and Discussion

Numerous experiments were performed and readings of the temperature are noted and based on the same different properties is calculated. Based on the properties of different parameters graphs are plotted to compare the heat transfer coefficient between nanofluid at different concentrations and base fluid water. This chapter deals with the plots obtained from the experiments to arrive at a result.

The experiments are performed by keeping the Reynold number of the hot fluid same and varying the Reynold number of Nanofluid and repeat the same by varying the Reynold numbers of hot fluid and also repeating the above steps by adding different concentrations of Nano particles in the base fluid and calculating heat transfer coefficient of above readings and comparing the same with reference to water to water heat transfer coefficient.

4.1 Property table of the nanofluids

Table 4.1: Properties of Nanofluid

CuO nanofluid					Al_2O_3nanofluid				
ρ_{bf}	ρ_{np}	ϕ	ρ_{nf}	μ	ρ_{bf}	ρ_{np}	ϕ	ρ_{nf}	μ
997.1	2200	0.05	997.70	0.00891	997.1	3200	0.05	998.20	0.00891
997.1	2200	0.1	998.30	0.00892	997.1	3200	0.1	999.30	0.00892
997.1	2200	0.25	1000.11	0.00895	997.1	3200	0.25	1002.60	0.00895
997.1	2200	0.50	1003.11	0.009	997.1	3200	0.50	1008.11	0.009
997.1	2200	1	1009.13	0.0091	997.1	3200	1	1019.13	0.0091

SiO_2nanofluid				
ρ_{bf}	ρ_{np}	ϕ	ρ_{nf}	μ
997.1	4300	0.05	998.75	0.00891
997.1	4300	0.1	1000.40	0.00892
997.1	4300	0.25	1005.37	0.00895
997.1	4300	0.50	1013.62	0.009
997.1	4300	1	1030.13	0.0091

4.2 Convective heat transfer co-efficient ratio of the base and CuO, Al_2O_3 and SiO_2 nanofluids

The convective heat transfer coefficient has been found out from overall heat transfer coefficient. Mass flow rate has been varied from 1 LPM to 3 LPM. As the mass flow rate increases the Reynold number also increases because the temperature of cold inlet is constant. The results of studying the parameters affecting the convective heat transfer coefficient of nanofluids flow with volume concentrations of 0, 0.05, 0.1, 0.25, 0.50 and 1% in the copper tube are shown in fig. 4.1 As the Reynold number increases it leads to increase in heat transfer coefficient. At lower concentration value 0.05%, ratio of $\frac{h_{i,nf}}{h_{i,bf}}$ is nearly equal to one which means that convective heat transfer co-efficient for nanofluids and base fluid at 0.05% concentartion is same. Higher the concentration higher is the ratio of $\frac{h_{i,nf}}{h_{i,bf}}$. It is easy to observe from fig.4.1 the results that ratio of $\frac{h_{i,nf}}{h_{i,bf}}$ nanofluids increases as compared to base fluid. The heat transfer co-efficient with 1% volume concentration is higher because of increased overall heat transfer co-efficient of the nanofluids over other considered concentrations. Comparision has been done to find friction factor for three different nano fluids. Values of heat transfer co-efficient are $h_{inf,CuO} < h_{inf,Al_2O_3} < h_{inf,SiO_2}$. Higher the value of heat transfer co-efficient better is the nanofluid.

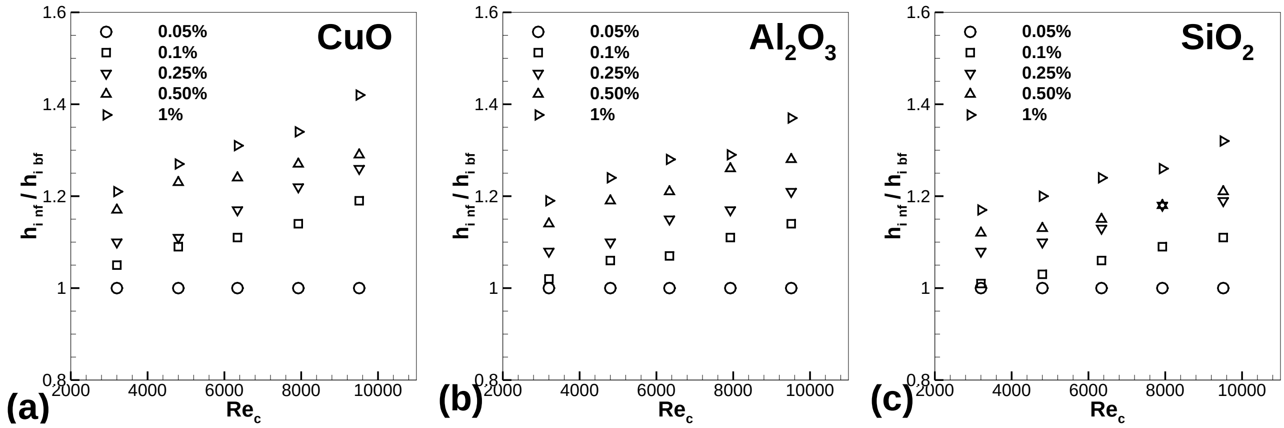

Figure 4.1: Heat transfer Co-efficient ratio Vs Reynolds number

4.3 Nusselt number ratio of the base and CuO, Al_2O_3 and SiO_2 nanofluids

Before conducting the experiments for estimation of nanofluid heat transfer and hence the Nusselt number, the reliability of the fabricated experimental setup is checked by conducting experiments with pure water. The experimental Nusselt number results obtained for water are compared with the Nusselt correlations. The result clearly shows that the experimental Nusselt numbers of the present work are closely matching with both the Nusselt correlations. This indicates that the fabricated experimental setup is a reliable one and can be used to generate experimental data.
After ensuring the experimental reliability, experiments are carried out with the base fluid as well as nanofluids of all the five concentrations under investigation one after the other in the Reynolds number ranging from 3000 to 10000. The nanofluids are allowed to flow in a circular tube in tube pipe with a constant heat flux as the boundary conditions. After ensuring steady condition, the temperatures are noted. The average experimental convective heat transfer coefficients and experimental Nusselt number for all the nanofluids are estimated using the thermo physical properties of nanofluids taken.The experimental for Nusselt number at different Reynolds number rates are shown in the Fig.4.2
It is observed from the results that Nusselt number ratio increases with increases of Reynolds number, temperature difference across the tube increases which increases overall heat transfer coefficient and also with increase in the nanoparticles volume concentration in the base fluid. The enhancement in the heat transfer can be attributed to high thermal conductivity of nanofluids. Increased surface areas of nanoparticle, intense forced convection accompanied by Brownian motion of nanoparticles in the vicinity of tube wall are other reasons for heat transfer enhancement. The results of studying the parameters affecting the Nusselt number of nanofluids flow with volume concentrations

of 0, 0.05, 0.1, 0.25, 0.50 and 1% in the copper tube are shown in fig.4.2. From the fig.4.2 seems that there were no significant increament in the Nusselt number is observed when particle concentration is 0.05%. But after that when the concentration of the nanoparticles increaese that was increament in the Nusselt number of the nanofluids. The ratio of Nusselt number of base fluid to nanofluid were prepared for the better data reduction. When the concentration was increaesed up to 1% the significant changes in the Nusselt number and for the 1% nano particles the enhancement in the Nusselt number was maximum. Fig.4.2(a) is for CuO nanofluid. As the concentratrion increases the ratio of $\frac{Nui,nf}{Nu_{i,bf}}$ increases. The maximum value obtained is at 1% concentration which is 1.43. Fig. 4.2(b) is for Al_2O_3nanofluid. The maximum value is obtained at 1% concentration which is 1.34. Fig. 4.2(c) is for SiO_2nanofluid. The maximum value is obtained at 1% concentration which is 1.24.

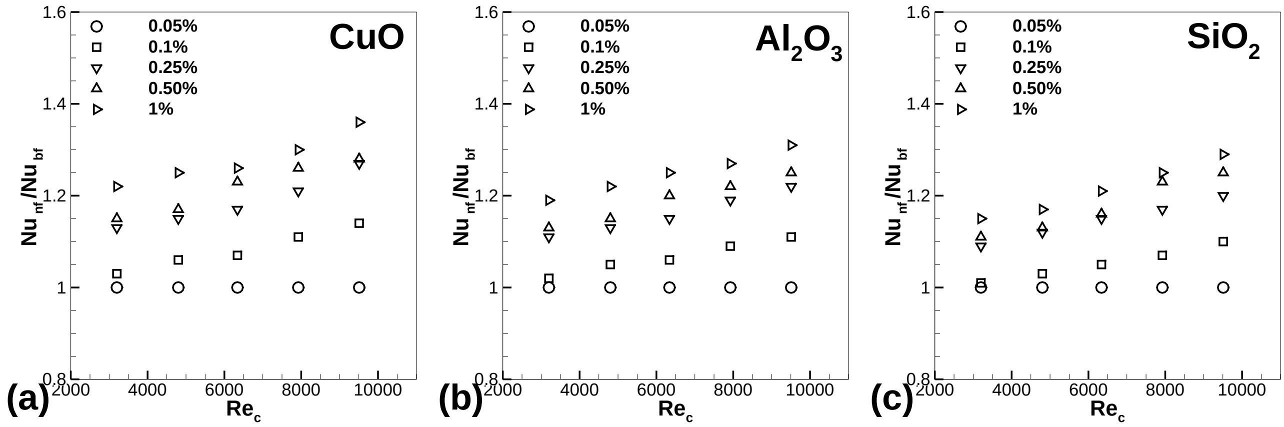

Figure 4.2: Nusselt Number ratio Vs Reynolds number

4.4 Pressure drop ratio of the base and CuO, Al_2O_3 and SiO_2 nanofluids

Apart from its ability in heat transfer, another important factor that has to be considered in the practical application of nanofluids is pressure drop. The pressure drop of nanofluid along the test section was measured by a U-tube manomete. Higher the frictional value higher is the power consumption. Increase in power consumption value means higher pressure drop. As the Reynold number increases it leads to increase in pressure drop. The variation of relative pressure drop with the Reynolds number is in fig4.3. The results of studying the parameters affecting the pressure drop of nanofluids flow with volume concentrations of 0.05, 0.1, 0.25, 0.50 and 1% in the copper tube are shown in fig. 4.3. Another point is that there is an increase in relative pressure drop with the rise of volume fraction. As shown in this fig.4.3 , there is not significant increament in pressure drop at laminar flow. Therefore, the nanoparticles at laminar flow have less significant effect in pressure drop. However, there is higher pressure loss in high turbulent flow regimes. In turbulent flow regimes, nanofluids increase the pumping power, hence an optimum concentration must be found for each nanofluid system in which more heat transfer enhancement. The pressre drop with 1% volume concentration is higher because of increased in pumping power of the nanofluids. Comparision has been done to find pressure drop for three different nano fluids. As shown in fig. 4.3 (a) value of pressure drop at 1% concentration is maximum and it is 1.3 times compare to base fluid. As shown in fig.4.3(b) is 1.35 times higher compare to base fluid at 1% concentration. As shown in fig.4.3(c) has higher value of pressure drop and it is 1.4 times higher than base fluid. Values of pressure drop ratio are $\Delta P_{nf,CuO} < \Delta P_{nf,Al_2O_3} < \Delta P_{nfSiO_2}$. Lower the value of pressure drop better is the nanofluid.

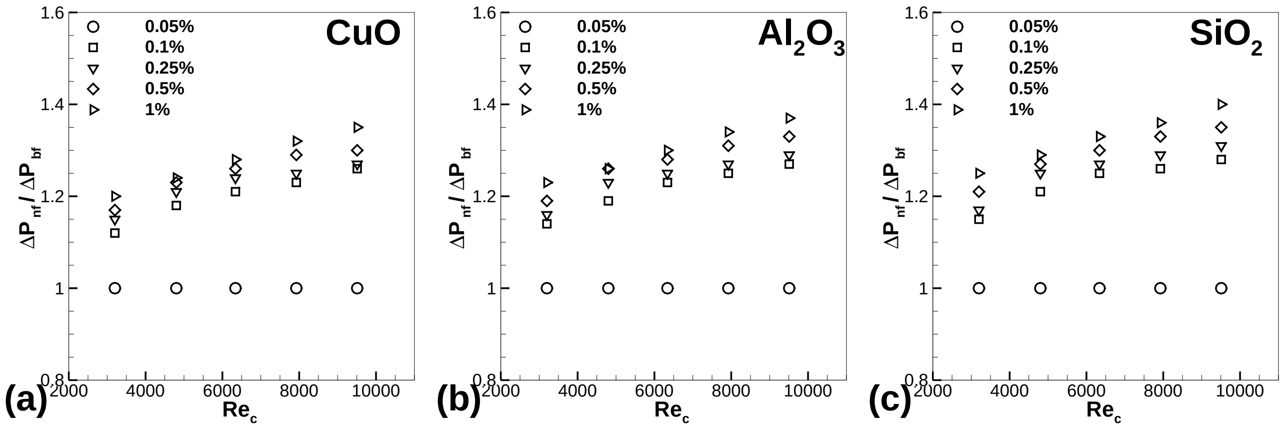

Figure 4.3: Pressure drop ratio Vs Reynolds number

4.5 Friction factor ratio of the base and CuO, Al_2O_3 and SiO_2 nanofluids

The reliability of the present experiment is also tested for friction factor calculations. The experiment was conducted using pure water and the experimental friction factor was calculated. Experiments were then conducted with the distilled water as a base fluid and three different nanofluids. The friction factor value increases as mass flow rate of nanofluids increases and the same can be understood from fig.4.4 which shows variation of nanofluids leads to change in friction factor. The results of studying the parameters affecting the friction factor of nanofluids flow with volume concentrations of 0, 0.05, 0.1, 0.25, 0.50 and 1% in the copper tube are shown in fig. 4.4. An important reason for the increased friction factor in the nanofluid flow is addition of nanofluids to the base fluid that increases the dynamic viscosity of the nanofluid. It is easy to observe from the results that the friction factor of nanofluids increases as compared to base fluid. The friction factor with 1% volume concentration is higher because of increased dynamic viscosity of the nanofluids over other considered concentrations. The variation of friction factor with Reynolds number in turbulent region is higher as compared to laminar and transition flow. While experimenting with 0.05% concentration the friction factor remains constant. Comparision has been done to find friction factor for three different nano fluids. As shown in fig.4.4(a), (b) and (c) Friction factor of the nanofluid CuO, Al_2O_3, SiO_2 was increased by 1.2, 1.3, 1.4 times higher respectively, as compared to pure water. Values of friction factor are $f_{nf,CuO} < f_{nf,Al_2O_3} < f_{nf,SiO_2}$. . Lower the friction factor better is the nano fluid.

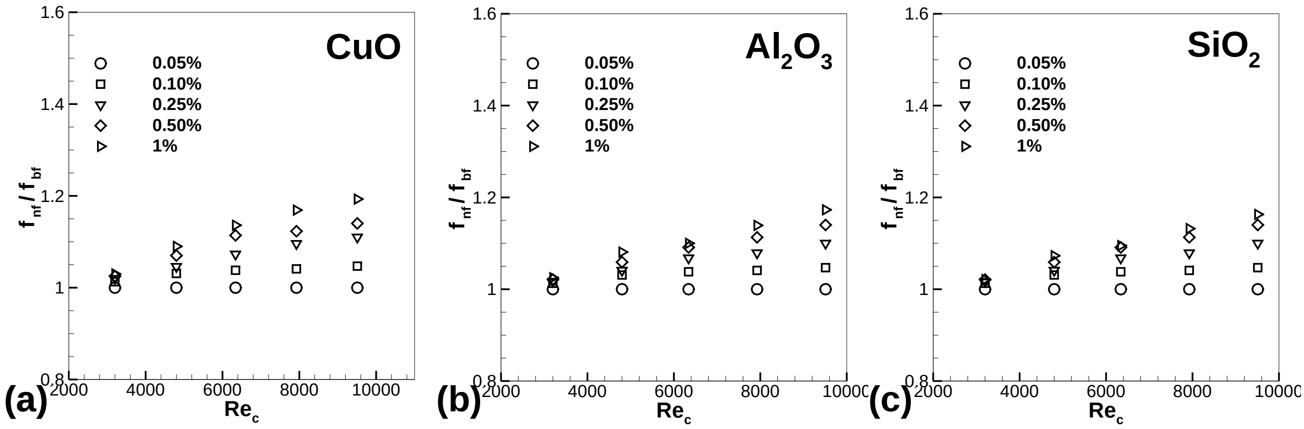

Figure 4.4: Friction factor ratio Vs Reynolds number

4.6 Thermal performance of the base and CuO, Al_2O_3 and SiO_2 nanofluids

The thermal performance factor is defined as the ratio of the Nusselt number ratio to the friction factor ratio at the same pumping power. Where Nu and f are respectively, the Nusselt number and friction factor. The variation of thermal performance factor with Reynolds number is illustrated in fig.4.5. As shown, thermal performance increases as the Reynolds number increases. This implies that the use of nanofluid is feasible in terms of energy saving at higher Reynolds numbers in turbulent regime. The results also show that the thermal performance factor increases with increasing concentration of nanofluid. The use of nanofluid with higher concentration provides considerably higher thermal performance for all Reynolds number studied. This is a result of a superior efficient of nanofluid disturbance and thus heat transfer caused by the nanofluid compared to the base fluid at the same pumping power. The thermal performances of nanofluid with 1% is higher.

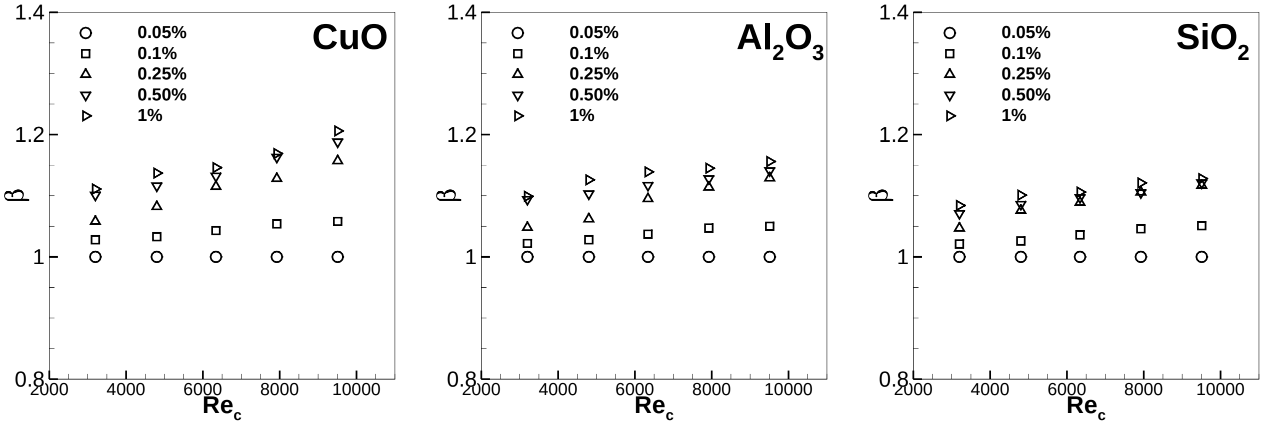

Figure 4.5: Thermal Performance factor Vs Reynolds number

Chapter 5

Conclusion

This chapter includes the conclusion derived from the experimentation. And the future work that can be carried out in order to elaborate more into the knowledge of this very new field of nanofluids.

In the present study, experiments were done for a wide range of Reynolds number and nanoparticle volume concentrations. The experimental results clearly indicate that the Al_2O_3, CuO and SiO_2 are a promising candidate for the enhancement of overall convective heat transfer coefficient of water and the following conclusions are arrived at based on the experimental results.

5.1 Conclusion

- It was found that the nanofluids CuO, Al_2O_3 and SiO_2have maximum of 40%, 30% and 23% higher heat transfer coefficient compared to base fluid at mass fraction of 1% concentration, respectively, because the overall heat transfer coefficient increases.
- The Nusselt number of nanofluids increases with increasing Reynolds number and heat transfer coefficient compared to base fluid at mass fraction of 1%. The CuO, Al_2O_3 and SiO_2nanofluids Nusselt number are 38%, 28% and 20% compared to base fluid at mass fraction of 1%.
- The pressure drop of CuO, Al_2O_3 and SiO_2 nanofluids increases up to 15%, 20% and 23% with increasing Reynolds number, respectively and there is a small increase with increasing particle concentrations. This is caused by increase in the viscosity of nanofluids, and it means that nanofluids incur little penalty in pressure drop.
- The friction factor of nanofluid flow increased with increasing volume fraction of nanofluids in all internal Reynolds numbers. The maximum increase in friction

factor (~32%) was related to maximum concentration of nanofluid, which is due to unwanted increase in viscosity with increasing volume fraction.

- At 1% concentration for CuO, Al_2O_3 and SiO_2nanofluids the heat transfer performance is higher than unity. This factor reveals the capability of an improved heat exchanger to enhance the heat transfer rate at the same pumping power. The heat transfer performance for CuO, Al_2O_3 and SiO_2nanofluids are 1.35, 1.26, 1.20 respectively.

- As per the experimental results CuO nanoparticle is suitable compared to Al_2O_3 and SiO_2nanoparticles.

5.2 Future work

1. Working on higher concentration of same nanoparticles.

2. Working with different nanoparticles and different sizes of nanoparticles.

3. Error analysis.

4. Changing of more parameters like change of base fluid, variation of temperature, variation of Reynolds Number etc.

5. CFD modelling of the above experimenation.

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