

NUMERICAL SIMULATION OF NANOFLUID FORCED CONVECTION HEAT  
TRANSFER

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I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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## ABSTRACT

The thesis deals with the numerical simulation of nanofluid forced convection heat transfer under the turbulent flow with different volume concentrations. The objective of this thesis is to study the heat transfer coefficient of nanofluid at various volume concentrations and Reynolds number using Computational Fluid Dynamic (CFD) software. This thesis describes the CFD analysis techniques to predict the heat transfer coefficient using FLUENT software. Aluminum Oxide,  $\text{Al}_2\text{O}_3$ /Water with 0.02%, 0.1% and 0.5% of volume concentration were studied in this thesis which commonly available nanofluid in market. The structural three-dimensional solid modelling of plain pipe tube was developed using the computer aided-drawing software, SolidWorks. The strategy of validation of CFD model was developed by comparing the result from water simulation with the available equation in the study of forced convection heat transfer. The CFD analysis was then performed using FLUENT with nanofluid as the working fluid. The CFD model of components was analyzed using the pressure based solver and k-epsilon viscous model. Finally, the bulk temperature and wall temperature of the working fluid obtained from the simulation are used to calculate the heat transfer coefficient of the fluid. From the result, it is observed that the heat transfer coefficient of base fluid, water is increased about 20% in the presence of nanoparticles when Reynolds number and volume concentration are increase. But, increase in heat transfer coefficient by increasing volume concentration of nanofluid is valid when Reynolds number below 10,000. Results obtained from simulation were then compared with the experiment and it is observed that a close agreement between simulation and experiment is achieved. Both simulation and experiment results concluded that the heat transfer coefficient increase when nanofluid is used as the working fluid. These results are significant to improve today cooling fluid in the way of increasing the heat transfer coefficient.

## ABSTRAK

Tesis ini berurusan dengan simulasi numerik konveksi paksa perpindahan panas bendalir nano di bawah aliran gerlora dengan kepekatan isipadu yang berbeza. Tujuan tesis ini adalah untuk mempelajari pekali perpindahan panas bendalir nano pada pelbagai kepekatan isipadu dan bilangan Reynolds dengan menggunakan perisian Bendalir Dinamik Berkomputer (BDB). Tesis ini membincangkan teknik-teknik analisis BDB untuk mengagak pekali pemindahan panas menggunakan perisian FLUENT. Aluminium Oksida,  $\text{Al}_2\text{O}_3/\text{Water}$  dengan kepekatan isipadu 0.02%, 0,1% dan 0,5% tela dipelajari dalam tesis yang merupakan bendalir nano yang biasa terdapat di pasaran. Pemodelan padat struktur tiga-dimensi untuk tabung paip polos dibangunkan dengan menggunakan komputer perisian dibantu-rekabentuk, SolidWorks. Strategi untuk mengesahkan model BDB yang dibangunkan adalah dengan membandingkan dengan hasil dari simulasi air dan dengan persamaan yang terdapat dalam kajian konveksi paksa perpindahan panas. Analisis BDM kemudian dilakukan dengan menggunakan FLUENT dengan nanofluid sebagai bendalir kerja. Model komponen BDB dianalisis menggunakan penyelesaian bersaskan tekanan dan model kelikatan k-epsilon. Akhirnya, suhu massa bendalir kerja dan suhu dinding paip yang diperolehi daripada simulasi digunakan untuk mengira pekali perpindahan panas dari bendalir. Dari hasil tersebut, dilihat bahawa pekali perpindahan panas bendalir asas, air meningkat sebanyak 20% dengan kehadiran partikel nano apabila bilangan Reynolds dan kepekatan isipadu meningkat. Namun begitu, peningkatan pekali perpindahan panas dengan meningkatkan kepekatan isipadu bendalir nano ketika bilangan Reynolds di bawah 10,000. Keputusan yang diperolehi daripada simulasi kemudian dibandingkan dengan eksperimen dan diamati bahawa terdapat persetujuan yang erat antara simulasi dan eksperimen. Daripada hasil simulasi dan eksperimen dapatlah disimpulkan bahawa pekali pemindahan panas meningkat disaat nanofluid digunakan sebagai bendalir kerja. Hasil daripada keputusan ini dapatlah digunakan untuk meningkatkan cairan pendingin hari ini dengan cara meningkatkan pekali perpindahan panas.

## TABLE OF CONTENTS

	<b>Page</b>
<b>SUPERVISOR'S DECLARATION</b>	ii
<b>STUDENT'S DECLARATION</b>	iii
<b>DEDICATION</b>	iv
<b>ACKNOWLEDGEMENTS</b>	v
<b>ABSTRACT</b>	vi
<b>ABSTRAK</b>	vii
<b>TABLE OF CONTENTS</b>	viii
<b>LIST OF TABLES</b>	xi
<b>LIST OF FIGURES</b>	xii
<b>LIST OF SYMBOLS</b>	xvi
<b>LIST OF ABBREVIATIONS</b>	xviii
<b>CHAPTER 1      INTRODUCTION</b>	<b>1</b>
1.1    Introduction	1
1.2    Problem Statement	2
1.3    Significant of Study	3
1.4    Project Objectives	3
1.5    Scope of Project	3
<b>CHAPTER 2      LITERATURE REVIEW</b>	<b>5</b>
2.1    Introduction	5
2.2    History of Heat Transfer	6
2.3    Theory of Heat Transfer	7
2.3.1    Convection Mechanism	8
2.3.2    Forced Convection	9
2.3.3    Internal Forced Convection	10
2.3.4    Average Velocity and Temperature	10
2.3.5    Flows in Tubes	12
2.3.6    Turbulent Flow in Tube	12
2.3.7    The Entrance Region	13
2.3.8    Entry Lengths	14
2.3.9    Pressure Drop	15

2.4	Engineering Parameters for Heat Transfer	16
2.5	Heat Transfer Coefficient	17
2.6	Nanofluids	18
2.6.1	Basic Concept of Nanofluids	19
2.6.2	Nanofluid Structure	20
2.6.3	Materials for Nanoparticles and Base Fluids	21
2.6.4	Technology for Production of Nanoparticles and Nanofluids	22
2.6.5	Techniques Used in Production of Nanofluids	23
2.6.6	Potential Benefits of Nanofluids	23
2.7	Previous Experiment Study of Nanofluid	24
2.7.1	Experimental Study of Nanofluid Thermal Conductivity	25
2.7.2	Experimental Study of Nanofluid Heat Transfer	25
2.7.3	Experiment Study on Heat Transfer Performance and Pressure Drop of Nanofluids	26
2.8	Previous Numerical Study of Nanofluids	26
2.8.1	Numerical Study of Heat Transfer Dioxide (TiO <sub>2</sub> )	27
2.8.2	Numerical Study of Turbulent Flow and Heat Transfer on Nanofluid Characteristics	31
2.8.3	Numerical Study of Turbulent Forced Convection of a Nanofluid in a Tube with uniform Heat Flux using a Two Phase Approach	36
2.9	Conclusion	38
<b>CHAPTER 3</b>	<b>METHODOLOGY</b>	<b>39</b>
3.1	Introduction	39
3.2	Method	42
3.3	Software	42
3.4.1	SolidWorks Software	42
3.4.2	GAMBIT Software	43
3.4.3	FLUENT Software	44
3.5	Terms Used in Software	45
3.6	Numerical Analysis	46
3.6.1	Designing Tube in SolidWorks	46
3.6.2	Setting up Mesh and Boundary Layer for Tube in GAMBIT	49



3.6.3	Setting up Parameters Involved in FLUENT	55
3.7	Conclusion	67
<b>CHAPTER 4</b>	<b>RESULTS AND DISCUSSION</b>	68
4.1	Introduction	68
4.2	Numerical Simulation Modeling	69
4.3	Thermophysical Properties	70
4.4	Calibration Test	71
4.5	Nanofluid Simulation	74
4.5.1	Data Contribution Simulation Result for (Al <sub>2</sub> O <sub>3</sub> /Water) with $\Phi=0.02\%$	74
4.5.2	Data Contribution Simulation Result for (Al <sub>2</sub> O <sub>3</sub> /Water) with $\Phi=0.1\%$	76
4.5.3	Data Contribution Simulation Result for (Al <sub>2</sub> O <sub>3</sub> /Water) with $\Phi=0.5\%$	78
4.6	Data Comparison	79
4.6.1	Wall Temperature Effect	82
4.7	Result Validation	83
<b>CHAPTER 5</b>	<b>CONCLUSION AND RECOMMENDATIONS</b>	84
5.1	Introduction	84
5.2	Conclusion	84
5.3	Recommendation	85
<b>REFERENCES</b>		86
<b>APPENDICES</b>		88
A	Gantt Chart FYP 1	88
B	Gantt Chart FYP 2	89
C	List of Equations 1	90
D	List of Equations 2	91
E	Input Parameters at Inlet	92

## LIST OF TABLES

<b>Table No.</b>	<b>Title</b>	<b>Page</b>
2.1	Independent parameters	16
2.2	Dependent parameters	16
2.3	Dimensionless parameters of general convection (Free and forced)	17
2.4	Dimensionless parameters of free convection	17
2.5	Dimensionless parameters of forced convection only	17
2.6	Typical values of convection heat transfer coefficient	18
2.7	Parameters used in the simulation	28
3.1	List of terms used in the software	45
3.2	The boundary types input	54
3.3	The thermophysical properties of nanofluids at 30°C	64
4.1	Thermophysical properties of materials used in the simulation	71
4.2	Data distribution from simulation of water	72
4.3	Data contribution simulation result for (Al <sub>2</sub> O <sub>3</sub> /Water) with $\Phi=0.02\%$	74
4.4	Data contribution simulation result for (Al <sub>2</sub> O <sub>3</sub> /Water) with $\Phi=0.1\%$	76
4.5	Data contribution simulation result for (Al <sub>2</sub> O <sub>3</sub> /Water) with $\Phi=0.5\%$	78

## LIST OF FIGURES

Figure No.	Title	Page
2.1	Average velocity $V_{avg}$ for fully developed laminar pipe flow is half of maximum velocity	11
2.3	The development of the velocity boundary layer in a tube	13
2.3	The development of the thermal boundary layer in a tube	14
2.4	Bright-field transmission electron micrograph of copper nanoparticles	20
2.5	Schematic cross section of nanofluid structure	21
2.6	Numerical domain (test section of the horizontal pipe)	28
2.7	Comparison between the simulation results, predictions by the empirical Shah equation, and the experimental data for pure water flow	29
2.8	Axial profiles of the convective heat transfer coefficient for a constant wall heat flux of $4000 \text{ W/m}^2$	30
2.9	Radial profiles of local axial velocity of nanofluid for nanoparticle volume concentration of 0.6% and heat flux of $4000 \text{ W/m}^2$	30
2.10	Grid layout used in the analysis, axisymmetric about X-axis	32
2.11	Variation of Prandtl number with Reynolds number in the simulations for various nanofluid	33
2.12	Comparison of Nusselt number versus Reynolds number for three different nanofluids and the base fluid	33
2.13	Effect of nanoparticle volume concentration on the wall shear stress for CuO nanofluids in the fully developed region	34
2.14	Comparison of heat transfer coefficient of different nanofluids over the base fluid EG/water.	35
2.15	Axial evolution of the centerline turbulent kinetic energy for pure water and nanofluid	36
2.16	Nusselt along number along the tube axis	37

<b>Figure No.</b>	<b>Title</b>	<b>Page</b>
3.1	The flow diagram of the project	40
3.2	The flow diagram of the analysis	41
3.3	The SolidWorks Graphical User Interface (GUI)	43
3.4	The GAMBIT Graphical User Interface (GUI)	44
3.5	FLUENT Graphical User Interface (GUI)	45
3.6	Diameter of the circle	47
3.7	Circle with a line in the middle	48
3.8	Circle after trimming process	48
3.9	Half 3D cylinder design	49
3.10	Gambit Startup window	50
3.11	Import IGES File window	51
3.12	Mesh Volumes subpad	52
3.13	Volume List (Multiple) subpad	52
3.14	The cylinder after meshing process	53
3.15	Input for cylinder boundary types	54
3.16	Input for cylinder continuum types	54
3.17	The Fluent Versions panel	55
3.18	The data from saved file	56
3.19	The grid size of the cylinder	57
3.20	The Solver panel	57
3.21	The Viscous Model panel	58
3.22	The Materials panel	59
3.23	The Fluent Database Materials panel	60

<b>Figure No.</b>	<b>Title</b>	<b>Page</b>
3.24	The Open Database box	61
3.25	The Materials Properties panel	61
3.26	Edit Property Methods	62
3.27	The User-Defined Materials panel	63
3.28	The Boundary conditions panel	64
3.29	The Velocity Inlet panel input data	64
3.30	The Wall panel input data	65
3.31	The Solution Controls panel	66
3.32	The Solution Initialization panel	66
3.33	The Iterate panel	67
4.1	The design of inner pipe tube in SolidWorks	69
4.2	The inner pipe tube design after the meshing process	70
4.3	Graph comparison between simulation, experiment and calculation	72
4.4	The temperature distribution at lowest Reynolds number for water	73
4.5	The temperature distribution at highest Reynolds number for water	74
4.6	The contour of temperature distribution for Aluminum Oxide, $\text{Al}_2\text{O}_3$ /Water with 0.02% concentration at lowest Reynolds number, $\text{Re}=3480.80$	75
4.7	The contour of temperature distribution for Aluminum Oxide, $\text{Al}_2\text{O}_3$ /Water with 0.02% concentration at highest Reynolds number, $\text{Re}=18141.79$	76
4.8	The contour of temperature distribution for Aluminum Oxide, $\text{Al}_2\text{O}_3$ /Water with 0.1% concentration at lowest Reynolds number, $\text{Re}=3549.97$	77

<b>Figure No.</b>	<b>Title</b>	<b>Page</b>
4.9	The contour of temperature distribution for Aluminum Oxide, $\text{Al}_2\text{O}_3$ /Water with 0.1% concentration at highest Reynolds number, $\text{Re}=19665.67$	77
4.10	The contour of temperature distribution for Aluminum Oxide, $\text{Al}_2\text{O}_3$ /Water with 0.5% concentration at lowest Reynolds number, $\text{Re}=3636.99$	78
4.11	The contour of temperature distribution for Aluminum Oxide, $\text{Al}_2\text{O}_3$ /Water with 0.5% concentration at highest Reynolds number, $\text{Re}=19891.31$	79
4.12	Comparison of Nusselt number and Reynolds number from simulation	80
4.13	Comparison of Nusselt number and Reynolds number from experiment	80
4.14	Comparison of heat transfer coefficient and Reynolds number for simulation	81
4.15	Comparison of heat transfer coefficient and Reynolds number for experiment	81
4.16	The wall temperature of nanofluid and pure water versus Reynolds number from simulation data	83

## LIST OF SYMBOLS

$\rho$	Density
$Re$	Reynolds Number
$\Phi$	Volume concentration
$L$	Length
$Pr$	Prandtl Number
$Nu$	Nusselt Number
$T_b$	Bulk Temperature
$T_w$	Wall Temperature
$T_\infty$	Fluid Temperature
$H_2O_3$	Water
$T_s$	Surface Temperature
$Cu$	Copper
$\dot{m}$	Mass Flow Rate
$A_c$	Cross Sectional Area
$f$	Friction Factor
$Al_2O_3$	Aluminum Oxide
$C_p$	Specific Heat
$V$	Velocity
$k$	Dynamic Viscosity
$h$	Heat Transfer Coefficient
$A_s$	Heat Transfer Surface Area
$\dot{Q}_{conv}$	Heat Transfer for Convection
$u(r)$	Velocity Profile

$d_p$	Diameter Particle
$d_{max}$	Diameter Maximum
$k_{nf}$	Thermal Conductivity of Nanofluid
$\mu_{nf}$	Dynamic Viscosity of Nanofluid
$C_{P_{nf}}$	Specific Heat of Nanofluid
$k_w$	Thermal Conductivity of Water
$\mu_w$	Dynamic Viscosity of Water
$C_{P_w}$	Specific Heat of Water
$g$	Gravity



**LIST OF ABBREVIATIONS**

FYP	Final Year Project
CFD	Computational Fluid Dynamic
GUI	Graphical User Interface
CAD	Computer Aided Design
MMGS	Milimeter, gram and second
TI	Turbulent Intensity

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 INTRODUCTION**

In today's globalized and modern world, there are many products available for consumers to be used in all ranges, from food to clothing, electrical appliances to transportation. But do we know, lots of these products such as electronic devices (e.g., laptops, computers, and game consoles), heat exchangers (e.g., refrigerator, heater, and air conditioner) and transportation vehicles need to have a liquid coolant to prevent the overheating or to improve the rate of heat transfer. However, the liquid coolants or heat transfer fluids that we have today such as water, engine oil, and ethylene glycol generally has poor thermal properties. For more than 100 years, many scientists and engineers have made great efforts to improve the inherently poor thermal conductivities of these traditional heat transfer fluids (J.C. Maxwell, 1873).

An innovative way of improving the thermal conductivities of heat transfer fluids is to suspend small solid particles in the fluids. In order to achieve this, nanofluids have been used. Nanofluids are nanometer-sized particles ( $<100$  nm) dispersed in a base fluid such as water, ethylene glycol or propylene glycol. Addition of high thermal-conductivity metallic nanoparticles (e.g., aluminum, copper, silicon and silver) increases the thermal conductivity of such mixtures; thus enhancing their overall energy transport capability. This term was made up by Choi in 1995 at Argonne National Laboratory of USA (S.U.S. Choi, 1995).

Nanofluids are thought to be the next-generation heat transfer fluids, and they offer exciting possibilities due to their enhanced heat transfer performance compared to ordinary fluids. Some of the advantages of these nanofluids are:

- (i) Better stability and heat transfer ability compared to those fluids containing micro or mili sized particles.
- (ii) Higher thermal conductive capability than the base fluids themselves because of large surface size for heat transfer due to smaller size of particles.

Nanofluids are proposed for various uses in important fields such as electronics, transportation, medical, and Heating Ventilating and Air Conditioning (HVAC). Hence, there is a need for fundamental understanding of the heat transfer behavior of nanofluids in order to exploit their potential benefits and applications. Nanofluids with metallic nanoparticles and oxide nanoparticles have been investigated by several researchers such as Choi, Yu, Maxwell, Das et al., Xuan et al., Eastman et al., Lee et al., Hester et al. and many other scientists and researchers.

## **1.2 PROBLEM STATEMENT**

As we already known, energy costs have escalated rapidly in the last decade and there are tremendous needs for new kinds of heating or cooling fluids, which will increase heating system thermal performance, reduce the overall size and energy consumption. This is because many conventional coolant fluids today are poor in thermal conductivities, which is not very practical to be used in industrial sector now.

In order to reduce our rely on today's conventional coolant fluids which is not very cost effective, research must be carry out numerically and experimentally to find the alternative way to solve this problem which is more valuable to people, society, country and world.

### **1.3 SIGNIFICANT OF STUDY**

There are few significances of this study when objectives have been achieved as follows:

- (i) Commercialize these nanofluids as a new era of liquid coolants which are very practical to be used in industrial sector.
- (ii) People can enjoy new liquid coolants which are more reliable compared to conventional liquid coolants which are poor in thermal properties.
- (iii) Apply the advantages of nanofluids as new coolant fluids in our country to overcome the overheating and to increase the rate of heat transfer in electrical devices, transportation engine and HVAC.

### **1.4 PROJECT OBJECTIVES**

In order to complete a project successfully, the objectives for the project must be determined and the objectives of this project includes:

- (i) To investigate numerically the behaviors of nanofluid (Aluminum Oxide,  $\text{Al}_2\text{O}_3$ /Water nanofluid) for different Reynolds number and volume concentration during the forced convection heat transfer using FLUENT.
- (ii) To compare the results obtained from the numerical simulation software with the experimental and previous study.

### **1.5 SCOPES OF THE PROJECT**

The scopes of this project are limited to:

- (i) Simulate the nanofluid forced convection heat transfer under turbulent flow condition using numerical method.
- (ii) Simulate forced convective heat transfer of  $\text{Al}_2\text{O}_3$ -water based nanofluid for different Reynolds number and volume concentrations.

- (iii) Study the optimum working condition of nanofluid by considering some special requirements such as even suspension, stable suspension, durable suspension, low agglomeration of particles, and no chemical change of the nanofluid.
- (iv) Analyze nanofluid numerically using three different approaches which are:
  - The first approach assumes that the continuum assumption is still valid for fluids with suspended nanosize particles.
  - The second approach is to consider one-phase model for description of both the fluid and the solid phases.
  - The third approach is to adopt the Boltzmann theory.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 INTRODUCTION**

Heat is the form of energy that can be transferred from one system to another as a result of temperature difference. The science that deals with the determination of the rates of such energy transfer is called heat transfer.

In other word, heat transfer is the transition of thermal energy from a hotter mass to a cooler mass. When an object is at a different temperature than its surroundings or another object, transfer of thermal energy, also known as heat transfer, or heat exchange, occurs in such a way that the body and the surroundings reach thermal equilibrium; this means that they are at the same temperature. Heat transfer always occurs from a higher-temperature object to a cooler-temperature one as described by the second law of thermodynamics or the Clausius statement. Where there is a temperature difference between objects in proximity, heat transfer between them can never be stopped; it can only be slowed.

In the simplest of terms, the discipline of heat transfer is concerned with only two things: temperature, and the flow of heat. Temperature represents the amount of thermal energy available, whereas heat flow represents the movement of thermal energy from place to place.

On a microscopic scale, thermal energy is related to the kinetic energy of molecules. The greater a material's temperature, then the greater the thermal agitation of its constituent molecules (manifested both in linear motion and vibration modes). It is

natural for regions containing greater molecular kinetic energy to pass this energy to regions with less kinetic energy.

Several material properties serve to modulate the heat transferred between two regions at differing temperatures. Examples include thermal conductivities, specific heats, material densities, fluid velocities, fluid viscosities, surface emissivity, and more. Taken together, these properties serve to make the solution of many heat transfer problems an involved process.

For this chapter, a little bit of historical background and a brief explanation of the basic theory of heat transfer will be discussed. Then some discussion on concepts of nanofluids, technology for production of nanofluids and the benefits of nanofluids in industry will be explained. Besides, some discussion on the materials used for making the nanofluids and together with the previous study in both experimental and numerical about nanofluids will be discussed. Then it is followed by some of the result from previous study by researchers have been included as a references to this study. Finally, this chapter is ends by a little bit conclusions from overall of this study.

## **2.2 HISTORY OF HEAT TRANSFER**

First modern chemist to study heat was Joseph Black (1728 - 1799). Black tried to explain heat in terms of a fluid. He explained how a kettle of water placed over a fire increased in temperature but a kettle filled with water and ice placed over a fire did not change in temperature till all the ice was melted. He said that until the ice was saturated with the heat-fluid and thus became melted could its temperature rise. French chemist Antoine Lavoisier (1743-1794) accepted this theory and proposed a theory based from this phenomenon called as “caloric theory”. The caloric theory states that heat is a fluid-like substance called “caloric” (Latin word for heat) that is a mass less, colorless, odorless, and tasteless substance that can be poured from one body into another. When caloric was added to a body, its temperature increased; and when caloric was removed from body, its temperature decreased.

Another idea competed with the caloric theory. Scientist knew that kinetic energy of motion plus the stored energy called potential energy was given the name mechanical energy and that friction was a part of the conservation of these energies. They knew friction could warm up an object so maybe the invisible motion of invisible particles was what we call heat. Summed up; friction was converting mechanical energy into heat. The problem was this idea of really small particles of matter (i.e., atoms and molecules).

An English physicist, James Prescott Joule (1818-1889) was attempting to find the mechanical equivalent of heat. In the end he found that a given amount of energy of whatever form always yielded that same amount of heat (at 4.18 joules per calorie). The relationship of the motion of atoms to temperature and heat was placed on firm theoretical basis about 1860 by the Scottish physicist James Clerk Maxwell and thus put the caloric theory to the rest.

## **2.3 THEORY OF HEAT TRANSFER**

From the introduction, heat is defined as the form of energy that can be transferred from one system to another as a result of temperature difference. The transfer of energy as heat is always from the higher temperature medium to the lower one. This transfer process stops when both medium reach the same temperature.

Heat can be transferred in the three different mechanisms which are conduction, convection, and radiation. These three mechanisms of heat transfer require the existence of a temperature difference, and begin from the high temperature medium to a lower temperature medium. Below is the brief description of each mechanism of heat transfer:

### **(i) Conduction:**

Regions with greater molecular kinetic energy will pass their thermal energy to regions with less molecular energy through direct molecular collisions, a process known as conduction. In metals, a significant portion of the transported thermal energy is also carried by conduction-band electrons.