

# **PERFORMANCE EVALUATION OF HEAT SINK FOR ELECTRONIC COOLING USING (H<sub>2</sub>O & Al<sub>2</sub>O<sub>3</sub>-H<sub>2</sub>O) AS A COOLANT**

**A  
Thesis**

*submitted in partial fulfillment of the requirements for the award of degree of*

**Master of Engineering (M.E.)**

**In  
Thermal Engineering**

**Submitted by  
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**UNDER THE GUIDANCE OF**

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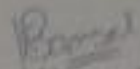
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JULY 2015**

## CERTIFICATION

I, Kamal Kumar Bansal, declare that this thesis report entitled "*Performance Evaluation Of Heat Sink For Electronic Cooling Using (H<sub>2</sub>O & Al<sub>2</sub>O<sub>3</sub>-H<sub>2</sub>O) As A Coolant*", submitted towards fulfillment of the requirements for the award of Master's Degree in Thermal Engineering, in Mechanical Engineering Department of Thapar University, Patiala, is entirely my own work. This document has not been submitted for any degree in any other institution.

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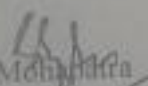
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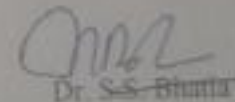
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## **ACKNOWLEDGEMENT**

I would like to express my deepest gratitude to my supervisor, Dr. V.P. Agrawal, for his excellent guidance, caring, patience, and providing me with an excellent atmosphere for doing research. Your advice on both research as well as on my career have been priceless. The opportunity, support, exposure and atmosphere provided by the Thapar University, Patiala, to carry out my studies are highly appreciated. The financial support provided by the Department of Science and Technology (DST) and Council of Scientific and Industrial Research (CSIR) to carry out my studies is greatly appreciated.

A special debt of gratitude is owed to the authors whose works I have consulted and quoted in this work. Last but not least, I am forever grateful to my parents, family and friends for their unconditional support and best wishes.

## ABSTRACT

Mini channel heat exchangers have become successful in applications such as electronics micro-electromechanical devices and other devices where small size objects are to be cooled, reason due to possibilities of reducing weight, size and cost of heat exchangers as compared to the conventional methods. Due to high volume to surface ratio, mini channel heat exchangers are thermally efficient devices and can transfer more heat. Accurate design for pressure drop and heat transfer is necessary for the application of mini-channel heat exchanger. This dissertation aims to study the fundamentals of single phase and double phase heat transfer and pressure drop in mini channels using water and  $\text{Al}_2\text{O}_3$ -Water nanofluids at different flow rates and different concentrations of nano particles. Results of heat sink will also be validated with the use of Computational Fluid Dynamics. To increase thermal efficiency for better cooling and also for reducing the size of electronics.

Experiments were done on the mini channel with dimensions 2.7 mm depth and 2.95 mm width which was made on the aluminum heat sink. A flat plate heater was used as a heat source and was attached to the bottom of the aluminium heat sink. Temperature at the inlet and outlet of the sink was measured and analyzed at different flow rates for a two phase flow using water and nano fluids containing aluminium oxide ( $\text{Al}_2\text{O}_3$ ) at different concentrations. pressure drop was also measured simultaneously. effect of reynolds number on pressure drop, friction factor, fanning friction factor and temperature change was studied. due to effective heat transfer, mini channel heat exchanger can be used for cooling purpose in electronics.

# TABLE OF CONTENTS

	<b>Page No.</b>
CERTIFICATION	i
ACKNOWLEDGEMENT	ii
ABSTRACT	iii
TABLE OF CONTENTS	iv
LIST OF FIGURES	vi
LIST OF TABLES	ix
LIST OF SYMBOLS AND ABBERVIATIONS	x
<b>CHAPTER 1: Introduction and objectives</b>	<b>1</b>
1.1 Introduction	1
1.2 History	3
1.3 Objectives of Two- Phase Test	4
1.4 Nanofluids	5
1.5 Computational Fluid Dynamics	7
1.6 Objectives	8
<b>CHAPTER 2: Literature Review</b>	<b>9</b>
2.1 Liquid Cooling	9
2.2 Liquid Coolants for Electronic Cooling	9
2.3 Dielectric Liquid Coolants	12
2.4 Non- Dielectric Liquid Coolants	13
2.5 Other Exotic Coolant Chemistries	14
2.6 Nanofluids	15

2.7 Losses in Minichannels	18
2.8 Reynolds Number	19
2.9 Heat Transfer Rate	20
2.10 Previous research work	20
<b>CHAPTER 3: Experimental work and Simulation Procedure</b>	<b>31</b>
3.1 Experimental Setup	31
3.2 Calibration	38
3.3 Operational Procedure	39
3.4 Properties of alumina (Al <sub>2</sub> O <sub>3</sub> ) nanoparticle	40
3.5 Preparation of Nanofluid	41
3.6 Instruments used for preparation of nanofluid	42
3.7 Simulation Procedure	44
<b>CHAPTER 4: Results and Discussions</b>	<b>48</b>
4.1 Purpose of Study	48
4.2 Property Comparisons	48
4.3 Results Comparisons	51
<b>CHAPTER 5: Conclusion and future scope</b>	<b>68</b>
5.1 Conclusion	68
5.2 Future scope of work	69
<b>REFERENCES</b>	<b>70</b>
<b>APPENDIX: A1</b>	<b>76</b>

## LIST OF FIGURES

	<b>Page No.</b>
<b>Fig. 3.1</b> Schematic of Experimental Setup	31
<b>Fig.3.2</b> Experimental Setup	32
<b>Fig 3.3</b> Minichannel heat sink	33
<b>Fig. 3.4</b> Pump	35
<b>Fig 3.5</b> Thermocouple	36
<b>Fig 3.6</b> Position of Thermocouples in Mini Channel Heat Sink	37
<b>Fig 3.7</b> Differential manometer	38
<b>Fig. 3.8</b> Rotameter	38
<b>Fig.3.9</b> Calibration Curve for Thermocouple	39
<b>Fig.3.10</b> Magnetic Stirrer	41
<b>Fig.3.11</b> Ultra sonicator water bath	41
<b>Fig.3.12</b> Prepared samples: (a) distilled water, (b) 0.01% vol. conc. Al <sub>2</sub> O <sub>3</sub> -H <sub>2</sub> O (DI) nanofluid, (c) 0.05% vol. conc. Al <sub>2</sub> O <sub>3</sub> -H <sub>2</sub> O (DI) nanofluid	42
<b>Fig.3.13</b> Rheometer	43
<b>Fig.3.14</b> Densitymeter	43
<b>Fig.3.15</b> KD2 Pro	43
<b>Fig.3.16</b> Geometric Model of Heat Sink	44
<b>Fig.3.17</b> Meshed Geometry of Heat Sink	45
<b>Fig 4.1</b> Density versus temperature at different concentration of water	49

<b>Fig. 4.2</b> Viscosity versus temperature at different concentration of water	50
<b>Fig. 4.3</b> Conductivity versus temperature at different concentration of water	51
<b>Fig 4.4</b> Variation of Pressure Drop with Reynolds number.	52
<b>Fig 4.5</b> Variation of Friction Factor versus Reynolds Number	53
<b>Fig 4.6</b> Inlet and Outlet temperature versus Reynolds Number for Water	54
<b>Fig 4.7</b> Inlet and Outlet temperature versus Reynolds Number for 0.01% Vol. Conc.	
Nano Fluid	55
<b>Fig 4.8</b> Inlet and Outlet temperature versus Reynolds Number for 0.05% Vol. Conc.	
Nano Fluid	55
<b>Fig 4.9</b> Fanning Friction Factor versus Reynolds Number	56
<b>Fig. 4.10</b> Temperature Difference versus Reynolds Number	57
<b>Fig. 4.11</b> Heat Transfer versus Reynolds Number	58
<b>Fig. 4.12</b> Temperature Difference versus Reynolds Number for CFD and	
Experimental Results for water	59
<b>Figure 4.13</b> Pressure Drop versus Reynolds Number for CFD and Experimental Results	60
<b>Figure 4.14</b> Temperature Difference versus Reynolds Number for CFD and	
Experimental Results for 0.01% vol. conc	61
<b>Fig. 4.15</b> Pressure drop versus Reynolds Number for CFD and Experimental	
Results for 0.01% vol. conc.	62
<b>Fig. 4.16</b> Temperature Difference versus Reynolds Number for CFD and Experimental	
Results for 0.05% vol. conc	63

**Figure 4.17** Pressure drop versus Reynolds Number for CFD and Experimental

Results for 0.05% vol. conc.

64

**Fig.4.18** Pressure Contour

65

**Fig.4.19** Temperature Contour

66

**Fig4.20** Velocity Path lines

67

## LIST OF TABLES

	<b>Page No.</b>
<b>Table 2.1</b> Properties of different liquid coolant at 20°C	11
<b>Table 3.1</b> Dimensions of Minichannel	34
<b>Table 3.2</b> Different Parameters of the system	35
<b>Table 3.3</b> Properties of nanoparticles	40
<b>Table 3.4</b> Meshing Details	45
<b>Table 3.5</b> Thermophysical properties of various materials used in CFD.	46
<b>Table 3.6</b> Flow conditions used in CFD	47
<b>Table A1:</b> Calibration of thermocouple data	76
<b>Table A2:</b> Experimental data for water	76
<b>Table A3:</b> Experimental data for 0.01% vol. conc. nanofluid	76
<b>Table A4:</b> Experimental data for 0.05% vol. conc. nanofluid	77
<b>Table A5:</b> Data for property calculation at different temperatures for water	77
<b>Table A6:</b> Data for property calculation at different temperatures for 0.01% vol. conc. nanofluid	78
<b>Table A7:</b> Data for property calculation at different temperatures for 0.05% vol. conc. nanofluid	79

## LIST OF SYMBOLS AND ABBREVIATIONS

Re	Reynolds Number
v	Velocity (m/s)
L	Test Section Length (m)
$h_L$	Height of mercury in manometer (m)
f	Friction Factor
$D_h$	Hydraulic diameter (m)
g	Gravity ( $m/s^2$ )
$\Delta P$	Pressure drop (bar)
$\rho$	Density ( $kg/m^3$ )
V	Volume ( $m^3$ )
$\mu$	Dynamic viscosity (kg/m-s)
q	Rate of heat transfer (W)
Q	Volumetric flow rate ( $m^3/s$ )
$C_p$	Specific Heat (kJ/kg K)
$A_s$	Surface Area ( $m^2$ )
A	Heat Transfer Area ( $m^2$ )
P	Perimeter (m)
T	Temperature ( $^{\circ}C$ )
$T_{in}$	Inlet temperature ( $^{\circ}C$ )
$T_{out}$	Outlet temperature ( $^{\circ}C$ )

**1.1 Introduction**

In recent years, need of electronic cooling in various electrical devices has been a major concern area. There is requirement of different cooling systems for these devices to make them more efficient and life longing. So a system is needed that is effective, compact as well as capable enough in maintaining the electronic equipment's, telecommunications and computers etc. that involves high heat flux and operating temperature.

In electric components, method commonly used is air cooling. It is easily available, assessable, and economically suitable and can be easily used in small components. Only drawback of air cooling is its effectiveness as compared to liquid cooling due to property of more heat carrying capacity of liquid.

Mini channels are channels of fluid flow with hydraulic diameters between 200  $\mu\text{m}$  to 3 mm and microchannels 10  $\mu\text{m}$ -200  $\mu\text{m}$  as classified by Kandlikar and Grande(2003) by air or liquid coolants are some of those cooling systems which are considered to be suitable and economic. These systems are easy to install, effective, easy to handle, small and easily assessable when we compare them with their respective operating costs.

The single phase heat transfer becomes extremely efficient in mini/micro channels when combination of the above said features comes into existence. The applications of micro-channels are widely used in closed system where the clean fluids are mostly preferred as working fluids such as non-reacting gases, liquid and refrigerants. An increment in the thermal duty and energy efficiency has been analyzed while more restrictions have been analyzed due to the space constraints. Greater heat transfer rate per unit volume are the

major area of concern in the micro-channels operated cooling system. In these applications, the hot side of the evaporator are generally air, gas or condensing vapor. Due to surface area densities, heat transfer coefficients have been increased with advancement in the air side fin geometry. More complex heat transfer designs are implemented on the evaporating side as the air side heat transfer goes on decreasing that result in the use of micro-channels on the liquid side as flow passage. In recent evaporator and condensers the major changes in the design for compact heat exchanger and automotive applications involve the small hydraulic diameters as flow passages which are arranged in a multichannel configuration on the liquid side.

Micro/mini-channels have various applications including:-

1. Bioengineering
2. Cooling of gas turbine blades
3. Automotive
4. Power and process industries
5. Superconductors
6. Refrigeration and air conditioning
7. Microelectronics

Advantages of micro/mini-channels include:-

1. Compactness for space critical applications
2. High volumetric heat flux
3. Robust design

## 1.2 History

Since the development of the first electronic computers in 1940s, the development of faster and denser circuit technologies and packages has been accompanied by increasing heat flux at the chip and package levels. Over the years, significant advances have been made in the application of air cooling techniques to manage increased heat flux. Although air cooling continues to be the most widely used method for cooling electronic packages, it has long been recognized that significantly higher heat flux can be accommodated through the use of liquid cooling. Application of liquid cooling for microelectronics may be categorized as either indirect or direct.

In an investigation on the application of conventional refrigeration system to cool IBM's S/390 mainframe, Schimdt (2003) showed that the chip temperatures can be maintained below that of comparable air-cooled systems, but well above cryogenic temperatures. The development of a Kleemenko cooler, which provides 80 watts of refrigeration for the CPU at 96<sup>0</sup>C, is perhaps one of the significant advances in cooling of computers.

Minichannels are found in many biological systems providing very high heat and mass transfer rates in organs such as the brain, lung, liver and kidney. Many high flux cooling applications are effectively utilizing their high heat transfer capabilities for these channels. Small channel diameters are at the heart of all biological systems. Fluid flow and mass transfer in the human body, for example, utilize the high heat and mass transfer coefficients associated with minichannels. Following nature's lead, many heat transfer devices are utilizing minichannels in emerging novel applications, such as heat flux cooling of lasers and digital microprocessors.

The potential of Minichannels in high heat flux removal application was first brought to our attention by the pioneering work of Tuckerman and Pease (1981). The experimental investigation that followed in the next ten year's focused on obtaining the single-phase heat transfer and pressure drop characteristics in these channels. A wide array of disparaging results were reported, with frictional pressure drop being very different (higher as well as lower compared to conventional channels), and early transition to turbulence, in some cases as early as Reynolds number of 300-400. The need for smaller, faster and lighter products has put considerable demands on the thermal management of microelectronics.

### **1.3 Objectives of Two-Phase Tests**

The objective of the dissertation is to gain a fundamental understanding of two-phase flow heat transfer and pressure drop in micro/mini channels with water and other coolants as the test fluid. Electronic equipments have made its way into practically every aspect of modern life, from toys and appliances, to high power computers. The reliability of the electronics depend on the passage of electric current to perform their duties, and they become potential sites for excessive heating, since the current flow through a resistance is accompanied by heat generation. Continued miniaturization of electronic system has resulted in dramatic increase in amount of heat generated result in high operating temperatures for electronic equipment, which jeopardizes its safety and reliability.

The invention of the bipolar transistor in 1948 marked the beginning of a new era in the electronic industry, and the next turning point in electronics occurred in 1959 with the introduction of the integrated circuits where several components such as diodes,

transistors and capacitors are placed in a single chip. The number of components packed in a single chip has been steadily increasing since then at an amazing rate. The developments of the microprocessor in early 1970s make another beginning in the electronic industry. The current flow through a resistance is always accompanied by heat generation in the amount of  $I^2R$ , the heat flux encountered in electronic devices ranges from less than  $1\text{W}/\text{cm}^2$  to more than  $100\text{W}/\text{cm}^2$ .

Heat is generated in a resistive element for as long as current continues to flow through it. This creates a heat build up and a subsequent temperature rise at and around the components. The temperature of the component will continue to rise until the component is destroyed unless heat is transferred away from it. The temperature of the component will remain constant when the rate of heat removal from it equals the rate of heat generation.

#### **1.4 Nanofluids**

Thermal properties of the liquid have a very important role to play in the cooling and heating applications in the industries. To decide the thermal efficiency of any system, thermal conductivity is considered as very important physical property. For the ultra-high cooling applications, conventional cooling liquids are not much effective due to their inherently poor thermal conductivity. By adding some solid additives to the base liquid, scientists have tried to enhance the heat carrying capacity of these inherently poor thermal conductive fluids.

Thermal conductivity in the liquid as compare to the gases is more and hence much higher heat transfer coefficient is associated with them. Therefore we prefer liquid cooling over

gas cooling. But liquid cooling has its own disadvantages or risks such as corrosion, leakage, condensation and extra weight. Therefore liquid cooling is limited to fir those applications which involves too high power densities for safe dissipation by air cooling.

The classification of liquid cooling can be done as direct cooling and indirect cooling. In direct cooling system, heat generated in the specimen can be directly transferred to the liquid as there is direct contact with the liquid. In the indirect cooling system heat generated is not carried away by the liquid directly. In the system heat is firstly transferred to the medium that can be a cold plate and then further it is carried away by the liquid. Also classification of liquid cooling system can be done as open loop & closed loop system. It depends upon whether the liquid is re-circulated after it is heated or discarded. Generally in the open loop system, heat is carried away by the tap water and after heating up the liquid is discarded into the drains.

Along with the various shapes of the cross-sections, the study has been done on the various fluids which are used to carry away the heat from the heat sink through the micro-channels. The fluids which are taken for the study considerations are silicon oxide ( $\text{SiO}_2$ ), alumina ( $\text{Al}_2\text{O}_3$ ), copper oxide ( $\text{CuO}$ ). Further, out of the two fluids, solution of  $\text{Al}_2\text{O}_3\text{-H}_2\text{O}$  is used at two different concentrations. In the solution of nanofluids, various concentrations of nano-particles in the water is taken as per requirements or required cooling performance. Concentration of the nano-particles in the water plays a vital role in the heat carrying capacity of the nano fluid. As the quantity of nano particles in the water increases it leads to the more heat carrying capacity of the fluid. Also, distilled water also have been used as heat carrying medium in the process to have variety of results which help us to analyze the problem more accurately.

Making of the solution of nano particles with base fluids or distilled water is generally done at the chemistry laboratory. Nano sized particles of nano-particles has been used in the powder form to get the required solution. Prescribed amount of quantity of the powder is been used to get the solution of relative concentration. Certain procedures are also followed to get the distilled water in the laboratory as a base fluid.

### **1.5 CFD (Computational Fluid Dynamics)**

Computational fluid dynamics is a branch of fluid mechanics which analyze and solve the problems which involve fluid flows. The techniques that are used in CFD are numerical methods and algorithms. To simulate interactions of the liquids & gases with the surfaces, computers are required which are used to perform the calculations with the help of boundary conditions. Computational fluid dynamics gives the approximate results yet they may be very close to the real behavior. Even super-computers may be able to give the approximate result of the fluid flow behavior.

In CFD codes, FVM (Finite Volume Method) is adopted as a common approach. Mainly, this approach has advantages in high Reynolds numbers turbulent flow, memory usage, solution speed, source term dominated flows and especially for the large problems. The finite volume equation yields governing equations.

In the finite volume method, the governing partial differential equations (typically the Navier-Stokes equations, the mass and energy conservation equations, and the turbulence equations) are recast in a conservative form, and then solved over discrete control volumes. This discretization guarantees the conservation of fluxs through a particular control volume. The finite volume equation yields governing equations in the form:

$$\frac{\partial}{\partial t} \iiint Q dV + \iint F dA = 0,$$

Where  $Q$  is the vector of conserved variables,  $F$  is the vector of flux (see Euler equations or Navier–Stokes equations),  $V$  is the volume of the control volume element, and  $A$  is the surface area of the control volume element.

## 1.6 Objectives

The following specific objectives are undertaken:

- (i) To experimentally investigate the thermophysical parameters of minichannel cooling using water and  $\text{Al}_2\text{O}_3$ /water based nanofluid as cooling medium.
- (ii) To perform the CFD simulation for aluminium heat sink cooling using water and  $\text{Al}_2\text{O}_3$ /water nanofluid as cooling medium and validation of results with experimental results.

**2.1 Liquid Cooling**

Liquids normally have much higher thermal conductivities than gases, and thus much higher heat transfer coefficients associated with them. Therefore, liquid cooling is more effective than gas cooling. However liquid cooling has its own risks such as leakage, corrosion, extra weight and condensation. Therefore, liquid cooling is reserved for applications involving proper densities that are too high for safe dissipation by air cooling.

Liquid cooling systems can be classified as direct cooling and indirect cooling systems. In direct cooling systems, there is direct contact with the liquid, and thus the heat generated in the components is transferred directly to the liquid. In indirect cooling systems, however there is no direct contact with the components. The heat generated in this case is first transferred to medium such as cold plate before carried away by the liquid. Those cooling systems are also classified as closed loop and open loop systems depending on whether the liquid is discarded or recirculated after it is heated. In open loop systems, tap water flows through the cooling system and discarded into drain after it is heated.

**2.2 LIQUID COOLANTS FOR ELECTRONIC COOLING**

Coolants are used in both single phase and two-phase applications. A single phase cooling loop consists of a pump, a heat exchanger (cold plate, mini or micro channels), and a heat sink (radiator with a fan or a liquid-to-liquid heat exchanger with chilled

water cooling). The heat source in the electronics system is attached to the heat exchanger. Liquid coolants are also used in two-phase systems, such as heat pipes, thermo siphons, sub-cooled boiling, spray cooling and direct immersion systems.

### **2.2.1 Requirements for a Liquid Coolant for Electronics**

There are many requirements for a liquid coolant for electronics applications. The requirements may vary depending on the type of application. Following is a list of some general requirements:

- Good thermo-physical properties (high thermal conductivity and specific heat; low viscosity; high latent heat of evaporation for two-phase application).
- Low freezing point and burst point (sometimes burst protection at  $-40^{\circ}\text{C}$  or lower is required for shipping and/or storage purpose).
- High atmosphere boiling points for single phase system; a narrow desired boiling point for a two-phase system.
- Good chemical and thermal stability for the life of the electronic system.
- High flash point and auto-ignition temperature (sometimes non-combustibility is a requirement).
- Non-corrosive to materials of construction (metals as well as polymers and other non-metals).
- No or minimal regulatory constraints (environmentally friendly, nontoxic and possibly biodegradable).
- Economical

The best electronics coolant is an inexpensive and nontoxic liquid with excellent thermo-physical properties and a long service life. A high flash point and auto-ignition

temperature are desired so that the fluid is less susceptible to ignition. Good thermo-physical properties are required to obtain the high heat transfer coefficients and low pumping power needed for the fluid to flow through a tube or a channel.

Electrical conductivity of a coolant becomes important if the fluid comes in direct contact with the electronics (such as in direct immersion cooling), or if it leads out of a cooling loop or is spilled during maintenance and comes in contact with the electrical circuits. In certain applications, a dielectric coolant is a must, whereas in many other applications it is not a requirement because of the very remote chance of coolant leakage (or in case of a leak, the coolant does not come in contact with the electronics)

**Table 2.1** Properties of different liquid coolant at 20°C

Coolants	Viscosity $\text{kg}\cdot\text{m}^{-1}\cdot\text{s}^{-1}$	Thermal Conductivity $\text{W}\cdot\text{m}^{-1}\cdot\text{s}^{-1}$	Density $\text{kg}\cdot\text{m}^{-3}$
Aromatic	0.001	0.14	860
Silicate-ester	0.009	0.132	900
Aliphatic	0.009	0.137	770
Silicone	0.0014	0.11	850
EG/Water (50:50 v/v)	0.0038	0.37	1087
PG/Water (50:50 v/v)	0.0064	0.36	1062

Al <sub>2</sub> O <sub>3</sub> nanoparticles 0.01% vol. conc.	0.000847	0.613	1026
Al <sub>2</sub> O <sub>3</sub> nanoparticles 0.01% vol. conc.	0.0012	0.617	1146

## 2.3 Dielectric Liquid Coolants

### 2.3.1 Aromatics

Synthetic hydrocarbons of aromatic chemistry (i.e., diethyl benzene [DEB], dibenzyl toluene, diary alkyl, partially hydrogenated terphenyl) are very common heating and cooling fluids used in a variety of applications. However, these compounds cannot be classified as non-toxic. Also, some of these fluids (i.e., alkylated benzene) have strong odours, which can be irritating to the personnel handling them.

### 2.3.2 Silicate-ester

This chemistry (i.e., Coolanol 25R) was widely used as a dielectric coolant in Navy airborne radar Air Force and Navy missile systems. These fluids have caused significant and sometimes catastrophic problems due to their hygroscopic nature and subsequent formation of flammable alcohols and silica gel. Therefore, these fluids have been replaced by more stable and dielectric aliphatic chemistry (polyalphaolefins or PAO).

### 2.3.3 Aliphatics

Aliphatic hydrocarbons of paraffinic and iso-paraffinic type (including mineral oils) are used in a variety of direct cooling of electronics parts as well as in cooling transformers.

Many petroleum based aliphatic compounds meet the Food and Drug Administration (FDA) and United States Department of Agriculture (USDA) criteria for incidental food contact. These petroleum based fluids do not form hazardous degradation byproducts. Most of these fluids have a non-discernible odour and are nontoxic in case of contact with skin or ingestion. As mentioned before, aliphatic PAO-based fluids have replaced the silicate-ester fluids in a variety of military electronics (and avionics) cooling applications in the last decade.

#### **2.3.4 Silicones**

Another class of popular coolant chemistry is dimethyl and methyl phenyl-poly (siloxane) or commonly known as silicone oil. Since this is a synthetic polymeric compound, the molecular weight as well as the thermo-physical properties (freezing point and viscosity) can be adjusted by varying the chain length. Silicone fluids are used at temperatures as low as  $-100^{\circ}\text{C}$  and as high as  $400^{\circ}\text{C}$ . These fluids have excellent service life in closed systems in the absence of oxygen. Also, with essentially no odour, the non-toxic silicone fluids are known to be workplace friendly. However, low surface tension gives these fluids the tendency to leak around pipe-fittings, although the low surface tension improves the wetting property. Similar to the aliphatics, high molecular weight silicone oils have also found applications in cooling transformers.

#### **2.4 Non-Dielectric Liquid Coolants**

Non-dielectric liquid coolants are often used for cooling electronics because of their superior thermal properties, as compared with the dielectric coolants. Non-dielectric coolants are normally water-based solutions. Therefore, they possess a very high specific

heat and thermal conductivity. De-ionized water is a good example of a widely used electronics coolant. Some other popular non-dielectric coolant chemistries are discussed below:

#### **2.4.1 Ethylene Glycol (EG)**

Commonly used as antifreeze in automotive engine cooling. EG also has found use in many industrial cooling applications. Common applications include process cooling at lower temperatures. Ethylene Glycol is colourless and practically odourless and is completely miscible with water. When properly inhibited, it has a relatively low corrosivity. However, this coolant is classified as toxic and should be handled and disposed of with care. The quality of water used for the preparation of a glycol solution is very important for the system.

#### **2.4.2 Propylene Glycol (PG)**

In its inhibited form, PG has the same advantages of low corrosivity shown by ethylene glycol. In addition, propylene glycol is considered non-toxic. Other than lack of toxicity, it has no advantages over ethylene glycol, being higher in cost and more viscous.

### **2.5 Other Exotic Coolant Chemistries**

The number of journal publications in this field has increased exponentially in the recent years. However, there are still a large amount of unknown factors (i.e., long term reliability, agglomeration, settling, and blockage of micro-channels) existing in the utilization of nano particles in a coolant. Phase Change Materials (PCM) in their micro or

nano encapsulated form have been utilized in a coolant medium to increase the specific heat capacity. Again, reliability has been a problem in utilizing them.

Ionic liquids (room temperature liquid salts) have also shown some potential to become next-generation coolants based on their thermal stability, extremely low vapor pressure and other properties. Currently, their application is limited to solvents in chemical reactions and extractions. These chemistries will take a number of years to become technically and economically competitive with the existing coolants.

There are several coolants (both dielectric and non-dielectric) that are commercially available. However, selection of the best coolant for a particular application requires a proper understanding of all the characteristics and thermo physical properties of these fluids. Dielectric fluids can be used in contact with the electronics, whereas non-dielectric coolants are used with a cold plate. In the future, coolants with better properties (thermal conductivity, specific heat, thermal stability) may be available, but their popularity will depend on their reliability and economics.

## **2.6 NANOFUIDS**

Fine nanomaterials having average size less than 100nm poised with the conventional base fluid like heat transfer oil, water, molten salt, ethylene glycol etc. is known as nanofluid. Firstly, in 1995, this nanofluid term was invented by Choi. He represented the innovative grade nanotechnology which is based on the working fluids having excellent thermo physical properties as compared to conventional base fluids. So, the objective of nanotechnology is to attain the excellent thermo physical properties at minimum concentration by homogeneous and steady suspension of nanomaterials.( Das et al. 2008).

The various nanomaterials employed for nanofluids are, such as diamond, aluminum. Silver, gold, carbon nanotubes, copper oxide, aluminum oxide etc.

### **2.6.1 Factors on which Thermal conductivity of Nanoparticles depend:**

- 1) Particle material
- 2) Particle volume fraction
- 3) Particle Size
- 4) Particle Shape
- 5) Base fluid properties
- 6) Temperature

### **2.6.2 Challenges in the Nanofluids:**

1) There is an influence of many factors on the thermal conductivity of the nanofluid. So it is a challenge to keep the nanofluid mixture balanced. The influences are:

- a) Influence of nano-particles
- b) Influence of base fluid
- c) Influence of solid-liquid interface

2) From the previous studies, specific heat of the nanofluid has found to be lower than that of base fluids. But for an ideal coolant, it is important to possess the higher value of specific heat to carry away or remove more heat when compared to the base fluid.

3) From the previous researches, viscosity of the nanofluid has found to be higher than that of base fluids. It was dependent on both the concentration of the nanofluid and their type of particles.

4) Increased pressure drop is also a type of challenge during the flow of nanofluid through the heat exchanger or some other cooling system.

5) Production of the nanofluid is a costly process as it require one step method & two step method to be produced and it may lead to hinder the application of the nanofluid in the industries. Both the methods require advanced and sophisticated equipment's.

### **2.6.3 Advantages of the Nanofluids**

1) They are potential heat transfer fluids with enhanced heat transfer performance and can be implemented in many devices.

2) They are the fluids with improved thermo-physical properties and can be used in various electronic devices for the better performances.

3) Based upon the previous studies, it is strongly observed that the nanofluids have higher thermal conductivity which make them a capable cooling medium in the various cooling systems.

4) They possess temperature-dependent thermal conductivity at a very low particle concentration.

5) Nanofluids have high absorptance capacity thus soalr collector efficiency is enhanced when it is used as a main working fluid.

6) Emission issues and energy demands can be properly addressed by the spectacular capabilities of the nanofluids.

## **2.6.4 NANOFLUIDS APPLICATIONS**

Various applications of nanofluids are:

- In industrial chilling applications for saving huge energy and secretion reduction
- In nuclear appliances to enhance various irrigate-chilled nuclear system performance (Wong et al. 2009).
- Using as smart fluid in laptops and cell phones for controlling heat flow
- Removal of geothermal power and another energy resources by chilling the equipment and machinery working in high temperature and high friction environment
- In automotive applications due to its better heat transfer properties (Wong et al. 2009).
- In lubrication, soil remediation, oil recovery.
- In biomedical applications like nanodrug delivery, cancer therapeutics, cryopreservation, nano cryosurgery.

## **2.7 Losses in Minichannels**

### **2.7.1 Friction Losses**

The fluid flow is required to overcome resistance occurred due to frictions offered by walls of mini channel and friction by fluid viscosity. As fluid flow through the mini channels fluid energy is dissipated to overcome these resistances.

According to Darcy-Weisbach equation:

$$h_L = \frac{fLv^2}{2gD_h}$$

In case of fully developed laminar flows in circular channels, product of friction factor and Reynolds number is

$$f Re = 64, \text{ for } Re < 2.3 \times 10^3$$

### **2.7.2 Pressure losses**

Most common approach to calculate Pressure Loss due to inlet, outlet and entrance effects was to utilize loss coefficient, K.

Pressure Drop was calculated according to formula:

$$\Delta P = \frac{1}{2} \rho K V^2$$

Value of K is based on conventional analytical and empirical data. For small scale applications little data is available.

### **2.8 Reynolds Number**

Reynolds Number is calculated from the relation

$$Re = \frac{\rho v D_h}{\mu}$$

## 2.9 Heat Transfer Rate

Rate of heat transfer is calculated as:

$$q = \rho Q C_p (T_{\text{out}} - T_{\text{in}})$$

## 2.10 Previous research work related to minichannels, nanoparticles and computational fluid dynamics

A significant number of studies has been available on minichannels, nanoparticles and computational fluid dynamics, which has been review in papers as follow:

Ali Ijam et al. (2012) in this paper, thermal conductivity, pumping power and heat transfer of 2 nanofluids flowing through copper minichannel heat sink have been investigated mathematically. Flow used was laminar and steady. Maximum improvement of 11.98% and 9.97% was obtained in thermal conductivity by adding  $\text{Al}_2\text{O}_3$  nanoparticles and  $\text{TiO}_2$  nanoparticles at 4% Vol. Conc. to water as compared to water.

Ali Ijam et al. (2012) in this paper, nanofluid as a coolant for electronic devices was studied. SiC and  $\text{TiO}_2$  nanofluids with different volume of nanoparticles were analyzed on minichannel heat sink at turbulent flow. Maximum improvement in thermal conductivity was 14.44% and 9.99% was obtained by adding SiC and  $\text{TiO}_2$  nanoparticles to the water as compared to the water. Improvement in heat transfer was obtained when nanoparticles were added to water at different concentrations and flow rates.

Mohamed M. Mousa et al. (2013) carried out an experiment on mini channel having rectangular and triangular cross sectional area. The experiment was done on a copper block

using air as cooling medium. It was found that mini channel of rectangular cross sectional area have better thermal performance than triangular. Performance of the sink also increases with increase in air mass flow rate.

William Grande et al. (2002) in this paper, thermophysical performance of microchannel flow were studied for its applications in cooling microelectronics. Significantly higher heat transfer rates are obtained as by reducing dimensions of channel, larger surface area for heat transfer is obtained. Also surface roughness is increased when channel dimensions are so less.

Moraveji Mostafa et al. (2013) CFD modelling was carried out for laminar force convection through a mini channel employing  $\text{Al}_2\text{O}_3\text{-H}_2\text{O}$  nanofluid.  $\text{Al}_2\text{O}_3$  nano particles of 33nm was used. Three different weight conc. 0.5%, 1% and 6% are used. Reynolds Number was varied between 130-1600. CFD modelling was carried out using different models that is single phase, volume of fraction and eulerian model. It was evaluated that two phase model were accurate as compared to single phase model.

Javedi et al. (2013) examined analytically the consequences of  $\text{Al}_2\text{O}_3$  - liquid nitrogen,  $\text{TiO}_2$ - liquid nitrogen and  $\text{SiO}_2$  liquid nitrogen based nanofluids on the plate fin heat exchanger. After that, its results were compared with liquid nitrogen which was used as a base fluid. The effect of nanofluids on the entropy generation & the pressure drop were also examined. And it was found that the thermal conductivity, heat transfer rate and the heat transfer coefficient of the base fluid were enhanced by mixing the nanomaterials in it.

Maddah et al (2013) experimentally examined the influence of  $\text{Al}_2\text{O}_3$  and Ag nanomaterials on electrical conductivity, thermal conductivity and viscosity. The average diameters of  $\text{Al}_2\text{O}_3$  and Ag nanomaterials were taken as 40 nm and 20 nm. The different volumetric concentrations were taken as 0.25%, 0.5%, 1%, 2%, 3%, 4%, and 5% at 15 c temperature. It was found out that the thermal conductivity and viscosity of nanofluids enhanced when the volumetric concentration of nanomaterials is also enhanced.

Satish G. Kandilkar et al. (2003) this paper gives us the review of recent research, classifications, history and terminology related to micro and mini channels. Some biological systems consist of microchannels and minichannels which provide high heat and mass transfer rates in the body organs such as liver, lung, brain and kidney. High heat capabilities of the channels are being utilized by many high flux cooling application. In this paper overview of the historical perspective of some issues related to microchanel and minichannels is presented and analyzed through some of the techniques.

Taylor et al. (2011) used experimental and modeling approach to determine the nanofluid's optical properties. For this, they compared the experimental and modeling results to measure the extinction coefficient vs wavelength having range of 0.25-0.5 $\mu\text{m}$ . it was also found that graphite – water based nanofluid and aluminum – water based nanofluid showed good response but other metals and base fluid ie. oil showed less well response.

Satish G. Kandilkar et al. (2004) In this paper the application of the small hydraulic diameters are implemented in the electronic cooling, fuel cell evaporators, compact evaporator passages and the other electronic devices. The characteristics of the high pressure drop of the passages are very important particularly because they are responsible

for the heat transfer and alter the flow, especially in parallel multichannel configuration. In some passage there is dry out due to pressure drop oscillations while single phase mode is applied to their neighboring passages. a comprehensive review of the literature of this paper on evaporation in small area/diameter passages along with some of the results that have been concluded by the auther fot water that is evaporating in 1mm hydraulic diameter of the multichannel passages.

Azari et al. (2014) conducted CFD simulation of  $Al_2O_3$  based nanofluid in laminar flow flow regime. They used two phase model. And concluded that the heat transfer rate is increased by increasing the volume concentration of nanomaterials. And also concluded that two phase model give more precise results as compared with single phase model.

Laura et al. (2012) has given the information about stability, viscosity and thermal conductivity of water-based nanofluids containing  $TiO_2$  nanoparticles. With increase in mass concentration and temperature, thermal conductivity of  $TiO_2$ -water nanofluids was increased. The performance of viscosity was calculated by means of a Rheometer in the temperature range between 283K and 343 K as a function of concentration and temperature.

Jajja Saad Ayub et al. (2014) CFD was carried out on five different forms of heat sinks having fin spacing of 0.2mm, 0.5mm, 1mm and 1.5mm along flat plate heat sink. Effect of spacing on the performance of heat sink was evaluated. It was reported that as the fin space is made to decrease then corresponding decrement in the thermal resistance was witnessed. With 0.2mm spacing, thermal resistance was reduced to 0.03 K/W from 0.216 K/W.

John Bean et al. (2006) in this paper, experiment is done of 3 coil inlet header configurations that is in single, dual and distribution inlet header. Computational Fluid Dynamics models are generated to simulate refrigerant flow of these 3 configurations. Among these 3 configurations, distributed header performed most uniform refrigerant flow distribution with good flow symmetric contour. Dual inlet configuration also improves refrigerant flow distribution symmetry and uniformity.

S. Murshed et al. (2008) As we know that now a day sizes of heat transfer devices decreases and at the same time adequate cooling must be provided. It is difficult for the devices to operate under high operating speed, therefore temperature of devices increases to very high value which makes the devices to operate at high power.

Satish G. Kandilkar et al. (2004) in this paper for the compact heat exchangers and the conventional channels, techniques of the heat transfer enhancement for the single phase are presented. the major techniques which consisting of breakup of boundary layer, electric fields, secondary flow and mixtures, flow transition, entrance region, vibrations are discussed in the paper. For the single phase flows in the microchannels and the minichannels, applicability of these techniques are evaluated. For the critical applications, applicability of the single phase cooling is extended by heat transfer enhancement devices for the microchannels and minichannels.

Das et al. (2003) investigated the thermal conductivity enhancement with temperature of  $\text{Al}_2\text{O}_3$  and  $\text{CuO}$  water-based nanofluids. Temperature Oscillation technique was used to measure the thermal conductivity. Average diameter of alumina particles was 38.4 nm and for  $\text{CuO}$  was 28.6 nm the experimental results showed that with increased in temperature

thermal conductivity increased. Nanofluid containing smaller particles (CuO) showed greater enhancement in thermal conductivity with temperature. Enhancement in conductivity also depended on particle concentration, as concentration increased thermal conductivity increased.

Schmidt, R. et al. (2003) in this paper the problems regarding the heat transfer and fluid flow were highlighted associated with electronic cooling. In the heat transfer and fluid flow, classical approaches are not being followed by solution to these problems. Solution to the problems are generally combination of application of the technical tools and engineering judgments. The component junction temperature and system operating has strong function i.e. performance and reliability of electronic systems. Requirement of the understanding of governing physical laws is essential to find correct solution to the problem. Concurrently, it is very important to know that where this physical law should be implemented and what each law controls. In the cooling of electronic system, two forms of energy transport are presented i.e. heat transfer and fluid flow. In many cooling problems these two phenomena are strongly coupled. As a result, for obtaining the solution for these problems may require numerical simulation or experimentation as problems become complex.

Poh-Seng Lee et al. (2005) Experimental investigation is presented to explore the classical correlation's validity for analyzing the thermal behavior in single phase rectangular micro-channels that is based on conventional sized channels. The range of the micro channel is considered from 194  $\mu\text{m}$  to 534  $\mu\text{m}$  in width, with the channel depth is taken as five times the width of the channel in each case. There were ten micro-channels in parallel and each piece was made of copper. The de-ionized water was used for the experiment and an Reynold's no. was ranging from approximately 300 to 3500. Numerical predictions those

obtained were based upon the continuum and classical approach. Those predictions were found in a appropriate agreement with the data showing average deviation of 5%.

R.R. Riehl et al. (1998) In this paper heat transfer correlation is compared for the single and two phase micro-channel flows for the micro-electronics cooling. Four heat transfer correlations are compared for single phase and six heat transfer correlation are compared for two phase micro-channel flow had been analyzed, Reynold's no. analyzed the same was ranging between 300 and 80,000. The analyzed results were very close for the single phase correlations and two phase flow for this range, for low mixture quality. There was a higher value of the nusselt no. for two phase correlation, for the higher mixture qualities. Correlations were compared from several investigations with the equivalent flow conditions and three different working fluids. A consistent correlations of boiling and convective no. was found while there was a need of an extensive study with other develop correlation for liquid flows and potential modification were also required for the micro-channel base flow problems.

X.N. Jiang, Z.Y.Zhou et al. (1997) In this paper It is explained that in the past decade there are various theoretical an experimental analysis have been reported. The experimental studies of the liquid having laminar flow is presented through small hydraulic diameter with different cross sections. The experimental results come out quite similar as the results which we get through the theoretical studies for the conventional ducts. Power densities and increase of power dissipation at the chip and module level has become the most important aspects of the electronic packaging in thermal management. Conventional cooling technology are not enough to meet the requirement of the future semiconductor

devices. For the more efficient heat dissipation or cooling the small scale system cooling technologies are to be implemented for the electronic and optical devices.

J. Judy et al. (2002) in their paper investigates pressure driven liquid flow through round and square micro channels fabricated from fused silica and stainless steel. Pressure drop data are used to characterize the friction factor for channel diameters in the range 15-150  $\mu\text{m}$  and over a Reynolds number range 8-2300. Distilled water, methanol, and isopropanol were used in this study based on their distinct polarity and viscosity properties. Distinguishable deviation from Stokes flow theory was not observed for any channel cross-section, diameter, material, or fluid explored.

D. B. Tuckerman et al. (1981) This paper tell about how planar integrated circuits come across some problems when it comes to achieve compact and high performance forced liquid cooling. To achieve low thermal resistance the convective heat-transfer factor 'h' was found as primary impediment between the substrate and coolant. The convective heat-transfer factor 'h' scales inversely with the channel width to get the microscopic channels desirable when it comes to laminar flow in confined channels. Thermal resistance would get reduced by increase in surface area caused by use of high aspect ratio channels. Based on these considerations, very compact and water cooled heat sink for silicon integrated circuits had been designed and then tested. Substrate temperature rise of  $71^{\circ}\text{C}$  was measured above input water temperature at the power density of  $790 \text{ W/cm}^2$ , in good agreement with the theory. The feasibility of ultrahigh-speed VLSI circuits may greatly enhanced by heat sink by allowing such high power densities.

Satish G. Kandilkar et al. (2001) studied the effect of surface roughness on heat transfer and fluid flow characteristics in small diameter tubes. Single and two phase flow and heat transfer in small channels is receiving considerable attention recently in an effort to enhance the performance of heat exchange equipment. It is well known that by increasing the channel size, we get an enhancement in the heat transfer coefficient with an increasing in pressure drop. For small hydraulic diameter passages, the small roughness features on the wall play an important role in heat transfer and pressure drop characteristics of the flow.

Colgan et al. (2005) the paper facilitates the investigation of single phase liquid heat transfer by certain experimental methods and in a variety of micro-channels pressure drop is also measured. The experimental facility was very much capable of measuring heater surface temperature, differential pressure in test section, heat transfer rates, and fluid temperature. Capability of the experimental facility is demonstrated by a microchannel section which is using silicon material as substrate. To provide heat input to the silicon substrate we fabricate copper resistor to the backside of the substrate. For calculating the different surface temperature and acquiring heater temperature several copper resistor were fabricated with four point measurement technique. For the formation of the micro-channel flow passages the chip got bonded by a transparent Pyrex cover. Fundamental data collection in microchannel flows gets supported by the experimental facility. Experiment facilitates you of optical visualization of dyes and particles using a traditional microscope. In selecting the equipment the uncertainties of the experiment had been carefully measured in the experimental facility.

Philips, Richard J. et al. (1987) presented microchannel heat sink used to cool a high power electronic device such as an integrated circuit comprising a plurality

of channels in close thermal contact to the integrated circuit and through which a liquid is passed to create either a developing laminar flow or a turbulent flow. The turbulent flow may be either developing or fully developed. The heat sink features a compensation heater surrounding the integrated circuit and heated at the same rate as the integrated circuit to thereby provide a more uniform temperature at the perimeter of the integrated circuit.

A.D. Ferguson et al. (2005) this paper tells about the experimental measurement, system components, error analysis and some other important issues which may have been discussed in other literatures. Their study is based upon experimental procedures and other useful guidelines which further help for research in micro fluidics.

Steinke et al. (2006) based upon the manufacturing techniques, underlying fluid mechanics and heat transfer theory, a new channel size classification is introduced. Six parallel channels were manufactured and tested experimentally with a hydraulic diameter of 207 micrometers. They measured the pressure drop in the micro-channels and observed the flow boiling patterns.  $930 \text{ k W/m}^2$  was the value of heat flux that was maintained throughout the experiment. Also, local heat transfer coefficient and quality was measured. Largest value of heat transfer coefficient was  $192 \text{ kW/m}^2\text{K}$  they could achieve. It was suggested by the authors that in micro-channels, conventional flow boiling patterns could be occurred.

A.G. Agwu Nnanna et al. (1996) Vapor compression system's (VCR) transient response is get investigated for rapid change in the evaporator for that heat load is presented. In this study, the designing and construction of VCR is specifically done for application to cool high end computers and high heat flux electronics. Measurement of temperature and

pressure is done at pre-selected locations and behavior of refrigeration system is studied to alterations in evaporator heat load. Results shows that the junction temperature of stimulated electronics is maintained at a much lower temperature by the VCR system when it is compared to conventional cooling systems. Experimental evidence shows that the evaporator time constants and thermostatic expansion valve are equal and have a value of 70 s. It is also shown by the experiment that at the thermostatic expansion valve prior to attain steady state condition and evaporator cold plate, there is oscillation in temperature occurs with time. Also, heat transfer consist of analytical model and the numerical models in the evaporator cold plate, it shown by the results that assumptions taken for the one dimensional temperature distribution is unrealistic.

Sylvain Reynaud et al. (2005) in this paper friction and heat transfer coefficients of 2D mini-channels are measured of thickness ranges from 1.12mm to 300 $\mu$ m. The measured pressure drop is helpful in calculating the friction factor along the whole channel. At the wall using a specific transducer, the heat transfer coefficient is calculated from local and direct measurement of both heat flux and temperature. Classical correlations relative to conventional size channels are in good agreement with the experimental results. The observed deviation is observed by two ways either by imperfections of experimental apparatus or by macroscopic effect.

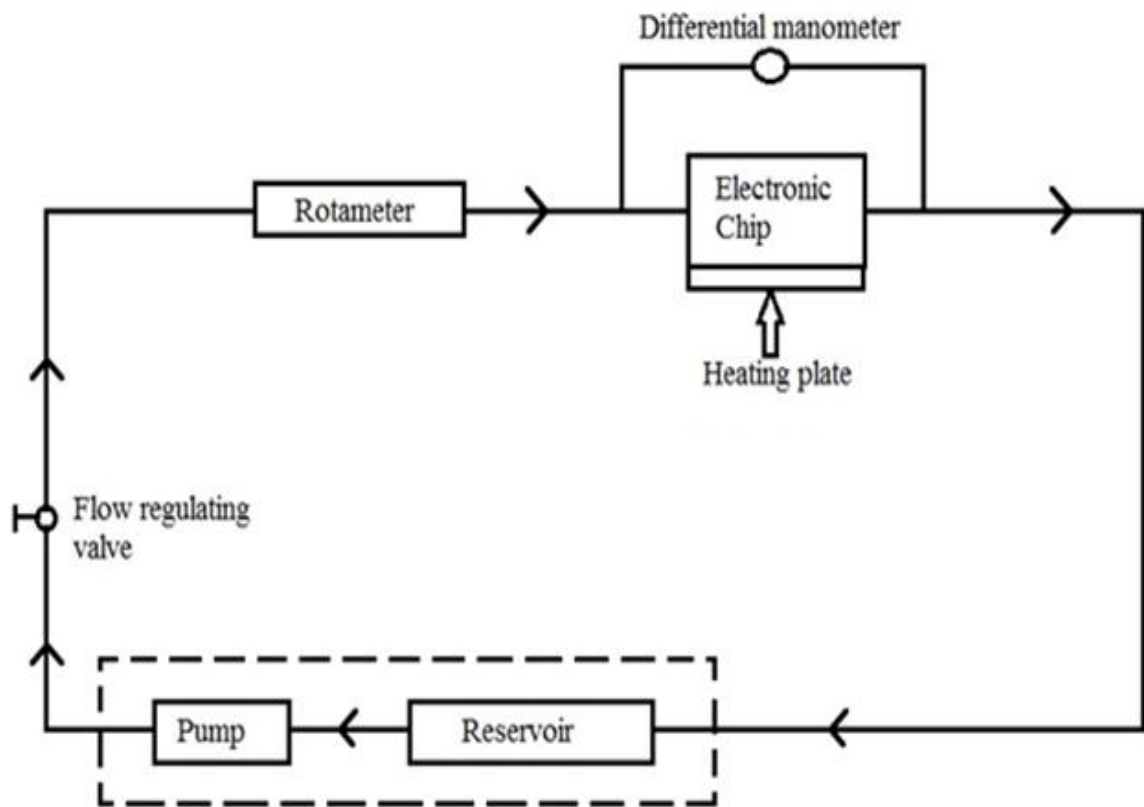
## CHAPTER 3                      EXPERIMENTAL WORK AND SIMULATION PROCEDURE

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Experimentation was done using Distilled Water, Nano Fluid containing Alumina Nano Particles at 0.01% Vol. Conc. and 0.05% Vol. Conc. at different mass flow rates.

### 3.1 Experimental Setup

A schematic diagram of experimental setup is shown in Fig.3.1



**Fig. 3.1** Schematic of Experimental Setup

Set up consists of Aluminium test block. Minichannel of particular dimensions was fabricated on aluminium block which was mounted by glass cover with the help of water

tight adhesive to make it leak proof and to visualize the fluid flow. Flat plate heater was attached at the bottom of the block to heat the fluid flow. Liquid contained by the fluid tank was driven by the pump at different flow rates. Rotameter is used to measure flow rate. Flow regulating valve is attached before the rotameter to adjust the flow. Differential manometer and thermocouples were used to measure the pressure drop and temperature respectively at inlet and outlet of minichannel. Coolants used in the experiment are Distilled water, nanofluid containing alumina nanoparticles at 0.01% Conc. Vol. and 0.05% Conc. Vol.



**Fig.3.2** Experimental Setup

### 3.1.1 Components of Experimental Setup

- Aluminium Heat Sink
- Flat Plate Heater
- Water Tank (Reservoir)
- Pump

#### Heat Sink

The test section consists of Aluminium block whose dimensions are:

Length = 85 mm

Breadth = 60 mm

Depth = 15 mm

Aluminium block covered with glass is shown in figure 3.3



**Fig 3.3** inichannel heat sink

Dimensions of minichannel are-

**Table 3.1** Dimensions of Minichannel

Length	245 mm
Area	7.965 mm <sup>2</sup>
Perimeter	11.3 mm
Hydraulic Diameter	2.81 mm
Width	2.95 mm
Depth	2.7 mm

Formula used to calculate hydraulic diameter is

$$\text{Hydraulic Diameter } (D_h) = 4 * \text{Area} / \text{Perimeter}$$

### **Flat Plate Heater**

Bottom attached flat plate heater is of dimensions 60 mm\*40 mm\*5 mm and heat load capacity of 150 Watt.

### **Tank (Reservoir)**

Cylindrical liquid tank used as a reservoir had capacity of 3 litres as shown in Fig. 3.1

## Pump

The pump (shown in figure 3.4) had maximum flow rate capacity of 1500 L/hr.



**Fig. 3.4** Pump

**Table 3.2** Different Parameters of the system

Heat sink material	Aluminium
Length	85 mm
Breadth	60 mm
Depth	15 mm
Max. capacity of water pump	1500 L/hr
Water tank capacity	3 L
Heating element	150W

### 3.1.2 Measuring Devices

Different measuring devices such as

- Thermocouples
- Differential Manometer
- Rotameter

were used to measure temperature, pressure drop and flow rate of the flowing liquid.

### **Thermocouple**

Thermocouple (shown in figure 3.5) had the range of  $0^{\circ}\text{C}$  to  $150^{\circ}\text{C}$ . Two thermocouples were used in the experiment.



**Fig 3.5** Thermocouple

### **Position of Thermocouples**

One thermocouple is positioned at the inlet of minichannel and second thermocouple at the outlet. Fig. 3.6 shows the position of thermocouples in aluminium heat sink.





**Fig 3.7** Differential manometer



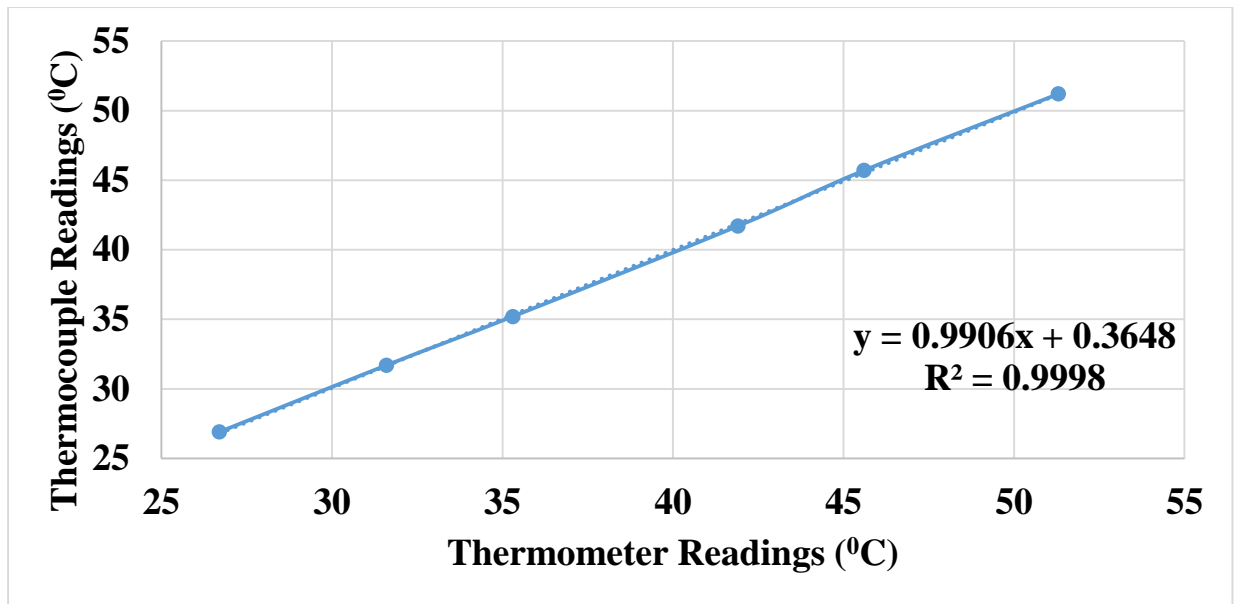
**Fig. 3.8** Rotameter

### **Rotameter**

Rotameter was used to measure the flow of fluid coming from the liquid tank as shown in Fig. 3.8. It had range of 10L/hr to 100L/hr.

### **3.2 Calibration**

Before performing experiment, calibration of thermocouple was done. Water is taken in 250 ml beaker and its temperature was measured using thermometer. Simultaneously, temperature was measured using thermocouple. Then the temperature of water was raised by keeping beaker on the hot plate and again its value was recorded. Similar procedure was performed for further procedure and following results were obtained:



**Fig.3.9** Calibration curve for thermocouple

### 3.3 Operational Procedure

After performing Calibration, the following experimental procedure is followed-

- 1) All the pipeline connections were checked for leakage and pump was switched on to make the flow of coolant in the circuit.
- 2) After this flow rate was measured with rotameter and then the flow was adjusted to the desired value with the help of flow regulating valve.
- 3) After setting the required flow rate when heater was switched on, steady state was reached in 100-120 minutes.
- 4) Temperature at inlet and outlet was measured with the help of thermocouples.
- 5) Simultaneously, pressure drop was measured using differential manometer at inlet and outlet of the minichannel.
- 6) Readings from thermocouples and manometer were stored to calculate further results.

7) Samples of each fluid was collected to measure their properties such as density, conductivity etc.

### 3.4 Properties of alumina (Al<sub>2</sub>O<sub>3</sub>) nanoparticle

Properties of the purchased alumina (Al<sub>2</sub>O<sub>3</sub>) nanoparticle are depicted in the table 3.3 below:

**Table 3.3** Properties of nanoparticles

Chemical name	Alumina Nano powder
Particle size	20-30 nm
Particle shape	Spherical
Appearance	White
pH value	6.6
Density	3.97 gm/cm <sup>3</sup>
Specific surface area	15-20 m <sup>2</sup> /gm
Crystal form	Alpha
High purity	99%
Thermal conductivity of particle	36 W/ m-K
Special heat of particle	765 J/ kg-K

### 3.5 Preparation of Nanofluid

For preparing a nanofluid of desired concentration, nanoparticles are dispersed into the base fluid i.e. water. Volume concentration of 0.01% was prepared by mixing 1.185 gm of nanoparticles in 3 L of distilled water. To make the nanoparticles more stable and more dispersed in water, ultra sonicator was used. Sonication was done for 3 hours before testing density, thermal conductivity & viscosity of the nanofluids. Then these properties were measured at various temperatures by heating nanofluids over hot plate. The Al<sub>2</sub>O<sub>3</sub>/water nanofluid sample stirred is shown in Figure 3.10



**Fig.3.10** Magnetic Stirrer



**Fig.3.11** Ultra sonicator water bath

#### Ultra Sonicator water bath

Ultra sonicator (as shown in Fig.3.11) produce ultrasonic sound wave energy to agitate the nanoparticles in base fluid, and to make them in suspension for longer time period. Sonication can be used to speed dissolution, by breaking intermolecular interactions. Figure 3.12 shows the water and prepared nanofluids which are to be used for the experiment.



(a)

(b)

(c)

**Fig.3.12** Prepared samples: (a) distilled water, (b) 0.01% vol. conc. Al<sub>2</sub>O<sub>3</sub>-H<sub>2</sub>O (DI) nanofluid, (c) 0.05% vol. conc. Al<sub>2</sub>O<sub>3</sub>-H<sub>2</sub>O (DI) nanofluid

### 3.6 Instruments used for preparation of nanofluid and to measure various properties of Al<sub>2</sub>O<sub>3</sub>/Water Nanofluid

The objective of the present work is to prepare nanofluid of Aluminium oxide with distilled water as base fluid, measurement of thermo-physical properties (thermal conductivity, viscosity and density). These measurements are performed by using KD2 pro thermal property analyzer, viscometer, Rheometer, densitometer.

#### 3.6.1 Rheometer

Dynamic viscosity of the nanofluid is measure through Brookfield rheometer (Anton Paar) which is shown in figure 3.13. It consists of cope and cone shape like device and a spindle is dipped into the sample whose property is to be measured. Spindle is made to rotate and due to which the viscous drag is produced in the fluid against the spindle. The viscous drag is measured with the help of deflection produced within the calibrated spring.



**Fig.3.13 Rheometer**



**Fig.3.14 Densitymeter**

### **3.6.2 Densitymeter**

Densitymeter (shown in figure 3.14) was used to measure the specific density of nanofluid.

### **3.6.3 Thermal properties analyzer KD2 PRO**

Thermal conductivity of nanofluid is measured by KD2 PRO (shown in figure 3.15). It consists of panel which is hand handler type and a sensor which is inserted in medium, through which thermal conductivity is measured. .



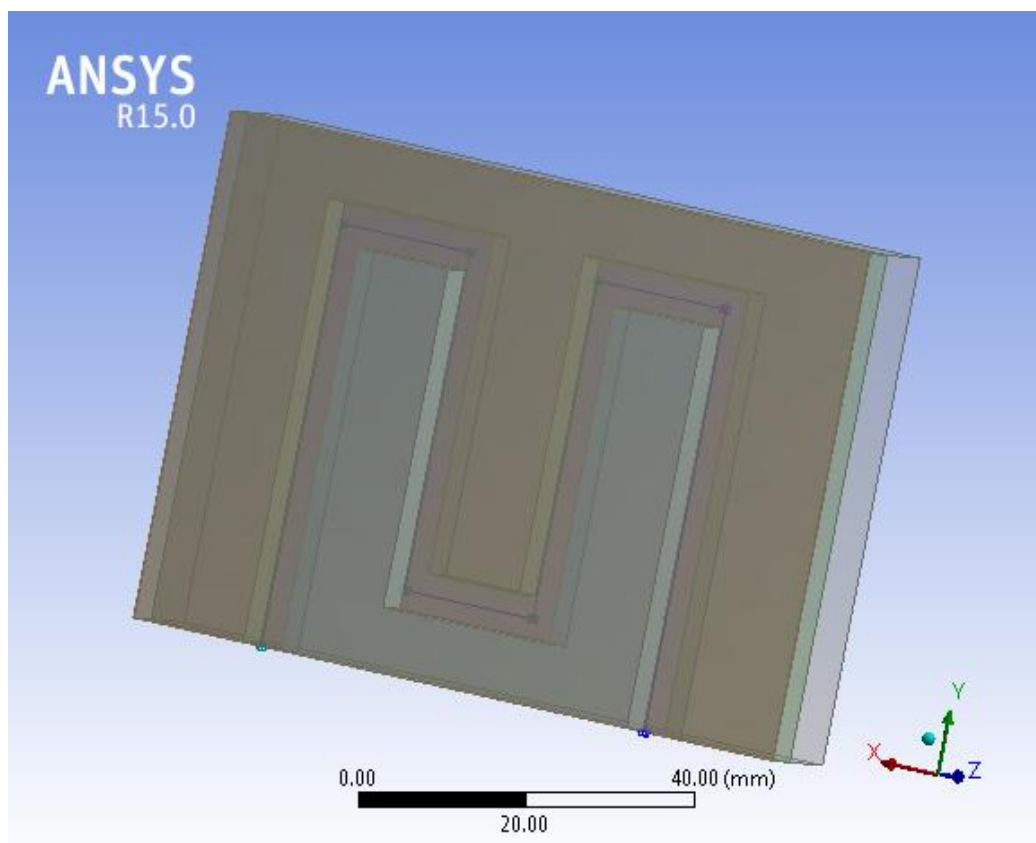
**Fig.3.15 KD2 Pro**

### 3.7 Simulation Procedure

Simulation of minichannel was performed using CFD, for water and nanofluid as cooling medium. The simulation procedure is given below.

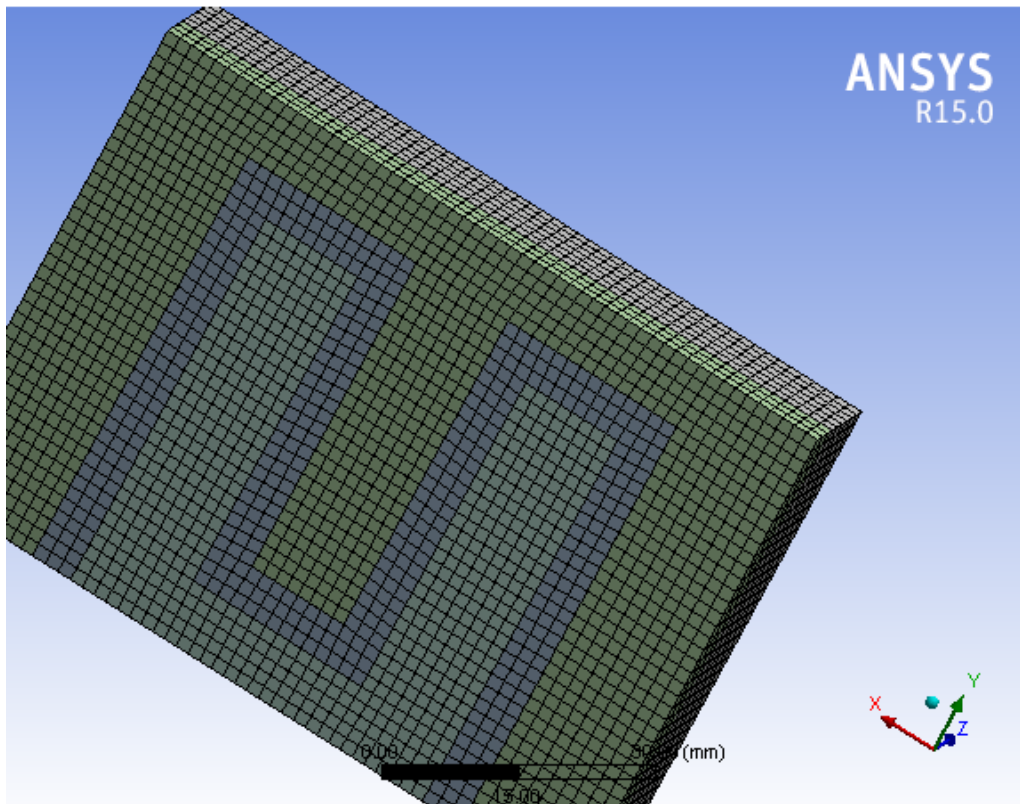
#### 3.7.1 Geometric Modelling

The geometry consists of Aluminium heat sink having dimensions length-85mm, width-60mm and depth-15mm. In this heat sink, mini channel of rectangular cross-section having dimension 2.81mm\*2.7mm is grooved with the profile shown in the following geometry.



**Fig.3.16** Geometric Model of Heat Sink

### 3.7.2 Meshing



**Fig.3.17** Meshed Geometry of Heat Sink

**Table 3.4** Meshing Details

Nodes	32416
Elements	23679
Mesh Metric	Skewness
Minimum	1.3057293693791 E-10
Maximum	0.292283360341277
Average	2.93673803052147 E-03
Standard Deviation	1.52932949023585 E-02

### 3.7.3 Material Model

Following materials are used in CFD simulation

- Distilled Water
- Aluminium
- Al<sub>2</sub>O<sub>3</sub>-water nanofluid (0.01% vol. conc. and 0.05% vol. conc.)

**Table 3.5** Thermophysical properties of various materials used in CFD.

<b>Thermophysical properties</b>	<b>Water</b>	<b>Aluminium</b>	<b>Al<sub>2</sub>O<sub>3</sub>-water (0.01% vol. conc.)</b>	<b>Al<sub>2</sub>O<sub>3</sub>-water (0.05% vol. conc.)</b>
<b>Density(kg/m<sup>3</sup>)</b>	998.2	2719	1020	1139
<b>Specific heat (J/kg/K)</b>	4182	871	3928	3484
<b>Thermal conductivity (W/mK)</b>	0.6	202.4	0.655	.667
<b>Viscosity (m<sup>2</sup>/s)</b>	0.001003	-	0.00062	0.00067

### 3.7.4 Boundary Conditions

#### a) Flow Conditions

The flow at the inlet was maintained as uniform mass flow at ambient temperature conditions. By varying velocity by 0.696 m/s, 1.393 m/s, 2.084 m/s and 2.435 m/s. The

outlet pressure is specified as Zero bar (gauge pressure). No slip condition was used for the walls.

**Table 3.6** Flow conditions used in CFD

<b>Velocity (m/s)</b>	<b>Temperature</b>
0.696	50
1.393	46.5
2.084	45.9
2.435	44.1

**b) Heat Flux Boundary Conditions**

For the Heating Surface, heat flux was assigned whereas adiabatic Boundary Conditions was used for all other faces of Aluminium heat sink.

### **4.1 Purpose of Study**

In the dissertation, liquid cooling in Mini-channel have been studied. Aluminium heat sink has been selected having mini-channel on it. Coolants choosed separately for the purpose are Distilled Water and mixture of Alumina ( $Al_2O_3$ ) Nanoparticles and Distilled Water at a concentration of 0.01% volume concentration and 0.05% volume concentration. The objective was to experimentally evaluate the performance of a mini-channel heat sink for cooling of electronic circuits. For all these three cases, pressure change and temperature profile were studied and compared.

### **4.2 Property Comparisons**

Some properties such as density, viscosity, and conductivity have been measured using instruments such as densitometer, rheometer and KD2 pro respectively at different temperatures. These properties have been represented graphically. In each graph, property of distilled water and nanofluids at 0.01% Vol. Conc. and 0.05% Vol. Conc. have been compared.

#### **4.2.1 Variation of Density with Temperature**

Fig. 4.1 shows the variation of density with temperature for distilled water and nanofluids at 0.01% Vol. Conc. and 0.05% Vol. Conc. Density has shown decreasing trend with increase in temperature. At particular temperature, density of water increases with increase in the concentration of nano particles. A decrease of 2.15% have been obtained for density

of water when the temperature was increased from 30<sup>0</sup> C to 76<sup>0</sup>C. An increase of 14.95% has been observed in density at room temperature, when the concentration of nano particles is raised from 0-0.05%

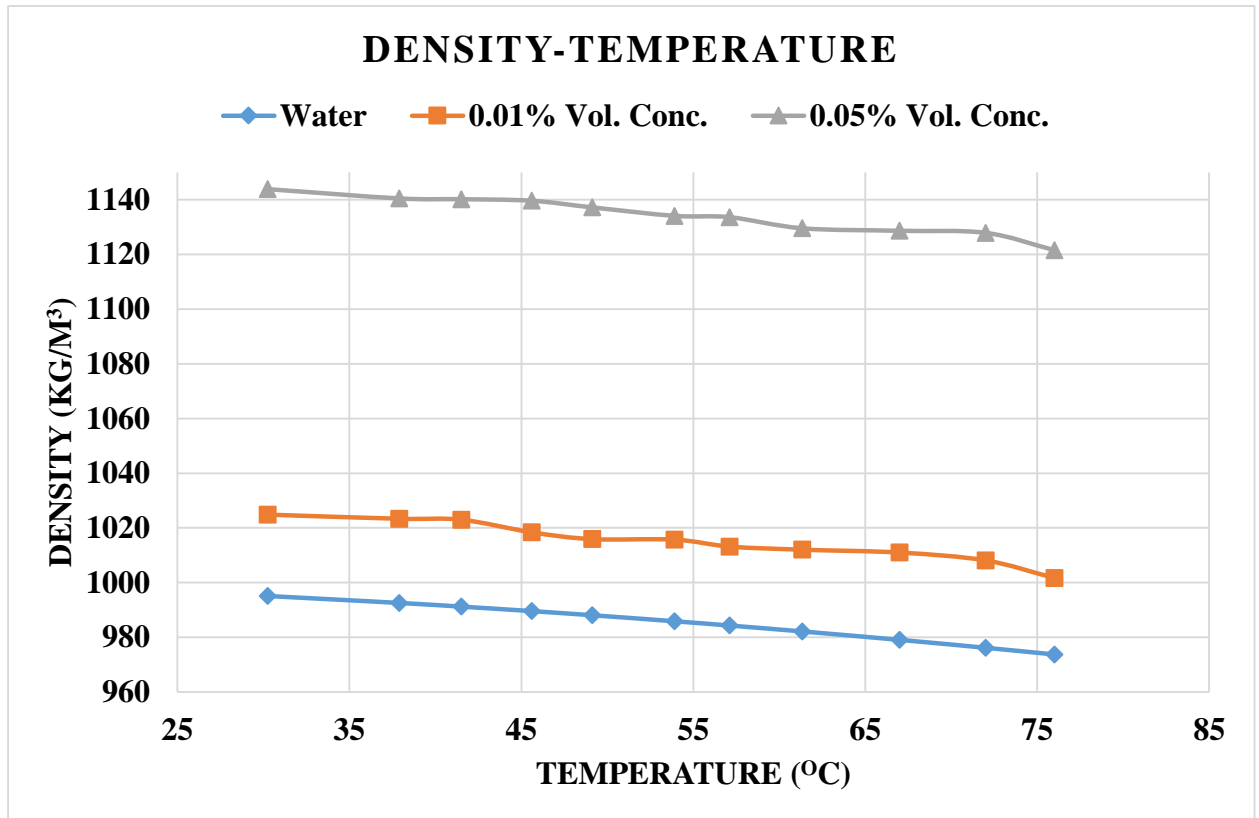


Fig 4.1 Density versus temperature at different concentration of water

#### 4.2.2 Variation of Viscosity with Temperature

Fig. 4.2 shows the variation of viscosity with temperature for distilled water and nanofluids at 0.01% Vol. Conc. and 0.05% Vol. Conc. Viscosity has shown decreasing trend with increase in temperature. A decrease of 52.9% have been obtained for viscosity of water when the temperature was increased from 31<sup>0</sup> C to 77<sup>0</sup>C. An increase of 13.6% has been observed in viscosity at room temperature, when the concentration of nano particles is raised from 0-0.05%

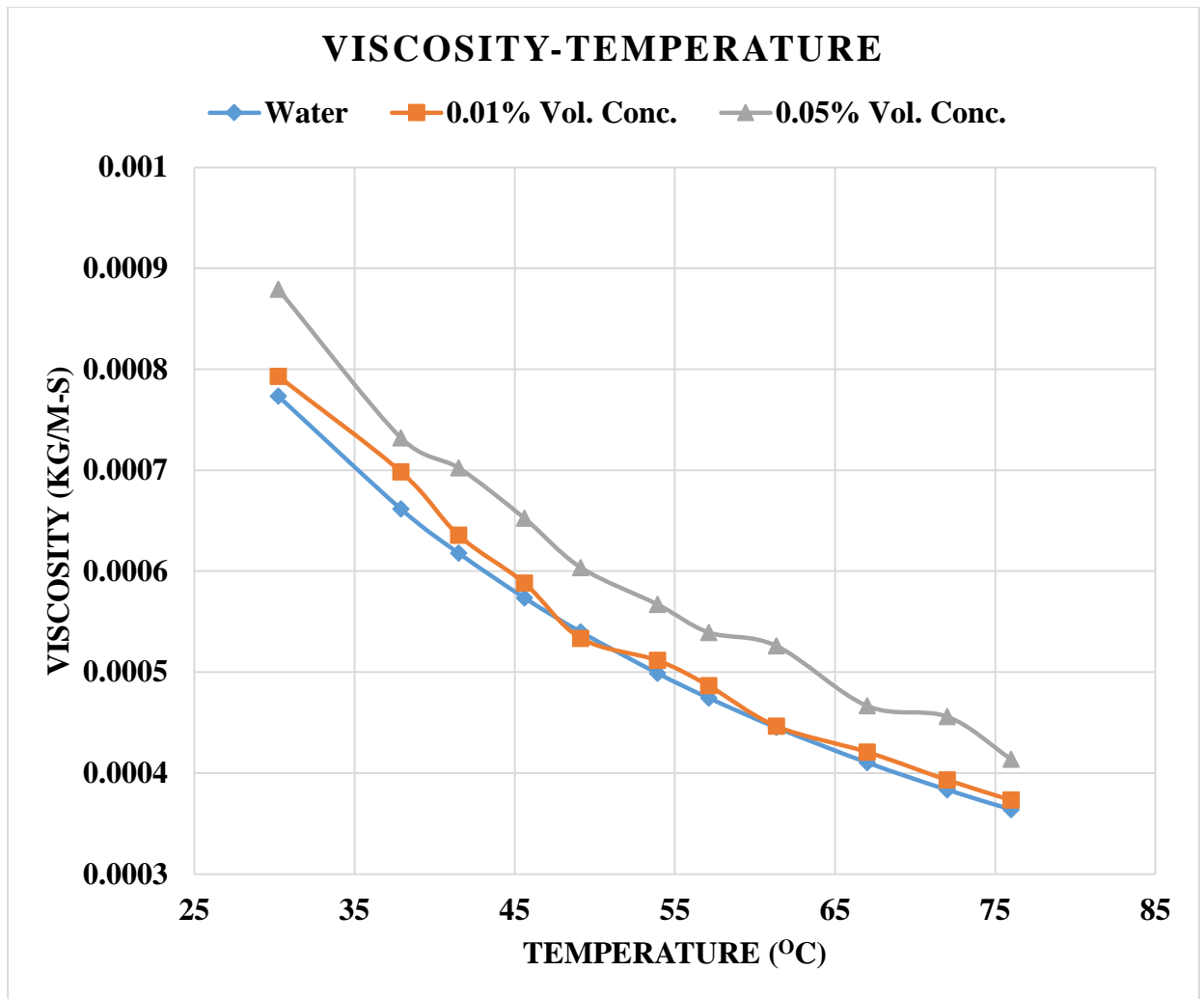
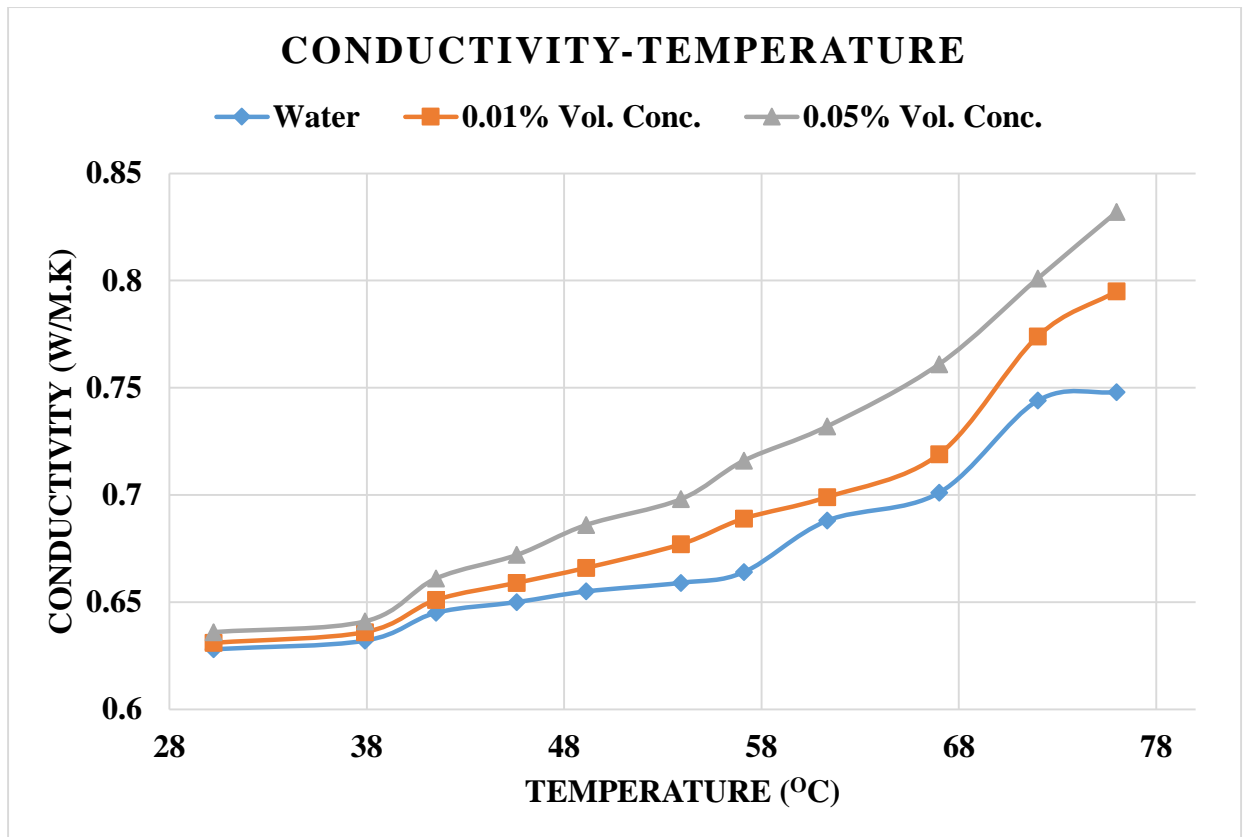


Fig. 4.2 Viscosity versus temperature at different concentration of water

#### 4.2.3 Variation of Conductivity with Temperature

Fig. 4.3 shows the variation of conductivity with temperature for distilled water and nanofluids at 0.01% Vol. Conc. and 0.05% Vol. Conc. Conductivity has shown increasing trend with increase in temperature. At particular temperature, conductivity of water increases with increase in the concentration of nano particles. An increase of 19.1 % have been obtained for conductivity of water when the temperature was increased from 30.6<sup>0</sup>C to 75.4<sup>0</sup>C. An increase of 1.2% has been observed in conductivity at room temperature, when the concentration of nano particles is raised from 0-0.05%



**Fig. 4.3** Conductivity versus temperature at different concentration of water

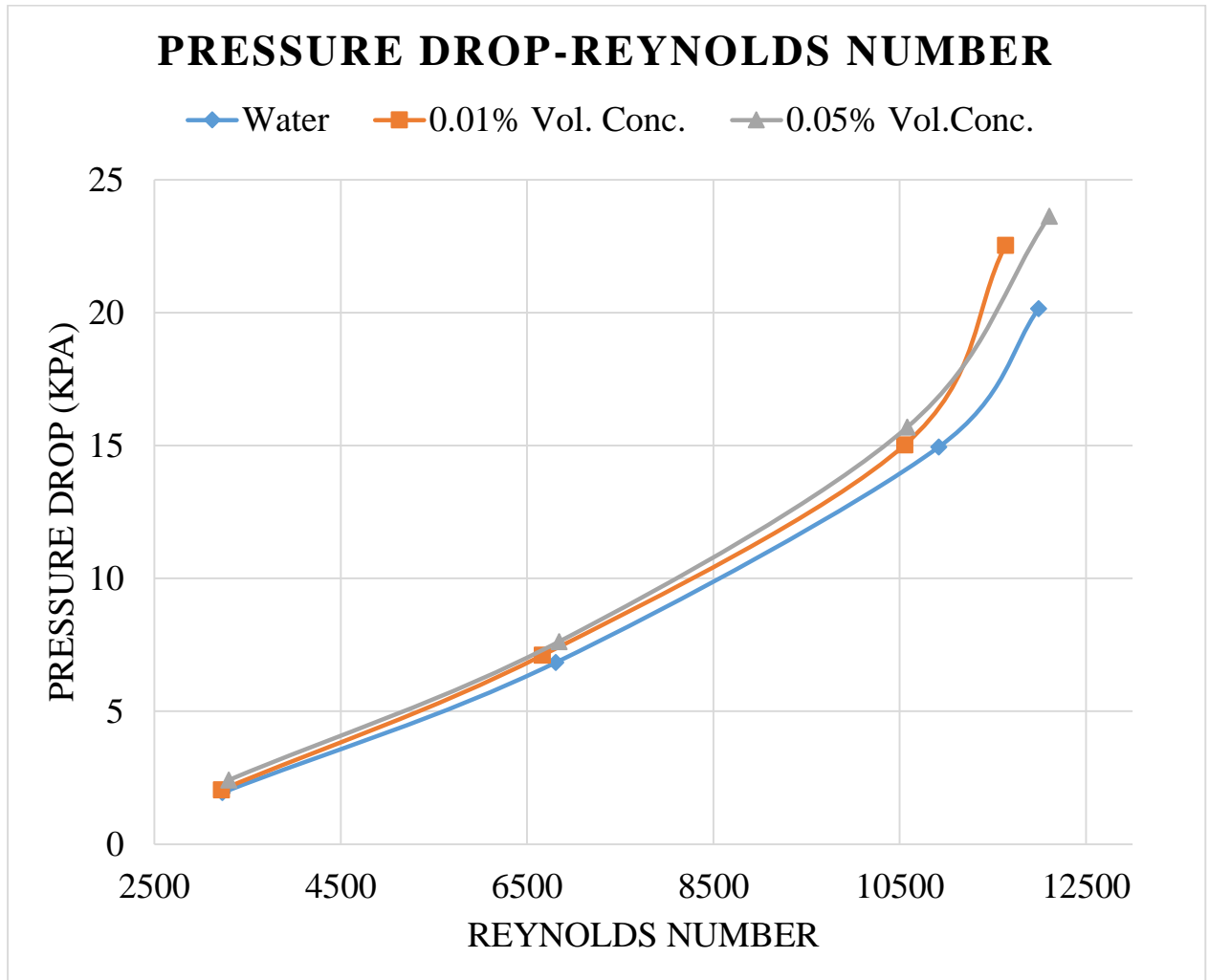
### 4.3 Results Comparison

All the readings obtained from the experiments have been represented graphically. Different graph showing the variation of pressure drop, friction factor, temperature (inlet and outlet) and fanning friction factor with Reynolds number have been drawn depicting all the coolants.

#### 4.3.1 Variation of Pressure Drop with Reynolds Number

From fig 4.4, it is clear that pressure drop has increased with increase in Reynolds number. The trend of increasing is almost parabolic which also satisfies the theoretical aspect as per the Darcy equation. According to which, pressure drop is directly proportional to square of

velocity, as Reynolds number signifies the variation of velocity. Hence, this trend of pressure drop with Reynolds number is justified for all concentrations. On addition of nanoparticles, there is not much change in the pressure drop value. This is because nanoparticles are added at very small concentrations.

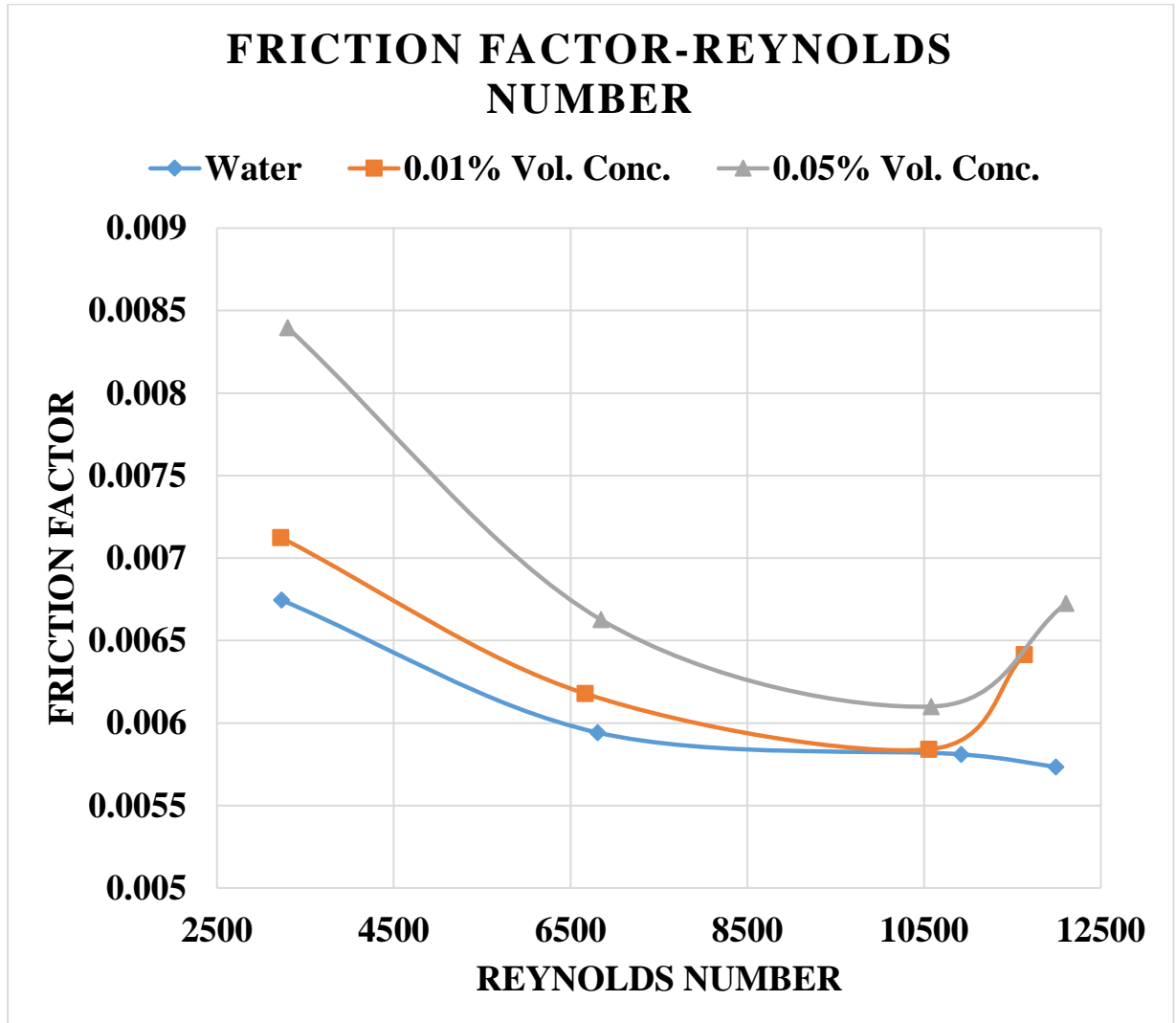


**Fig 4.4** Variation of Pressure Drop with Reynolds number.

#### 4.3.2 Variation of Friction Factor with Reynolds Number

Figure 4.5 shows that the friction factor has decreasing trend with increase in Reynolds number. Variation of friction factor is very small for water. In case of 0.01% Vol. Conc.,

variation is slightly more as compared to water. Very large variation was recorded in the case of 0.05% Vol. Conc.

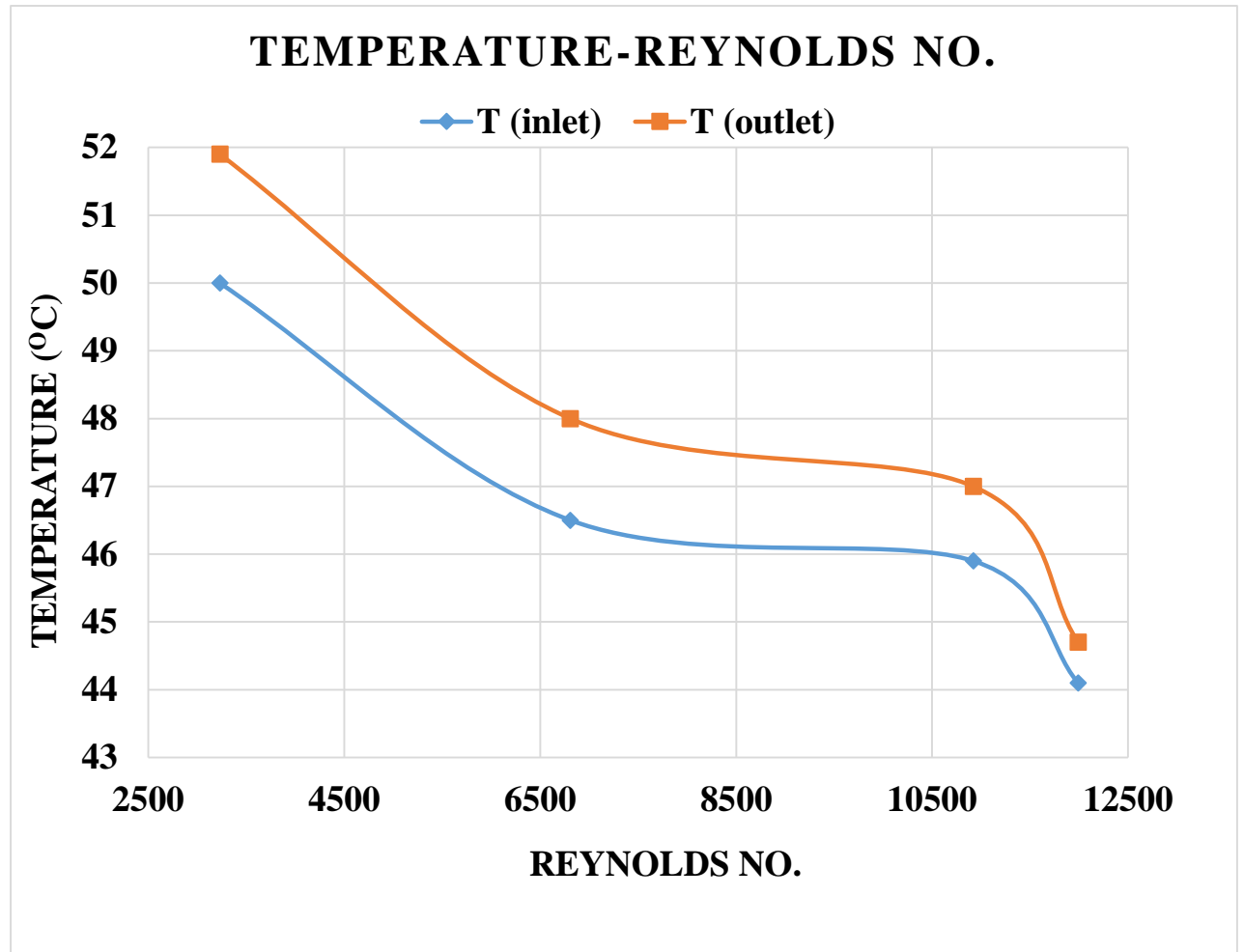


**Fig 4.5** Variation of Friction Factor versus Reynolds Number

### 4.3.3 Variation of Inlet and Outlet Temperature of channel with Reynolds Number

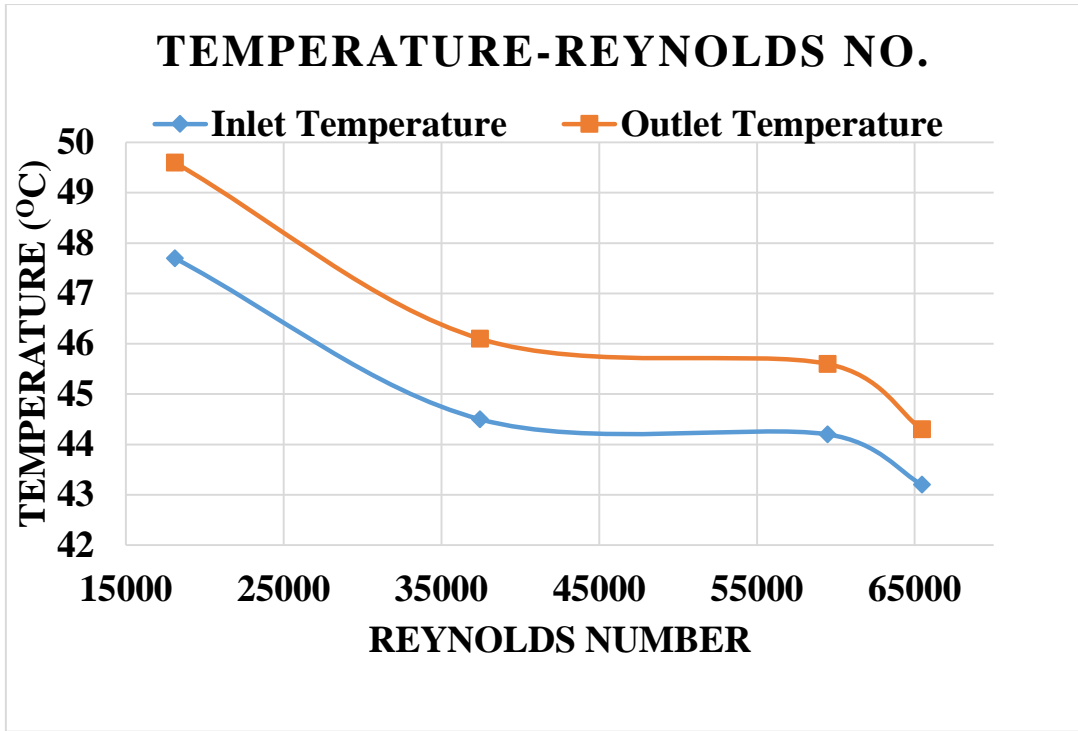
Figure 4.6 shows that inlet temperature has decreasing trend with increase in Reynolds number. It means with increase in flow rate system has reached steady state in smaller period. At low Reynolds Number there was much difference in between inlet and outlet

temperature. As Reynolds Number increases, difference between inlet and outlet temperature decreases. This is due to decrease in the available time for heat transfer because at high flow rates cooling medium has travelled with high velocities.



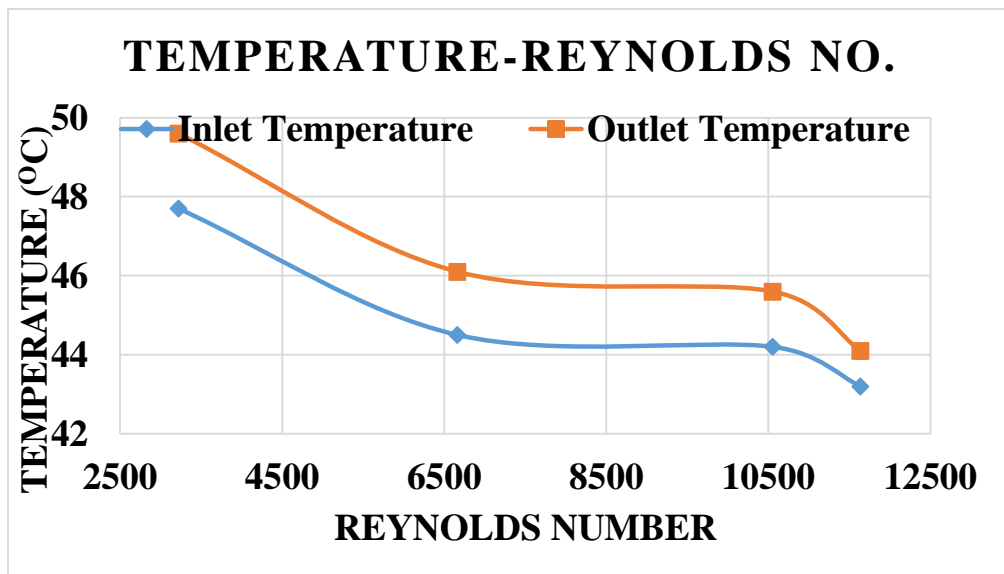
**Fig 4.6** Inlet and Outlet temperature versus Reynolds Number for Water

Figure 4.7 shows that temperature difference between inlet and outlet in nano fluid 0.01% vol. conc. is more as compared to water, which is expected because of more heat carrying property of nano fluid.



**Fig 4.7** Inlet and Outlet temperature versus Reynolds Number for 0.01% Vol. Conc. Nano Fluid

For nanofluid 0.05% vol. conc. (Figure 4.8) the temperature difference is more, which is an important parameter for electronic cooling. As the concentration of nano particles increases, the temperature difference also increases.



**Fig 4.8** Inlet and Outlet temperature versus Reynolds Number for 0.05% Vol. Conc. Nano Fluid

#### 4.3.4 Variation of Fanning Friction Factor with Reynolds Number

Figure 4.9 shows the variation of fanning friction factor for Reynolds Number varying from 2500 to 12500, for a minichannel having hydraulic diameter 2.81 mm, for water and nanofluid (0.01% Vol. Conc. and 0.05% Vol. Conc.). It was seen that with increase in mass flow rate, fanning friction factor also increases. However, not much rise in fanning friction factor was observed on addition of nano particles as concentration of nano particles is too less in the nano fluid mixture.

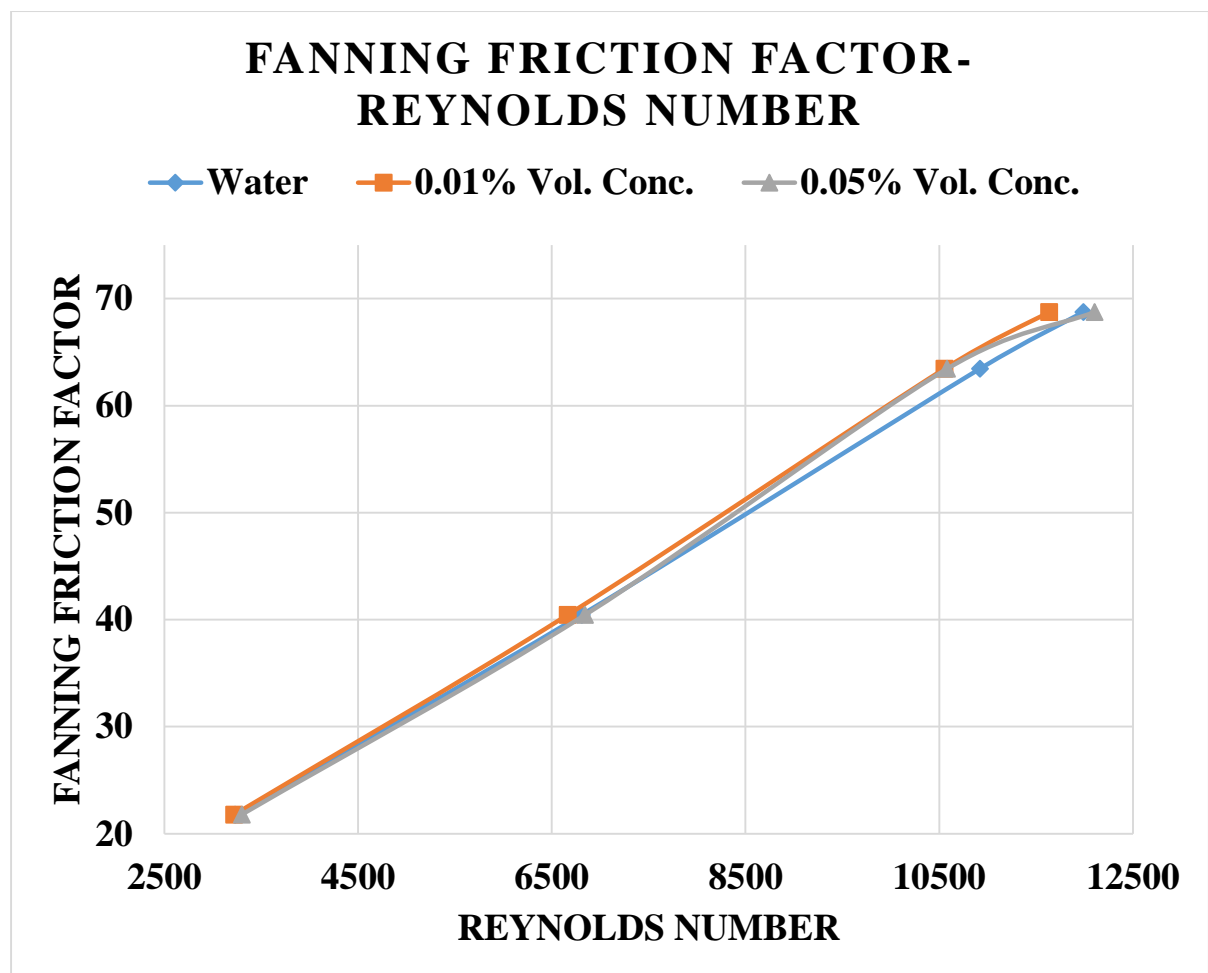


Fig 4.9 Fanning Friction Factor versus Reynolds Number

#### 4.3.5 Variation of Temperature Difference with Reynolds Number

Figure 4.10 shows that temperature difference decreases with increase in Reynolds Number for water. Similar trends were seen on addition of nano particles. Temperature difference for 0.01% Vol. Conc. is much similar to water whereas, temperature difference increases for all values of Reynolds Number in case of 0.05% vol. conc.

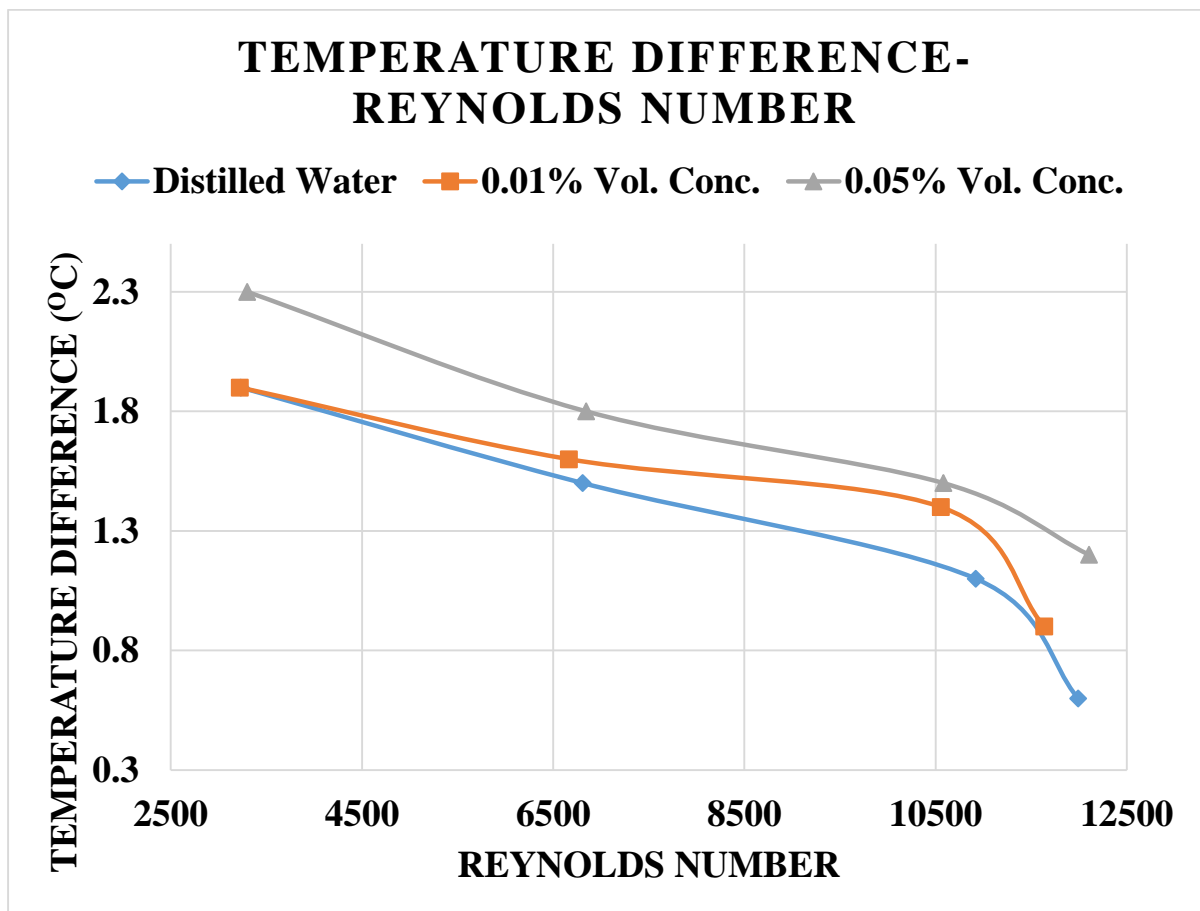


Fig. 4.10 Temperature Difference versus Reynolds Number

#### 4.3.6 Variation of Temperature Change with Reynolds Number

Fig. 4.11 shows the variation of heat transfer rate with Reynolds number at different concentrations of nanoparticles. Rate of heat transfer has increase with increase in Reynolds

number up to 10581 and after that it has decreased at all the concentrations. This is due to the fact that with increase in the Reynolds number, the time available for the heat transfer decreases which leads to decrease in heat transfer rate at high Reynolds number. Heat transfer rate has also increased on the addition of nanoparticles that is 0.05% vol. conc. nanofluids have max. heat transfer rate as compared to other lower concentration at all the Reynolds number.

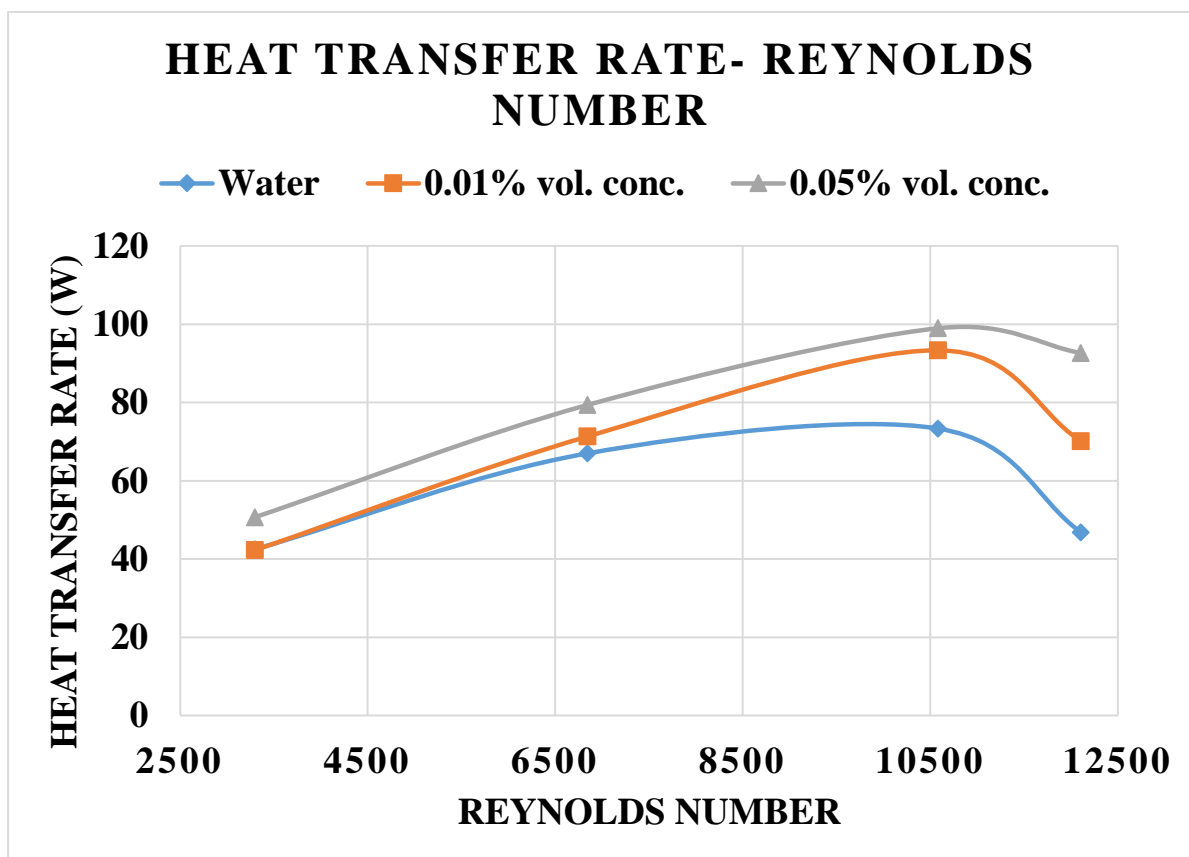
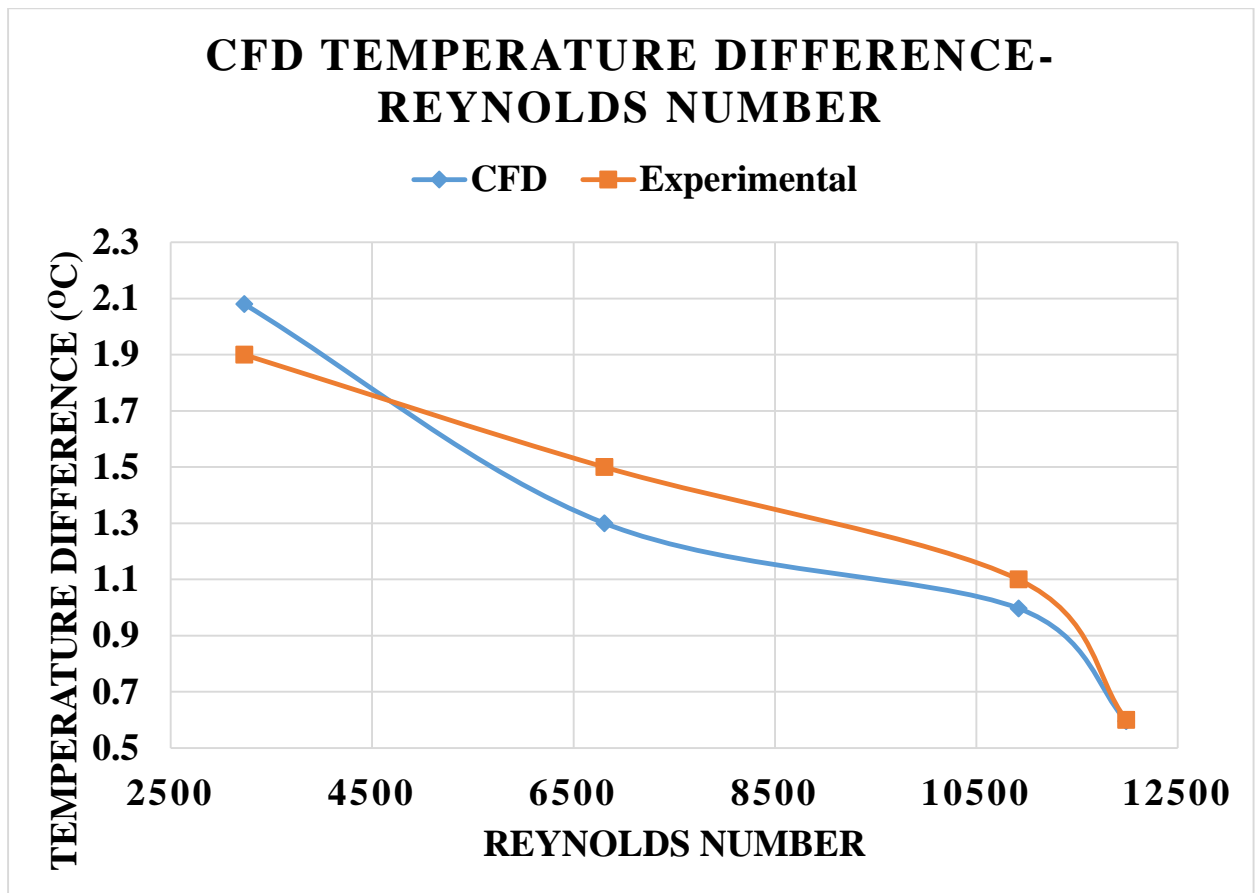


Fig. 4.11 Heat Transfer versus Reynolds Number

#### 4.3.7 Variation of Temperature Change with Reynolds Number using Computational Fluid Dynamics for distilled water

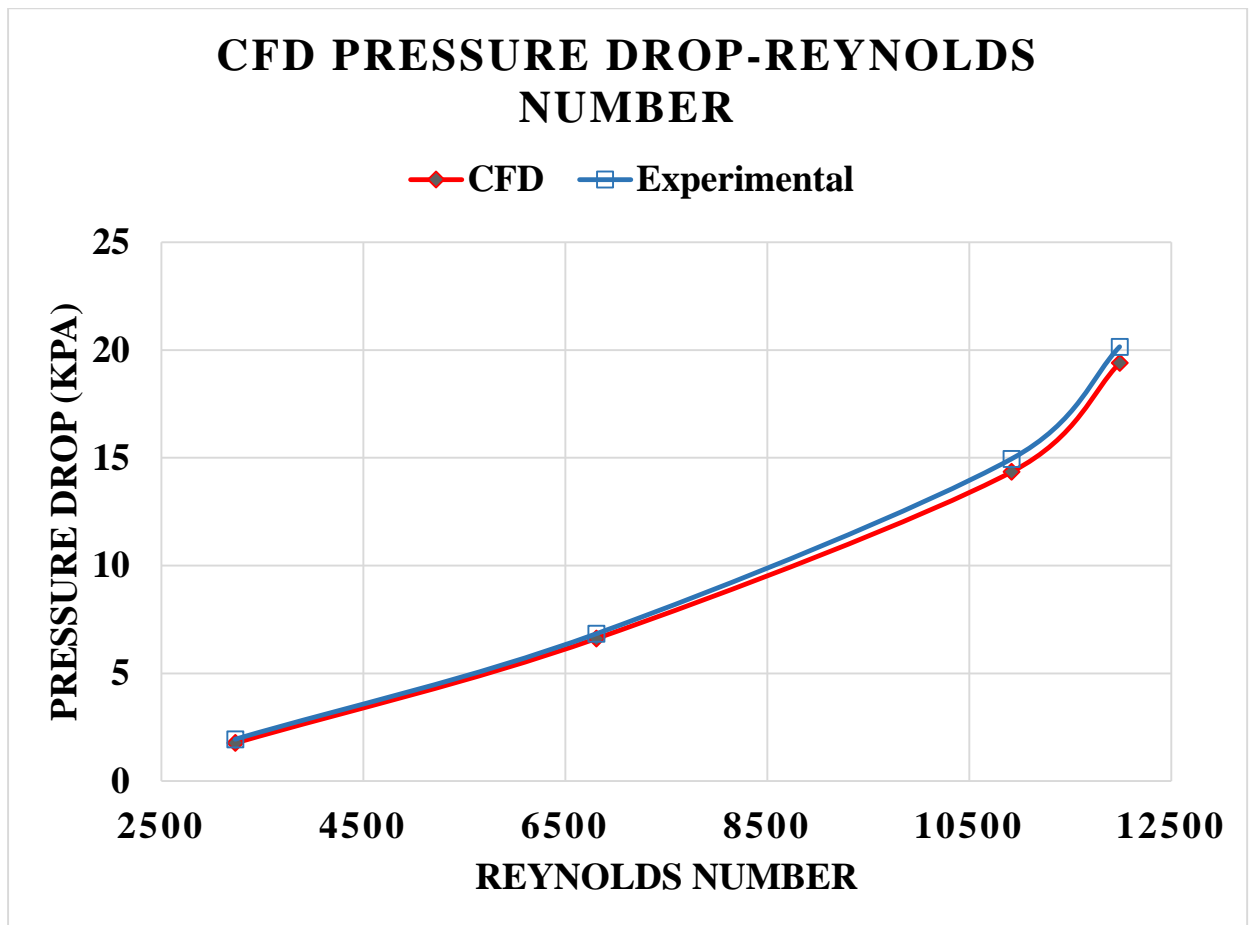
Figure 4.12 shows the comparison of Temperature change with Reynolds Number between the Computational Fluid Dynamics and Experimental Results for Distilled Water. Similar trends were seen in both cases. CFD results have shown deviation from experimental results at low Reynolds Number. Maximum over prediction of 13.33% was obtained from the CFD simulation results at Reynolds Number 6807 when compared with the experimental results.



**Fig. 4.12** Temperature Difference versus Reynolds Number for CFD and Experimental Results for water

**4.3.8 Variation of Pressure Drop with Reynolds Number using Computational Fluid Dynamics for distilled water**

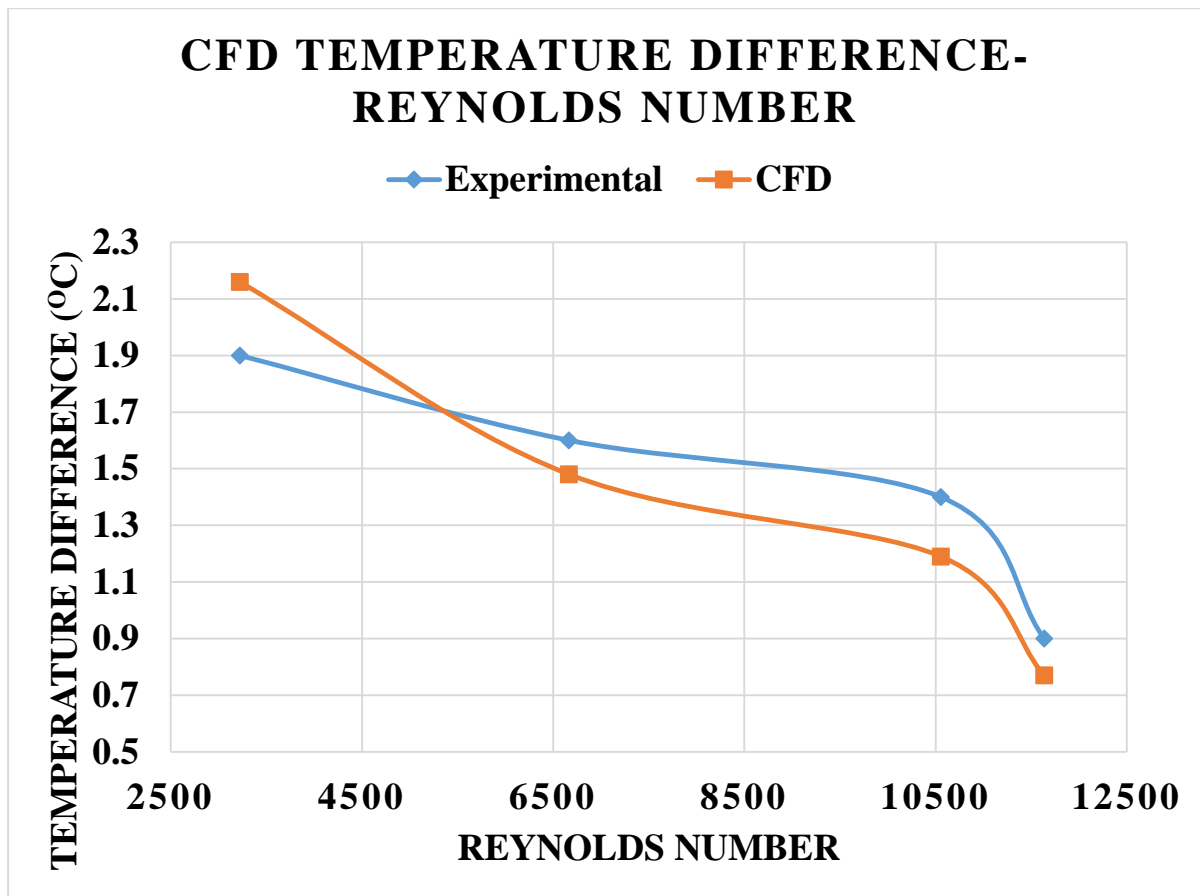
Figure 4.13 shows the comparison of Pressure Drop with Reynolds Number between the Computational Fluid Dynamics and Experimental Results for Distilled Water. CFD has shown little deviation for Pressure Drop as compared to Experimental data at high Reynolds Number. Maximum under prediction of 8.74% was obtained from the CFD simulation results at Reynolds number 3230 when compared to the experimental results.



**Figure 4.13** Pressure Drop versus Reynolds Number for CFD and Experimental Results

**4.3.9 Variation of Temperature Change with Reynolds Number using Computational Fluid Dynamics for Al<sub>2</sub>O<sub>3</sub>-Water nanofluid at 0.01% vol. conc.**

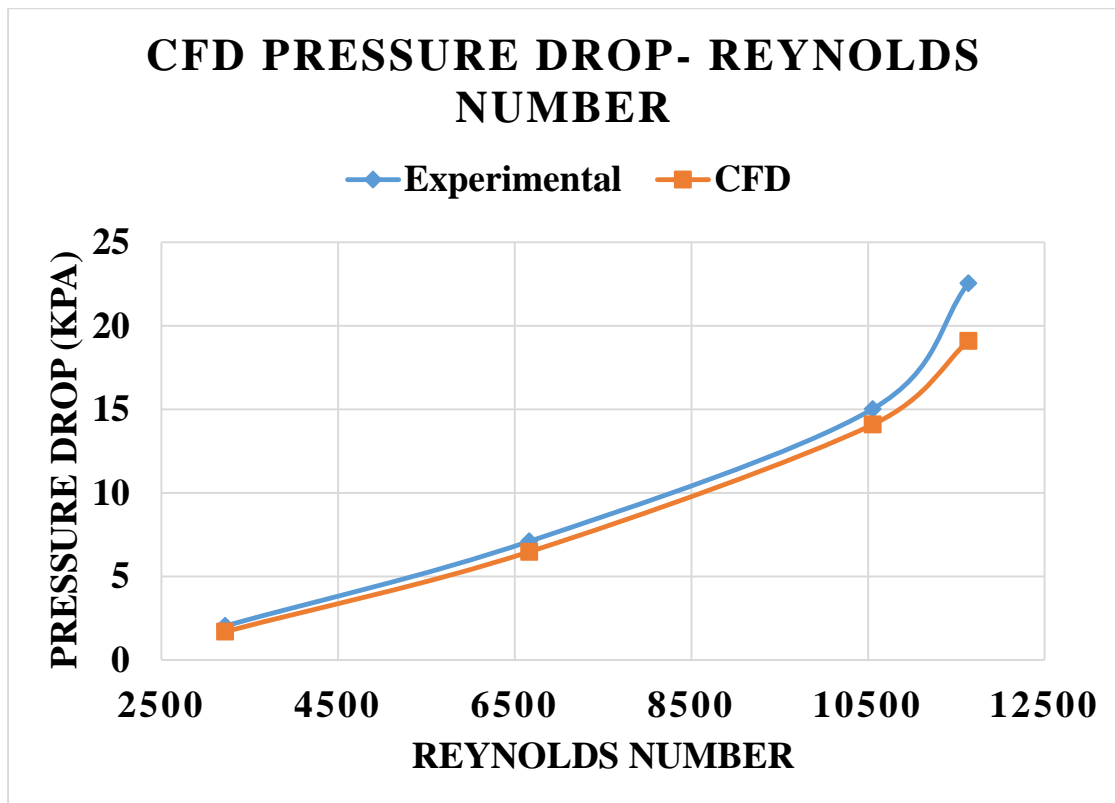
Figure 4.14 shows the comparison of temperature change with Reynolds Number between the Computational Fluid Dynamics and Experimental Results for 0.01% vol. conc. CFD has shown little deviation for temperature change as compared to experimental data. Maximum over prediction of 12.7% was obtained from the CFD simulation results at Reynolds number 3230 when compared to the experimental results.



**Figure 4.14** Temperature Difference versus Reynolds Number for CFD and Experimental Results for 0.01% vol. conc.

**4.3.10 Variation of Pressure Drop with Reynolds Number using Computational Fluid Dynamics for Al<sub>2</sub>O<sub>3</sub>-Water nanofluid at 0.01% vol. conc.**

Figure 4.15 shows the comparison of pressure drop with Reynolds Number between the Computational Fluid Dynamics and experimental results for 0.01% vol. conc. CFD has shown little deviation for pressure drop as compared to experimental data at high Reynolds Number. Maximum under prediction of 15.2% was obtained from the CFD simulation results at Reynolds number 11635 when compared to the experimental results.

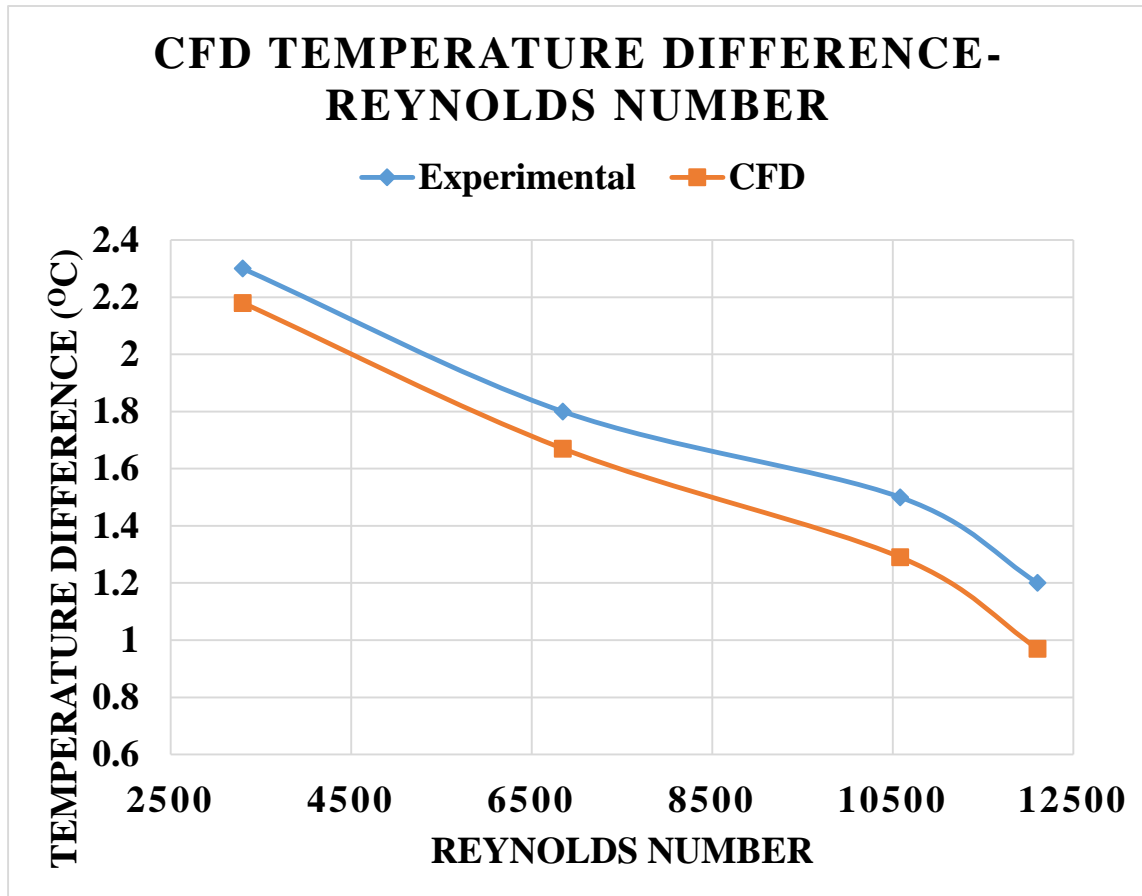


**Fig. 4.15** Pressure drop versus Reynolds Number for CFD and Experimental Results for 0.01% vol. conc.

#### **4.3.11 Variation of Temperature Change with Reynolds Number using Computational Fluid Dynamics for Al<sub>2</sub>O<sub>3</sub>-Water nanofluid at 0.05% vol. conc.**

Figure 4.16 shows the comparison of temperature change with Reynolds Number between the Computational Fluid Dynamics and experimental results for 0.05% vol. conc. CFD has

shown little deviation for temperature change as compared to experimental data. Maximum under prediction of 19.1% was obtained from the CFD simulation results at Reynolds number 11635 when compared to the experimental results.

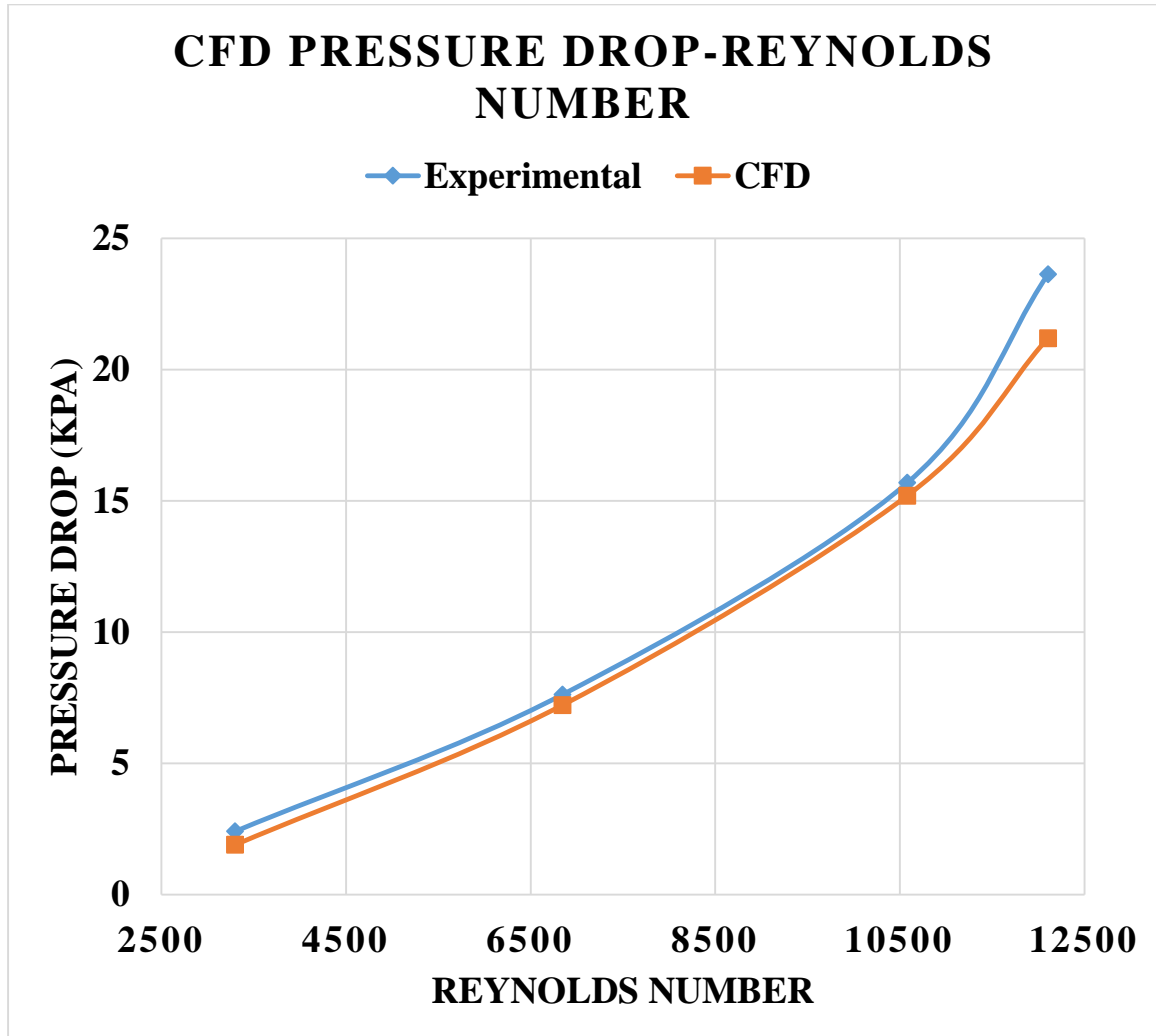


**Fig. 4.16** Temperature Difference versus Reynolds Number for CFD and Experimental Results for 0.05% vol. conc.

#### 4.3.12 Variation of Pressure Drop with Reynolds Number using Computational Fluid Dynamics for Al<sub>2</sub>O<sub>3</sub>-Water nanofluid at 0.05% vol. conc.

Figure 4.17 shows the comparison of pressure drop with Reynolds Number between the Computational Fluid Dynamics and experimental results for 0.05% vol. conc. CFD has shown little deviation for pressure drop as compared to experimental data at high Reynolds

Number. Maximum under prediction of 10.2% was obtained from the CFD simulation results at Reynolds number 11635 when compared to the experimental results.

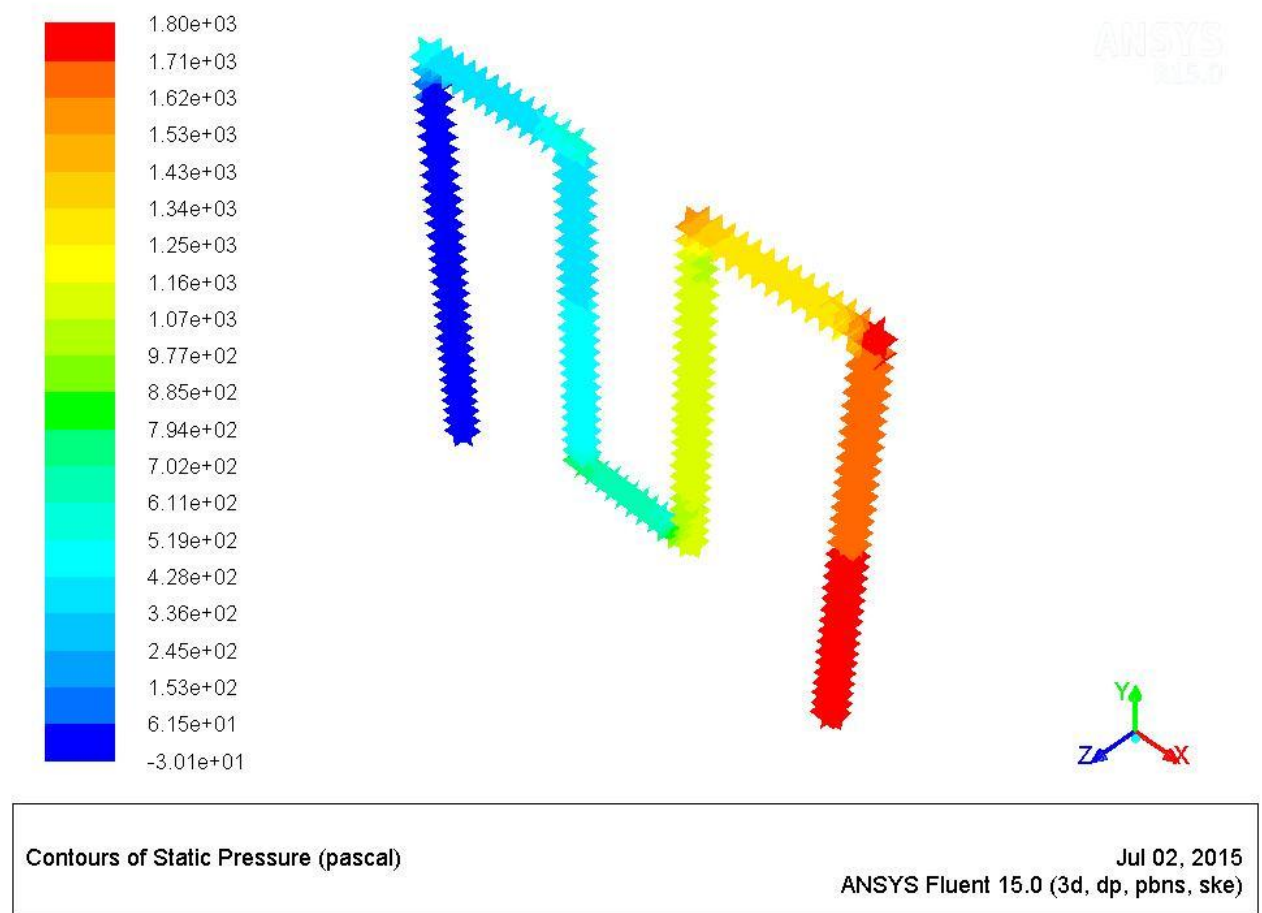


**Figure 4.17** Pressure drop versus Reynolds Number for CFD and Experimental Results for 0.05% vol. conc.

### Pressure Contour

From pressure contour, it can be seen that as the fluid travel from inlet to outlet along length of the channel, pressure has decreased. Local Pressure Maximum regions were obtained near the corners of the channel which signifies that channel must be made curved, for

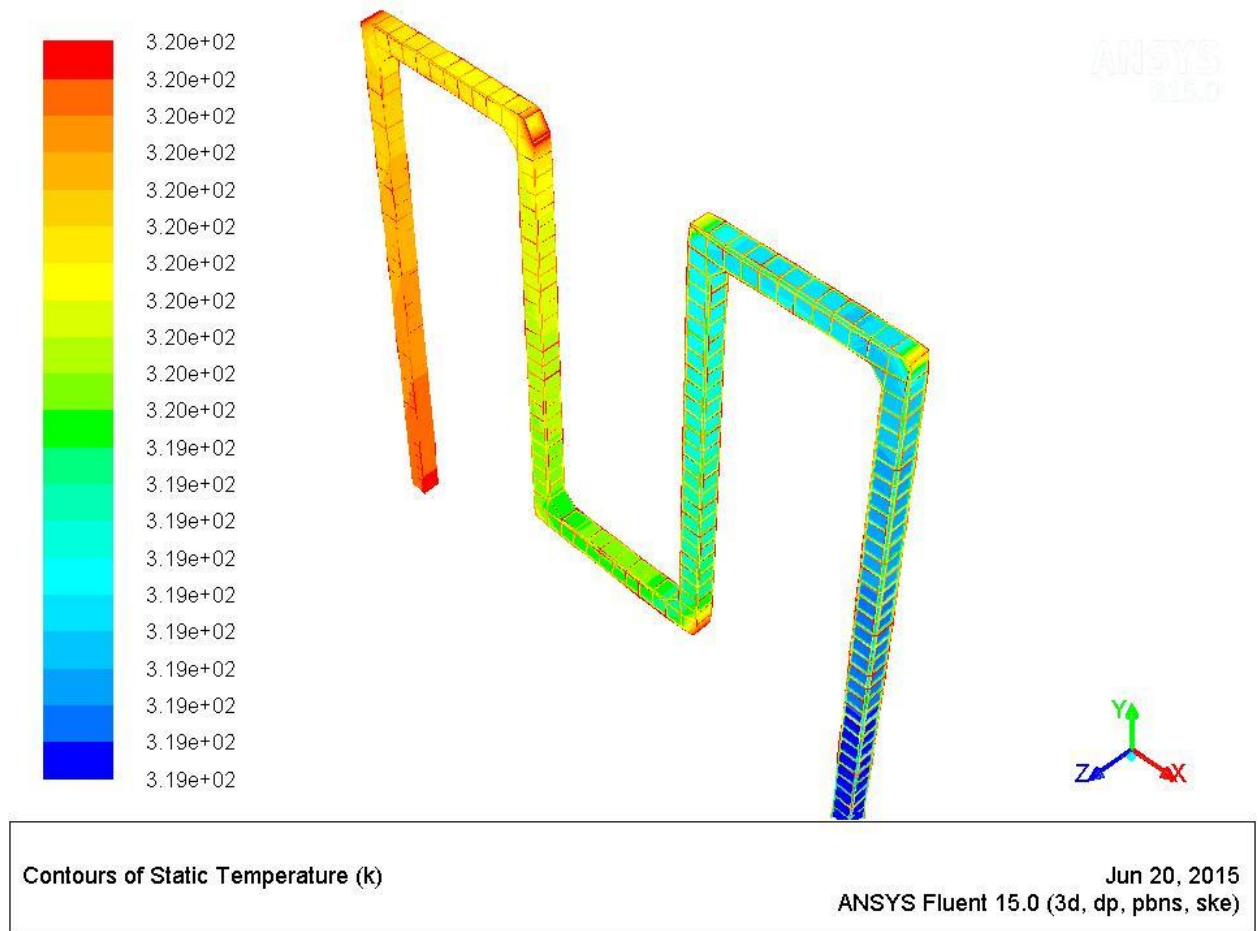
smoother flow of the cooler medium. It has also seen experimentally, that due to inertia of nano particles they strike to the corners of the channels and get collected over there.



**Fig.4.18** Pressure Contour

## Temperature Contour

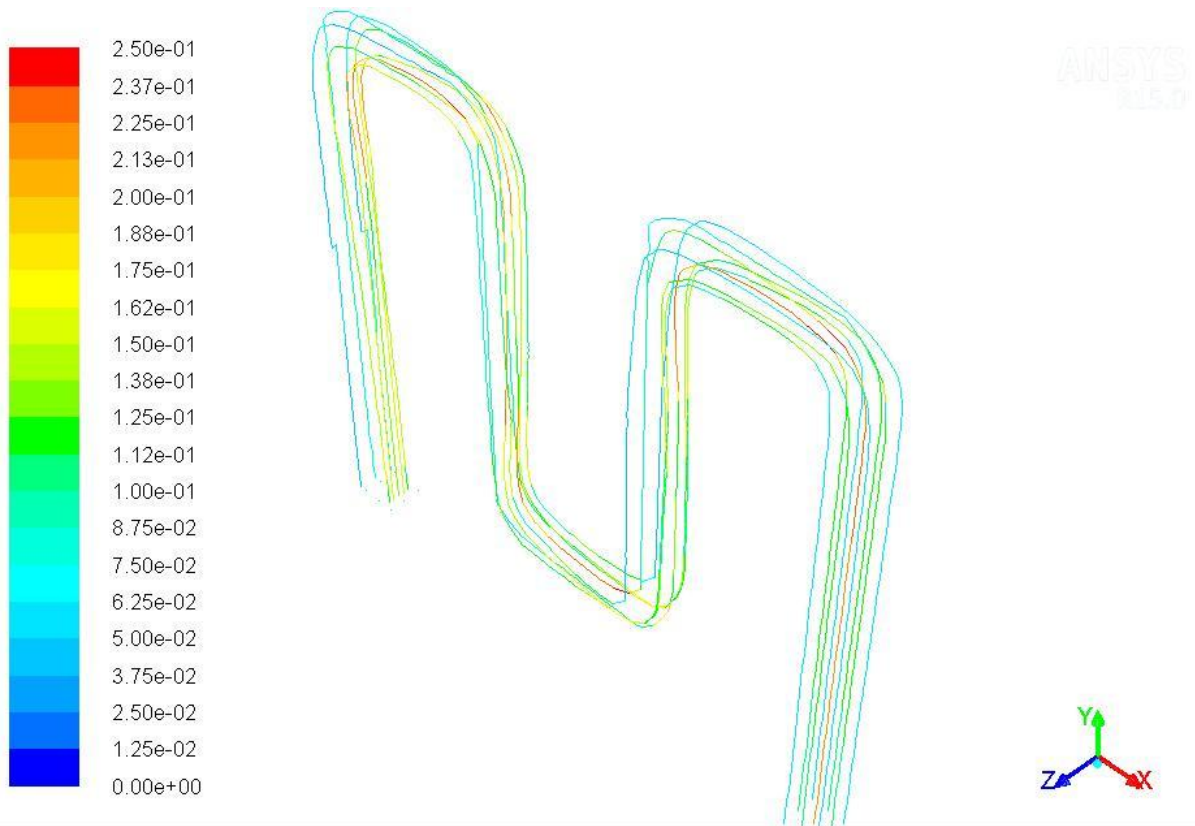
From temperature contour, it can be seen that as the fluid travel from inlet to outlet along length of the channel, temperature has increased. Temperature of fluid touching the surface is more as compared to temperature at inner side towards center. Also maximum temperature regions can be seen at the corners of the channel.



**Fig.4.19** Temperature Contour

### Velocity Distribution

From Velocity distribution, it can be seen that as the fluid travel from inlet to outlet along length of the channel, velocity has decreased. Velocity of liquid is less near the walls of minichannel due to friction between surface and flowing liquid. Velocity of liquid is more at center of mini-channel and less towards the outer surface due to viscosity. It has also seen experimentally, that due to inertia of nano particles they strike to the corners of the channels and get collected over there, which signifies that channel must be made curved, for smoother flow of the cooling medium.



**Fig4.20** Velocity Path lines

### 5.1 Conclusion

Experimental and simulation work has been carried out to study the cooling of aluminium heat sink using minichannel water as cooling medium. Nanoparticles were also added to water in order to enhance heat transfer rates. The following conclusions were made throughout the experimentation:

- Density and viscosity of nanofluids have decreased with increase in temperatures whereas both have increased on addition of nanoparticles. The changes in viscosity were more significant with temperature than change in density.
- Thermal conductivity of nanofluid has increased with increase in temperature. The conductivity has shown significant increase on addition of nanoparticles at higher temperatures.
- Pressure drop has shown parabolic increase with increase in the numbers. However pressure drop did not show any significant change on addition of nanoparticles because nanoparticles were added at very small concentrations.
- With increase in Reynolds number, friction factor has decreased. Higher values of friction factor were obtained at 0.05% vol. conc. of nanoparticles, it has decreased with decrease in concentration at all the Reynold numbers.
- Fanning friction factor has increased linearly with increase in Reynold number.
- Temperature difference between inlet and outlet of minichannel has decreased with increase in Reynolds number due to decrease in available time for heat transfer.

Higher values of temperature difference were obtained for nanofluids at higher concentrations in comparison to water at all the Reynolds numbers.

- On addition of nanoparticles, heat transfer rate has increased whereas at all the concentrations, it has decreased at high Reynolds number due to decrease in the time available.
- Results of temperature difference and pressure drop obtained from CFD were compared with experimental results. CFD has overpredicted the temperature difference at low Reynold numbers whereas pressure drop is underpredicted by CFD at higher Reynolds number.
- From pressure distribution contours, it can be seen that the sharp edges of minichannels resulted in higher pressure regions, so these should be eliminated to have smoother flow.
- Temperature of water has increased along the length of minichannel, maximum temperatures were recorded near the wall at outlet.

## **5.2 Future scope of work**

Further scope of work will include:

- (i) Different heat sink materials, nanoparticles and base fluid configuration can be used to further investigate the thermophysical parameters and maximize heat transfer rates.
- (ii) Minichannels of different geometrical configurations can be used to investigate the influence of geometrical parameters on heat transfer rates.

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## Appendix: A1

**Table A1:** Calibration of thermocouple data

Thermometer	Thermocouple
26.7	26.9
31.6	31.7
35.3	35.2
41.9	41.7
45.6	45.7
51.3	51.2

**Table A2:** Experimental data for water

Q(m <sup>3</sup> /s)	T <sub>in</sub> (°C)	T <sub>out</sub> (°C)	Δh(cm of Hg)	Re	q(watt)
0.00000555	50	51.9	1.4	3230.2	42.473
0.0000111	46.5	48	5.1	6807.88	66.98
0.0000166	45.9	47	11.2	10920	73.32
0.0000194	44.1	44.7	15.1	11990.3	46.82

**Table A3:** Experimental data for 0.01% vol. conc. nanofluid

Q(m <sup>3</sup> /s)	T <sub>in</sub> (°C)	T <sub>out</sub> (°C)	Δh(cm of Hg)	Re	q(watt)
0.00000555	47.7	49.6	1.5	3230.2	42.27
0.0000111	44.5	46.1	5.3	6807.88	71.30

0.0000166	44.2	45.6	11.2	10920	93.31
0.0000194	43.2	44.1	16.9	11990.3	70.14

**Table A4:** Experimental data for 0.05% vol. conc. nanofluid

Q(m <sup>3</sup> /s)	T <sub>in</sub> (°C)	T <sub>out</sub> (°C)	$\Delta h$ (cm of Hg)	Re	q(watt)
0.00000555	47.3	49.6	1.8	3230.2	50.68
0.0000111	46.3	48.1	5.7	6807.88	79.36
0.0000166	45.2	46.7	11.7	10920	98.95
0.0000194	43.2	42.6	17.7	11990.3	92.62

**Table A5:** Data for property calculation at different temperatures for water

T (°C)	Density(kg/m <sup>3</sup> )	Viscosity(kg/m-s)	Conductivity(W/m.K)
30.24	995.11	0.00077334	0.628
37.9	992.58	0.00066153	0.632
41.5	991.23	0.00061783	0.645
45.6	989.59	0.00057364	0.65
49.12	988.08	0.00053979	0.655
53.91	985.88	0.00049888	0.659
57.11	984.32	0.00047441	0.664

61.33	982.16	0.00044513	0.688
67	979.08	0.00041039	0.701
72	976.18	0.0003834	0.744
76	973.74	0.0003639	0.748

**Table A6:** Data for property calculation at different temperatures for 0.01% vol. conc.  
nanofluid

<b>T (°C)</b>	<b>Density(kg/m<sup>3</sup>)</b>	<b>Viscosity(kg/m-s)</b>	<b>Conductivity(W/m.K)</b>
30.24	1024.85	0.00079301	0.631
37.9	1023.35	0.000698	0.636
41.5	1023.01	0.0006355	0.651
45.6	1018.39	0.00058823	0.659
49.12	1015.89	0.00053352	0.666
53.91	1015.72	0.0005115	0.677
57.11	1013.17	0.00048648	0.689
61.33	1012.03	0.0004464	0.699
67	1010.98	0.00042083	0.719
72	1008.11	0.0003931	0.774
76	1001.70	0.000373	0.795

**Table A7:** Data for property calculation at different temperatures for 0.05% vol. conc.

nanofluid

<b>T (°C)</b>	<b>Density(kg/m<sup>3</sup>)</b>	<b>Viscosity(kg/m-s)</b>	<b>Conductivity(W/m.K)</b>
30.24	1143.85	0.000879	0.636
37.9	1140.45	0.000732	0.641
41.5	1140.16	0.000702	0.661
45.6	1139.61	0.000652	0.672
49.12	1137.17	0.000603	0.686
53.91	1134.08	0.000567	0.698
57.11	1133.60	0.000539	0.716
61.33	1129.55	0.000526	0.732
67	1128.62	0.000466	0.761
72	1127.87	0.000455	0.801
76	1121.55	0.000413	0.832