Ph.D. Thesis

STUDIES OF NATURAL AND MIXED CONVECTIVE HEAT TRANSFER FROM NARROW PLATES AS HEAT SINK

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Abstract

Heat sinks are widely used in various industrial applications to cool electronics and automotive components like diodes, IGBTs, CPU, power LED and engine etc. The increasing heat output of modern electronic devices requires good heat sink. If heat is not dissipated rapidly to its surrounding, this may results into rise in temperature of the system components. This high temperature leads to the system failure. The generated heat within the system must be rejected to its surrounding to maintain the system at recommended temperature for its efficient working. It is necessary to improve the performance of heat sink to avoid system failures. The performance of heat sink depends on geometric parameters such as, fin height and fin spacing and base to ambient temperature difference.

Present study deals with heat transfer enhancement by varying the geometrical parameters under the steady-state natural convection, mixed convection for vertical rectangular plate heat sink on a vertical base. The effects of various geometric parameters on the heat transfer rate of plate heat sink were determined. It is observed that effect of fin spacing on heat transfer rate was more dominant than other geometrical parameters. The effects of orientation of inclination on plate heat sinks were also studied. It is observed that natural convection heat transfer rate was more at vertically oriented heat sink than horizontal orientation. CFD simulation is used to understand the airflow structure through vertical and inclined plate heat sink.

It is apparent from experimental results that optimum fin spacing of heat sink lies between 7 mm to 9.5-mm. Optimization of fin spacing was carried out for improved heat transfer rate using response surface optimizer. The optimum spacing obtained from RSM is close as that of experimental result

To validate experimental results, response surface methodology (RSM) is used for formulating the mathematical models of convective heat transfer rate and temperature difference for heat sink. Result shows that models are true and accurate. In addition to RSM, artificial neural network (ANN) analysis is also carried out to validate the model developed. RSM and ANN results are in better agreement.

Contents

Nomenclature

Symbols	List of Symbols
As	Surface area, m^2
h	Convection heat transfer coefficient, $W/m^2 {}^\circ C$
g	Gravitational acceleration, m/s^2
θ	Angle of Inclination from vertical,°
H	Fin height, mm
K	Thermal conductivity, W/m°C
L	Fin length, mm
β	Volumetric thermal expansion coefficient, 1/K
Gr	Grashof number
Ra	Rayleigh number
Nu	Nusselt number
Pr	Prandult Number
Ri	Richardson Number
Re	Reynold number
n	Number of fins
S	Fin spacing, mm
t	Fin thickness, mm
W	Base plate width, mm
v	Air kinematic viscosity, m^2/sec
α	Thermal diffusivity, m^2/sec
ε	Emissivity
σ	Stefan-Boltzmann constant, W/m^2K^4
Ta	Ambient air temperature, °C
T_w	Average base temperature, °C
ΔT	Base-to-ambient temperature difference, °C

T_f	Film temperature, K
Q	Heat input to the heater, W
Qc	Convection heat transfer rate, W
Qr	Radiation heat transfer rate, W
A_b	Base plate area, m^2
v	Velocity of air m/s
V	Voltage ,Volt
I	Current, Amp

List of Abbreviations

Abbreviation	Description
RSM	Response Surface Methodology
ANN	Artificial Neural Network
CFD	Computational Fluid Dynamics
Nu_{McA}	Mac Adams Correlation for Nusselt number
Nu_{CCI}	Churchill chu's 1st correlation for Nusselt Number
Nu_{CCII}	Churchill chu's 2nd correlation for Nusselt Number
ANOVA	Analysis of Variance

CHAPTER 1

INTRODUCTION

1.1 Background

While designing electronics components, heat dissipation is one of the important parameters, which demands for improved cooling system designs. To maintain reliable operation of these devices, it is necessary that heat should be removed in efficient way.

In recent years, aggressive competition has increased substantially to provide aesthetically designed components in electrical and electronic applications. New researches and digitalisation of the system results into compact and tiny components. However, decreasing size of the components results into increased failure rate. In electronic devices, in order to increase the speed of the circuits, the circuit power has to be increased which lead to the temperature rise. Increase in temperatures creates problems for thermal management of the system. This has made the design of cooling system more challenging.

A heat sink is used to absorb and dissipate the heat. Heat sinks are an extremely useful component that can be used to lower the maximum temperature of electronic devices as well as increase their overall thermal efficiency and performance. Most of the heat sinks are metal devices, which consist of base as a flat surface. On top of this flat base, large numbers of fins are protruding out of the surface. These fins produce more surface area, which enhances the cooling performance of the devices.

The selection of the most appropriate heat sink for a particular application is very difficult, even though many design options are available. Plate heat sinks offer a low cost and reliable operation. This study focuses on the performance of vertical and inclined plate heat sink in natural convection and vertical heat sink under mixed convection to optimize the fin spacings.

1.2 Heat Transfer Enhancement Techniques

Heat transfer enhancement techniques can be classified as either passive techniques or active techniques. Passive techniques generally consist of modifying or adding structures to heated surfaces. It employ special surface geometries or fluid additives for heat transfer enhancement i.e. no direct application of external power. Passive techniques include treated surfaces, rough surfaces, extended surfaces, and displaced enhancement devices, swirl flow devices, coil tubes, surface tension devices, additives for liquid and additives for gases.

Active techniques require external power such as electric or acoustic surface vibrations. Active techniques include mechanical aids, surface vibrations, fluid vibrations, electro or magnetic fields, injection on suction and jet impinges. The active techniques have not found commercial interest because of the capital and operating cost of the enhancement devices and problems associated with vibrations or acoustic noise. [80]

1.3 Natural Convection over Surfaces

Natural convection heat transfer on a surface depends on the geometry of the surface as well as its orientation. It also depends on the variation of temperature on the surface and the thermo physical properties of the fluid involved. Some analytical solutions exist for natural convection, but such solutions lack generality since they are obtained for simple geometries under some simplifying assumptions. Therefore, with the exception of some simple cases, heat transfer relations in natural convection are based on experimental studies. Various correlations are developed for plates to show the relation between non-dimensional number and heat transfer enhancement.

The simple empirical correlation for the average Nusselt number (Nu) in natural convection is given by following equation [81].

$$Nu = \frac{hLc}{k} = C(GrL, \Pr)^n) = CRaL^n \qquad \text{... (1.1)}$$

where Ra is the Rayleigh number, which is the product of the Grashoff and Prandtl numbers. The values of the constants C and n depend on the geometry of the surface and the flow regime, which is characterized by the range of the Rayleigh number. The value of n is 1/4 usually for laminar flow and 1/3 for turbulent flow. The value of the constant C is normally less than 1.All fluid properties are to be evaluated at the mean film temperature. When the average Nusselt number and the average convection coefficient is known, the rate of heat transfer by natural convection from a solid surface at a uniform temperature T_s to the surrounding fluid is expressed by Newton's law of cooling.

1.4 Natural Convection for Finned Surfaces

Finned surfaces of various shapes, called heat sinks, are frequently used in the cooling devices. Energy dissipated by these devices is transferred to the heat sinks by conduction and from the heat sinks to the ambient air by natural or forced convection, depending on the power dissipation requirements. Natural convection is the preferred mode of heat transfer since it involves no moving parts, like the electronic components themselves. However, in the natural convection mode, the components are more likely to run at a higher temperature and thus undermine reliability. A properly selected heat sink may considerably lower the operation temperature of the components and thus reduce the risk of failure.

Natural convection from vertical finned surfaces of rectangular shape has been the subject of numerous studies. Bar-Cohen and Rohsenow have compiled the available data under various boundary conditions and developed correlations for the Nusselt number and optimum spacing [81]. The characteristic length for vertical parallel plates used as fins is usually taken to be the spacing between adjacent fins S, although the fin height L could also be used. The Rayleigh number is expressed as [81]

$$RaS = \frac{g\beta(Ts-T\infty)s^3}{\nu^2}Pr \qquad \text{... (1.2)}$$

$$RaL = \frac{g\beta(Ts-T\infty)L^3}{\nu^2}Pr = Ras\frac{L^3}{S^3} \qquad \text{... (1.3)}$$

The recommended relation for the average Nusselt number for vertical isothermal parallel plates is,

$$Nu = \frac{hS}{K} = \left[\frac{576}{(Ras\ S/L)^2} + \frac{2.873}{(Ras\ S/L)^{0.5}}\right]^{-0.5} \qquad \text{... (1.4)}$$

A question that often arises in the selection of a heat sink is whether to select one with closely packed fins or widely spaced fins for a given base area. A heat sink with closely packed fins will have greater surface area for heat transfer but a smaller heat transfer coefficient because of the extra resistance of the additional fins introduce to fluid flow through the inter fin passages. A heat sink with widely spaced fins, on the other hand, will have a higher heat transfer coefficient but a smaller surface area. Therefore, there is need to find an optimum spacing that maximizes the natural convection heat transfer from the heat sink for a given base area W×L, where W and

L are the width and length of the base of the heat sink, respectively, as shown in figure 1.1.

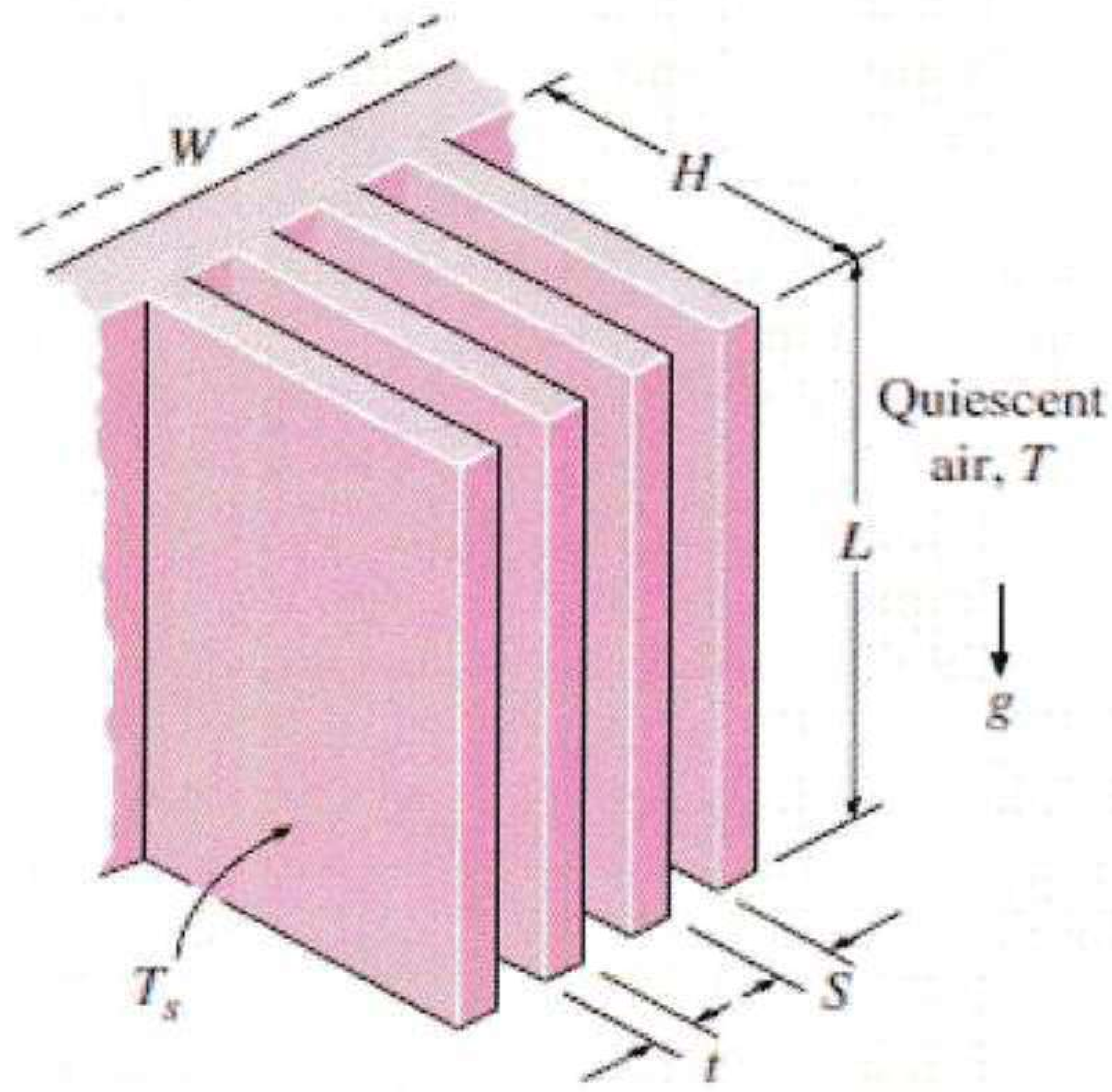


Figure 1.1 Vertical Plate Heat Sink [81]

H is the height of the fin and t is the thickness of the fin. When the fins are essentially isothermal and the fin thickness t is small relative to the fin spacing S, the optimum fin spacing for a vertical heat sink is determined by Bar-Cohen and Rohsenow relation.

$$Sopt = 2.714\left(\frac{S^3 L}{Ras}\right)^{0.25} = 2.714\frac{L}{Ral^{0.25}} \qquad \text{... (1.5)}$$

The rate of heat transfer by natural convection from the fins can be determined from

$$Qc = h(2nLH)(Ts - T\infty) \qquad \text{... (1.6)}$$

Where $n = W/(S + t) \approx W/S$ is the number of fins on the heat sink and Ts is the surface temperature of the fins. All fluid properties are to be evaluated at the average temperature $T_{avg} = (Ts + T\infty)/2$.

1.5 Mixed Convection

In the study of fluid flow over heated surfaces, the buoyancy forces are, generally neglected when the flow is horizontal. However, for vertical or inclined surfaces, the buoyancy forces exert strong influence on the flow field. Hence, it is not possible to neglect the effect of buoyancy forces for vertical or inclined surfaces and heat sink. In many applications, both modes have a contribution in cooling. Rectangular heat sinks are used to increase the heat dissipation rates from systems, because such fins are simple, cheap and easy to manufacture. The buoyancy forces do have significance influence on the flow and consequently on the heat transfer rate in such cases the flow around the body is mixture of free and forced convection. Such flows are referred to as mixed convection, which is normally associated with low velocities. Since the convective heat transfer coefficient is a strong function of the Reynolds number (Re) in forced convection and Grashof number (Gr) in natural convection. The parameter Gr/Re^2 represents the importance of natural convection relative to forced convection. Natural convection is negligible when $Gr/Re^2 < 0.1$, forced convection is negligible when $Gr/Re^2 > 10$, and neither is negligible when $0.1 < Gr/Re^2 > 10$. The ratio Gr/Re^2 is know as Richardson number (Ri), which gives a quantitative indication of the influence of buoyancy on forced convection [81].

1.5 Heat Sink Applications

The life of electronic devices is directly related to its operating temperature. The important part of thermal management system in electrical and electronic devices is heat sink. Because of their low cost, durability and reliability, it is a popular cooling or heat-removing device in this industry. Heat sink finds wide applications for low to medium power electronic components in computers, telecommunications devices and miniaturized devices. The devices like DC converters, Power modules, IGBTS, Relays, microprocessors and power handling semiconductors are examples of electrical devices that need a heat sink to reduce their temperature through increased thermal mass and heat dissipation. Electronic components such as diodes, transistors etc. are provided with finned surfaces for the dissipation of heat. Heat sink find wide applications not only in electronic industries but also in applications such as tubes of various heat exchangers e.g. radiator of cooling system, condensers tubes of domestic refrigerator, intercooler of air compressors, heat boiler waste, nuclear fuel model and many more. The head and cylinder of air-cooled engines and compressors are provided with fins.

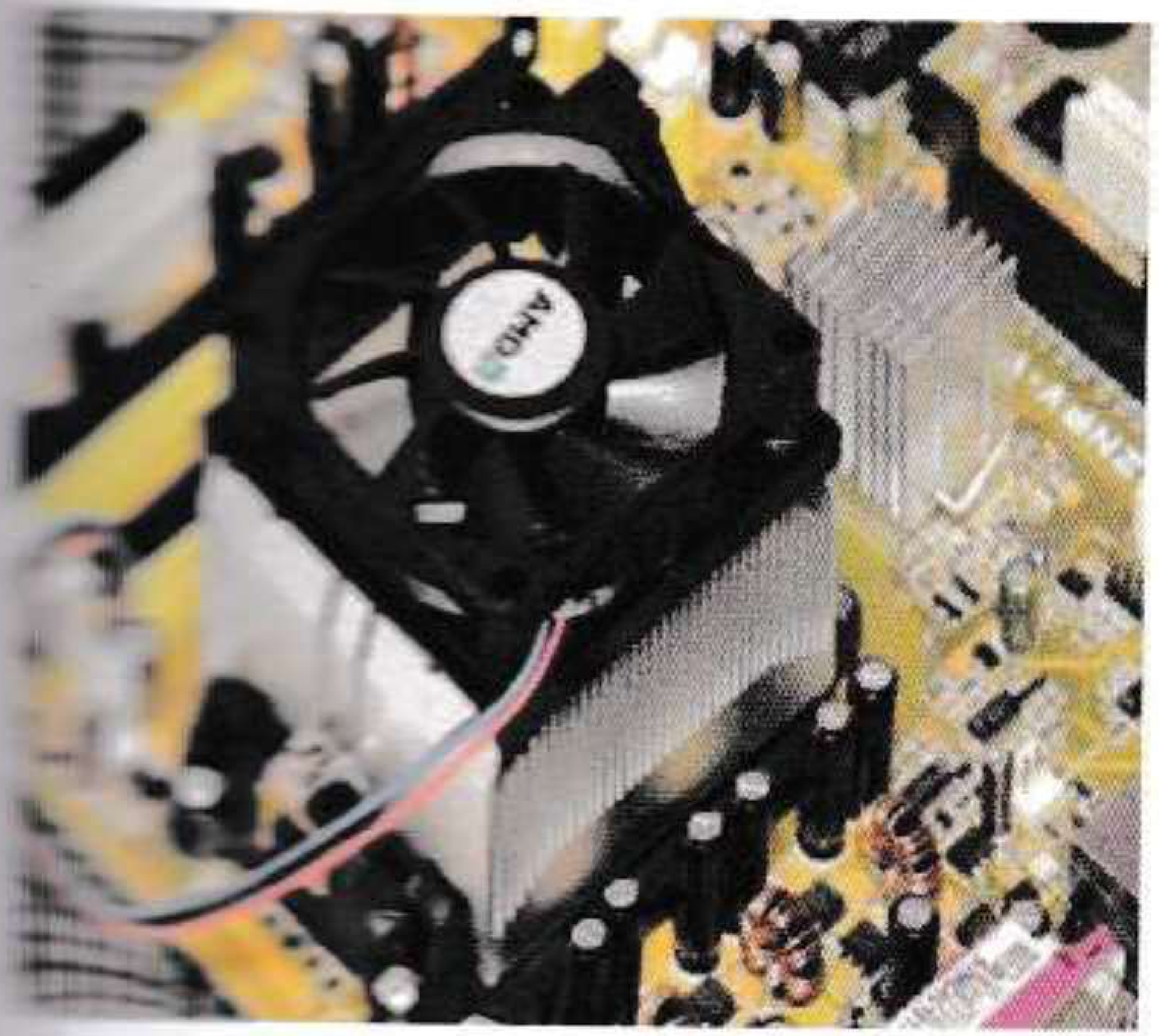


Figure 1.2 Heat Sink For Cooling of CPU

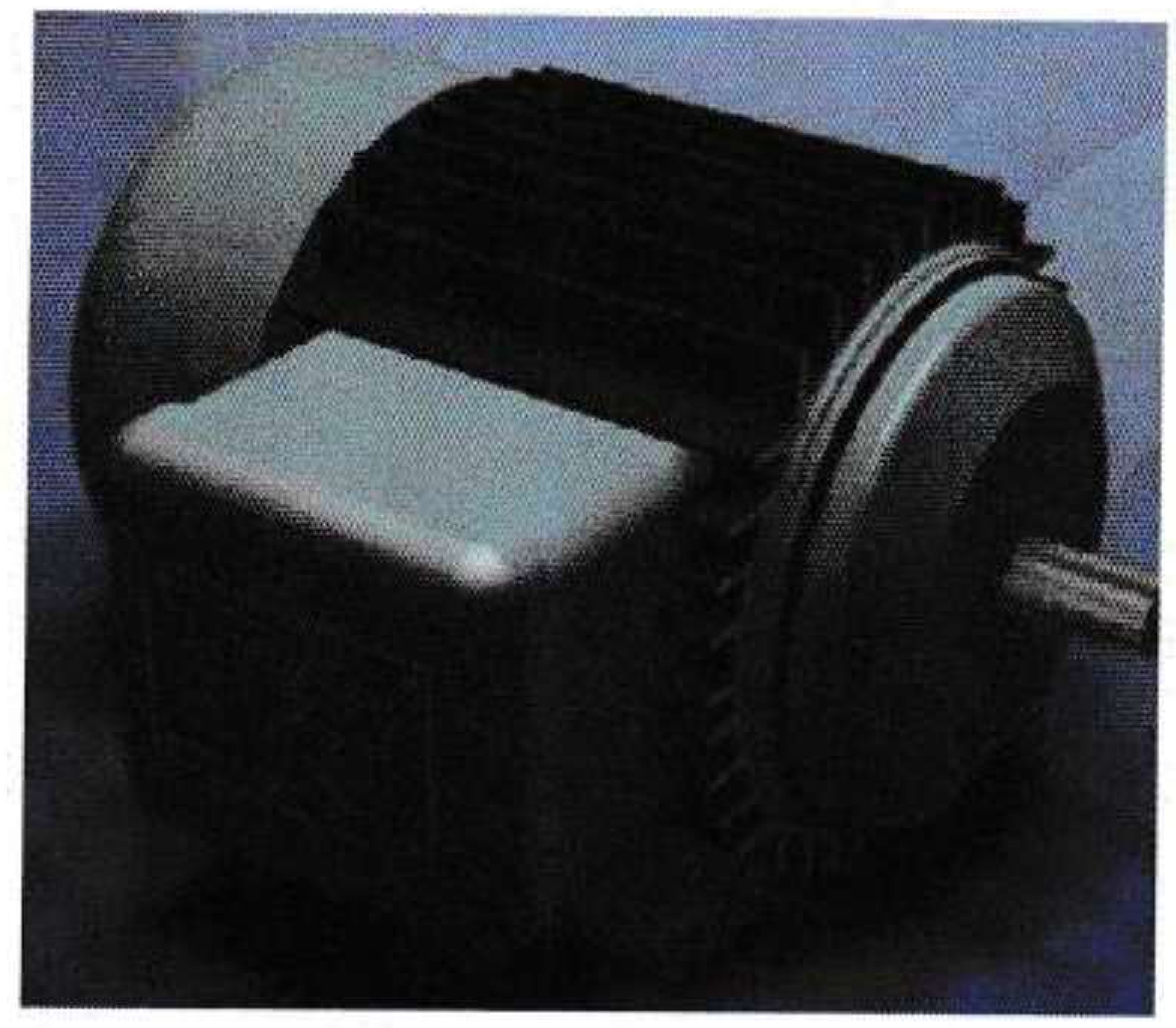


Figure 1.3 Heat Sink – Elect. Motor

Heat sink used for CPU is shown in figure 1.2. A DC fan is forcing the air over the heat sink for better heat dissipation. Figure 1.3 shows the application of rectangular plate fin heat sink for the dissipation of heat from electric motor in natural convection.

Figure.1.4 Heat Sinks of Air Cooled Engine

Figure 1.4 shows application of plate fin heat sink for cooling of internal combustion engine. The unwanted heat generated during combustion is dissipated through the fins.

1.7 Problem Statement

Day by day, the electronic and electrical components become compact and small. The characteristics of flow on these devices and heat transfer rate per unit area increases compared with the large components. Therefore there is need to study such small narrow plate fin heat sink. Generally, the plate fin heat sink is placed either vertical or [illegible] for dissipation of heat. From certain study observations, if heat sink is inclined then the buoyancy force act normal to the flow direction of the components, this can affect the performance of heat sink. Therefore, it is necessary to study the performance of heat sink when angle of inclination is change. Heat sinks used in combination with a fan will produce a more thermally efficient system but sudden failure of fan cause to failure of system. In such situation, it is necessary to study of performance of heat sink under mixed convection mode of heat transfer. Effect of geometrical parameters such as fin height, fin spacing and base to ambient temperature difference and effect of angle of inclination on the performance of heat sink are examined in this study.

1.8 Objectives of the Study

This study investigates the thermal performance of plate fin heat sink for different orientations from vertical to horizontal in natural convection and the effect of mixed convection for vertical plate fin heat sink. The prime objectives of the study are,

i. Study of vertical plate heat sink with different configurations.

ii. Effect of angle of inclination on convective heat transfer rate.

iii. Study of optimum fin spacing of plate heat sink.

iv. Study of flow pattern of plate heat sink for different inclinations.

v. Study of mixed convective heat transfer from plate heat sink for vertical orientation.

1.9 Organization of Thesis

The thesis is arranged and organized as follows,

Chapter 1 provides general background of different types of heat sink. Convective study of heat transfer from vertical surfaces and inclined plate fin heat sink various applications of heat sink and objectives of the work. Particular attention is given on the applications of heat sink for wide range of electrical and electronic cooling.

Chapter 2 elaborates the previous research studies related to the present work. It consists of review of heat transfer from flat plates and vertical and inclined heat sink under [illegible] study.

Chapter 3 gives detail of the experimental methodology for vertical orientation, inclined orientation and assisting flow mixed convection. This chapter also provides [illegible] of experimental setup and details of the instrumentation required for instrumentation.

Chapter 4 deals with the mathematical modelling and optimization methods for the optimization of fin spacing.

Chapter 5 illustrate the results and findings of the experimental work and CFD simulation. Effect of various parameters on the geometry of heat sink is analysed.

Chapter 6 summarises the conclusions of the experimental and statistical investigations. Some suggestions are made for future research in this area.

Appendix A shows the sample calculations.

Appendix B gives the detail of the observation tables.

Appendix C consist of ANN graphs and error tables.

Appendix D contains CFD images.

CHAPTER 2

LITERATURE SURVEY

2.1 Introduction

Many researchers have worked on fin geometry to improve the heat transfer. Still more efforts are needed in order to understand the complete behavior of geometry parameter and its effect on heat transfer and fluid flow application. In this chapter, a summary of the related research made with different geometry of heat sink is discussed. Among the literature found, area could be identified which are related to this experimental work.

2.2 Vertical and Inclined Flat Plate

Many authors studied natural convective heat transfers from flat plates. Patrick H. Oosthuizen, Jane T. Paul [1], studied natural convective heat transfer from narrow vertical plates, which have a uniform surface heat flux. With a narrow plate, the heat transfer rate was dependent on the flow near the vertical edges of the plate. The magnitude of the edge effects depends on the conditions existing near the edges of the plate. They numerically investigated the effect of the edge condition on the heat transfer rate. They revealed that the dimensionless plate width has to have a significant influence on the mean Nusselt number for natural convective heat transfer. These edge effects increase with decreasing dimensionless plate width and decreasing Rayleigh number. Empirical equations for the mean heat transfer rate from narrow plates have been derived from the numerical results. The protrusion of the heated plate from the surface tends to increase the Nusselt number, this effect increasing with decreasing heat flux Rayleigh number.

Natural convective heat transfer from flat narrow plates and short cylinders inclined at an angle to the vertical in laminar and transition flow regions with isothermal or constant heat flux conditions have been numerically and experimentally studied by Abdulla Kalendar,P. Oosthuizen [2]. When the narrow plate was inclined to the vertical, pressure changes normal to the plate surface arise and these pressure changes can alter the nature and the magnitude of the edge effects. When two narrow inclined rectangular flat plates of the same size separated vertically or horizontally, the flow interaction between these heated plates can have a significant effect on the heat transfer. The width of the plate has a considerable effect on the heat transfer rate.

Churchill and Chu [3] conducted experiments for different Prandtl numbers and for Rayleigh numbers covering laminar, transition and turbulent regions of flow. Different correlations for vertical and inclined flat plate was developed to calculate the Nusselt number.

Kamal Eldin Hassan and Salah A. Mohamed [4] determined local heat transfer coefficient using Boelter-Schmidt flux meter for a flat plate in natural convection. Experimentation for different plate inclinations was carried out. The result shows that flow separation takes place along trailing part at positive inclination angles.

Vliet [5] seems to be the first who presented experimental local heat transfer results for natural convection over constant heat flux inclined surfaces using water and air as the test fluids. The data was for Rayleigh numbers from 10^7 to 10^{16} and inclination angles from vertical to 30^0 from the horizontal, and included results for laminar, transitional, and turbulent flow regions. The effect of the leading, trailing and sides edges of the plate on the local heat transfer and flow regions was not investigated as side walls were attached to each side of the heated plate.

H.I. Abu-Mulaweh [6] examined the effects of backward-facing and forward-facing steps on turbulent natural convection along a vertical heated flat plate experimentally. The experiment was carried out for a step height of 22 mm and a temperature difference between the heated walls and the free stream of 30°C. The results reveal that the maximum Nusselt number occurs near the reattachment region. It was approximately twice for the case of backward-facing step and two and a half times for the case of forward-facing step, than that of the flat plate value at similar flow and thermal conditions.

The problem of determination of the turbulence onset in natural convection on heated inclined plates in an air environment has been experimentally studied by A. [illegible] Sevillano et al. [7] considered the onset of turbulence has been to take place where velocity fluctuations start to grow. Experiments have shown that the onset depends not only on the Grashof number defined in terms of the temperature difference between the heated plate and the surrounding air. A correlation between dimensionless Grashof and Reynolds numbers has been obtained, fitting quite well the experimental data.

[illegible] B. Premachandran [8] studied an experimental and semi-experimental investigation of steady laminar natural convection and surface radiation between three parallel vertical plates, viz., a central hot plate coated with blackboard paint and two unheated side plates that were polished, symmetrically spaced on each side, with air as the intervening medium. The experiments were done for six-plate spacings ranging from 12.66 to 52.2 mm and for an order of magnitude range of wall-to-ambient temperature difference. The analysis brings out the significance of radiation heat transfer rate even at low temperatures of 310 K. The average convective Nusselt numbers obtained from the experimental and semi-experimental investigation taking into account the variation of temperature along the plate and under the isothermal assumptions, shows that the isothermal approximation itself was adequate. A correlation for the average convective Nusselt number in terms of Grashof number and the aspect ratio was developed.

[illegible] Vertical and Horizontal Plate Heat Sink

Natural convection heat transfer from different types of heat sinks has been investigated in the literature both theoretically and experimentally. The selection of a particular heat sink depends on the required thermal performance and application. Among the literature, the most common studied heat sink was the rectangular plate fin heat sink.

Yuncu and Anbar [9] investigated the distinct role and performance of fin spacing, length and base-to-ambient temperature difference under free convection from horizontal based rectangular fins. It was found that fin height has strong effect on thermal performance and for a specific height, there was optimum fin spacing, which was [illegible] to temperature difference.

[illegible] et al. [10] studied the effects of a wide range of geometrical parameters like fin spacing, fin height, fin length and temperature difference between fin and surroundings on the heat transfer from horizontal fin arrays.They concluded that since produce more dominant single chimney flow, the overall value for the heat coefficient reduces with fin length.

Setio [11] developed a correlation for optimum fin spacing, which will heat transfer rate. For this purpose experimental data from previously experiments for heat dissipation from five aluminum, horizontally oriented fin referred. Effect of fin length and fin spacing was investigated. Two sets of were developed to predict effect of these geometrical parameters on heat transfer. Results of mathematical modeling showed that fin length and fin spacing were main parameters, which affected convective heat transfer heat sink.

Yeh, Shih-Pin Liaw and Ming Chang [12] analyzed the effect of optimum of longitudinal fin arrays in force convection. Four different fins array was They concluded that the optimum aspect ratio as well as spacing was the for rectangular fin and smallest for concave-parabolic profile fin. The total heat duty was largest for concave-parabolic fin array and was smallest rectangular fin array.

H.S. Wang, W.Q. Tao [13], conducted a numerical study to investigate natural convection heat transfer around a uniformly heated thin plate with inclination. They found that for inclination angle less than 10^0, the flow and characteristics were complicated and the average Nusselt number cannot by one equation while for inclination angle greater than 10^0 the average number can be correlated. They also found that for inclination angle less than the local natural convection heat transfer was very different for the upper and surfaces.

G.S.V.L Narasimham,et al.[14], developed mathematical formulation of convection heat and mass transfer over a shrouded vertical fin array .The base maintained at a temperature below the dew point of the surrounding moist there occurs condensation of moisture on the base plate, while the fins may or fully wet. The result shows that beyond a certain stream wise distance, fin length does not improve the sensible and latent heat transfer performance.

If dry fin analysis used under moisture condensation conditions, the overall heat transfer will be underestimated by about 50% even at low buoyancy ratios.

[illegible] Premachandran,et al. [15], did an experimental and investigation of steady laminar natural convection and surface radiation between three parallel vertical plates. The analysis brings out the significance of radiation heat transfer rate even at low temperatures of 310 K.

[illegible] H.Yuncu [16] studied the effects of fin spacing, fin height and fin length on flow dynamics were investigated. Two different types of buoyancy flow were found by them which were up and down type flow and single chimney type flow. The height to length ratio of the fin was found important for affecting the flow pattern.

[illegible] and Lesmana [17] investigated heat dissipation from miniaturized vertical rectangular fin arrays. Experiment was conducted under steady state heat on 10 sets of fin arrays. Fin length was considered 25 mm and 49 mm that was very less as compared with fin lengths from literature. It was observed that convective heat transfer got affected due to variation in fin spacing. Optimum fin spacing was obtained at 11 mm. It was also concluded that effect of the parameter W/L on heat dissipation rate was relatively less for the vertically base array.

[illegible] [18] experimentally investigated the natural convection heat transfer and fluid flow characteristics in horizontal and vertical narrow enclosures with heated rectangular finned base plate at a wide range of Rayleigh number for different fin spacings and fin lengths. It was found that increasing Ra increases Nusselt number and increases fin effectiveness.Nusselt number and finned surface effectiveness increases with decreasing S/H until S/H reaches a certain value beyond which the Nusselt number and finned surface effectiveness start to decrease with further decreasing of S/H.

[illegible] [19] discussed air-cooling characteristics of a uniform square modules array for electronic device heat sink. For this purpose various square modules array were experimentally investigated. The results indicated that the average heat transfer coefficient little increased with increasing the modules array temperature, but the increase was significantly higher with increasing the flowing air velocities. The increasing of module to channel height ratio seems to increase the average heat transfer coefficient.

[illegible], et al. [20] studied natural convection from an array of horizontal rectangular thick fins with short lengths attached on a horizontal base plate. The three dimensional elliptic governing equations of laminar flow and heat transfer were solved using finite volume scheme. They found that, the fin spacing S = 7 mm for fin arrays with H/L ≤ 0.24 gives higher heat transfer rate. For the fin arrays with H/L > 0.24 and S/L < 0.2, air can only enters into the channel from the fin end regions. However, for lower valves of H/L ≤ 0.24 and higher values of S/L ≥ 0.2, air can also enter into the channel from the middle parts between fins. Natural convection heat transfer coefficient increases with increasing temperature differences and fin spacing and decreases with fin length. The fin thickness and fin height does not affect the value of average heat transfer coefficient considerably.

B.Yazicioglu,H.Yuncu [21] performed experiments over thirty different fin configurations with 250 mm and 340 mm fin length. Optimum fin spacing of rectangular fins on vertical base was examined. The range of base-to-ambient temperature was kept quiet wide from 30°C to 150°C for fin height and fin spacing from 5 to 25 mm and 4.5 to 85.5 mm, respectively. It was found that optimum fin spacing varies for each fin height, which was between 6.1 and 11.9 mm. They developed Equation to evaluate the optimum fin spacing value and corresponding maximum heat transfer rate at given fin length and base-to-ambient temperature difference for vertical base fin array. They concluded that the larger fin height results in higher convective heat transfer from fin array but for low base-to-ambient temperature difference, it was insignificant.

A correlation was developed to investigate optimum fin spacing of vertically based rectangular fin arrays by Burak Yazicioğlu and Hafit Yüncü [22]. The fin length range from 100 mm to 500 mm, the fin height from 5 mm to 90 mm, the fin thickness from 1 mm to 19 mm, the width of rectangular base plate from 180 mm to 250 mm. The range of fin thickness was from 1 mm to 19 mm, the fin spacing from 3 mm to [illegible] mm, the fin height from 5 mm to 90 mm, the width of base plate from 180 mm to 250 mm. The average relative improvements in convection heat transfer rates from [illegible] spaced fin arrays for fin heights of 5, 15 and 25 mm were 37.44 %, 39.01 % and 41.28 %, respectively. They concluded that the convection heat transfer rate from fins increases as fin spacing decreases, attains a maximum and then starts to decrease with the further decrease in the fin spacing.

The effect that reduction of the base-plate dimensions as on the steady-state performance of the rate of natural convection heat transfer was investigated by Filino [illegible] et al [23]. They found that a reduction in the base-plate were by 74 percent increased natural convection coefficient by 1.5 times to 26.0 $Wm^{-2} K^{-1}$ for single fin [illegible] and by 1.8 times to 18 $W m^{-2} K^{-1}$ for fin arrays. It was found that increasing the [illegible] ratio by reducing the base-plate area through reducing L under conditions of constant H, S, and n, has the effect of increasing the average natural convection coefficient of fin arrays. They suggested that the fin length *L* and the number of fins *n* [illegible] geometric variables.

[illegible] Mostafavi et al. [24] have done investigation for external natural convection heat transfer from vertically mounted twelve rectangular interrupted fin arrays. The results showed that interrupted fins not only reduces weight of heat sink but also increases thermal performance. The optimum interruption length for maximum fin array thermal performance was found. They concluded that the purpose of these interruptions was to reset the thermal boundary layer associated with the fin in order to decrease thermal resistance.

[illegible] Yingjun Cheng et al. [25] studied the heat-transfer characteristics of 128 [illegible] plate-fin heat sinks used in a supercomputer chassis with CFD simulation. The fin pitches and fin thickness were the two most important parameters of the [illegible], which will affect the heat-transfer characteristics of heat sink greatly. They found that the convective heat-transfer coefficient was sensitive to fin pitch and fin thickness. Compared with conductive thermal resistance, convective thermal resistance of heat sink was a dominant factor affecting the heat transfer of heat sink. The Biot criterion was applicable to estimate the Biot number of large-scale plate-fin heat sink. The Biot criterion was not applicable for small-sized plate-fin heat sink, [illegible] fin pitch less than 5 mm. The optimal fin pitch was observed as 1.2–2 mm.

[illegible] and P.K. Das [26] performed an analytical study to investigate performance and optimum design analysis of four fin array types. In this regard, longitudinal rectangular fin array, annular rectangular fin array, longitudinal trapezoidal fin array and annular trapezoidal fin array under convective cooling conditions were investigated. Considerable effect of the conduction through the supporting structure and the convection from the interfin spacing was observed. A method was also developed for optimizing the fin dimensions when the total fin volume and the interfin spacing were given.

[illegible] Franco [27] analyzed the problem of the optimum thermal design of free and forced convection fin arrays composed of longitudinal fins with constant thickness. Two different cases were considered, the minimization of the weight for a given heat flow and the maximization of the heat flow for a given weight. They have observed that, the convective heat transfer coefficient depends on the dimensions of the inter fin spacing, both in natural and in forced convection. The available heat flow was maximum for open array compared to closed array. The fin efficiency was [illegible] for the closed array and 40% for the open array respectively.

[illegible] and Xiang Ling [28] designed a novel and high efficient diffusion welded [illegible] fin-plate radiator (HFPR) for electronic cooling.They experimentally investigated the effect of three parameters on thermal performance of HFPR: the working fluid filling ratios the vacuum degrees and the airflow velocities .A series of tests were carried out using distilled water and ethanol as working fluids, to find the influence of the above parameters on steady-state heat transfer characteristics of HFPR. They have found that, the filling ratio and vacuum degree had a significant influence on thermal performance of HFPR.

[illegible] Zhang and Dawei Liu [29] analytically and numerically determined the optimal spacing of vertical rectangular fin arrays in natural convection for maximum heat transfer. It was found that, the optimal plate-to-plate spacing was 4/3 of velocity boundary layer thickness. In a fixed two-dimensional volume, the shorter length of [illegible] preferred to enhance heat transfer.

[illegible] and R. Velraj [30] carried out the modeling and simulation of parallel [illegible] sink by using computational fluid dynamics package. They have observed [illegible] performance of heat sink depend on various geometric parameters such as [illegible] of fins, fin length, fin height, and base height. The DOE methodology was [illegible] find out the optimum parameter of the heat sink. The result shows that, 20 [illegible] of fins with 30mm fin height and 7.5mm base height gives lower thermal [illegible] and higher heat transfer compared to all other geometries.

[illegible] Kim, et al. [31] suggested the correlation for estimating the fin Nusselt [illegible] of natural convective heat sinks with vertically oriented plate-fins. The [illegible] investigations were performed for various channel widths, heights and [illegible]. The numerical simulation was conducted to verify experimental results [illegible] the fluid flow and heat transfer characteristics of a natural convective [illegible]. They also observed that, the optimal channel width was independent of the [illegible] but dependent of the heat sink length, the difference between the heat [illegible] and the ambient temperatures, and fluid property.

[illegible] S. Prasanna Devi, et al. [32] presented an approach for the [illegible] optimization of the flat plate heat sink using Taguchi design of [illegible] Grey relational analysis. Firstly, heat sink modeled using an soft [illegible] Structure Simulator (HFSS) software version 12 and the value of the [illegible] was obtained from simulation. The experimental investigation was [illegible] find the thermal resistance and emitted radiations from the heat sink and [illegible] experimental results were validated with the simulation model. [illegible] of experiments was performed by using Minitab software. The [illegible] considered for optimization as length and width of the heat sink, fin [illegible] number of fins, and fin thickness. They also carried out, ANOVA [illegible] out the contribution and impact of each heat sink design factor towards [illegible] of the heat sink.

[illegible] Mohammad Mahdi Naserian, et al. [33] investigated the natural [illegible] transfer coefficient on extended vertical base plates. The CFD [illegible] carried out using fluent software. They have observed that the [illegible] transfer rate from fin arrays depends on fin height, fin length, fin [illegible] and base-to-ambient temperature difference. The convective heat transfer [illegible] from the fin arrays increases with fin height, fin length and base-to-ambient temperature difference.

[illegible] Fahiminia,et al.[34] studied the natural convection heat transfer from rectangular fin arrays on a vertical base. They have observed that, the average heat transfer coefficient decreased as the number of fins increased, since the flow rate of the cooler air entering the spaces between the fins decreased and the air was heated [illegible] quickly on account of the reduced space between fins. The increasing the number of fins more than optimum number decreases natural convection heat transfer.

[illegible] Kim, KyuHyung et al. [35] suggested the closed form correlations for thermal optimization of vertical plate-fin heat sinks under natural convection. In order to [illegible] closed form correlations, the volume averaging approach was used to [illegible] analytical solutions for velocity and temperature distributions for the heat sinks with [illegible] channel-aspect-ratios. From the analytical solutions, explicit correlations were proposed for optimal fin thickness and optimal channel width, which minimize thermal resistance for given height, width, and length of heat sink.

[illegible], et al. [36] analyzed natural convective heat transfer of nanocoated [illegible] fins using Taguchi method. Carbon nano tubes using PVD to enhance the heat transfer rate of fins coated the rectangular aluminum fins. The convective heat transfer rates for coated and non-coated surfaces were calculated and compared. The [illegible] and heat transfer characteristics were investigated using Nusselt, Grashof, Prandtl and Rayleigh numbers and also optimized by Taguchi method and ANOVA [illegible]. The convective heat transfer and Nusselt number increases for coated [illegible] surface due to considerable increase in surface area of carbon nano tube [illegible] temperature difference between coated surface and ambient temperature. The [illegible] improvement in fin efficiency was 5 % for coated aluminum surface.

[illegible] Vittorio Ferraro, et al.[37] performed the theoretical and experimental [illegible] of a heat sink with vertical orientation in natural convection. The results [illegible] were subsequently compared with the heat sink properties provided by the manufacturer. The values suggested by the manufacturer's characteristic curve were [illegible] greater than those recorded experimentally therefore it was necessary to [illegible] the heat sink so as to avoid encountering overheating problems.

[illegible] et al. [38] presented the multi objective design optimization of a plate-fin heat sink using teaching-learning based optimization algorithm. The entropy generation rate and material cost with five constraints were taken to measure the performance of the heat sink. Number of fins, height of fins, spacing between two fins and incoming air velocity were considered as the design variables. The dynamic heat dissipation performance of plate-fin heat sink was investigated using finite element software ANSYS 12.1. The results obtained by using the TLBO algorithm were compared with the other optimization methods it was found that the TLBO algorithm was better or competitive to the other optimization algorithms.

[illegible] Daming Sun,et al. [39] experimentally and numerically studied the orientation effects on the fluid flow and heat transfer of rectangular fin heat sinks under natural convection. The performance was evaluated for different rectangular fin arrays in eight orientations. The results indicated that denser fin arrays were more sensitive to orientation. They proposed the Nusselt number correlations in a simple form $Nu = CRa^m$ for various orientations and Rayleigh numbers. It was observed that the value of exponent m almost the same for 45^0, 135^0, 225^0, and 315^0 orientation. The mismatch between the heat rejection area and natural convection flow and the blockage of the convection flow were the two dominant factors that deteriorate heat dissipation.

[illegible] et al. [40] experimentally investigated the heat transfer and flow pattern [illegible] horizontal rectangular fin array under natural convection. They were carried out temperature mapping and the prediction of the flow patterns over the fin array with variable fin spacing. The single chimney flow pattern was observed from 8 to 12 mm fin spacing. The average heat transfer coefficient was very small at 100 W for S = 5–12 mm. The h was very small (1.12–1.8 W/m^2 K) at 100 W for 2–4 mm fin spacing due to choked fin array end condition. The central bottom portion of fin array channel does not contribute much in heat dissipation for S = 2–4 mm. The optimum spacing was observed in the range of 8–10 mm. They also found that the average Nusselt number as a function of Grashof number and fin spacing to height ratio.

[illegible] E. Papanicolaou, et al. [41] evaluated the performance of a novel [illegible] of a three-section plate-fin heat sink that employs rectangular channels of [illegible] hydraulic diameter. It has been found that fluid friction in the third heat [illegible] of micro scale dimensions accounts for approximately 95% of the overall [illegible] pressure drop, which was found to be in the range 484-961 Pa.

[illegible] Lin and Yi-Jin Chen [42] employed the theoretical approach to [illegible] the adequate design parameters of an arrayed plate-fins heat sink based on [illegible] heat flow. They have studied geometric parameters such as the fin space, [illegible] fin length and fin thickness. The effect of radiation on heat transfers was [illegible]. They have observed that, increasing the dimensions of geometric [illegible] increases the heat dissipations up to critical value but when the fin space [illegible] enlarges to a critical value then the heat flow will start diminishing.

[illegible] Singh et al. [43] studied natural convection heat transfer from a finned [illegible] in both laminar and turbulent regimes. The computations were performed for [illegible] number by varying the fin-height-to-sphere-diameter ratio and the fin-[illegible]-diameter ratio. The numerically obtained Nusselt number for a simple [illegible] was compared with that of the previous correlations. It was found that the [illegible] of fins and the height of the fins should be lowest for a sphere with non-[illegible] fins for maximum heat transfer and should be maximum for a sphere with [illegible] fins in turbulent heat transfer.

[illegible] [44] investigated the performance of rectangular fins on a vertical [illegible] free convection heat transfer. During experiments, the length, width and [illegible] of fins on arrays were kept fixed, but other parameters such as fin spacing [illegible] were varied. The effects of fin height, fin spacing and base-to-ambient [illegible] difference on the heat transfer performance of fin arrays was observed for [illegible] inputs. According to the experimental results,it was deduced that fin [illegible] the most important parameter in the thermal performance of fin arrays [illegible] optimum fin spacing can be found for every fin height, for a given base-to-[illegible] temperature difference. This result revealed that optimum fin spacing [illegible] two main parameters, fin height and base-to-ambient temperature [illegible] It was concluded that for vertically based fin arrays, higher heat transfer [illegible] can be achieved.

[illegible] Yildiz [45] have investigated natural convective heat transfer from annular [illegible] experimentally. Eighteen sets of annular fin arrays were tested to observe their [illegible] transfer performances. The fin arrays were heated with several heat inputs and [illegible] base and ambient temperature differences were recorded. Using the [illegible] data, total heat transfer rates from fin configurations were evaluated. Then [illegible] contributions were subtracted from total heat dissipations to obtain essential [illegible] heat transfer rates. It was concluded that the convection heat transfer rate [illegible] fin arrays depends on fin diameter, fin spacing and base-to-ambient [illegible] difference.

[illegible] et al. [46] tested micro-fin geometry under natural convection. Copper [illegible] was kept horizontally oriented to determine effect of micro fin height and fin [illegible] fin height ranging from 0.25 to 1.0 mm and fin spacing from 0.5 to [illegible] respectively. The highest value for convective heat transfer coefficient of was [illegible] lowest fin height of 0.25 mm and spacing of 1.0 mm.

[illegible] fin arrays were tested by S.S. Sane, et al.[47].They found 41.82% [illegible] in heat dissipation through notch fins. Fluent software was used for [illegible] fluid dynamic analysis. Increase in height of fin, at air entry ends of fin [illegible] by conductivity of fin material. Thus for an area compensated fin, [illegible] may be possible.

[illegible] et.al. [48] have studied combined convection and radiation analysis. [illegible] were conducted for horizontal fins over vertical base. Natural convection [illegible] heat transfer from a vertical base and horizontal fins in a fin array was [illegible] It was observed that convective heat transfer rates from a fin array [illegible] increasing of fin length at all fin spacing

[illegible] Bhowmik [49] studied the conjugated free convection heat transfer [illegible] fin in a vertical heat sink.The analysis is done using CFD for optimizing [illegible] It is concluded that an optimal spacing requires atrade off between the [illegible] of natural convection and the heat transfer area available per unit length of heat sink wall, which increases and decreases with increase in the fin spacing respectively.

Ko-Ta Chiang et al.[50] analyze an effective procedure of response surface methodology (RSM) has been successfully developed finding the optimal values of designing parameters of a pin-fin type heat sink. Various design parameters, such as height and diameter of pin-fin and width of pitch between fins were explored by experiment. The thermal resistance and pressure drop were considered as the multiple thermal performance characteristics. The results identify the significant influence factors to minimize thermal resistance and pressure drop.

Jenn-Tsong Horng[51] An effective artificial neural network together witha genetic algorithm have been demonstrated for predicting theoptimal thermal performance of plain plate-fin heat sinks in a ducted flow under multi-constraints such as pressure drop, mass,and space limitations. A series of constrained optimal designs can be efficiently performed. Comparisons of the optimal results between the artificial neural network with genetic algorithm (ANN-GA) and the response surface methodology with sequential quadratic programming (RSM-SQP) methods were made.

Starner and McManus [52] investigate in detail the thermal performance of natural convection heat sinks as a function of the geometry (spacing and height) and angle of base plate orientation. Four different fin array configurations with three base types (vertical, horizontal, and 45°) were investigated and heat transfer coefficients were calculated. From experimental data, it was found that heat transfer rates for vertical orientation were generally lower than the values those of similarly spaced parallel plates. It was concluded that fin height, fin spacing and base orientation have significant effect on rate of heat transfer from fin arrays.

Welling and Wooldridge [53] summarize the experimental findings of natural convection from a vertical rectangular fin array, which was almost isothermal. Results of fin heat transfer are found to lie between the heat transfer results of vertical plate and the square duct/infinite parallel plate. The effect of boundary layer interference involving lower heat transfer was observed for the case of closely spaced fins that induced air motion over the fin surface. Maximum heat transport was found for an optimum fin height to spacing ratio.

Jones and Smith [54] report experimental findings of the optimum fin spacing for vertical rectangular fins on a horizontal base undergoing natural convective heat transport. Local heat transfer coefficient was determined by measuring temperature gradient of fluid with the aid of interferometer. Average heat transfer coefficient of the fin array was then determined by integrating the measured local heat coefficients. Heat transfer coefficients measured thus was solely due to convection component excluding the radiation component, if any. The fin spacing was turned out to be the key geometric parameter, which affects the heat transfer performance.

Harahap and McManus [55] present experimental finding on the free convection heat transfer from a vertical fin array attached to a horizontal base. Two series of horizontal rectangular fin arrays having the same spacing and height were compared. The fin array having shorter fin length showed considerable higher average convection coefficients. This indicates that the fin length was an important factor to be considered in fin design.

Bilitzky [56] find the optimum fin spacing for the maximum rate of natural convection heat transfer from vertically placed fins in the laminar flow regime and developed the correlation which relates the ratio of average heat transfer coefficient function of fin spacing to vertical heat transfer coefficient.

Experimental investigation on free convection from the vertical rectangular fins protruding from both horizontal as well as vertical rectangular base is extended by Leung et al. [57] keeping base temperature constant. The effect of fin length on optimum fin spacing was reported. It was revealed that heat dissipation rate per unit base area increases with the increase in fin length for both vertical and horizontal base positions. Additionally, the optimal fin spacing on horizontal base was found to decrease with the increased fin length. All these consequences revealed that the effect of fin length on heat transfer performance of fin arrays was significant.

Leung, C.W and S.D.Probert [58] have studied the effect of varying the fins' length on the steady-state rate of heat loss from rectangular-based heat exchanger. The investigation was carried out with a base width of 190mm, a duralumin fin thickness of [illegible] mm and a protrusion of 60mm. The optimal fins length, to achieve a maximum rate of heat transfer under natural convection conditions. They concluded that the shorter length system was preferred because the magnitude of *(Q_/WL)* was then much greater.

An attempt has been made to study the detail flow and heat transfer mechanisms for three cases namely an isothermal vertical flat plate, a single fin attached to a heated horizontal base and a fin array by C. B. Sobhan and Venkateshan,et al. experimentally. They concluded that Maximum values of local heat fluxes were encountered at a height of 20%- 30% from the fin base for both single fin and multiple fin arrays in all steady cases analyzed. An optimum fin spacing was noticed in a fin array, which depends on the thermal conductivity of the fin material.

Inclined Plate Heat Sink

Tari and Mehrtash [60] investigated steady state natural convection from heat sink of rectangular fins on a vertical base. The effects of geometric parameters and base-to-ambient temperature difference on the heat transfer performance of fin arrays were observed and the optimum fin separation values were determined. Thirty fin configurations were tested. Two sets were prepared of fin length 250 mm and 340 mm. By keeping these fin length, width and thickness constant fin heights was varied as mm, 15 mm and 25 mm. Fin spacing was also varied from 5 mm to 85.5 mm. Heat input was varied from 25 W to 125 W. It was observed that convective heat transfer increases as fin spacing increases, reaches to maximum at a certain fin spacing value, termed as optimum fin spacing and beyond that further increase in fin spacing leads to decrease in heat transfer rate. In addition, it was found that the optimum fin spacing varied between 10 mm to 12 mm for a proposed range of fin length, width and height. A correlation for optimum fin spacing was proposed.

Tari and Mehrtash [61] have tested heat sink for wide range of angle of inclination with upward and downward orientations. By modifying Grashof number with cosine of inclination angle, they suggest the modified correlation, which was best suited for inclination angle interval of -60° $\leq \theta \leq$ +80°. It was also observed that the flow separation inside the fin channels of the heat sink was an important phenomenon. For [illegible] facing inclinations, they observed that the flow separation location plays an [illegible] role. Also, they found that the optimum fin spacing does not significantly [illegible] with inclinations suggesting the value as 11.75 mm. It was concluded that [illegible] convective heat transfer rate was obtained for vertical orientation.

[illegible] Awasarmol, et al. [62] studied the heat transfer performance of perforated fin [illegible] natural convection by varying the diameter of perforation from 4-12 mm and [illegible] of inclination form 0-90^0. They observed that, the temperature along the [illegible] fin length was considerably less than that of solid fin. The perforated fins [illegible] heat transfer rate than solid fins. The magnitude of heat transfer [illegible] also depends upon angle of orientation, diameter of perforations and [illegible] input. Average heat transfer coefficient was increases with increase in angle of [illegible]. At 0^0 angle i.e. vertical surface and horizontal fins, the resistance to the [illegible] was more, so this obstruction can be reduced by increasing the inclination [illegible] from 0^0 to 90^o. At 90^o angle, obstruction to the flow was very less. The [illegible] of fins enhances the heat dissipation rates and at the same time decreases [illegible] for fin materials. The fins with 12 mm diameter of perforation gives [illegible] transfer at an angle of 45^0.

[illegible] studied effect of inclination of base of heat sink on heat transfer. [illegible] study was conducted. Five different inclination angles 0°, 30°, 45°, [illegible] selected. Fin length was kept at 153 mm, width at 100 mm. fin thickness [illegible] as 3 mm. Fin height was varied for 20 mm and 40 mm. Fin spacing was [illegible] 47 mm. It was observed that the convection heat transfer rates were [illegible] decreasing from 30° to 45° and again increasing from 45° to 60° [illegible] inclination for orientation of vertical base with vertical fins.

[illegible] Convection

[illegible] tested heated flat plate in a wind tunnel to study mixed convection in [illegible] downward positions. It was found that the local heat transfer [illegible] dependent on the free stream velocity and the temperature [illegible] the surface and the free stream. The buoyancy effect was more [illegible] the heated plate facing upward. The points of onset of instability [illegible] buoyancy effect were also examined and correlation was summarized [illegible] mixed and natural convection in terms of the dimensionless groups.

[illegible] F.P.Incropera [65] investigated the effects of longitudinal fins on [illegible] convection in airflow between parallel plates. Several aspects of mixed [illegible] have been considered for these parallel plates experimentally for relative [illegible] for a range of fin spacing's and Rayleigh numbers. It is observed that [illegible] data exhibited lower Nusselt numbers than the corresponding unfinned [illegible] This effect was most pronounced for smaller fin heights.

[illegible] flow and the heat transfer process in a horizontal channel heated [illegible] studied experimentally by C.Gau,Y.C.Jeng et al.[66] The channel was [illegible] vertical parallel plates with one of the plates heated uniformly and the [illegible] well insulated. The gap between the parallel plates was small and the [illegible] of the channel cross section was 6.67. Both flow visualization and [illegible] along the heated wall were measured. The effect of the Reynolds [illegible] buoyancy parameter on the heat transfer was studied. A correlation of [illegible] the averaged Nusselt number in terms of the buoyancy parameter [illegible]

[illegible] parametric study was made by M.Dogan et al. [67] to investigate [illegible] fin height and magnitude of heat flux on mixed convection heat [illegible] rectangular fin arrays heated from below in a horizontal channel. For [illegible] heat transfer, the results obtained from experimental study show [illegible] fin spacing which yields the maximum heat transfer was S = 8–9 [illegible] fin spacing depends on the value of Ra.

[illegible] [68]. investigated mixed convection heat transfer in a horizontal and [illegible] duct under bottom wall constant heat flux conditions has been [illegible] numerically. It was concluded that the flow acceleration and the [illegible] heat transfer enhancement increase with increase in the inclination [illegible]

[illegible] [69] experimentally studied combined free and forced convection [illegible] square duct in laminar region. The importance of mixed convection is [illegible] by the value of the Richardson number (Ri). It was observed that the mixed convection heat transfer was observed in the lower range of Reynolds number. It was observed that the influence of Richardson number (Ri) on the average Nusselt number (Nu) was more prominent at low Reynolds number than that for higher Reynolds number.

[illegible] B.F. Armaly et al. [70] described the local Nusselt numbers for mixed convection flows on vertical, inclined, and horizontal flat plates are presented for the entire mixed convection regime over a wide range of Prandtl numbers. Simple correlation equations provide local and average mixed convection. Nusselt numbers that agree very well with the analytically predicted values for both buoyancy assisting and opposing flow conditions. It was found that the buoyancy or forced flow effect can increase the surface heat transfer rate from pure forced or pure free convection by about [illegible] percent.

[illegible] T. Oshio, [71] found that as the fin length increases the effective thermal resistance decreases, which corresponds to an increasing performance. At air velocity less than [illegible] m/s the natural convection starts to dominate heat transfer mechanism. Thus the thermal performance of fin heat sink was improved when fin length was increased.

[illegible] et al. [72] studied experimental study of heated horizontal rectangular fin array under natural and assisting mode of mixed convection. Mainly two type of flow patterns were studied single chimney flow pattern and sliding chimney flow pattern for small spacing less than 6 mm or so. It was envisaged to use mixed convection in assisting mode to convert sliding chimney to single chimney flow pattern and take advantage of large area due to small S and favorable flow to augment heat dissipation from the fin array. An empirical equation has been developed to correlate the average Nusselt number as a function of Re, Gr and S/H.

[illegible] Concluding Remark

Although rectangular finned heat sink geometries were investigated, most of the studies were carried out for limited range of fin configurations. The main objective of this study is to determine the effects of geometric parameters and base-to-ambient temperature difference on the heat transfer rate and optimum spacing of the finned heat sink. A survey of literature indicates that not much attention has been paid on [illegible] effect that was effect of angle of inclination on the performance of heat [illegible] assisting flow mixed convection. This work gives novel way not addressed in [illegible] characterize the narrow plate heat sink. Correlation developed by different [illegible] important role in the development of heat transfer equation.

CHAPTER 3

EXPERIMENTAL METHODOLOGY

3.1 Introduction

In most of the industry, it is common practice to increase the heat transfer rate by increasing the surface area and varying the geometry of the heat sink. The main objective of the research is to perform experimentation to verify the effect of the geometrical parameters on heat transfer. This chapter deals with brief introduction of the material and instruments used for the experimentation. It also gives information about calibration of the set up.

3.2 Experimental Setup

The experimental set-up primarily consists of enclosure, concrete block and control panel. The enclosure is mounted on single shaft which has bearing at the support. At one end of the shaft, protractor is kept in-built so as to measure the inclination of the heat sink. The front surface of the frame is covered with acrylic sheet, which has arrangement to replace heat sink. The test section was kept in controlled room to maintain natural convection over heat sink. A schematic view of the experimental set-up for natural convection and mixed convection are shown in figure 3.1(a) and 3.1(b) respectively.

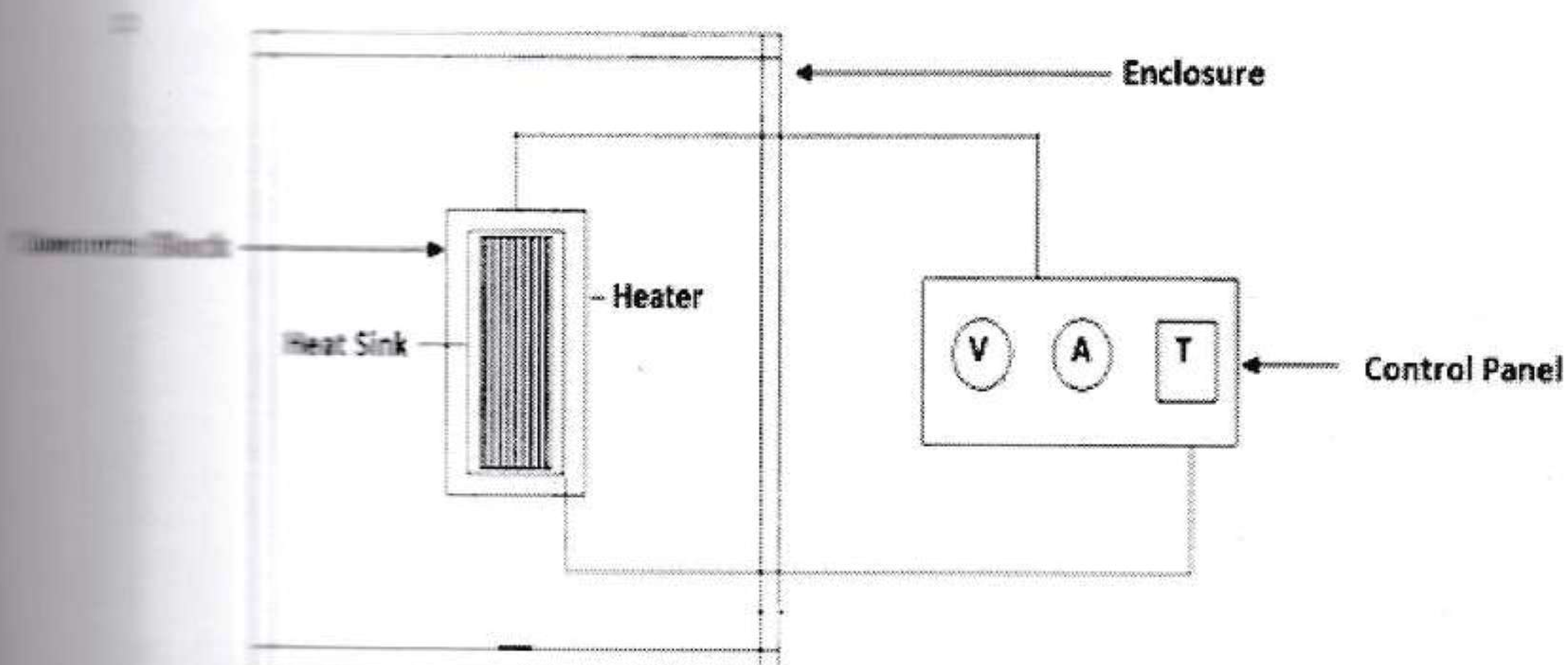


Figure 3.1 (a) Experimental Setup for Natural Convection

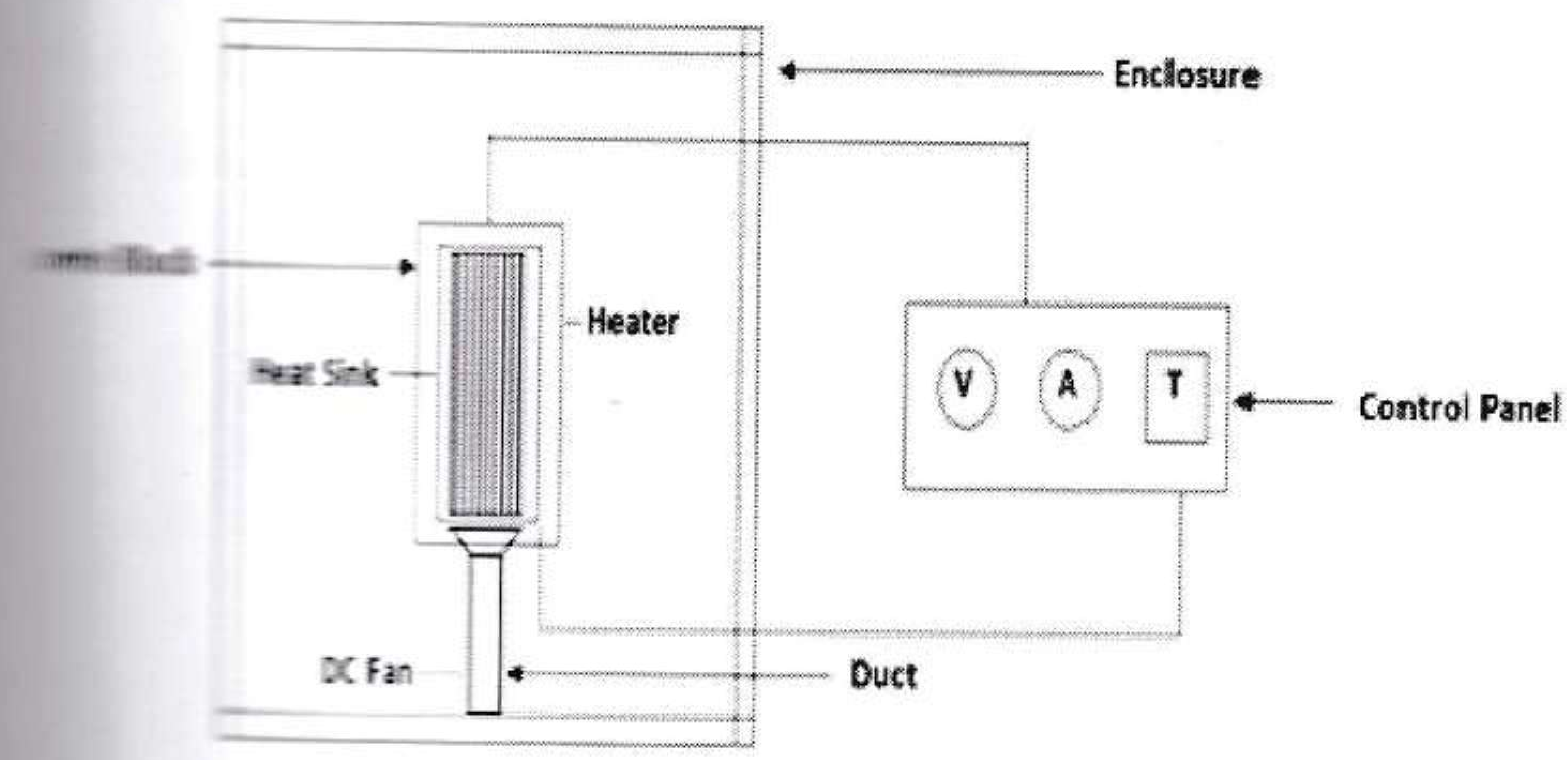


Figure 3.1 (b) Experimental Setup for Mixed Convection

The setup used for mixed convection is same, which is used for natural convection with an addition of fan blower. Heat sink samples, concrete block, heater and control panel, thermocouples are the important part of the experimental setup. Brief description of the components of the experimental setup are given below.

[illegible] Heat Sink Samples

Aluminium has high thermal conductivity (205W/mK), low cost, low weight, and ease of manufacture, hence it is selected as material for heat sink. The plate heat sinks of various specifications were manufactured on milling machine. The fins were integral with the base-plate. For all heat sink specifications, the base-plate thickness, fin thickness and the width of the heat sink were kept constant at 5 mm, 2.5 mm and [illegible] mm, respectively. The lengths of all heat sink were kept 200 mm.The samples of [illegible] plate heat sink is shown in the figure 3.2.

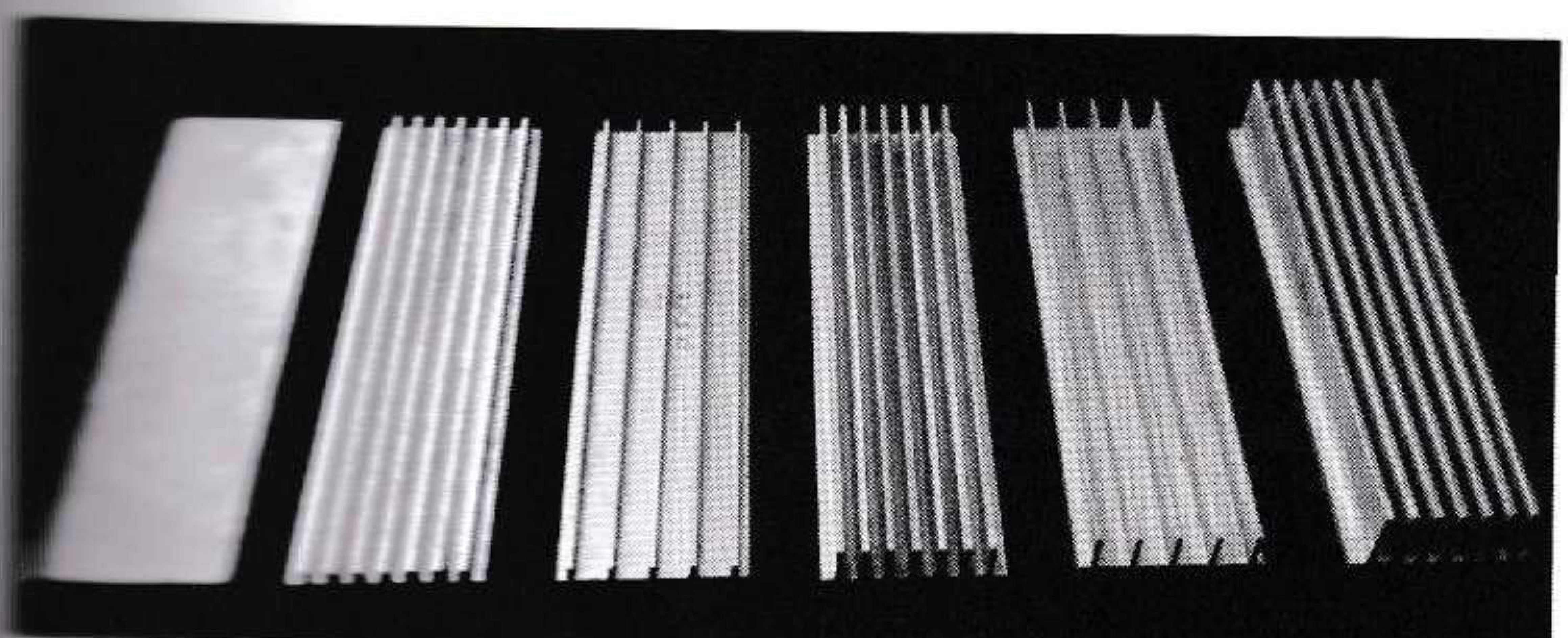


Figure 3.2 Heat Sink Samples

The geometry of the heat sink and the symbols used to denote the dimensions are illustrated in figure 3.3. Table 3.1 shows the specifications of heat sink used for the experimentation.

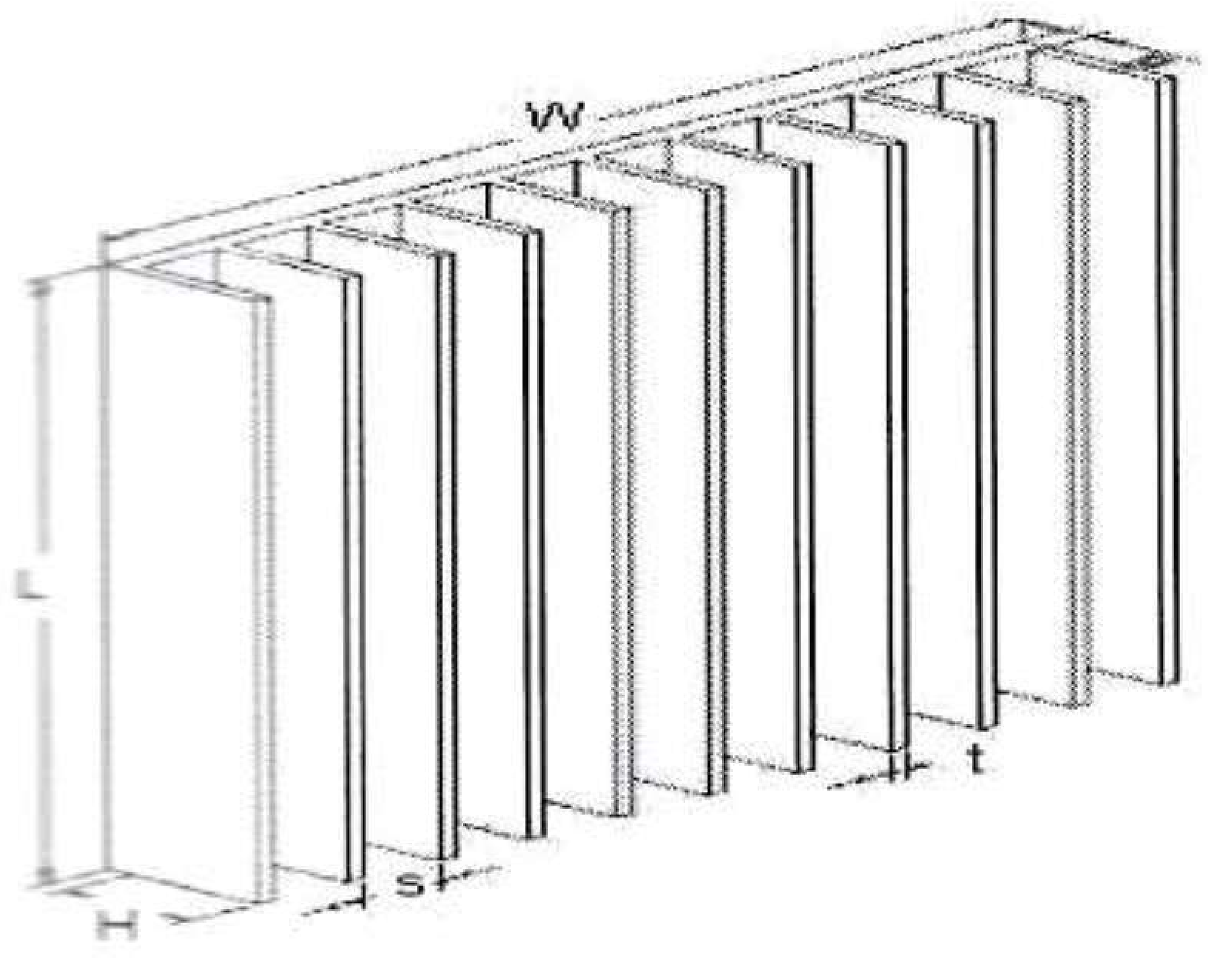


Figure 3.3 Dimensions of Heat Sink

Table 3.1 Heat Sink Specifications

Sl No.	Fin length L(mm)	Fin width W(mm)	Fin thickness t(mm)	Fin height H(mm)	Fin spacing S(mm)	No of fins(n)
1	200	75	2.5	5	5.5	9
2	200	75	2.5	5	7	7
3	200	75	2.5	5	9.5	6
4	200	75	2.5	5	13.5	5
5	200	75	2.5	5	17	4
6	200	75	2.5	10	5.5	9
7	200	75	2.5	10	7	7
8	200	75	2.5	10	9.5	6
9	200	75	2.5	10	13.5	5
10	200	75	2.5	10	17	4
11	200	75	2.5	15	5.5	9
12	200	75	2.5	15	7	7
13	200	75	2.5	15	9.5	6
14	200	75	2.5	15	13.5	5
15	200	75	2.5	15	17	4
16	200	75	2.5	20	5.5	9
17	200	75	2.5	20	7	7
18	200	75	2.5	20	9.5	6
19	200	75	2.5	20	13.5	5
20	200	75	2.5	20	17	4
21	200	75	2.5	25	5.5	9
22	200	75	2.5	25	7	7
23	200	75	2.5	25	9.5	6
24	200	75	2.5	25	13.5	5
25	200	75	2.5	25	17	4

[illegible] Concrete Block

[illegible] heater plate is placed on the concrete block. The concrete block has [illegible] fix heater plate into it. A unidirectional heat transfer takes place from [illegible] plate. The concrete block has high insulation quality, high temperature [illegible] and it can be shaped easily for necessary processes .The concrete block, [illegible] assembly is as shown in figure 3.4.

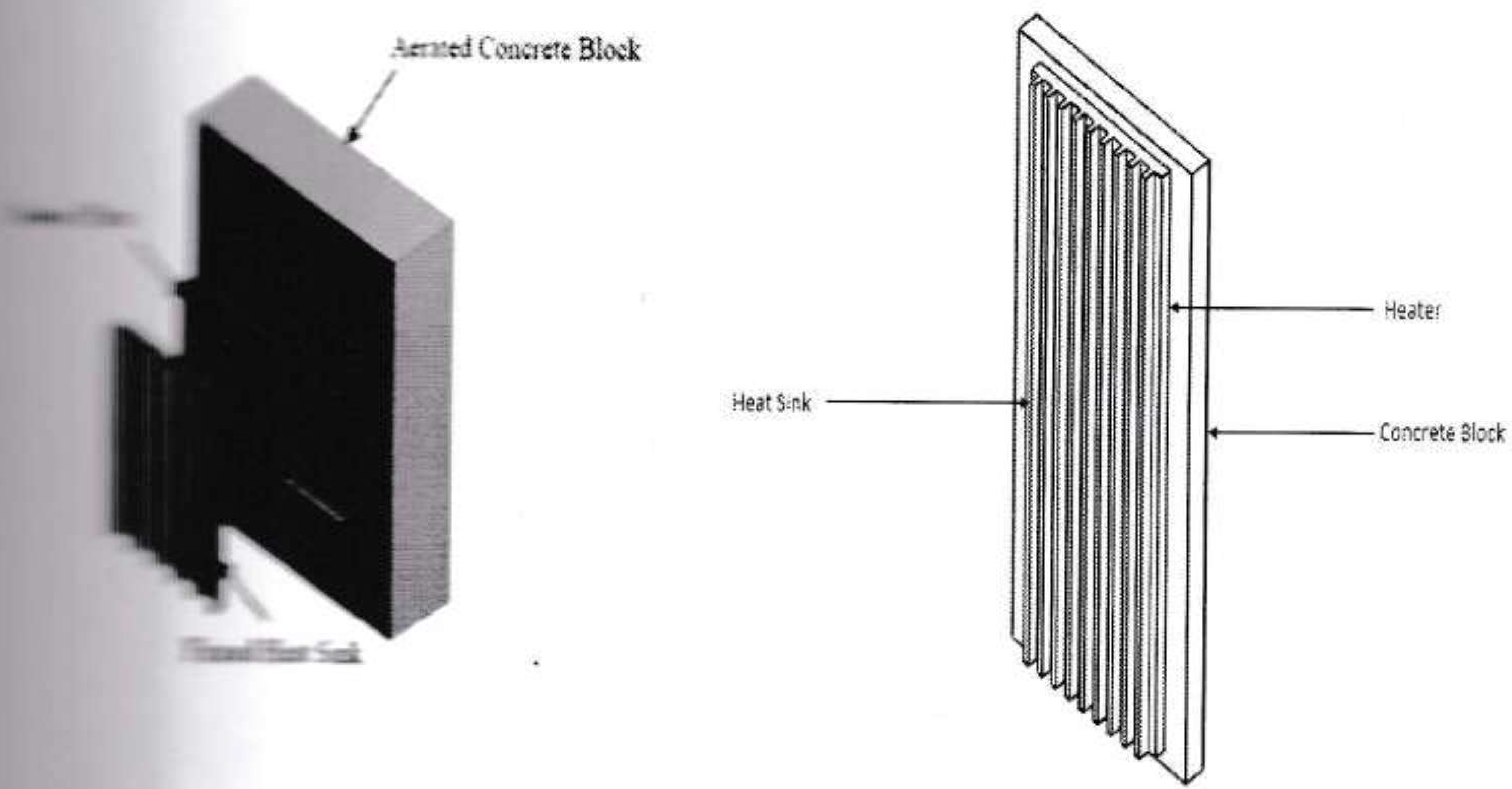


Figure 3.4 Concrete Block with Heat Sink

[illegible] Heater and Control Panel

[illegible] used to heat the heat sink samples. Heater wattage was adjusted by [illegible] which was controlled by 480V, 5A; power supply. The mica plate heater [illegible] with nickel chromium ribbon wire wound around a mica sheet which [illegible] mica-sheets.

[illegible] panel consists of dimmer stat, voltmeter, ammeter, and multi point digital [illegible] indicator. A calibrated voltmeter and ammeter is used to measure the heat [illegible] The voltmeter is single phase-2 wire AC supply with input voltage range of 50- [illegible] The digital ammeter is used to measure the current supply to the heater plate. [illegible] single phase-2 wire AC supply with input current range of 50mA-5A.

[illegible] Thermocouples

[illegible] Copper-Constantan) calibrated thermocouples were used to measure the [illegible] temperatures of the heat sink. In order to perceive the variations along the [illegible] thermocouple were mounted at five locations as shown in figure 3.5. The average base plate temperature was used for the analysis.To avoid disturbance of the flow, temperature were not measured at the fin tips. Since fin material (aluminum) has high thermal conductivity and fin heights are short, it was assumed that the temperature along the fin and at the fin tip did not vary significantly from the base-plate. The ambient temperature was noted. All the thermocouples were connected to multi point temperature indicator.

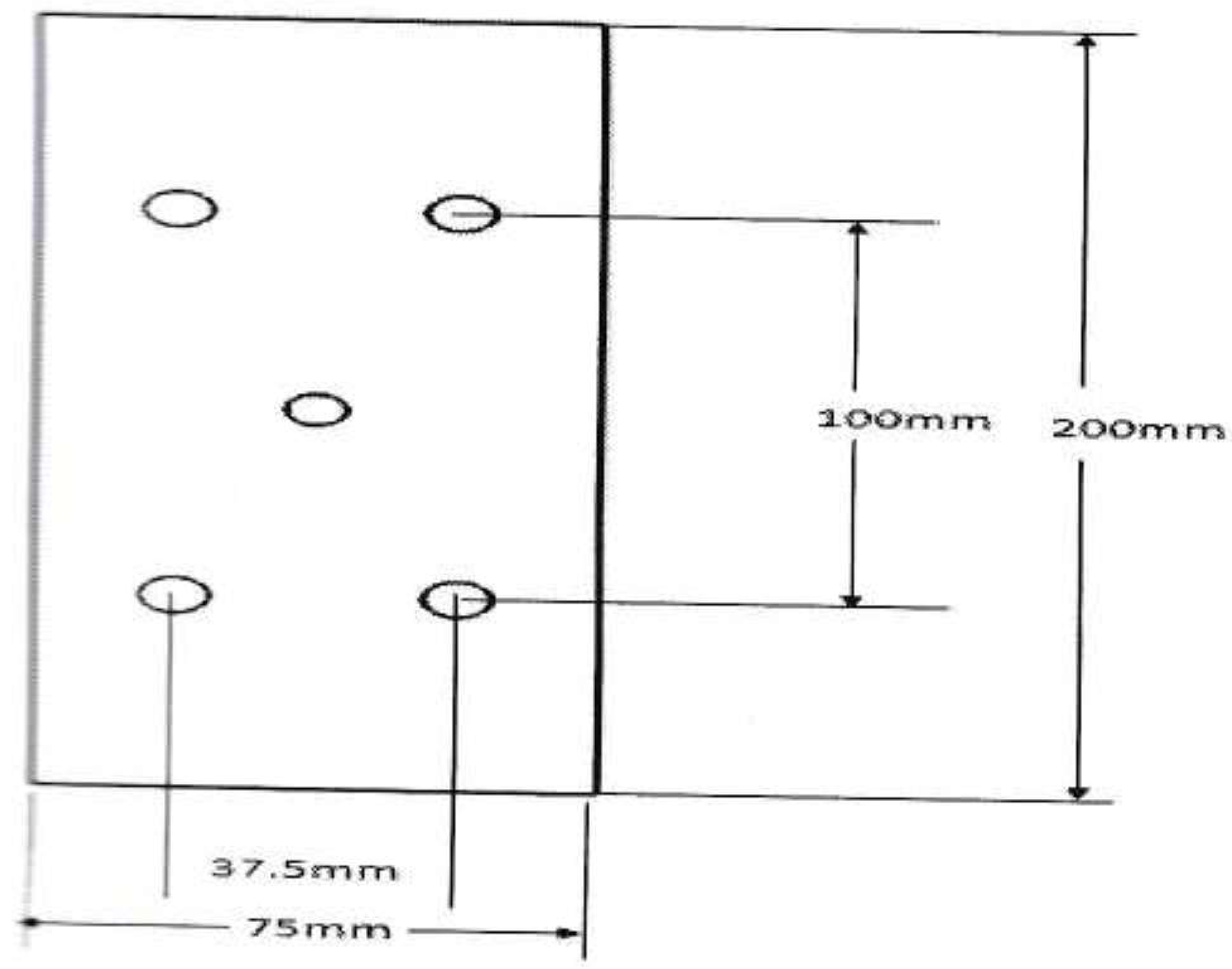


Figure 3.5 Locations of Thermocouples on Heat Sink

Calibration of Experimental Set-up

In order to determine the convective heat transfer performance of plate under steady state conditions, total heat losses from the experimental setup should be considered. Calibration of experimental set-up is carried out and the calibration method was applied before starting experiments. The total heat, which occurs as a result of the power inputs to the heaters, is dissipated from the surfaces of the test unit by conduction and to the surroundings by natural convection and radiation. Since the heat transfer coefficients can not be determined by the current experimental method, the estimation of the convection heat transfer rate from the plate is not possible. Thus, after calculating total heat transfer rate, the radiation contribution should be subtracted from it to determine the convection heat transfer rate.

For the calibration of the set-up, the heat transfer rate from the heated base-plate should be determined. The experimental set-up and procedure adopted during

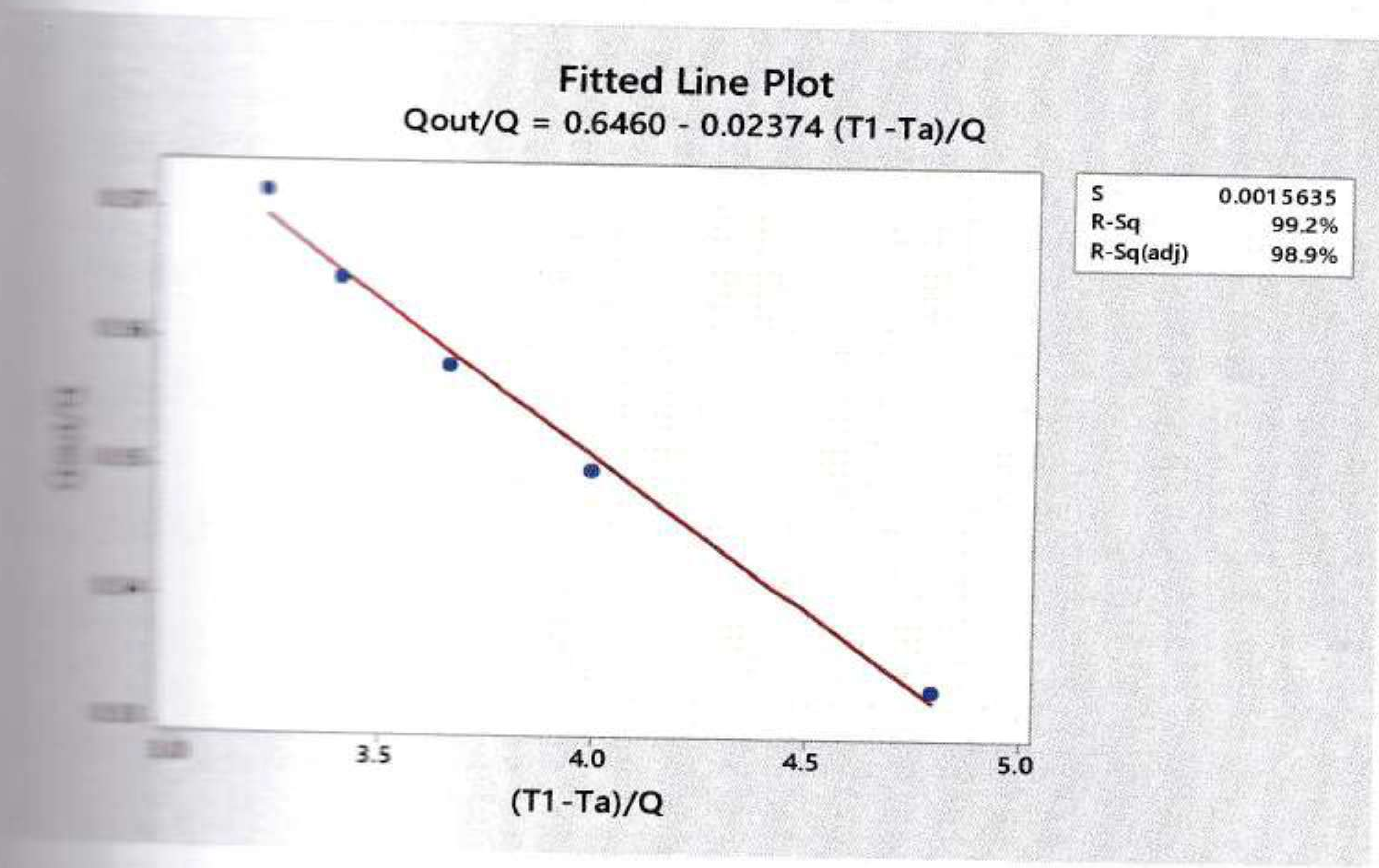


Figure 3.7 Calibration curve

... coefficient of the data was determined as 99.2%.Using this plot, the ... was obtained as,

$$... - 0.02374 \frac{Tw-Ta}{Q} \quad \ldots (3.3)$$

... 0.6460 is dimensionless and 0.02374 has unit, W/K.

... of Calibration Method

... the validity of the used calibration equations and method, a set ... conducted on a vertical plate. Using the experimental results, ... theoretically estimated Nusselt numbers were compared for ... inputs were supplied to the vertical plates. Under steady-state ... plate temperatures Tw, the ambient temperatures Ta and the ... measured. The measurement results and sample calculations are ... Appendix A.

... the total heat transfer rate from vertical plate was calculated by ... data into eq.3.3.Then, the radiation heat transfer rate from ... estimated by assuming the environment as a blackbody at ambient ...

$$... (T_w^4 - Ta^4) \quad \ldots (3.4)$$

The convective heat transfer rate was calculated as,

$$Qc_{conv} = (Qo)_{out} - (Qo)_{rad} \qquad \ldots (3.5)$$

Rayleigh number was defined as,

$$Ra = \frac{g \times \beta \times Lc^3 \times (Tw - Ta)}{\nu \times \alpha} \qquad \ldots (3.6)$$

The heat transfer coefficient based on the surface area of the vertical plate was determined as,

$$h_{expt.} = \frac{Qc}{As \times (Tw - Ta)} \qquad \ldots (3.7)$$

Nusselt numbers were also evaluated from the definitions as,

$$Nu = \frac{h \times Lc}{K} \qquad \ldots (3.8)$$

Where Lc, the length of the vertical plate is the characteristic length. The thermo physical properties necessary to evaluate Rayleigh and Nusselt numbers were taken at the film temperature, $T_f = \frac{Tw+Ta}{2}$.

After determining experimental Nusselt numbers, several correlations from literature were used to evaluate and compare the Nusselt numbers.

McAdam's correlation

$$Nu = 0.59 \times Ra^{0.25} \qquad \ldots (3.9)$$

Churchill and Chu's first correlation (For laminar and turbulent flows)

$$Nu = \left[0.825 + \frac{0.387 \times Ra^{1/6}}{\left[1+\left(\frac{0.492}{Pr}\right)^{9/16}\right]^{8/27}}\right]^2 \qquad \ldots (3.10)$$

Churchill and Chu's Second correlation (For laminar flow only)

$$Nu = 0.68 + \frac{0.67 \times Ra^{1/4}}{\left[1+\left(\frac{0.492}{Pr}\right)^{9/16}\right]^{4/9}} \qquad \ldots (3.11)$$

The theoretical and experimental dimensionless numbers were plotted in the same graph as shown in figure 3.8.

Table.3.2 Comparison of Dimensionless Number

Sl.No.	Heat Input(Q)	Ra	Nu_{plate}	Nu_{McA}	Nu_{CCI}	Nu_{CCII}
1	10	31429492	41.3	44.18	43.37	39.15
2	20	45396671	47.8	48.19	48.01	42.64
3	30	53374732	50.1	50.43	50.62	44.58
4	40	58069921	52.8	50.82	51.89	45.50
5	50	59953266	57.1	51.46	52.37	45.86

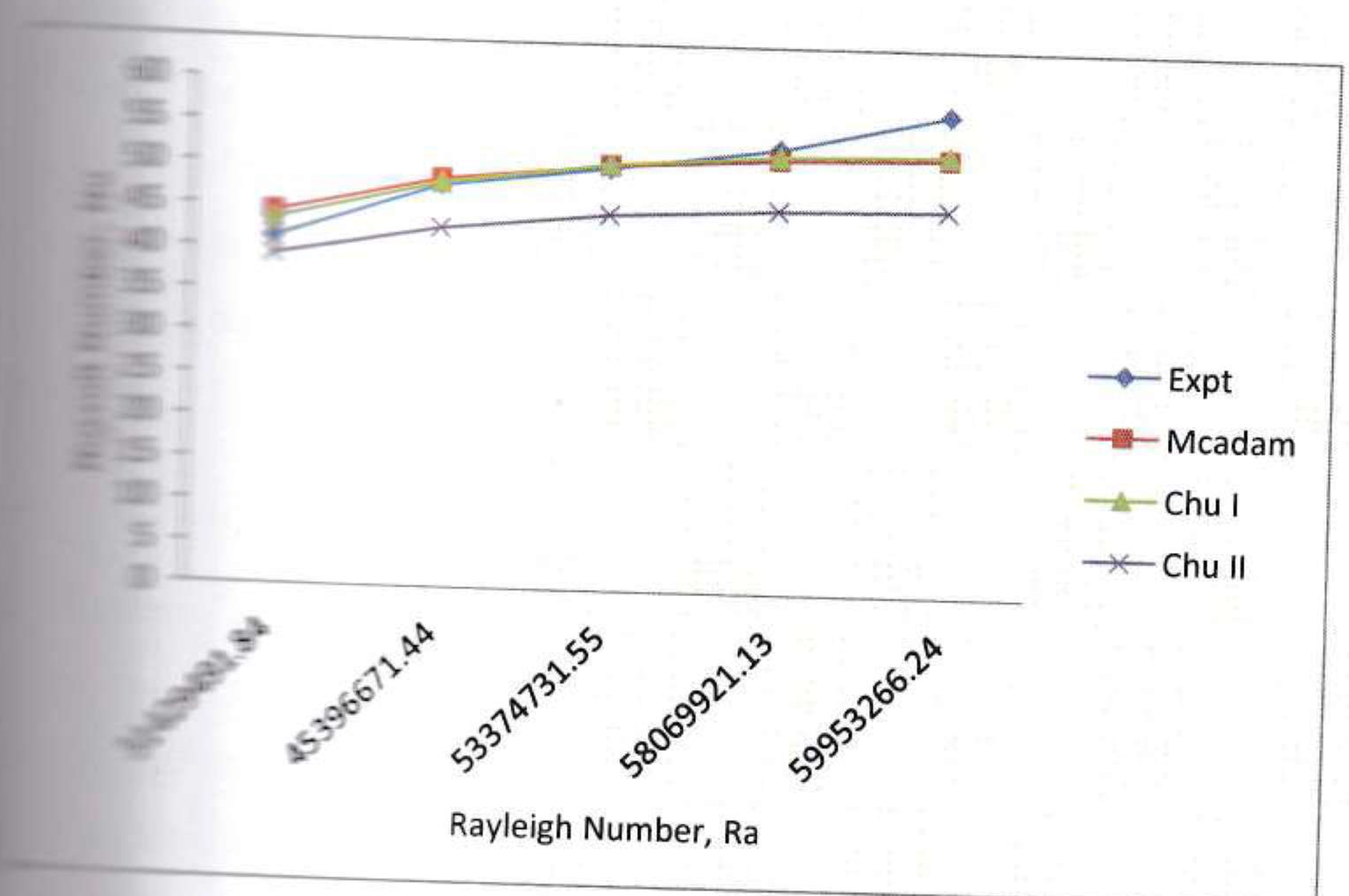


Figure 3.8 Comparison of Experimental and Theoretical Dimensionless Numbers

The experimental data is in a good agreement with the correlations, which is tabulated in table 3.2 and shown in figure 3.8.These results indicate the validity of the experimental set-up with calibration method, which shows that the experimental measurement is correct.

3.4 Testing Procedure of Heat Sink

After the experimental set-up was calibrated and the calibration method is verified. The heat sinks were placed into the enclosure. An experimental study is divided into three parts i.e. natural convection for vertical orientation, natural convection for inclined orientation and assisting mixed flow convection for vertical orientation.

3.4.1 Natural Convection for Vertical Plate Heat Sink

Twenty-five heat sink were mounted on the setup. For each of the heat sink, the power input was adjusted to 10 W initially and the base-plate was heated about eight hours. Then, the base temperature was measured by means of five thermocouples mounted on the base plate. In order to decide whether the heat sink was at steady-state or not, the thermocouple readings were taken at thirty minute intervals and this condition was assumed to be reached when the difference between two successive readings of each thermocouple was less than 0.5°C.The base-plate temperature Tw, the ambient temperature Ta and the power input to the heater Q were recorded at steady-state. The testing procedure mentioned above was repeated for the power inputs 20 W, 30 W, 40 W and 50 W for all the heat sink. The observations were given as table B1 in the Appendix B. The calibration equation, 3.3 is employed to evaluate the total heat transfer rate from the heat sink. The convection heat transfer rate were calculated as,

$$(Q)_{conv} = (Q)_{net} - (Q)_{rad} \qquad \text{... (3.12)}$$

3.4.2 Natural Convection for Inclined Plate Heat Sink.

The procedure of natural convection for vertical orientation of plate heat sink is used for varying the direction of the gravitational acceleration (g) in order to create the effect of inclination without any change in the experimental setup. The experimental setup arranged in such a way that the whole frame is mounted on single shaft which has bearing at the support. At one end of the shaft, inbuilt protractor is kept to measure inclination of the heat sink. Same procedure is adopted for the angle of inclination from 0°, 30°, 45°, 60° and 90°for all heat sink as that of vertical plate heat sink. The observations are given as table B2 in the Appendix B. The convection heat transfer rate was calculated by using eq. 3.12.

Mixed Convection for Vertical Plate Heat Sink

Vertical oriented heat sink calibration setup by varying the velocity with the help of an air blower is used for mixed convection. The flow velocity is measured with the help of anemometer. Total five heat sink were tested with different fin spacing of 5.5 mm to 9.5 mm at constant height of 25mm. The velocity is varied from 0.8 m/s to 1.2 m/s.All experiments were carried out with extreme care. The observations are given in table B8 of Appendix B.

Experimental Procedure

The experimentation was carried out for vertical flat plate. The temperature readings were noted for different heat input to determine the heat rate. After experimentation of flat plate, twenty-five vertical plate heat sink with different heat input were tested to determine the heat rate and optimum fin spacing. It is apparent from the experimentation that maximum heat transfer rate was obtained for vertical plate heat sink at fin spacings between 7 mm to 9.5 mm. Therefore, the experimentation for inclined orientation is carried out only for 15 heat sink with fin spacing of 7mm to 9.5mm. The results for vertical and inclined plate heat sink shows that the maximum heat transfer rate is achieved at fin spacing between 7 mm to 9.5 mm for fin height H=25 mm and heat input Q= 50W. Accordingly the experimentation for mixed convection is carried out for 5 different heat sink with fin spacing from 5.5 mm to 9.5mm at H=25mm and Q=50W.

The results obtained from experimentation for vertical flat plate, vertical heat sink, inclined heat sink and assisting flow mixed convection are presented in table 3.3, 3.4, 3.5 and 3.6 respectively.

Table 3.3 Results for Vertical Flat Plate in Natural Convection

[illegible]	ΔT(°C)	Qc(W)	Nu Expt.	Pr	Gr	Ra
[illegible]	52	4.35	41.27	0.70553	44547350	31429492
[illegible]	90	8.97	47.75	0.70406	64478413	45396671
[illegible]	125	13.45	50.14	0.70259	75968533	53374732
[illegible]	155	17.96	52.81	0.7014	82791447	58069921
[illegible]	178	22.73	57.12	0.70035	85604721	59953266

Table 3.4 Results for Vertical Plate Heat Sink in Natural Convection

	H=5mm															
[illegible]	S=5.5mm			S=7.00mm			S=9.5mm			S=13.5mm			S=17mm			
	[illegible]	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Q c(W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)
[illegible]	[illegible]	62.1	42.1	4.36	60.9	40.9	4.62	57.8	37.8	4.48	61.8	41.8	4.34	66	46
[illegible]	[illegible]	92.8	72.8	8.78	90	70	9.09	88	68	8.78	95.2	75.2	8.37	104.8	84.8
[illegible]	[illegible]	120.6	100.6	13.16	118.4	98.4	13.49	117.8	97.8	13.21	125	105	12.91	133.2	103.2
[illegible]	[illegible]	146	126	17.33	143.3	123.3	17.75	142.8	122.8	17.34	152	132	16.91	162	142
[illegible]	[illegible]	167.2	147.2	21.56	166.4	146.4	22.16	165.6	145.6	21.68	175.6	155.6	21.34	185	165

	H=10mm														
[illegible]	S=5.5mm			S=7.00mm			S=9.5mm			S=13.5mm			S=17mm		
	[illegible]	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)
[illegible]	[illegible]	49.4	29.4	4.68	48.5	28.5	4.90	47	27	4.74	51.2	31.2	4.64	55	35
[illegible]	[illegible]	71.2	51.2	9.30	70.6	50.6	9.59	69.8	49.8	9.20	78	58	9.10	83.2	63.2
[illegible]	[illegible]	92	72	14.1	90.5	70.5	14.49	90	70	14.09	99	79	13.77	108	88
[illegible]	[illegible]	112.2	92.2	18.36	111.5	91.5	18.92	110.8	90.8	18.26	123	103	17.86	133.8	103.8
[illegible]	[illegible]	127.2	107.2	23.26	126.4	106.4	23.94	125.9	105.9	22.98	141	121	22.17	156.2	136.2

	H=15mm														
[illegible]	S=5.5mm			S=7.00mm			S=9.5mm			S=13.5mm			S=17mm		
	[illegible]	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)
[illegible]	[illegible]	42.4	22.4	4.87	41.8	21.8	5.05	41	21	4.96	44	24	4.77	48.9	28.9
[illegible]	[illegible]	59.5	39.5	9.66	59	39	9.95	58.5	38.5	9.62	65.5	45.5	9.41	72	52
[illegible]	[illegible]	76	56	14.57	75.5	55.5	15.00	75	55	14.5	83	63	14.32	92	72
[illegible]	[illegible]	92.5	72.5	19.08	92	72	19.67	91.5	71.5	19.1	102	82	18.6	114	94
[illegible]	[illegible]	104	84	24.26	103.4	83.4	24.73	104.2	84.2	24.6	115	95	18.5	115.5	95.5

	H=20mm														
[illegible]	S=5.5mm			S=7.00mm			S=9.5mm			S=13.5mm			S=17mm		
	[illegible]	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)
[illegible]	[illegible]	38.2	18.2	4.98	37.6	17.6	5.17	37	17	4.97	41	21	4.87	44.6	24.6
[illegible]	[illegible]	52.2	32.2	9.92	51.4	31.4	10.21	51	31	9.83	58	38	9.63	64.2	44.2
[illegible]	[illegible]	66.1	46.1	14.91	65.4	45.4	15.37	64.8	44.8	15.05	72	52	14.69	81	71
[illegible]	[illegible]	79	59	19.69	78.3	58.3	20.31	77.6	57.6	19.60	89	69	19.14	100	80
[illegible]	[illegible]	89.1	69.1	24.92	88.4	68.4	25.67	87.8	67.8	25.02	99	79	24.38	112	92

	H=25mm														
[illegible]	S=5.5mm			S=7.00mm			S=9.5mm			S=13.5mm			S=17mm		
	[illegible]	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)
[illegible]	[illegible]	35.4	15.4	5.06	34.8	14.8	5.14	34.1	14.1	5.04	38.2	18.2	5.03	40	20
[illegible]	[illegible]	47	27	10.09	46.3	26.3	10.16	45.7	25.7	10.05	52	32	9.83	58	38
[illegible]	[illegible]	59.1	39.1	15.03	58.5	38.5	15.63	57.8	37.8	15.25	65	45	15.05	72	52
[illegible]	[illegible]	70.2	50.2	20.05	69.3	49.3	20.66	68.8	48.8	20.13	78	58	19.83	87	67
[illegible]	[illegible]	78.2	58.2	25.28	77.6	57.6	25.69	77	57	25.48	88	68	24.9	100	80

Table 3.5 Results for Inclined Plate Heat Sink in Natural Convection

H=5mm, S=7mm																
	10W			20W			30W			40W			50W			
[illegible]	Qc (W)	Tw (^oC)	ΔT (^oC)	Qc (W)	Tw (^oC)	ΔT (^oC)	Q c(W)	Tw (^oC)	ΔT (^oC)	Qc (W)	Tw (^oC)	ΔT (^oC)	Qc (W)	Tw (^oC)	ΔT (^oC)
[illegible]	[illegible]	61	41	8.78	90	70	13.16	118.5	98.5	17.32	143.3	123.3	21.55	166.5	146.5
[illegible]	[illegible]	63	43	8.64	92	72	13.03	120	100	17.15	145	125	21.39	168	148
[illegible]	[illegible]	65	45	8.49	94	74	12.86	122	102	16.96	147	127	21.17	170	150
[illegible]	[illegible]	68	48	8.27	97	77	12.6	125	105	16.67	150	130	20.83	173	153
[illegible]	[illegible]	71	51	8.05	100	80	12.34	128	108	16.37	153	133	20.5	176	156

H=10mm ,S=7mm															
	10W			20W			30W			40W			50W		
[illegible]	Qc (W)	Tw (^oC)	ΔT (^oC)	Qc (W)	Tw (^oC)	ΔT (^oC)	Q c(W)	Tw (^oC)	ΔT (^oC)	Qc (W)	Tw (^oC)	ΔT (^oC)	Qc (W)	Tw (^oC)	ΔT (^oC)
[illegible]	[illegible]	48.5	28.5	9.31	70.5	50.5	14.1	90.5	70.5	18.36	111.5	91.5	23.25	126.5	106.5
[illegible]	[illegible]	50	30	9.18	72	52	13.96	92	72	18.19	113	93	23.08	128	108
[illegible]	[illegible]	52	32	9.01	74	54	13.77	94	74	17.97	115	95	22.84	130	110
[illegible]	[illegible]	55	35	8.75	77	57	13.47	97	77	17.64	118	98	22.47	133	113
[illegible]	[illegible]	58	38	8.49	80	60	13.18	100	80	17.3	121	101	22.1	136	116

H=15mm , S=7mm															
	10W			20W			30W			40W			50W		
[illegible]	Qc (W)	Tw (^oC)	ΔT (^oC)	Qc (W)	Tw (^oC)	ΔT (^oC)	Q c(W)	Tw (^oC)	ΔT (^oC)	Qc (W)	Tw (^oC)	ΔT (^oC)	Qc (W)	Tw (^oC)	ΔT (^oC)
[illegible]	[illegible]	42	22	9.66	59	39	14.57	75.5	55.5	19.08	92	72	24.25	103.5	83.5
[illegible]	[illegible]	44	24	9.46	61	41	14.41	77	57	18.84	94	74	24.05	105	85
[illegible]	[illegible]	46	26	9.27	63	43	14.19	79	59	18.6	96	76	23.79	107	87
[illegible]	[illegible]	49	29	8.97	66	46	13.86	82	62	18.23	99	79	23.4	110	90
[illegible]	[illegible]	52	32	8.67	69	49	13.52	85	65	17.85	102	82	22.99	113	93

H=20mm,S=7mm															
	10W			20W			30W			40W			50W		
[illegible]	Qc (W)	Tw (^oC)	ΔT (^oC)	Qc (W)	Tw (^oC)	ΔT (^oC)	Q c(W)	Tw (^oC)	ΔT (^oC)	Qc (W)	Tw (^oC)	ΔT (^oC)	Qc (W)	Tw (^oC)	ΔT (^oC)
[illegible]	[illegible]	37.9	17.9	9.91	51.5	31.5	14.9	65.5	45.5	19.67	18.06	58.5	24.91	88.5	68.5
[illegible]	[illegible]	39	19	9.748	53	33	14.72	67	47	19.47	17.81	60	24.7	90	70
[illegible]	[illegible]	41	21	9.53	55	35	14.48	69	49	19.21	17.48	62	24.42	92	72
[illegible]	[illegible]	44	24	9.197	58	38	14.12	72	52	18.8	16.96	65	23.99	95	75
[illegible]	[illegible]	47	27	8.857	61	41	13.74	75	55	18.39	16.44	68	23.54	98	78

H=25mm,S=7mm															
	10W			20W			30W			40W			50W		
[illegible]	Qc (W)	Tw (^oC)	ΔT (^oC)	Qc (W)	Tw (^oC)	ΔT (^oC)	Q c(W)	Tw (^oC)	ΔT (^oC)	Qc (W)	Tw (^oC)	ΔT (^oC)	Qc (W)	Tw (^oC)	ΔT (^oC)
[illegible]	[illegible]	35	15	10.07	46.5	26.5	15.14	58.5	38.5	20.03	69.5	49.5	25.45	77.5	57.5
[illegible]	[illegible]	37	17	9.888	48	28	14.95	60	40	19.81	71	51	25.22	79	59
[illegible]	[illegible]	39	19	9.646	50	30	14.68	62	42	19.53	73	53	24.92	81	61
[illegible]	[illegible]	42	22	9.275	53	33	14.28	65	45	19.09	76	56	24.45	84	64
[illegible]	[illegible]	45	25	8.896	56	36	13.86	68	48	18.64	79	59	23.98	87	67

H=5mm,S=9.5mm															
	10W			20W			30W			40W			50W		
[illegible]	Qc (W)	Tw (^oC)	ΔT (^oC)	Qc (W)	Tw (^oC)	ΔT (^oC)	Q c(W)	Tw (^oC)	ΔT (^oC)	Qc (W)	Tw (^oC)	ΔT (^oC)	Qc (W)	Tw (^oC)	ΔT (^oC)
[illegible]	[illegible]	58	38	9.091	88	68	13.47	118	98	17.73	143	123	22.11	166	146
[illegible]	[illegible]	60	40	8.956	90	70	13.31	120	100	17.55	145	125	21.91	168	148
[illegible]	[illegible]	62	42	8.819	92	72	13.15	122	102	17.37	147	127	21.7	170	150
[illegible]	[illegible]	65	45	8.611	95	75	12.91	125	105	17.09	150	130	21.39	173	153
[illegible]	[illegible]	68	48	8.4	98	78	12.66	128	108	16.81	153	133	21.07	176	156

H=10mm, S=9.5mm																
	10W			20W			30W			40W			50W			
[illegible]	[illegible]	Tw (^{0}C)	ΔT (^{0}C)	Qc (W)	Tw (^{0}C)	ΔT (^{0}C)	Q c(W)	Tw (^{0}C)	ΔT (^{0}C)	Qc (W)	Tw (^{0}C)	ΔT (^{0}C)	Qc (W)	Tw (^{0}C)	ΔT (^{0}C)
[illegible]	[illegible]	47	27	9.575	70	50	14.49	90	70	18.9	111	91	23.93	126	106
[illegible]	[illegible]	49	29	9.419	72	52	14.32	92	72	18.7	113	93	23.71	128	108
[illegible]	[illegible]	51	31	9.26	74	54	14.14	94	74	18.5	115	95	23.49	130	110
[illegible]	[illegible]	54	34	9.019	77	57	13.87	97	77	18.19	118	98	23.15	133	113
[illegible]	[illegible]	57	37	8.774	80	60	13.59	100	80	17.88	121	101	22.81	136	116

H=15mm, S=9.5mm															
	10W			20W			30W			40W			50W		
[illegible]	[illegible]	Tw (^{0}C)	ΔT (^{0}C)	Qc (W)	Tw (^{0}C)	ΔT (^{0}C)	Q c(W)	Tw (^{0}C)	ΔT (^{0}C)	Qc (W)	Tw (^{0}C)	ΔT (^{0}C)	Qc (W)	Tw (^{0}C)	ΔT (^{0}C)
[illegible]	[illegible]	42.5	22.5	9.864	59.5	39.5	14.9	76	56	19.56	92.5	72.5	24.85	104	84
[illegible]	[illegible]	44	24	9.731	61	41	14.7	78	58	19.4	94	74	24.61	106	86
[illegible]	[illegible]	46	26	9.552	63	43	14.5	80	60	19.18	96	76	24.37	108	88
[illegible]	[illegible]	48	28	9.279	66	46	14.2	83	63	18.84	99	79	24.01	111	91
[illegible]	[illegible]	[illegible]	31	9	69	49	13.88	86	66	18.49	102	82	23.63	114	94

H=20mm, S=9.5mm															
	10W			20W			30W			40W			50W		
[illegible]	[illegible]	[illegible]	ΔT (^{0}C)	Qc (W)	Tw (^{0}C)	ΔT (^{0}C)	Q c(W)	Tw (^{0}C)	ΔT (^{0}C)	Qc (W)	Tw (^{0}C)	ΔT (^{0}C)	Qc (W)	Tw (^{0}C)	ΔT (^{0}C)
[illegible]	[illegible]	[illegible]	17.5	10.21	51	15.35	15.35	20.27	45	20.27	78	58	25.64	88	68
[illegible]	[illegible]	[illegible]	19	10.02	53	15.14	15.14	20.03	47	20.03	80	60	25.39	90	70
[illegible]	[illegible]	[illegible]	21	9.82	55	14.92	14.92	19.79	49	19.79	82	62	25.13	92	72
[illegible]	[illegible]	[illegible]	24	9.516	58	14.58	14.58	19.43	52	19.43	85	65	24.74	95	75
[illegible]	[illegible]	[illegible]	27	9.207	61	14.24	14.24	19.05	55	19.05	88	68	24.34	98	78

H=25mm, S=9.5mm															
	10W			20W			30W			40W			50W		
[illegible]	[illegible]	[illegible]	ΔT (^{0}C)	Qc (W)	Tw (^{0}C)	ΔT (^{0}C)	Q c(W)	Tw (^{0}C)	ΔT (^{0}C)	Qc (W)	Tw (^{0}C)	ΔT (^{0}C)	Qc (W)	Tw (^{0}C)	ΔT (^{0}C)
[illegible]	[illegible]	[illegible]	14.5	10.38	46	26	15.61	58	38	20.64	69	49	26.18	77	57
[illegible]	[illegible]	[illegible]	16	10.17	48	28	15.37	60	40	20.38	71	51	25.91	79	59
[illegible]	[illegible]	[illegible]	18	9.948	50	30	15.13	62	42	20.12	73	53	25.64	81	61
[illegible]	[illegible]	[illegible]	21	9.613	53	33	14.77	65	45	19.73	76	56	25.22	84	64
[illegible]	[illegible]	[illegible]	24	9.27	56	36	14.39	68	48	19.33	79	59	24.79	87	67

H=5mm, S=13.5mm															
	10W			20W			30W			40W			50W		
[illegible]	[illegible]	[illegible]	ΔT (^{0}C)	Qc (W)	Tw (^{0}C)	ΔT (^{0}C)	Q c(W)	Tw (^{0}C)	ΔT (^{0}C)	Qc (W)	Tw (^{0}C)	ΔT (^{0}C)	Qc (W)	Tw (^{0}C)	ΔT (^{0}C)
[illegible]	[illegible]	[illegible]	42	8.8	95	75	13.21	125	105	17.34	152	132	21.74	175	155
[illegible]	[illegible]	[illegible]	44	8.667	97	77	13.06	127	107	17.16	154	134	21.54	177	157
[illegible]	[illegible]	[illegible]	46	8.532	99	79	12.9	129	109	16.98	156	136	21.34	179	159
[illegible]	[illegible]	[illegible]	49	8.327	102	82	12.66	132	112	16.7	159	139	21.03	182	162
[illegible]	[illegible]	[illegible]	52	8.119	105	85	12.42	135	115	16.42	162	142	20.71	185	165

H=10mm, S=13.5mm															
	10W			20W			30W			40W			50W		
[illegible]	[illegible]	[illegible]	ΔT (^{0}C)	Qc (W)	Tw (^{0}C)	ΔT (^{0}C)	Q c(W)	Tw (^{0}C)	ΔT (^{0}C)	Qc (W)	Tw (^{0}C)	ΔT (^{0}C)	Qc (W)	Tw (^{0}C)	ΔT (^{0}C)
[illegible]	[illegible]	[illegible]	[illegible]	9.282	77	57	14.09	99	79	18.36	122	102	23.09	140	120
[illegible]	[illegible]	[illegible]	33	9.131	79	59	13.92	101	81	18.16	124	104	22.88	142	122
[illegible]	[illegible]	[illegible]	35	8.978	81	61	13.74	103	83	17.96	126	106	22.66	144	124
[illegible]	[illegible]	[illegible]	38	8.745	84	64	13.48	106	86	17.66	129	109	22.32	147	127
[illegible]	[illegible]	[illegible]	41	8.508	87	67	13.21	109	89	17.35	132	112	21.98	150	130

[illegible]			20W			30W			40W			50W		
						H=15mm,S=13.5mm								
[illegible]	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Q c(W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)
[illegible]	[illegible]	24	9.622	65.5	45.5	14.64	83	63	19.13	102	82	24.3	115	95
[illegible]	[illegible]	26	9.496	67	47	14.46	85	65	18.92	104	84	24.07	117	97
[illegible]	[illegible]	28	9.326	69	49	14.27	87	67	18.71	106	86	23.84	119	99
[illegible]	[illegible]	31	9.067	72	52	13.98	90	70	18.38	109	89	23.48	122	102
[illegible]	[illegible]	34	8.803	75	55	13.68	93	73	18.05	112	92	23.12	125	105

[illegible]			20W			30W			40W			50W		
						H=20mm, S=13.5mm								
[illegible]	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Q c(W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)
[illegible]	[illegible]	[illegible]	9.836	58	38	15.05	72	52	19.6	89	69	25.02	99	79
[illegible]	[illegible]	38	9.65	60	40	14.85	74	54	19.38	91	71	24.78	101	81
[illegible]	[illegible]	40	9.462	62	42	14.64	76	56	19.14	93	73	24.53	103	83
[illegible]	[illegible]	43	9.175	65	45	14.33	79	59	18.79	96	76	24.15	106	86
[illegible]	[illegible]	46	8.882	68	48	14	82	62	18.43	99	79	23.77	109	89

[illegible]			20W			30W			40W			50W		
						H=25mm, S=13.5mm								
[illegible]	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Q c(W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)	Qc (W)	Tw (°C)	ΔT (°C)
[illegible]	[illegible]	17	10.05	52	32	15.25	65	45	20.13	78	58	25.48	88	68
[illegible]	[illegible]	19	9.85	54	34	15.03	67	47	19.89	80	60	25.22	90	70
[illegible]	[illegible]	21	9.644	56	36	14.81	69	49	19.65	82	62	24.95	92	72
[illegible]	[illegible]	24	9.331	59	39	14.47	72	52	19.27	85	65	24.55	95	75
[illegible]	[illegible]	27	9.012	62	42	14.12	75	55	18.89	88	68	24.14	98	78

Table 3.6 Results of Vertical Plate Heat Sink in Mixed Convection

				v=0.8 m/s				
[illegible]	Ta(°C)	ΔT(°C)	Qc(W)	h(W/m²°C	Nu	Gr	Re	Ri
[illegible]	20	45	24.55	5.14	37.45	36763439	9169.422	0.43
[illegible]	20	42	26.37	7.35	53.49	35080580	9249.41	0.41
[illegible]	20	47	26.19	7.31	53.46	37838494	9116.861	0.45
[illegible]	20	55	25.72	7.12	51.23	41788180	8912.507	0.52
[illegible]	20	64	25.21	6.98	49.58	46012851	8693.29	0.60

				v=1 m/s				
[illegible]	Ta(°C)	ΔT(°C)	Qc(W)	h(W/m²°C	Nu	Gr	Re	Ri
[illegible]	20	44	24.76	5.30	38.68	36212002	11494.91	0.27
[illegible]	20	40	26.71	7.77	57.04	33910084	11629.39	0.25
[illegible]	20	46	26.35	7.56	55.02	37305555	11428.83	0.28
[illegible]	20	58	25.27	6.63	47.53	43134068	11047.77	0.35
[illegible]	20	66	24.79	6.56	46.42	47141651	10807.54	0.39

				v=1.2 m/s				
[illegible]	Ta(°C)	ΔT(°C)	Qc(W)	h(W/m²°C	Nu	Gr	Re	Ri
[illegible]	20	42	25.17	5.64	41.31	35080580	13874.12	0.18
[illegible]	20	36	27.37	8.85	65.29	31446839	14120.47	0.15
[illegible]	20	41	27.12	8.73	63.98	34500293	13914.58	0.17
[illegible]	20	60	24.96	6.33	45.27	43993003	13184.06	0.25
[illegible]	20	70	24.50	6.30	44.46	47861266	12829.56	0.29

CHAPTER 4

[illegible]ATICAL MODELLING AND OPTIMIZATION

4.1 Introduction

[illegible] surface methodology (RSM) is used to frame the mathematical models for [illegible] heat transfer rate and average base to ambient temperature difference. [illegible] artificial neural network (ANN) is used to predict the response. Artificial [illegible] network and response surface methodology are compared for their prognostic [illegible]. Regression analysis is used to derive mathematical models for [illegible] of the results when combinations of these parameters interact. Response [illegible] is used to optimize fin spacing for minimum temperature difference and [illegible] heat transfer rate.

4.2 Response Surface Methodology

[illegible] is a widely accepted statistical technique used for experimental [illegible] approach proceeds with carrying out statistically designed experiments, [illegible] evaluating the coefficients in a mathematical model and the prediction of [illegible] and examining the sufficiency of the model. It is very useful for modeling [illegible] the output affected by a number of input variables with the aim of [illegible] the responses. [50]

[illegible] steps in response surface methodology are as follows,

- [illegible] the independent input and output variables.
- [illegible] the experiments and develop the regression equation.
- [illegible] of variance (ANOVA) for the independent input variables to validate the model.
- [illegible] the optimal design parameters with the design constrains.

4.3 Mathematical Modeling

[illegible] modeling is relationship between input and output variable. It explains [illegible] response as a function of the input parameters. It gives organized [illegible] of the experimental data. The most common forms of mathematical models are first or second-order regression equation. Multiple regressions is used for building the experimental models required in response surface methodology. To develop an empirical model relating the response y for input variable x_1 and x_2. A first-order response surface model describe this relationship as below,

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon \quad \ldots(4.1)$$

This is a multiple linear regression model with two independent variables. β_0, β_1 and β_2 are regression coefficient. ε is termed as difference between input and output parameter. Second order equation response surface model is given by following equation,

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{12} x_1 x_2 + \varepsilon \quad \ldots (4.2)$$

The method of least squares is used to estimate the regression coefficients. Minitab 17 is used for estimating the regression coefficient and formulating the response surface regression equation. ANOVA checks the appropriateness of the mathematical models. [[illegible]]

4.4 ANOVA Test

Analysis of variance (ANOVA) test is performed to verify the fitness of the model. Residual plots are plotted to confirm the assumptions of the ANOVA.MINITAB 17 is used for mathematical modeling. Response optimizer is used for multi objective optimization. [84]

4.5 Regression Equations for Vertical Plate Heat Sink

Equation 4.3 and 4.4 represents mathematical models developed with the help of Minitab-17 for vertical plate heat sink in natural convection to predict ΔT and Qc. Figure 4.1 and 4.2 shows the residual plots for different responses. Summary of the ANOVA tables are shown in table 4.1.

<u>Regression Equation for Temperature Difference</u>

ΔT = [illegible] - 3.965 H - 4.150 S + 3.184 Q + 0.11351 H*H + 0.1874 S*S - 0.00993 Q*Q
[illegible]476 H*S - 0.07741 H*Q + 0.03996 S*Q ... (4.3)

Regression Equation for Convective Heat Transfer Rate

$$Q_c = -3.489 + 0.0868\,H + 0.6434\,S + 0.4076\,Q - 0.003539\,H*H - 0.02881\,S*S - 0.000009\,Q*Q + 0.000667\,H*S + 0.003854\,H*Q + 0.000421\,S*Q \qquad \ldots (4.4)$$

To validate the regression equations, residual plots are plotted for vertical plate fin heat sink for temperature difference i.e. average base to ambient temperature and convective heat transfer rate as shown in figure 4.1 and 4.2 respectively.

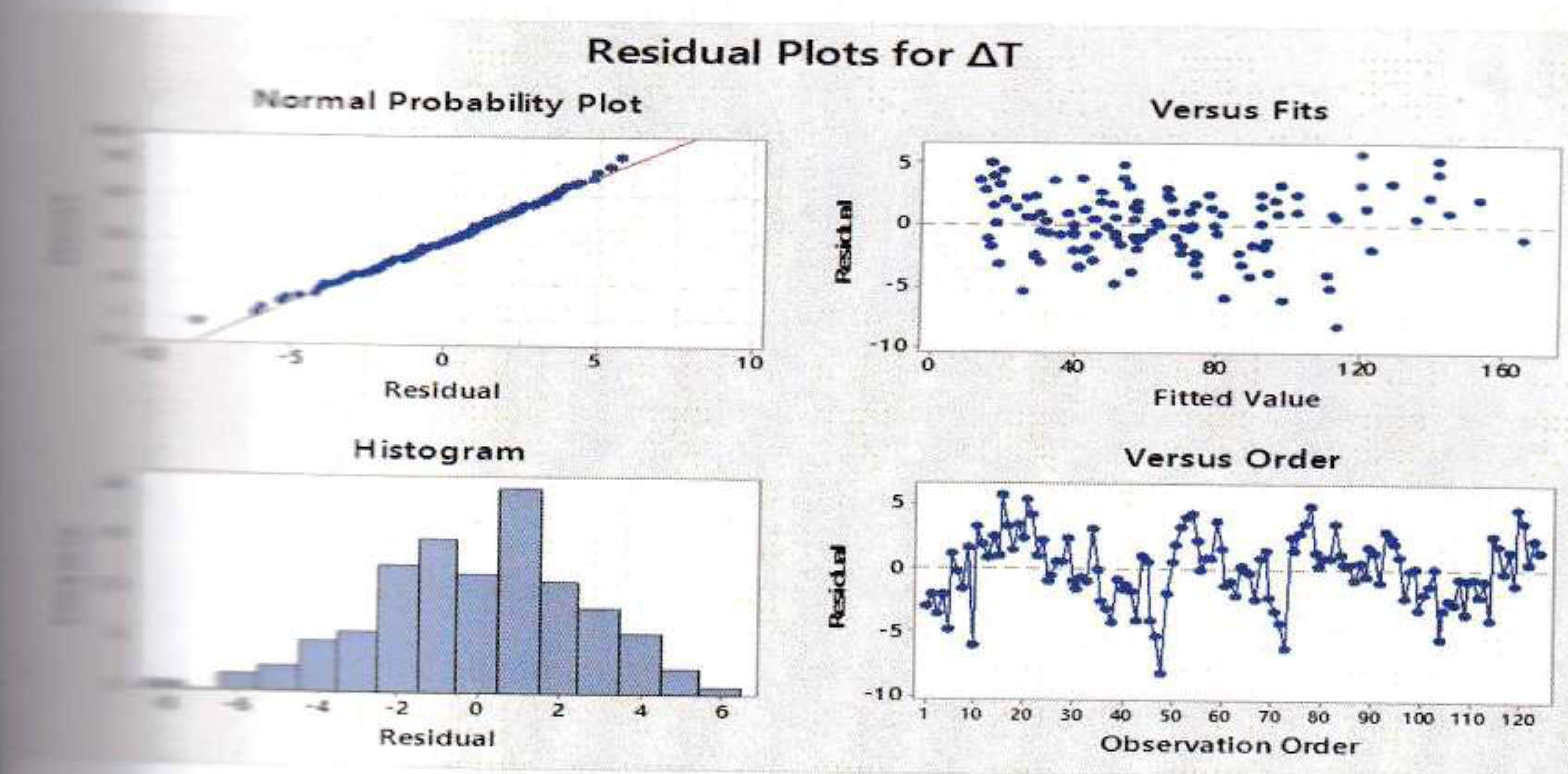


Figure 4.1 Residual Plots for Average Base to Ambient Temperature Difference

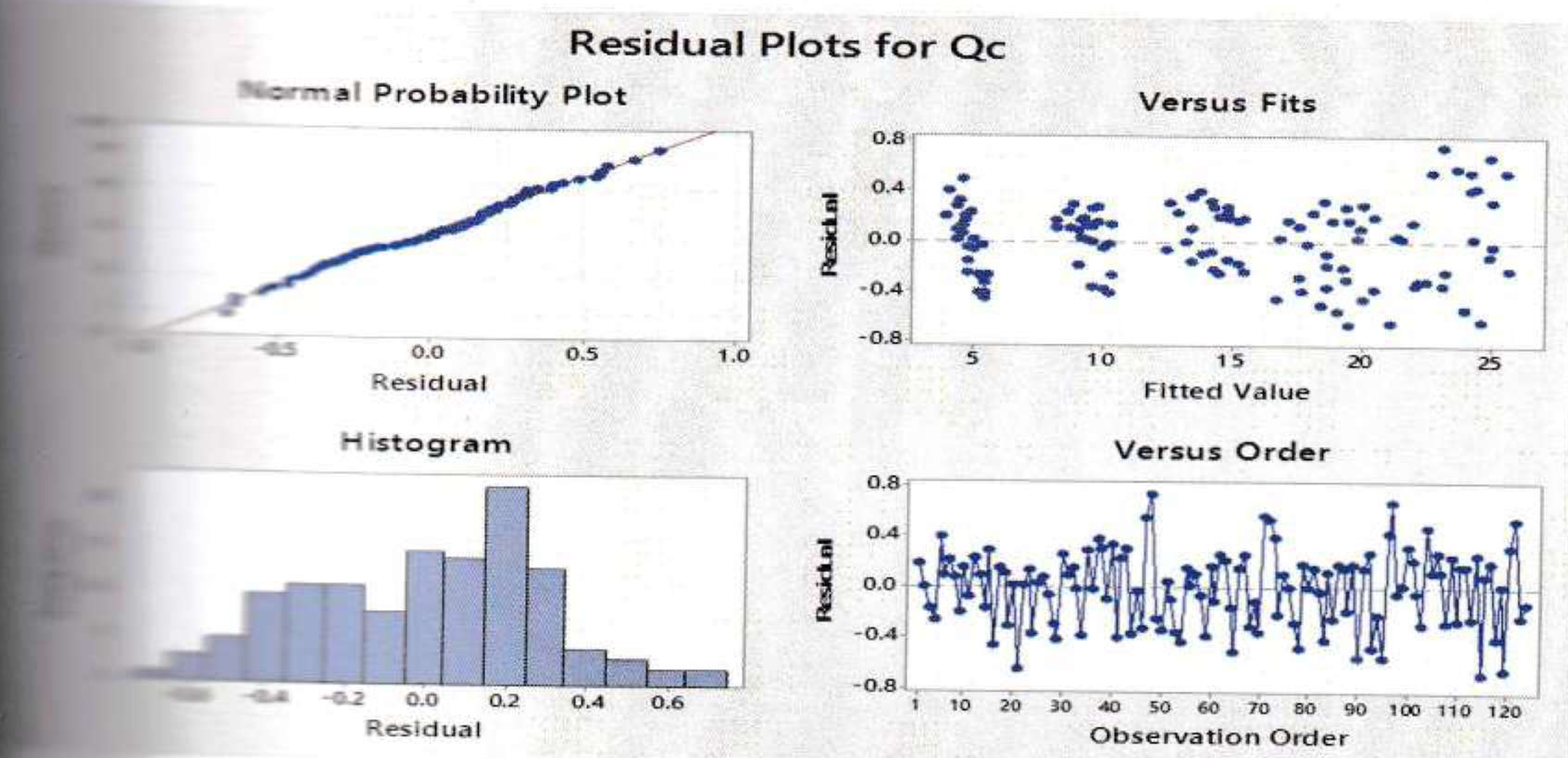


Figure 4.2 Residual Plots for Convective Heat Transfer Rate

If the model is adequate, the points on the normal probability plots of the residuals should form a straight line, which means the errors are normally distributed. Normal curve shows residual are falling on straight line. It indicates that model is satisfactory. The histogram shows that residuals are normally distributed. vs. fitted values graph shows residual are distributed randomly and have variance. Residual vs. order graph specifies that it is not following any pattern. This shows that variables are independent.

parameters, the nature of graph is analogous; this directs that the entire models are significant and adequate. This shows that the assumption for ANOVA satisfied.

Significance of P Value, R^2, R^2 Adjusted and R^2 Predicted

the probability value. Smaller value of the P indicates that the parameters influence on the response. R^2 measures percentage of the variation of regression equation. For better assessment of regression equation to R^2 should be closer to one. The higher value of R^2 means the model the better. Adjusted R^2 accounts for the number of predictors in your model for comparing models with different numbers of predictors. Predicted how well the model predicts responses for new observations. Larger predicted R^2 suggest models of greater predictive ability. [83,84]

Table 4.1 Summary of ANOVA for ΔT and Qc

Sr.No	Factor	ΔT	Qc
1	R^2 (%)	99.44	99.80
2	Adj.R^2 (%)	99.39	99.79
3	Pre.R^2 (%)	99.31	99.76
4	P value	0.000	0.000
5	F-Value	2230.7	6349

Table 4.1. R^2 value for both ΔT and Qc are 99.44% and 99.80%.These that model is accurate. P value for both ΔT and Qc is zero which model truly represent experimental data.

[illegible] Regression Equations for Inclined Plate Heat Sink

[illegible] 4.5 and 4.6 represents mathematical models developed with the help of [illegible] for inclined plate heat sink in natural convection to predict ΔT and Qc.

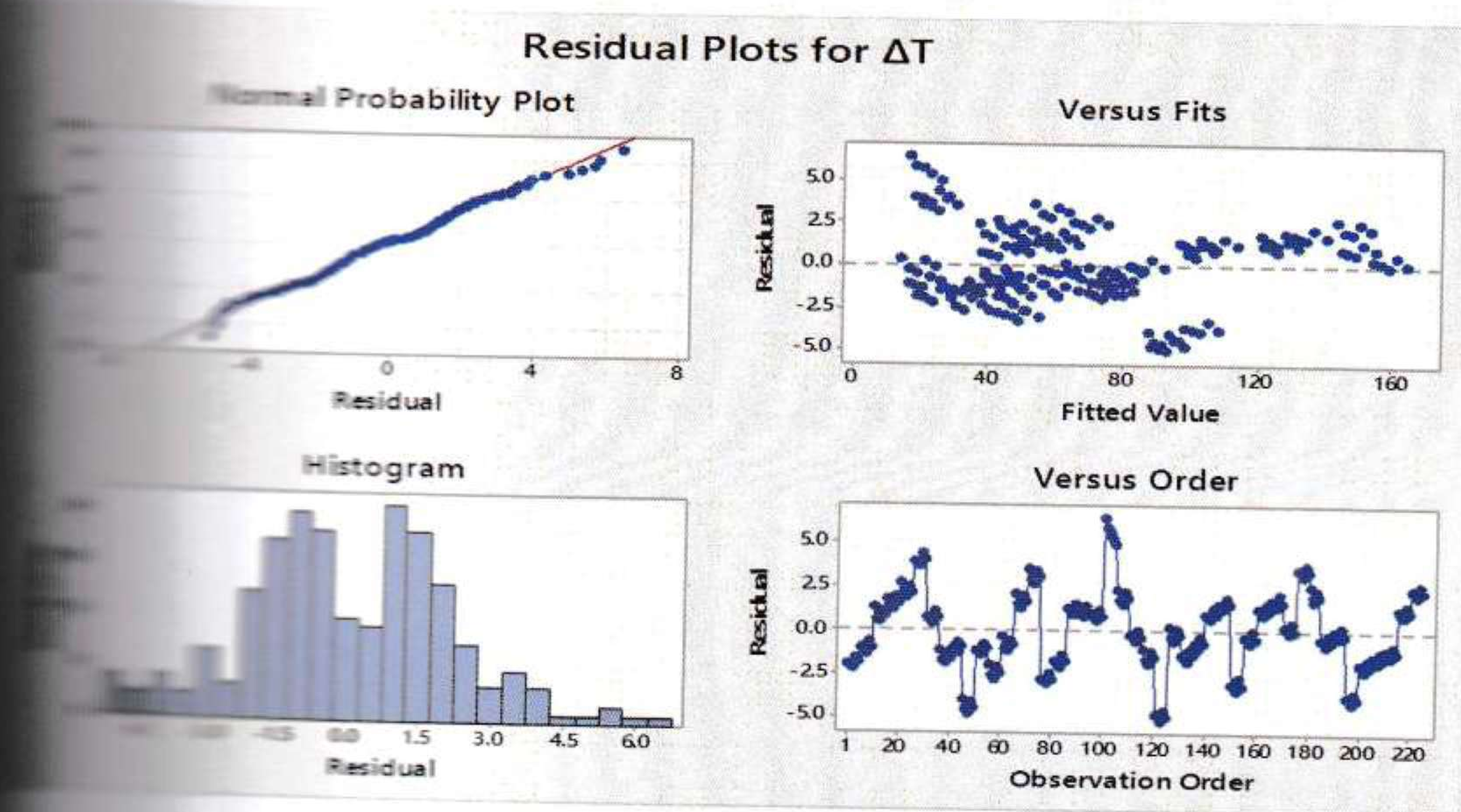
[illegible] Equation for Temperature difference

$$[illegible] - 3.10 \cos\theta - 4.025 H - 6.115 S + 3.2576 Q - 6.65 \cos\theta*\cos\theta + 0.11445 H*H$$
$$[illegible] S*S - 0.009600 Q*+ 0.0025 \cos\theta*H\ 0.026 \cos\theta*S - 0.0021 \cos\theta*Q$$
$$[illegible] H*S - 0.07888 H*Q + 0.03395 S*Q \qquad \ldots(4.5)$$

[illegible] Equation for convective heat transfer rate

$$[illegible] - [illegible] \cos\theta + 0.07378 H + 0.8128 S + 0.39954 Q + 0.648 \cos\theta*\cos\theta \quad -$$
$$[illegible] H*H - 0.03792 S*S + 0.000149 Q*Q + 0.01989 \cos\theta*H - 0.0166 \cos\theta*S$$
$$[illegible] \cos\theta*Q + 0.000076 H*S + 0.004034 H*Q - 0.000352 S*Q \qquad \ldots(4.6)$$

[illegible] plots are plotted for inclined plate heat sink for average base to ambient [illegible] and convective heat transfer rate as shown in figure 4.3 and figure 4.4 [illegible].



[illegible] Residual Plots for Average Base to Ambient Temperature Difference

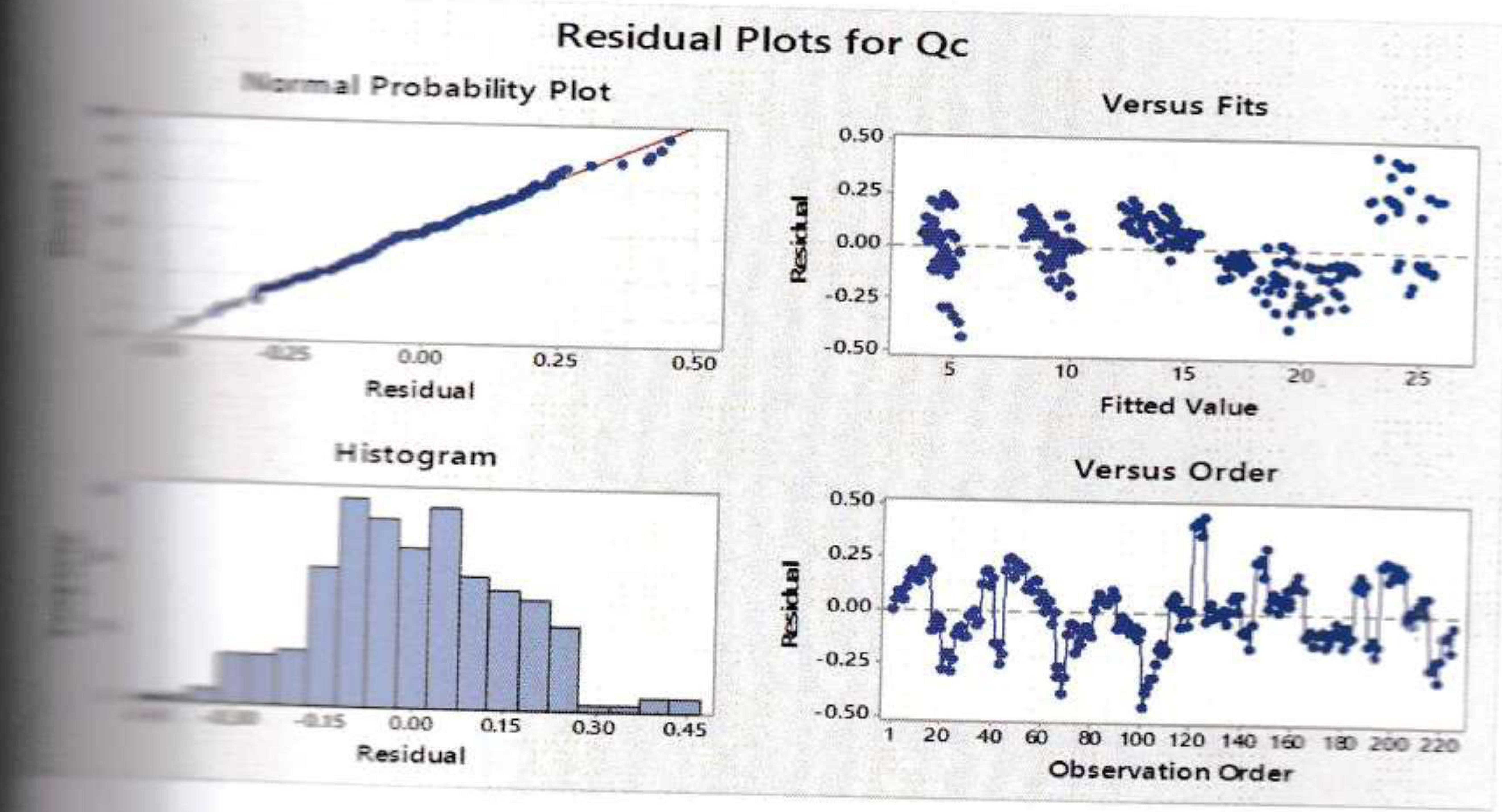


Figure 4.4 Residual Plots for Convective Heat Transfer Rate

... figure 4.3 and 4.4, normal probability curve shows residual are falling on ... line. It indicates that model is accurate and adequate. Symmetric nature of the ... designates that residuals are normally distributed. Residual vs. order graph ... that it is not following any structured pattern. This shows that variables are ... R^2 value for both ΔT and Qc are 99.65% and 99.95%.These values ... that model truly represent the experimental data.

... Regression Equations for Mixed Convection Heat Sink

... 4.7 and 4.8 represents the mathematical models developed with the help of ... for heat sink in vertical position under mixed convection to predict Qc and ...

... Equation for Convective Heat Transfer Rate

... 1.12 V + 0.893 Tw - 3.21 S + 1.03 V*V - 0.01192 Tw*Tw - 0.0670 S*S –

... V*Tw + 0.588 V*S + 0.0637 Tw*S ...(4.7)

... Equation for Nusselt Number (Nu)

... + 19.6 V + 1.76 Tw - 12.99 S + 6.70 V*V - 0.0417 Tw*Tw - 0.431 S*S -

... V*Tw + 4.43 V*S + 0.311 Tw*S ... (4.8)

Residual plots are plotted for vertical plate heat sink under mixed convection for convective heat transfer rate and Nusselt Number are as shown in figure 4.5 and 4.6 respectively.

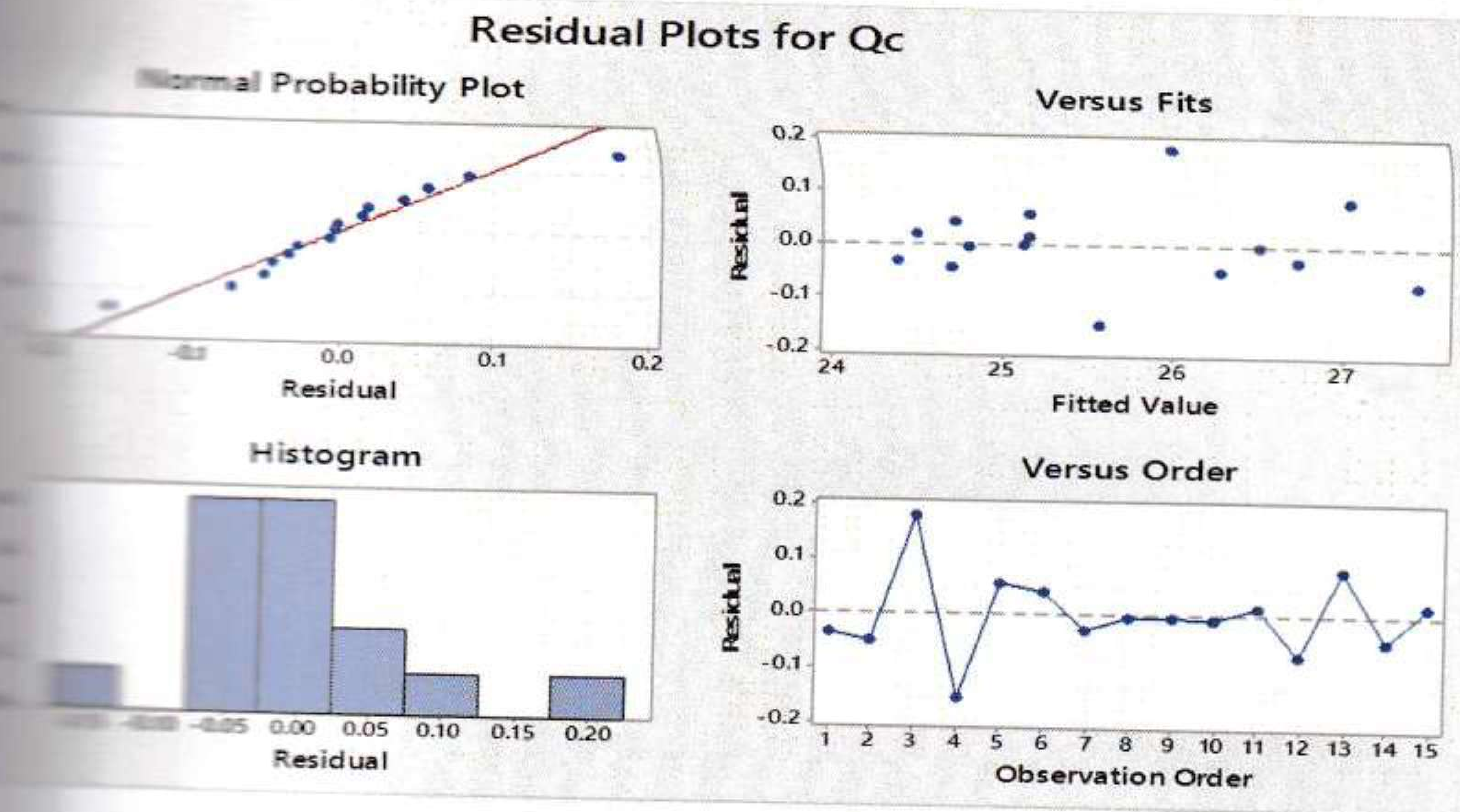


Figure 4.5 Residual Plots for Convective Heat Transfer Rate

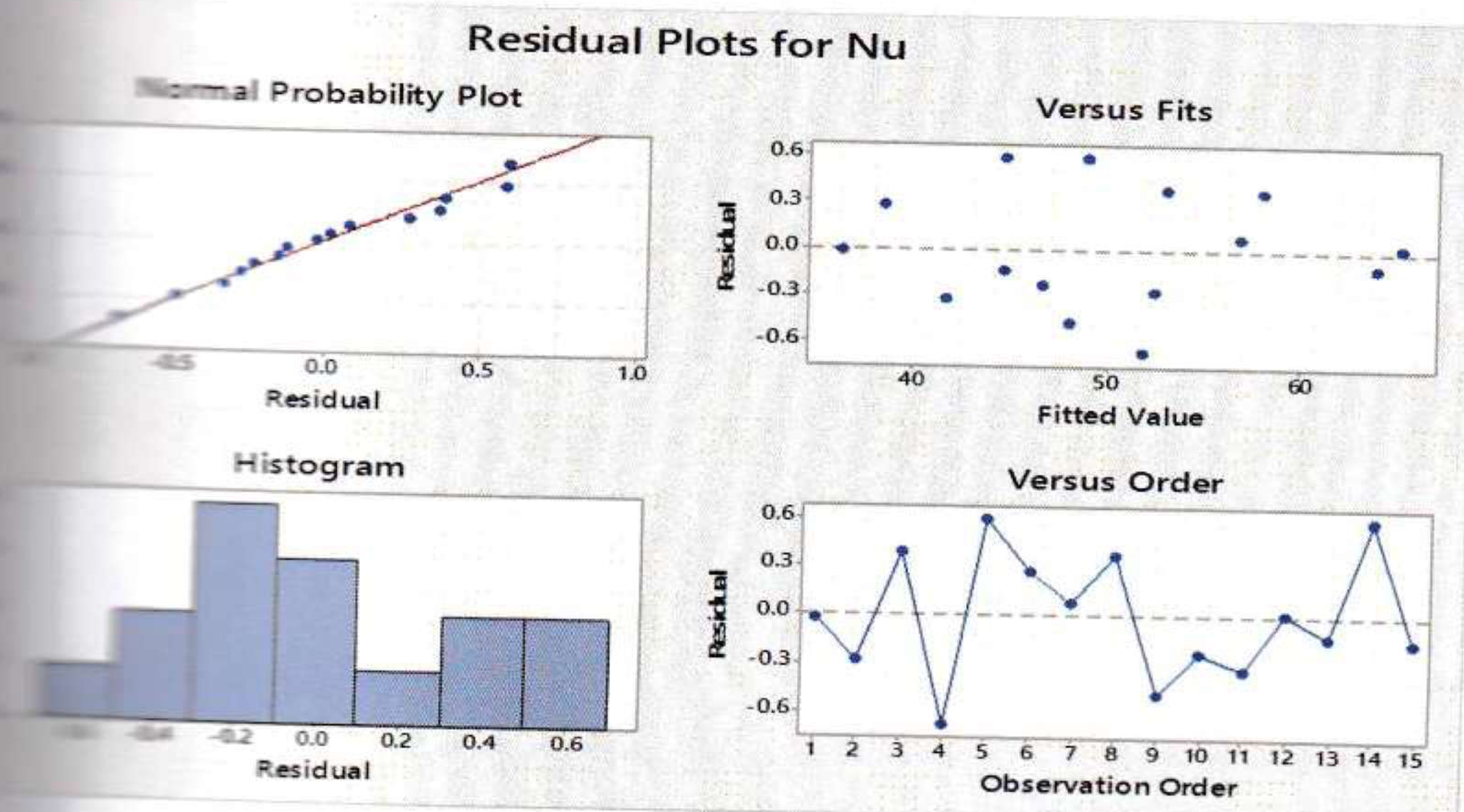


Figure 4.6 Residual Plots for Nusselt Number

Normal probability curve shows residual are falling on straight line as shown in figure 4.5 and 4.6. It indicates that model is exact and correct. The histogram shows residuals are normally distributed. R^2 value for both Qc and ΔT are 99.42% and [illegible] respectively which are close to 100%. This indicates that model is fitted well with experimental data.

Artificial Neural Network

An Artificial Neural Network (ANN) is an information processing system that has performance features in common with biological neural networks.

ANN consists of very simple and highly interconnected processors called neuron are a computational structure inspired by biological neural systems. The processors are analogous to biological neurons in the human head. The neurons are related to each other by weighted links over which signal scan goes. Each neuron receives multiple inputs from other neurons in proportion to their connection weights and gets a single product which may be distributed, to several other nerve cells. [79]

Artificial Neural Network (ANN) is one of the most common neural networks used in solving the engineering problems. Simulation consists of three layers. First layer is known as input layer. No. of neurons in input layer is equal to the no. of independent variables. Second layer is known as hidden layer. It consists of two numbers of neurons. The third layer is output layer. It contains one neuron as one of dependent variables at a time. Multilayer feed forward topology is decided for the network. [79]

Steps in formulation of ANN Simulation

The various steps followed in developing the algorithm to form ANN are as under.

- The experimental data is divided into two groups.i.e. input data or the data of independent pi terms and the output data or the data of dependent pi terms. The input data and output data are imported to the program respectively. Fin spacing, fin height and heat input are considered as the input data while the convective heat transfer rate and temperature difference parameter are the output data. The input layer of the network houses the design parameter in three nodes and output layer houses the response in one node.

- The input and output data is read by pre std function and appropriately sized. Function pre std is preprocesses the data so that the mean is 0 and standard deviation is 1.

- In preprocessing step the input and output data is normalized using mean and standard deviation.

4. The input and output data is then categorized in three categories viz. testing, validation and training. From the observations of each response, initial 75% of the observations is selected for training, last 75% data for validation and middle overlapping 50% data for testing.

5. The data is then stored in structures for training, testing and validation.

6. Looking at the pattern of the data, feed forward back propagation type neural network is chosen.

7. This network is then trained using the training data. The computation errors in the actual and target data are computed and then the network is simulated.

8. The regression analysis and the representation are done through the standard functions. The values of regression coefficient and the equation of regression lines are represented on the one different graph plotted for the one dependent pi terms.

ANN Program for Vertical Plate Heat Sink

MATLAB software is selected for developing ANN program. The program executed [illegible] for different input parameters are as follows.

[illegible]	7	40
[illegible]	9.5	40
[illegible]	13.5	40
[illegible]	17	40
[illegible]	5.5	50
[illegible]	7	50
[illegible]	9.5	50
[illegible]	13.5	50
[illegible]	17	50
[illegible]	5.5	10
[illegible]	7	10
[illegible]	9.5	10
[illegible]	13.5	10
[illegible]	17	10
[illegible]	5.5	20
[illegible]	7	20
[illegible]	9.5	20
[illegible]	13.5	20
[illegible]	17	20
[illegible]	5.5	30
[illegible]	7	30
[illegible]	9.5	30
[illegible]	13.5	30
[illegible]	17	30
[illegible]	5.5	40
[illegible]	7	40
[illegible]	9.5	40
[illegible]	13.5	40
[illegible]	17	40
[illegible]	5.5	50
[illegible]	7	50
[illegible]	9.5	50
[illegible]	13.5	50
[illegible]	17	50
[illegible]	5.5	10
[illegible]	7	10
[illegible]	9.5	10
[illegible]	13.5	10
[illegible]	17	10
[illegible]	5.5	20
[illegible]	7	20
[illegible]	9.5	20
[illegible]	13.5	20
[illegible]	17	20
[illegible]	5.5	30

[illegible]	7	30
[illegible]	9.5	30
[illegible]	12.5	30
[illegible]	17	30
[illegible]	5.5	40
[illegible]	7	40
[illegible]	9.5	40
[illegible]	12.5	40
[illegible]	17	40
[illegible]	5.5	50
[illegible]	7	50
[illegible]	[illegible]	50
[illegible]	[illegible]	50
[illegible]	[illegible]	50
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

[illegible]	7	20
[illegible]	[illegible]	20
[illegible]	[illegible]	20
[illegible]	[illegible]	20
[illegible]	[illegible]	30
[illegible]	7	30
[illegible]	[illegible]	30
[illegible]	[illegible]	30
[illegible]	[illegible]	30
[illegible]	[illegible]	40
[illegible]	7	40
[illegible]	[illegible]	40
[illegible]	[illegible]	40
[illegible]	[illegible]	40
[illegible]	[illegible]	50
[illegible]	7	50
[illegible]	[illegible]	50
[illegible]	[illegible]	50
[illegible]	[illegible]	50

```
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[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]meant,stdt] = prestd(p,t);
[illegible]max(pn),[125 1],{'logsig' 'purelin'},'trainlm');
[illegible]='mse';
[illegible].goal=.99;
[illegible].show=200;
[illegible].epochs=50;
[illegible].mc=0.05;
[illegible]pn,tn);
[illegible]pn);
[illegible]meant,stdt);
[illegible]
[illegible]
[illegible]'b-')
[illegible]mental','Neural');
[illegible]Red) and Neural Network Prediction (Blue) Plot');
[illegible]ment No.');
[illegible]
[illegible]
[illegible]
```

```
percentage=100*error./t
error_percentage)
'percentage error');
125 -100 100]);
Percentage Error Plot in Neural Network Prediction');
'Experiment No.');
'Error in %');

practical(ii)=(y2(ii,1));
neur(ii)=(a(1,ii))
practical_abs(ii)=(y2(ii,1));
neur_abs(ii)=(a(1,ii));



yy_practical_abs,'r-',x1,yy_neur_abs,'k-');
'Practical','Neural');
'Comparision between practical data, equation based data and neural based data');
'Experimental');

=mean(output3)
=mean(a)
```

Development of ANN Model for Vertical Plate Heat Sink

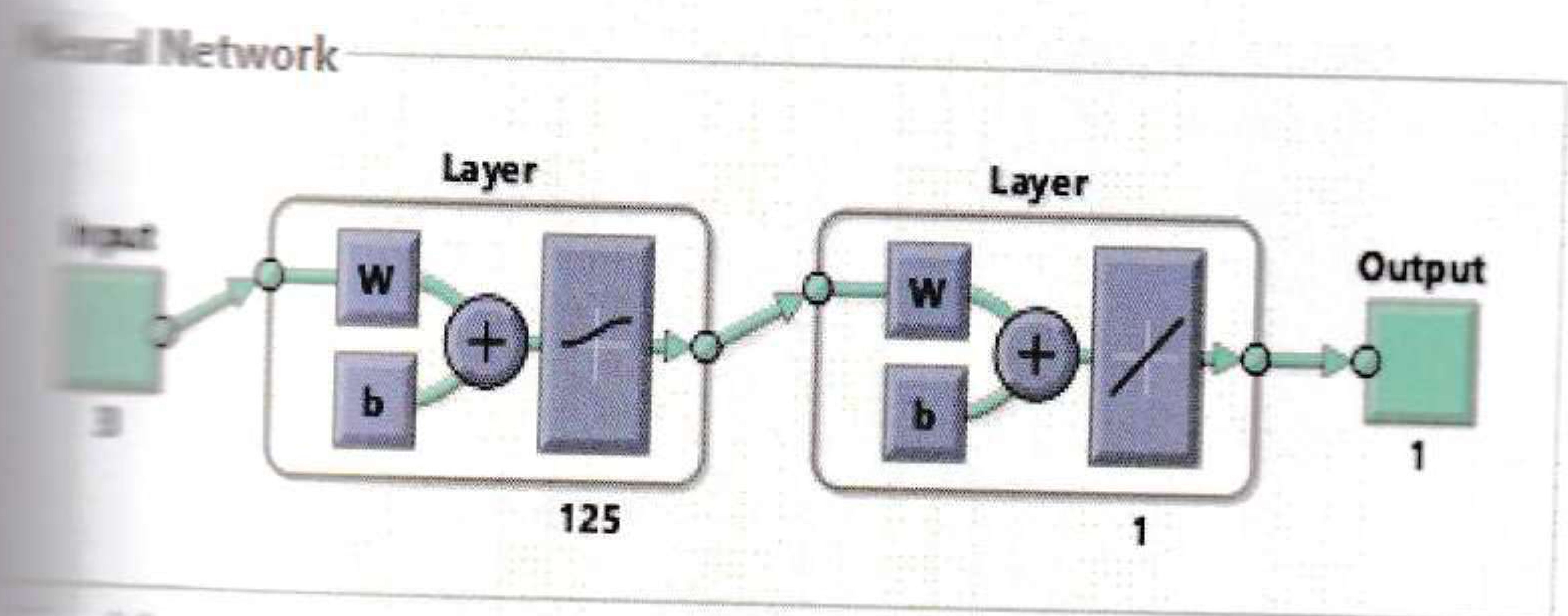


Figure 4.7 Architecture of ANN Model

repeated trials, it was found that a network with 125 hidden neurons produced performance. The architecture of ANN model is shown in figure 4.7. It has layer ANN, with tangent sigmoid transfer function at hidden layer with 125 and linear transfer function at output layer.

step in ANN is training the data. Figure 4.8 represents training of network of convective heat transfer rate. The train function outputs the trained network and history of the training performance. The errors for heat transfer rate are plotted with respect to training epochs. The means square error for best fit is 0.01083.

Figure 4.8 Training Performance of ANN for Convective Heat Transfer Rate

The next stage in authenticating the network for heat transfer rate and temperature difference for vertical plate heat sink is to generate a regression plot, which shows the relationship between the outputs of the network and the targets. If the training were perfect, the network outputs and the targets would be exactly equal, but the relationship is rarely perfect in practice.

The regression plots represent the training, validation, and testing data. The dashed line in figure 4.9. represents the perfect result – outputs = targets. The solid line represents the best-fit linear regression line between outputs and targets for heat transfer rate. The R-value is an indication of the relationship between the outputs and targets. Figure 4.9 shows experimental data are in perfect agreement with ANN data. The R-value is 0.9946. approaching to one shows training data indicates a good fit.

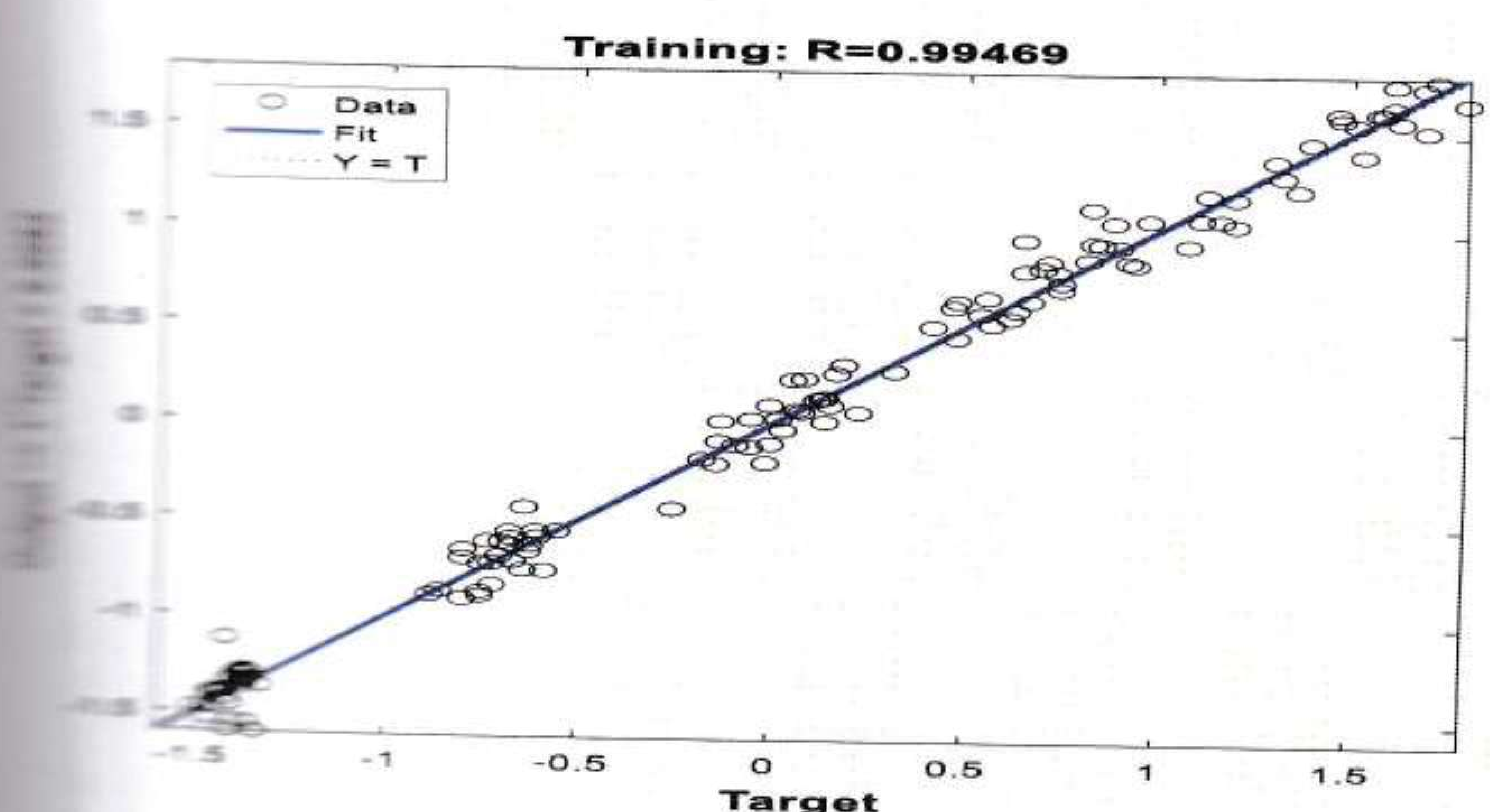


Figure 4.9 Regression Plot for Convective Heat Transfer Rate

The percentage error between the experimental results and ANN predicted values for heat transfer rate is shown in figure 4.10.

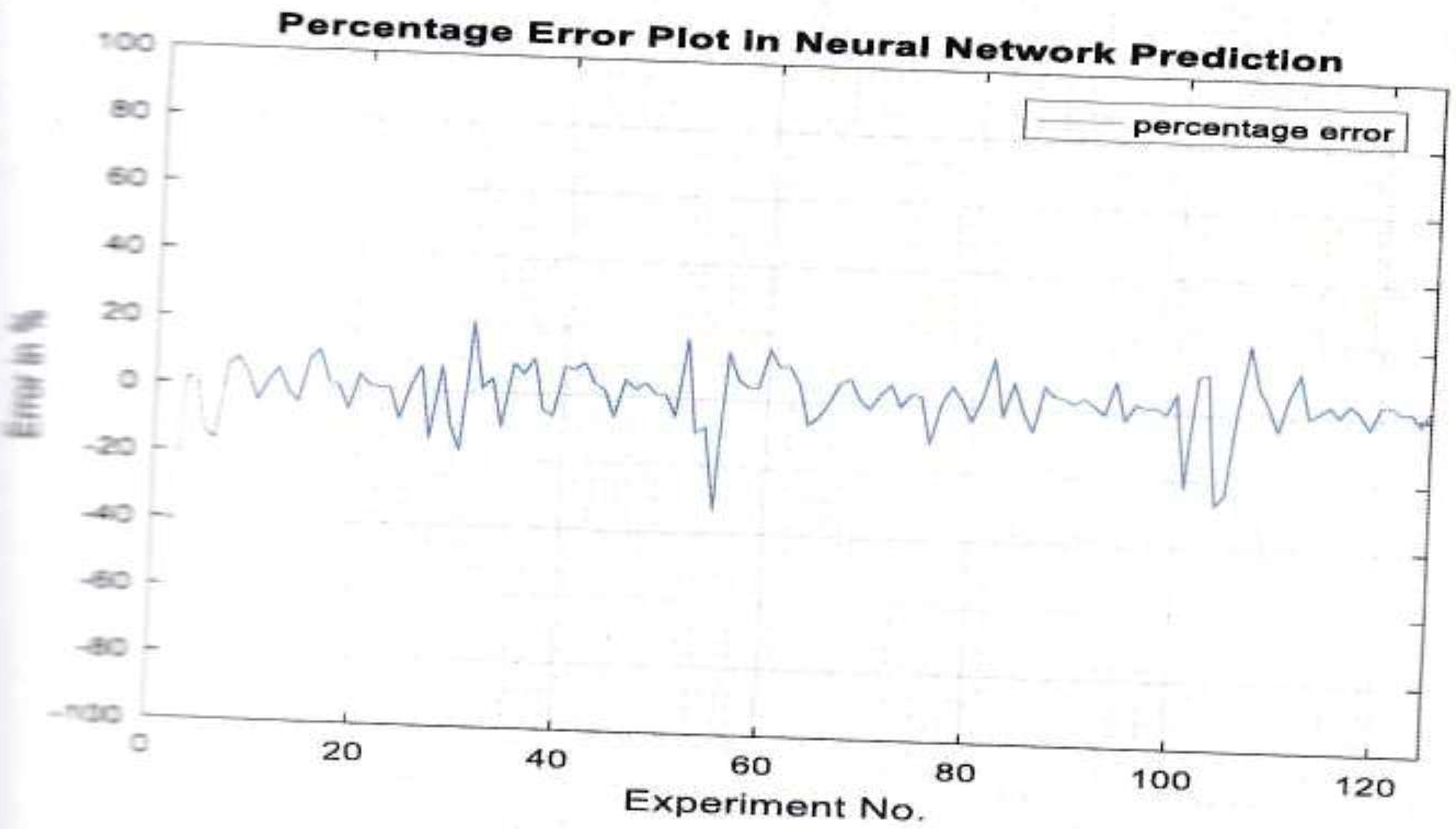


Figure 4.10 Percentage Error of Convective Heat Transfer Rate

The percentage error between the experimental results and ANN predicted values for temperature difference is shown in figure 4.11.

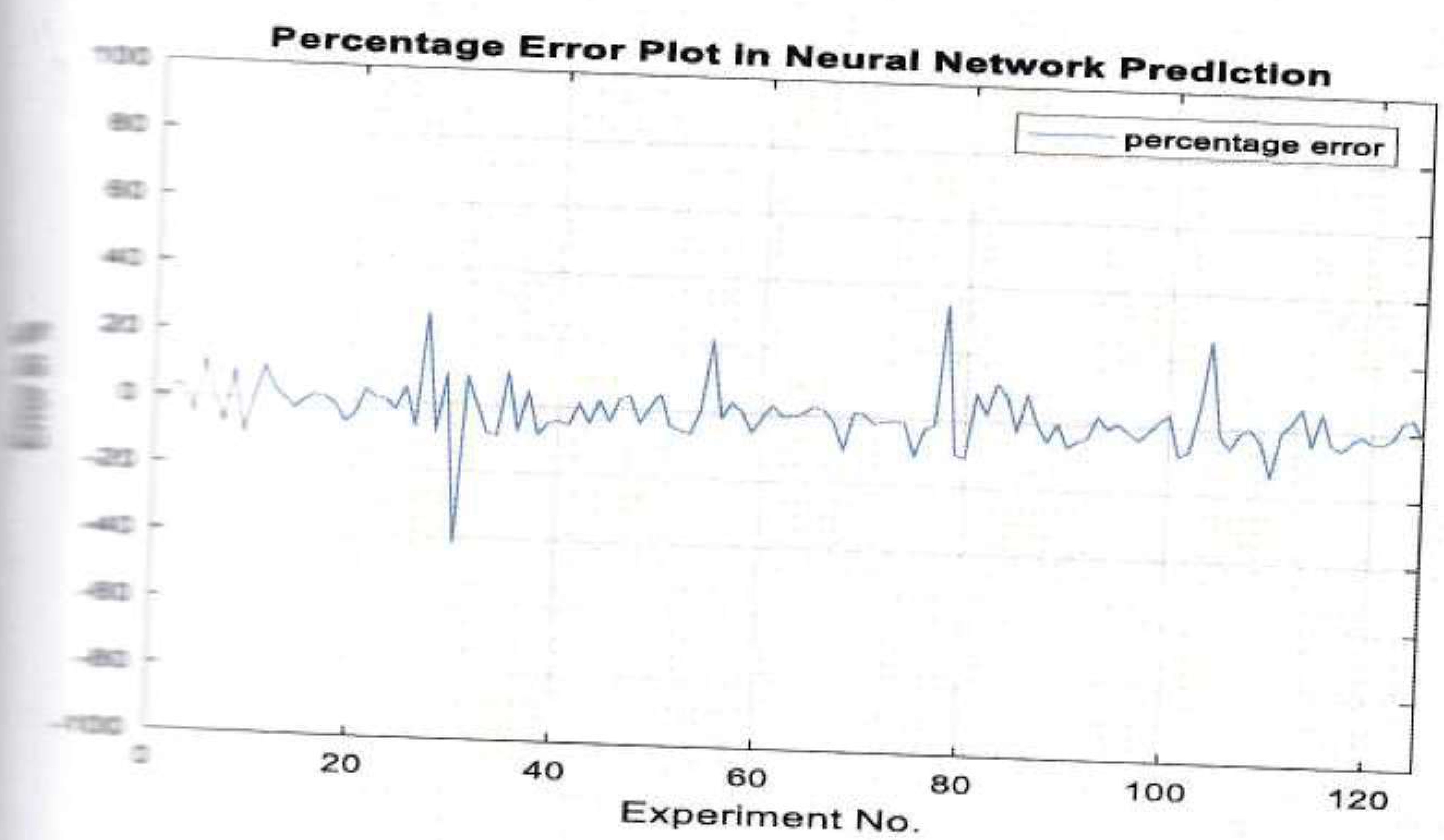


Figure 4.11 Percentage Error of Average Base to Ambient Temperature difference

The error percentage is very less which reveals that the models can be effectively used for predicting the convective heat transfer rate and average base to ambient temperature difference.

The regression plot and percentage error plots for inclined heat sink are added as figure C1, C2 and C3 in Appendix C. Figure C6 and C7 in Appendix C represents the regression plot and percentage error plots for mixed convection.

4.4.4 Comparison of Experimental and ANN Results for ΔT and Qc for Vertical Plate Heat Sink

The training, testing and validation of the ANN model was performed using experimental results for the response of average base to ambient temperature difference and convective heat transfer rate is as shown in figure 4.12 and 4.13 respectively.

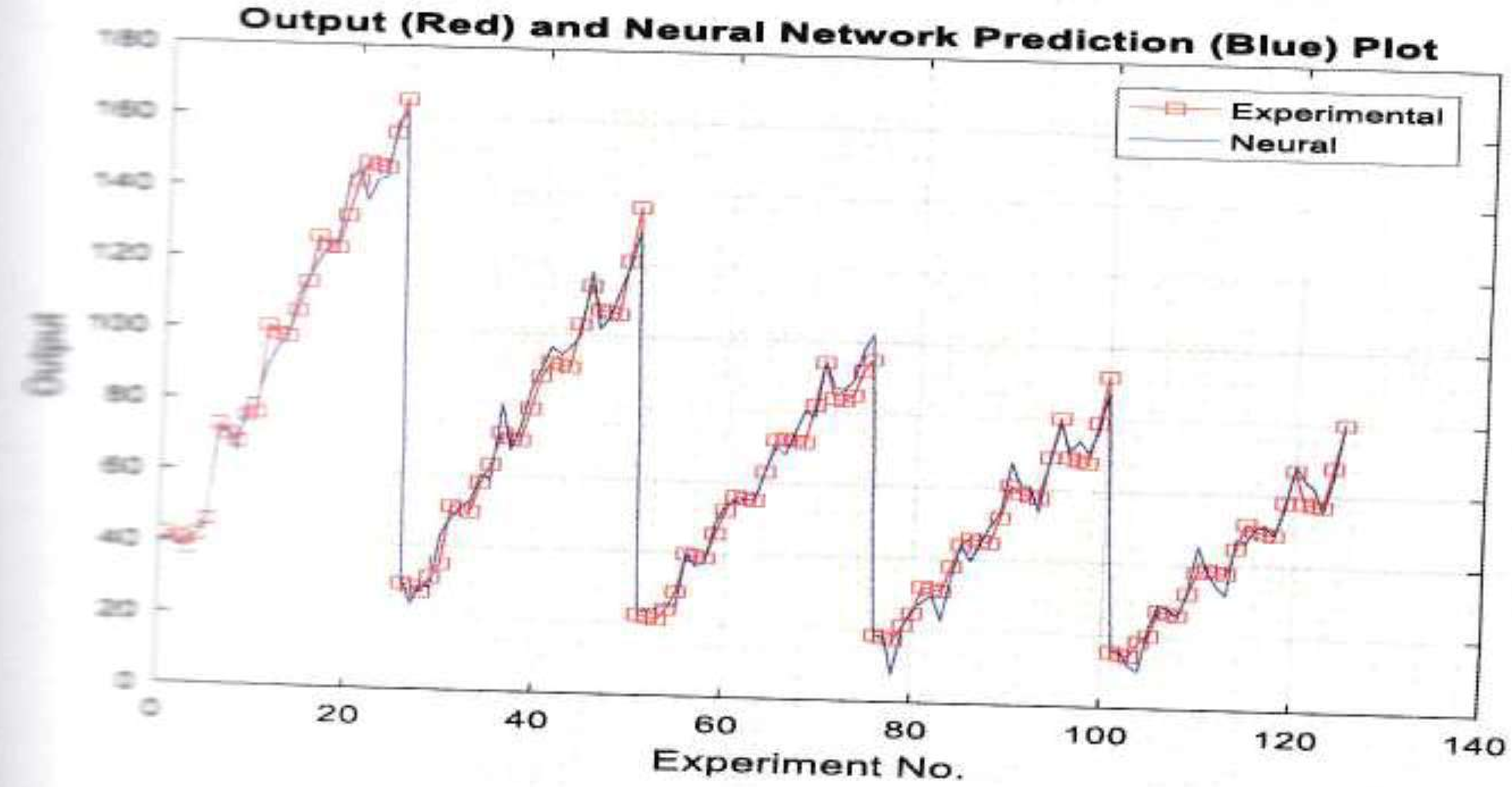


Figure 4.12 Comparison of Expt.and ANN Results for Average Base to Ambient Temperature difference

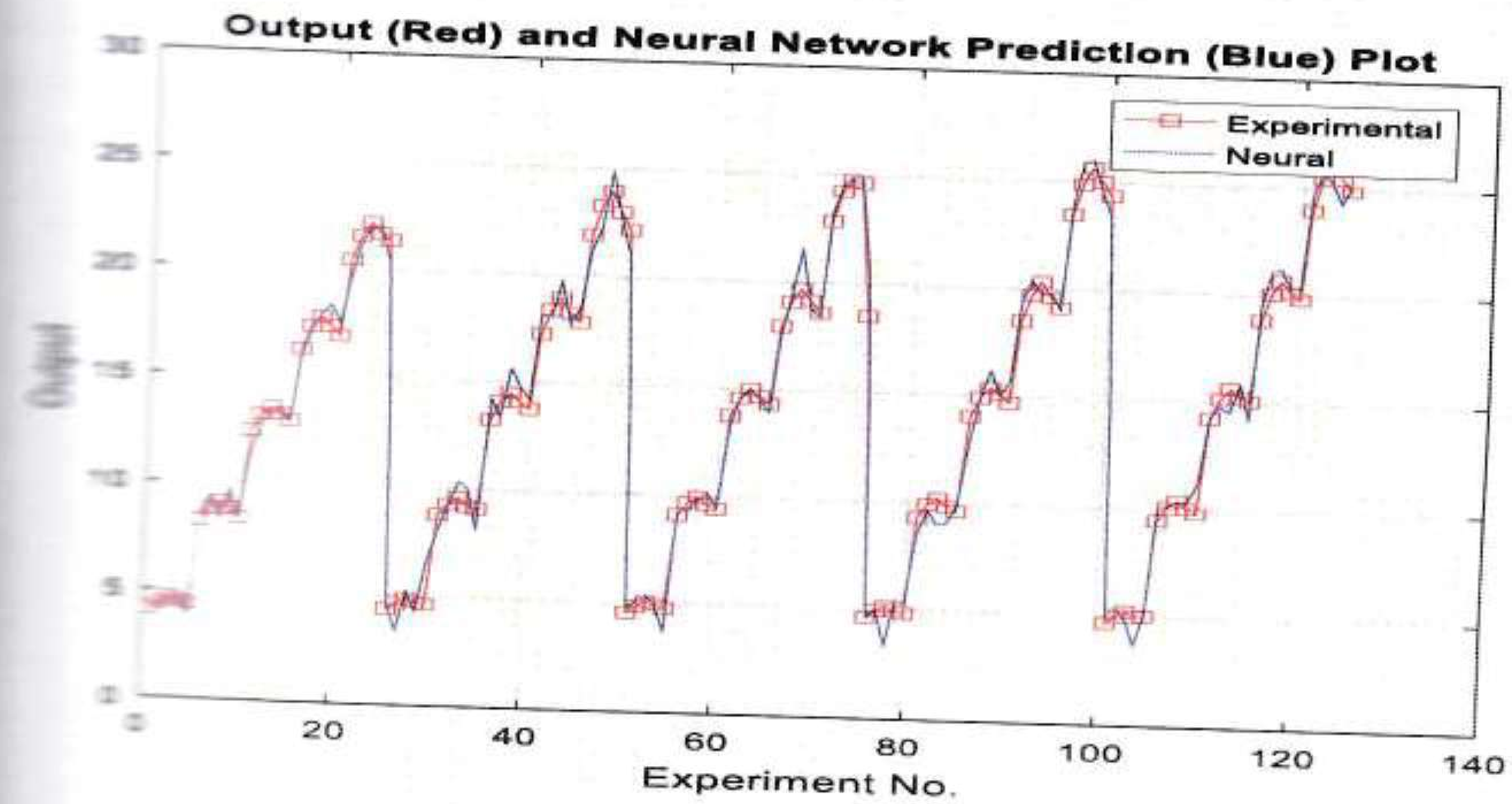


Figure 4.13 Comparison of Expt.and ANN Results for Convective Heat Transfer Rate

The percentage error of average base to ambient temperature difference and convective heat transfer rate (Qc) using RSM and ANN is represented in table 4.2 and 4.3 respectively. The tables for inclined heat sink and mixed convection are shown in Appendix C as table C1, C2 and C3.

The percentage average error for Qc is 5.10 % and average error for ΔT is 6.16%. The deviation between predicted value and experimental values are within acceptable limits. The results of the neural network are in agreement with the measured values. The tables representing the error variations and graphical analysis for vertical plate heat sink and vertical mixed convection heat sink are added in Appendix C.

Table 4.2 Percentage Error of ΔT using RSM and ANN for Vertical Plate Heat Sink

[illegible]	H (mm)	S (mm)	Q (W)	ΔT_{Expt} ^0C	ΔT_{RSM} ^0C	% Error Expt Vs. RSM	ΔT_{ANN} ^0C	% Error Expt. Vs ANN
[illegible]	5	5.5	10	42.1	44.51	5.42	41.17	2.21
[illegible]	5	7	10	40.9	42.44	3.62	38.08	6.91
[illegible]	5	9.5	10	37.8	40.85	7.46	40.34	6.72
[illegible]	5	13.5	10	41.8	43.18	3.20	42.10	0.71
[illegible]	5	17	10	46	50.15	8.27	44.86	2.48
[illegible]	5	5.5	20	72.8	71.70	1.53	69.68	4.28
[illegible]	5	7	20	70	70.22	0.32	71.80	2.57
[illegible]	5	9.5	20	68	69.64	2.35	65.11	4.25
[illegible]	5	13.5	20	75.2	73.57	2.22	79.94	6.30
[illegible]	5	17	20	76	81.93	7.24	79.49	4.59
[illegible]	5	5.5	30	100.6	96.90	3.82	89.10	11.44
[illegible]	5	7	30	98.4	96.03	2.47	94.51	3.95
[illegible]	5	9.5	30	97.8	96.44	1.41	97.04	0.78
[illegible]	5	13.5	30	105	101.97	2.97	109.10	3.90
[illegible]	5	17	30	113.2	111.73	1.32	114.39	1.05
[illegible]	5	5.5	40	126	120.12	4.90	119.27	5.34
[illegible]	5	7	40	123.2	119.84	2.80	122.88	0.26
[illegible]	5	9.5	40	122.8	121.25	1.28	125.41	2.13
[illegible]	5	13.5	40	132	128.38	2.82	141.73	7.37
[illegible]	5	17	40	142	139.54	1.76	145.31	2.33
[illegible]	5	5.5	50	147.2	141.35	4.14	136.57	7.22
[illegible]	5	7	50	146.4	141.67	3.34	142.41	2.73
[illegible]	5	9.5	50	145.6	144.08	1.05	143.14	1.69
[illegible]	5	13.5	50	155.6	152.81	1.83	158.31	1.74
[illegible]	5	17	50	165	165.36	0.22	161.42	2.17
[illegible]	[illegible]	5.5	10	29.4	29.46	0.21	30.51	3.78
[illegible]	[illegible]	7	10	28.5	27.42	3.94	23.71	16.82
[illegible]	[illegible]	9.5	10	27	25.89	4.27	29.59	9.59
[illegible]	[illegible]	13.5	10	31.2	28.32	10.16	28.60	8.35
[illegible]	[illegible]	17	10	35	35.37	1.04	43.57	24.47
[illegible]	[illegible]	5.5	20	51.2	52.78	2.99	47.89	6.46
[illegible]	[illegible]	7	20	50.6	51.34	1.44	51.08	0.95
[illegible]	[illegible]	9.5	20	49.8	50.81	1.99	52.82	6.06
[illegible]	[illegible]	13.5	20	58	54.84	5.77	60.35	4.05
[illegible]	[illegible]	17	20	63.2	63.28	0.13	58.89	6.82
[illegible]	[illegible]	5.5	30	72	74.11	2.85	80.28	11.49
[illegible]	[illegible]	7	30	70.5	73.27	3.78	67.41	4.38
[illegible]	[illegible]	9.5	30	70	73.74	5.07	74.29	6.13
[illegible]	[illegible]	13.5	30	79	79.37	0.46	84.44	6.89

[illegible]	H (mm)	S (mm)	Q (W)	ΔT_{Expt} ^0C	ΔT_{RSM} ^0C	% Error Expt Vs. RSM	ΔT_{ANN} ^0C	% Error Expt. Vs ANN
[illegible]	10	17	30	88	89.21	1.35	90.44	2.77
[illegible]	10	5.5	40	92.2	93.46	1.34	96.57	4.74
[illegible]	10	7	40	91.5	93.21	1.84	94.51	3.29
[illegible]	10	9.5	40	90.8	94.68	4.10	96.67	6.46
[illegible]	10	13.5	40	103	101.91	1.07	100.03	2.88
[illegible]	10	17	40	113.8	113.15	0.57	118.01	3.70
[illegible]	10	5.5	50	107.2	110.82	3.26	101.94	4.91
[illegible]	10	7	50	106.4	111.17	4.29	105.33	1.01
[illegible]	10	9.5	50	105.9	113.64	6.81	112.71	6.43
[illegible]	10	13.5	50	121	122.47	1.20	119.23	1.46
[illegible]	10	17	50	136.2	135.10	0.81	129.64	4.81
[illegible]	15	5.5	10	22.4	20.08	11.53	23.42	4.57
[illegible]	15	7	10	21.8	18.08	20.58	23.73	8.87
[illegible]	15	9.5	10	21	16.61	26.41	24.21	15.26
[illegible]	15	13.5	10	24	19.14	25.41	25.37	5.73
[illegible]	15	17	10	28.9	26.27	10.03	24.92	13.79
[illegible]	15	5.5	20	39.5	39.53	0.08	39.95	1.14
[illegible]	15	7	20	39	38.13	2.29	36.21	7.16
[illegible]	15	9.5	20	38.5	37.66	2.24	37.80	1.81
[illegible]	15	13.5	20	45.5	41.78	8.90	48.69	7.01
[illegible]	15	17	20	52	50.31	3.36	53.66	3.18
[illegible]	15	5.5	30	56	56.99	1.74	54.96	1.86
[illegible]	15	7	30	55.5	56.19	1.22	55.27	0.41
[illegible]	15	9.5	30	55	56.72	3.03	54.96	0.06
[illegible]	15	13.5	30	63	62.44	0.90	63.56	0.88
[illegible]	15	17	30	72	72.37	0.50	70.15	2.56
[illegible]	15	5.5	40	72.5	72.47	0.04	68.07	6.10
[illegible]	15	7	40	72	72.26	0.36	74.58	3.58
[illegible]	15	9.5	40	71.5	73.79	3.11	80.56	12.67
[illegible]	15	13.5	40	82	81.11	1.10	78.75	3.96
[illegible]	15	17	40	94	92.44	1.69	94.46	0.48
[illegible]	15	5.5	50	84	85.96	2.28	87.07	3.66
[illegible]	15	7	50	83.4	86.35	3.42	86.48	3.69
[illegible]	15	9.5	50	85	88.88	4.36	89.31	5.07
[illegible]	15	13.5	50	92	97.80	5.93	97.90	6.42
[illegible]	15	17	50	95	110.52	14.04	102.31	7.70
[illegible]	20	5.5	10	18.2	16.38	11.08	18.24	0.21
[illegible]	20	7	10	17.6	14.42	22.09	18.38	4.44
[illegible]	20	9.5	10	17	13.01	30.69	7.72	54.61
[illegible]	20	13.5	10	21	15.63	34.38	21.14	0.66
[illegible]	20	17	10	24.6	22.84	7.71	25.63	4.17
[illegible]	20	5.5	20	32.2	31.96	0.75	27.96	13.16
[illegible]	20	7	20	31.4	30.59	2.64	30.04	4.33
[illegible]	20	9.5	20	31	30.18	2.71	22.86	26.25
[illegible]	20	13.5	20	38	34.40	10.46	35.08	7.69
[illegible]	20	17	20	44.2	43.01	2.76	44.34	0.31
[illegible]	20	5.5	30	46.1	45.55	1.20	39.67	13.95
[illegible]	20	7	30	45.4	44.78	1.38	44.98	0.93
[illegible]	20	9.5	30	44.8	45.37	1.26	49.65	10.83
[illegible]	20	13.5	30	52	51.19	1.59	53.40	2.70
[illegible]	20	17	30	61	61.20	0.32	67.47	10.60
[illegible]	20	5.5	40	59	57.16	3.23	61.06	3.50

[illegible]	H (mm)	S (mm)	Q (W)	ΔT_{Expt} ^{0}C	ΔT_{RSM} ^{0}C	% Error Expt Vs. RSM	ΔT_{ANN} ^{0}C	% Error Expt. Vs ANN
[illegible]	20	7	40	58.3	56.99	2.31	60.82	4.32
[illegible]	20	9.5	40	57.6	58.58	1.66	54.05	6.16
[illegible]	20	13.5	40	69	65.99	4.56	68.43	0.82
[illegible]	20	17	40	80	77.40	3.36	78.63	1.71
[illegible]	20	5.5	50	69.1	66.78	3.48	70.92	2.64
[illegible]	20	7	50	68.4	67.20	1.78	73.92	8.07
[illegible]	20	9.5	50	67.8	69.79	2.85	70.62	4.16
[illegible]	20	13.5	50	79	78.81	0.25	76.66	2.96
[illegible]	20	17	50	92	91.61	0.42	87.69	4.69
[illegible]	25	5.5	10	15.4	18.36	16.12	15.86	2.96
[illegible]	25	7	10	14.8	16.43	9.90	15.32	3.52
[illegible]	25	9.5	10	14.1	15.08	6.49	11.74	16.76
[illegible]	25	13.5	10	18.2	17.79	2.29	10.14	44.30
[illegible]	25	17	10	20	25.09	20.28	22.46	12.30
[illegible]	25	5.5	20	27	30.07	10.20	28.82	6.73
[illegible]	25	7	20	26.3	28.73	8.46	27.65	5.14
[illegible]	25	9.5	20	25.7	28.38	9.45	25.44	1.02
[illegible]	25	13.5	20	32	32.70	2.13	32.52	1.61
[illegible]	25	17	20	38	41.39	-8.19	45.37	19.40
[illegible]	25	5.5	30	39.1	39.79	1.72	38.42	1.75
[illegible]	25	7	30	38.5	39.05	1.41	34.27	10.98
[illegible]	25	9.5	30	37.8	39.70	4.79	31.76	15.98
[illegible]	25	13.5	30	45	45.61	1.34	47.92	6.48
[illegible]	25	17	30	52	55.71	6.65	46.79	10.02
[illegible]	25	5.5	40	50.2	47.52	5.64	50.75	1.09
[illegible]	25	7	40	49.3	47.39	4.04	51.44	4.35
[illegible]	25	9.5	40	48.8	49.03	0.48	48.90	0.20
[illegible]	25	13.5	40	58	56.54	2.57	56.40	2.76
[illegible]	25	17	40	67	68.04	1.52	68.41	2.10
[illegible]	25	5.5	50	58.2	53.27	9.26	64.30	10.48
[illegible]	25	7	50	57.6	53.73	7.20	62.13	7.87
[illegible]	25	9.5	50	57	56.38	1.10	55.64	2.38
[illegible]	25	13.5	50	68	65.49	3.83	64.95	4.48
[illegible]	25	17	50	80	78.38	2.07	80.24	0.30

[illegible] Percentage Error of Qc using RMS and ANN for Vertical Plate Heat Sink

[illegible]	H (mm)	S (mm)	Q (W)	$Qc_{Expt.}$ (W)	Qc_{Pre} (W)	%Error Expt vs RSM	Qc Ann (W)	%Error Expt vs. ANN
[illegible]	[illegible]	5.5	10	4.107	3.83	6.67	4.20	2.32
[illegible]	[illegible]	7	10	4.361	4.27	2.10	4.20	3.72
[illegible]	[illegible]	9.5	10	4.627	4.71	1.75	4.50	2.74
[illegible]	[illegible]	13.5	10	4.485	4.66	3.93	4.73	5.44
[illegible]	[illegible]	17	10	4.348	3.86	11.12	3.84	11.71
[illegible]	[illegible]	5.5	20	8.22	8.12	1.19	8.17	0.59
[illegible]	[illegible]	7	20	8.783	8.56	2.49	9.45	7.60
[illegible]	[illegible]	9.5	20	9.091	9.01	0.84	8.29	8.76
[illegible]	[illegible]	13.5	20	8.787	8.98	2.25	9.74	10.81
[illegible]	[illegible]	17	20	8.374	8.20	2.06	8.33	0.58
[illegible]	[illegible]	5.5	30	12.41	12.41	0.00	11.21	9.69
[illegible]	[illegible]	7	30	13.16	12.86	2.29	12.75	3.09

[illegible]	5	9.5	30	13.49	13.32	1.27	13.41	0.63
[illegible]	5	13.5	30	13.21	13.31	0.72	13.54	2.48
[illegible]	5	17	30	12.91	12.54	2.88	12.91	0.02
[illegible]	5	5.5	40	16.25	16.70	2.74	15.98	1.66
[illegible]	5	7	40	17.33	17.15	1.04	17.13	1.15
[illegible]	5	9.5	40	17.75	17.62	0.73	17.95	1.11
[illegible]	5	13.5	40	17.34	17.62	1.64	18.37	5.94
[illegible]	5	17	40	16.91	16.87	0.23	17.51	3.54
[illegible]	5	5.5	50	20.43	20.98	2.69	19.69	3.63
[illegible]	5	7	50	21.56	21.44	0.56	21.23	1.54
[illegible]	5	9.5	50	22.16	21.92	1.08	21.97	0.84
[illegible]	5	13.5	50	21.68	21.94	1.21	22.07	1.82
[illegible]	5	17	50	21.34	21.20	0.64	20.35	4.63
[illegible]	10	5.5	10	4.387	4.21	3.97	4.69	6.81
[illegible]	10	7	10	4.689	4.65	0.75	3.42	27.06
[illegible]	10	9.5	10	4.905	5.10	4.00	5.31	8.25
[illegible]	10	13.5	10	4.744	5.07	6.82	4.32	9.02
[illegible]	10	17	10	4.641	4.28	7.73	6.57	41.47
[illegible]	10	5.5	20	8.792	8.69	1.11	8.05	8.39
[illegible]	10	7	20	9.302	9.14	1.72	9.29	0.08
[illegible]	10	9.5	20	9.59	9.60	0.10	10.36	8.05
[illegible]	10	13.5	20	9.207	9.58	4.09	10.03	8.89
[illegible]	10	17	20	9.108	8.81	3.24	8.17	10.34
[illegible]	10	5.5	30	13.24	13.17	0.49	14.23	7.46
[illegible]	10	7	30	14.1	13.63	3.34	13.46	4.56
[illegible]	10	9.5	30	14.49	14.10	2.71	15.66	8.10
[illegible]	10	13.5	30	14.09	14.10	0.05	14.78	4.92
[illegible]	10	17	30	13.77	13.34	3.12	14.31	3.90
[illegible]	10	5.5	40	17.27	17.65	2.22	18.18	5.25
[illegible]	10	7	40	18.36	18.11	1.35	18.08	1.53
[illegible]	10	9.5	40	18.92	18.59	1.73	19.76	4.41
[illegible]	10	13.5	40	18.26	18.61	1.91	17.81	2.46
[illegible]	10	17	40	17.86	17.87	0.04	18.50	3.60
[illegible]	10	5.5	50	21.91	22.13	1.00	21.22	3.17
[illegible]	10	7	50	23.26	22.60	2.86	22.27	4.27
[illegible]	10	9.5	50	23.94	23.09	3.57	24.89	3.98
[illegible]	10	13.5	50	22.98	23.12	0.61	22.73	1.08
[illegible]	10	17	50	22.17	22.39	1.00	21.06	5.00
[illegible]	15	5.5	10	4.559	4.42	3.15	4.77	4.55
[illegible]	15	7	10	4.871	4.86	0.19	5.14	5.62
[illegible]	15	9.5	10	5.06	5.32	5.08	5.39	6.57
[illegible]	15	13.5	10	4.965	5.30	6.69	4.92	0.96
[illegible]	15	17	10	4.776	4.52	5.29	3.74	21.59
[illegible]	15	5.5	20	9.112	9.09	0.24	9.26	1.65
[illegible]	15	7	20	9.661	9.54	1.23	9.35	3.19
[illegible]	15	9.5	20	9.951	10.01	0.58	9.90	0.51
[illegible]	15	13.5	20	9.622	10.01	3.98	10.15	5.46
[illegible]	15	17	20	9.419	9.25	1.83	9.52	1.10
[illegible]	15	5.5	30	13.74	13.76	0.16	13.34	2.89
[illegible]	15	7	30	14.57	14.22	2.39	14.64	0.47
[illegible]	15	9.5	30	15	14.70	2.01	15.03	0.18
[illegible]	15	13.5	30	14.64	14.71	0.49	14.56	0.53
[illegible]	15	17	30	14.32	13.97	2.46	14.56	1.69
[illegible]	15	5.5	40	17.94	18.43	2.75	17.59	1.95
[illegible]	15	7	40	19.08	18.90	0.95	19.39	1.60
[illegible]	15	9.5	40	19.67	19.39	1.44	21.58	9.73
[illegible]	15	13.5	40	19.13	19.42	1.50	18.82	1.62
[illegible]	15	17	40	18.6	18.69	0.47	18.41	1.03
[illegible]	15	5.5	50	22.86	23.10	1.06	23.26	1.73
[illegible]	15	7	50	24.26	23.57	2.83	24.52	1.07
[illegible]	15	9.5	50	24.73	24.07	2.66	24.90	0.70
[illegible]	15	13.5	50	24.64	24.12	2.11	24.92	1.14
[illegible]	15	17	50	23	23.40	1.76	20.49	10.90
[illegible]	20	5.5	10	4.653	4.44	4.56	4.79	2.96

20	7	10	4.988	4.89	1.92	5.06	1.53
20	9.5	10	5.175	5.36	3.50	3.39	34.40
20	13.5	10	4.979	5.35	7.44	5.48	10.09
20	17	10	4.873	4.59	5.86	5.41	11.01
20	5.5	20	9.309	9.31	0.01	8.53	8.33
20	7	20	9.92	9.77	1.55	9.70	2.21
20	9.5	20	10.21	10.24	0.30	9.05	11.39
20	13.5	20	9.836	10.25	4.21	9.07	7.79
20	17	20	9.635	9.50	1.37	9.89	2.64
20	5.5	30	14.02	14.17	1.10	12.81	8.61
20	7	30	14.91	14.64	1.83	14.98	0.44
20	9.5	30	15.37	15.12	1.61	16.18	5.28
20	13.5	30	15.05	15.15	0.66	15.05	0.03
20	17	30	14.69	14.42	1.86	15.70	6.88
20	5.5	40	18.5	19.04	2.90	19.43	5.02
20	7	40	19.69	19.51	0.93	20.41	3.64
20	9.5	40	20.31	20.00	1.51	19.77	2.67
20	13.5	40	19.6	20.05	2.28	19.83	1.19
20	17	40	19.14	19.33	0.99	19.04	0.52
20	5.5	50	23.47	23.90	1.83	23.88	1.74
20	7	50	24.92	24.38	2.18	25.89	3.90
20	9.5	50	25.67	24.88	3.07	26.05	1.50
20	13.5	50	25.02	24.94	0.31	24.63	1.56
20	17	50	24.38	24.24	0.58	23.50	3.62
25	5.5	10	4.709	4.29	8.90	5.11	8.55
25	7	10	5.063	4.75	6.26	5.41	6.87
25	9.5	10	5.27	5.22	0.98	4.96	5.93
25	13.5	10	5.034	5.22	3.79	3.71	26.32
25	17	10	5.061	4.47	11.59	5.16	1.99
25	5.5	20	9.472	9.35	1.29	10.01	5.73
25	7	20	10.09	9.81	2.75	10.20	1.05
25	9.5	20	10.42	10.30	1.20	10.40	0.23
25	13.5	20	10.05	10.32	2.67	10.39	3.40
25	17	20	9.836	9.58	2.57	11.20	13.86
25	5.5	30	14.24	14.41	1.18	14.33	0.61
25	7	30	15.14	14.88	1.74	14.79	2.33
25	9.5	30	15.63	15.37	1.66	14.56	6.87
25	13.5	30	15.25	15.41	1.05	15.88	4.13
25	17	30	15.05	14.69	2.40	14.23	5.47
25	5.5	40	18.81	19.46	3.48	19.52	3.80
25	7	40	20.05	19.94	0.55	21.11	5.28
25	9.5	40	20.66	20.44	1.05	21.19	2.58
25	13.5	40	20.13	20.50	1.84	20.29	0.80
25	17	40	19.83	19.79	0.18	20.37	2.71
25	5.5	50	23.99	24.52	2.20	24.71	3.01
25	7	50	25.44	25.00	1.73	25.78	1.34
25	9.5	50	26.18	25.51	2.54	25.28	3.43
25	13.5	50	25.48	25.59	0.43	24.32	4.54
25	17	50	24.9	24.90	0.01	25.13	0.93

Optimization

In many heat transfer problem, the selection of optimum geometrical parameter is an important step to improve heat transfer enhancement. The geometrical parameter used by practitioners of manufacturing industries for heat sink is sometimes too far from optimal conditions. Therefore, different mathematical techniques are used for obtaining optimized geometrical parameters of plate heat sink.

Multi Objective Optimization

Optimization is method of finding the best result under given circumstances. It can be defined as the process of finding the conditions that give the maximum or minimum value of a function. Desirability is used to verify the feasibility of optimization process. Value of desirability approaching one, which specifies that optimization process is realistic and reasonable. Response Optimizer is used to find the optimized amount of the input parameter. [84] The optimal plot for vertical plate fin heat sink is shown in figure 4.14.

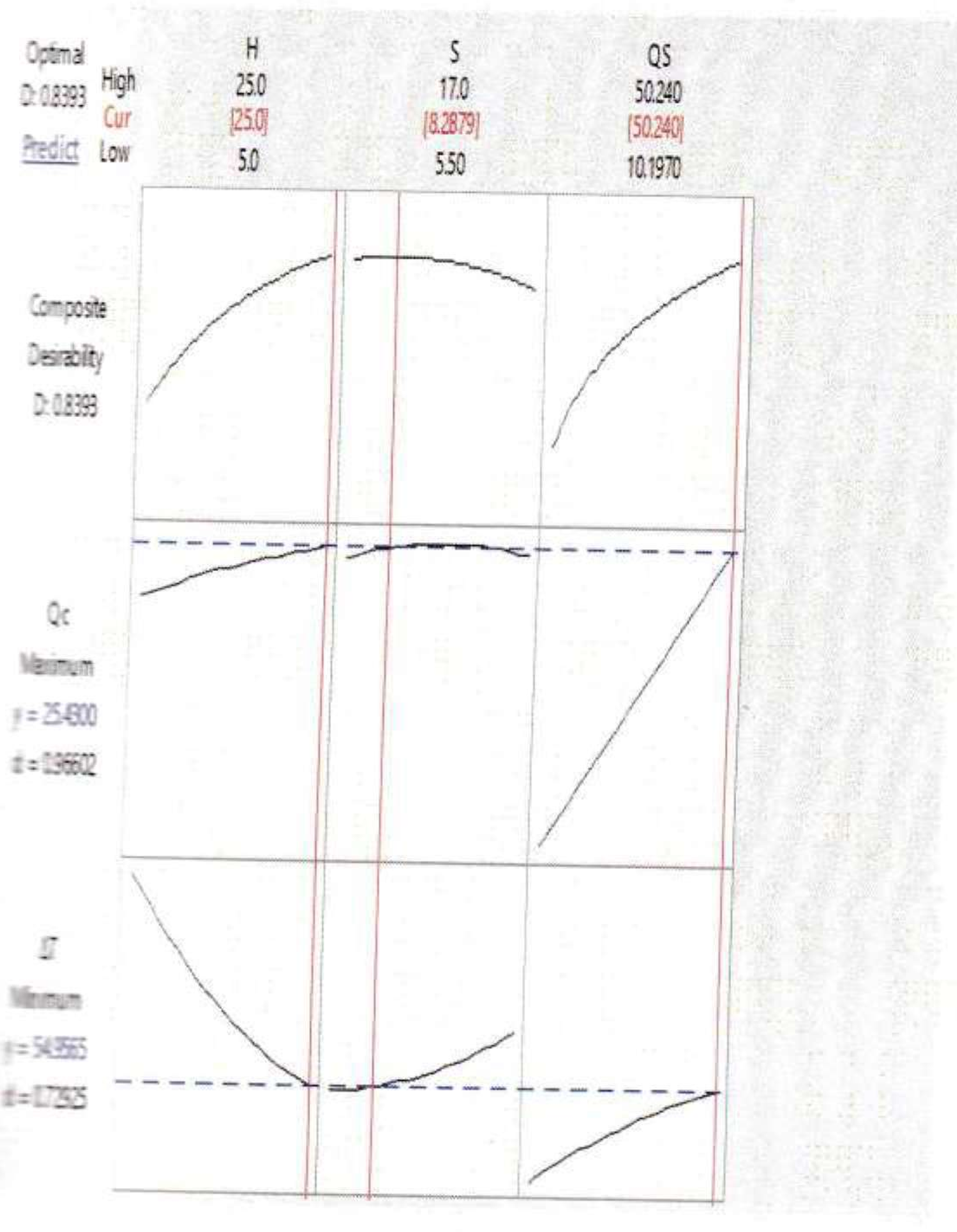


Figure 4.14 Optimal Plots for Vertical Plate Heat Sink

Optimized values obtained for minimum temperature difference and maximum heat transfer rate for vertical orientation plate heat sink are -height-25 mm, Spacing- and heat supplied-50W.

The optimal plot for inclined plate heat sink is shown in figure 4.15. The optimum spacing obtained for minimum temperature difference and maximum heat transfer rate for inclined plate is 8.44 mm at height, 25 mm and heat input of 50 W.

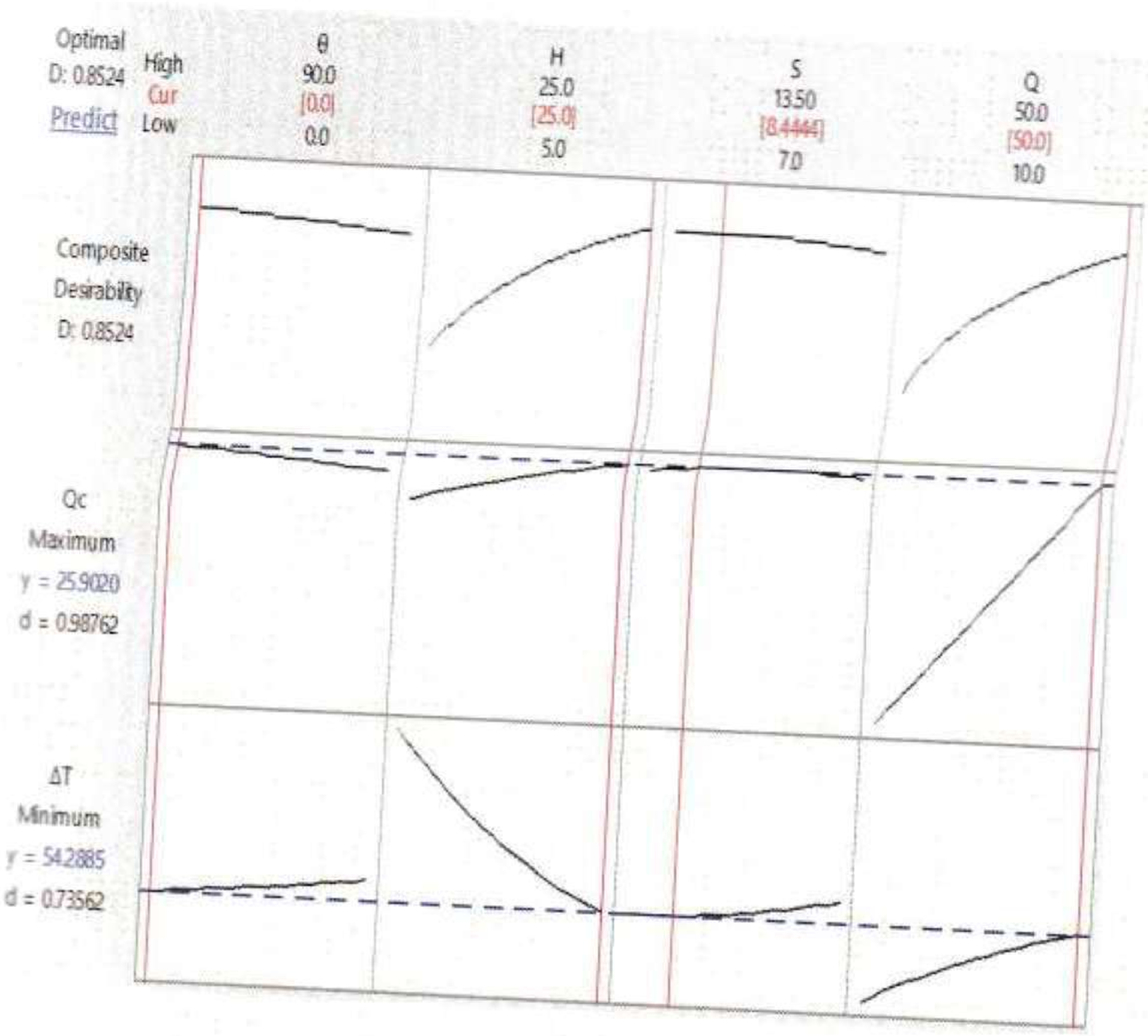


Figure 4.15 Optimal Plots for Inclined Plate Heat Sink

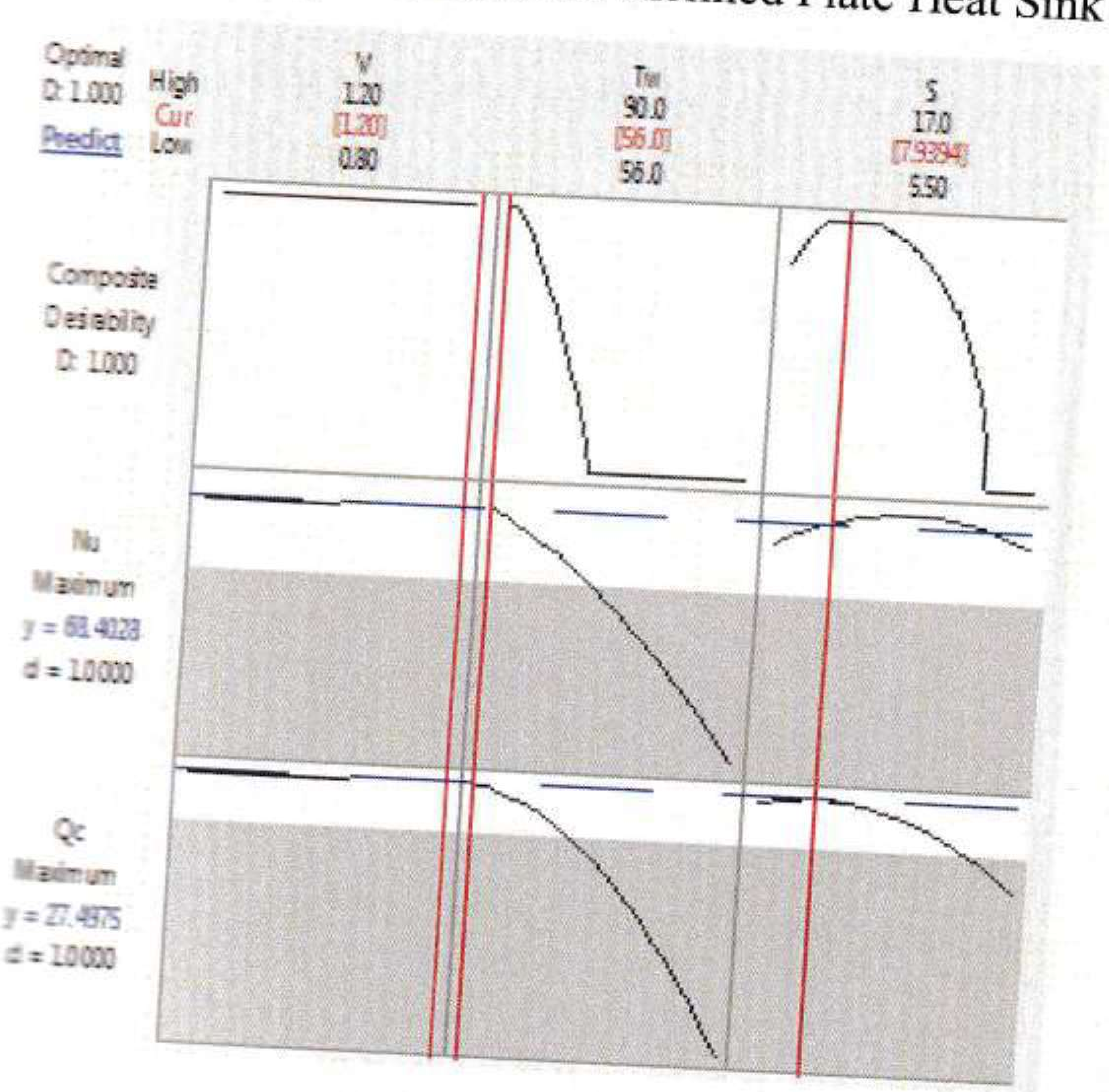


Figure 4.16 Optimal Plots for Vertical Plate Heat Sink in Mixed Convection

The optimal plot for assisting flow mixed convection vertical plate heat sink is shown in figure 4.16. The vertical red lines on the graph 4.14, 4.15 and 4.16 represent the input parameters. The numbers displayed in red at the top of a column shows the optimized values obtained. The horizontal blue lines and numbers represent the responses.

The optimized values obtained for maximum heat transfer rate are velocity-1.2 m/s, fin spacing-7.93 mm at 50W.The optimum fin spacing for different heat sink position are shown in table 4.4

Table 4.4 Optimum Fin Spacing for Experimental and RSM

S.No	Heat Sink positions	S_{opt} (mm)	
		Experimental	RSM
1	Vertical Natural Convection	7-9.5	8.28
2	Inclined Natural Convection	7-9.5	8.44
3	Vertical Mixed Convection	7-9.5	7.93

The optimized results of fin spacing obtained from experimentation and RSM are in close agreement, it states that regression equation developed to predict the response are accurate to predict the performance.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Introduction

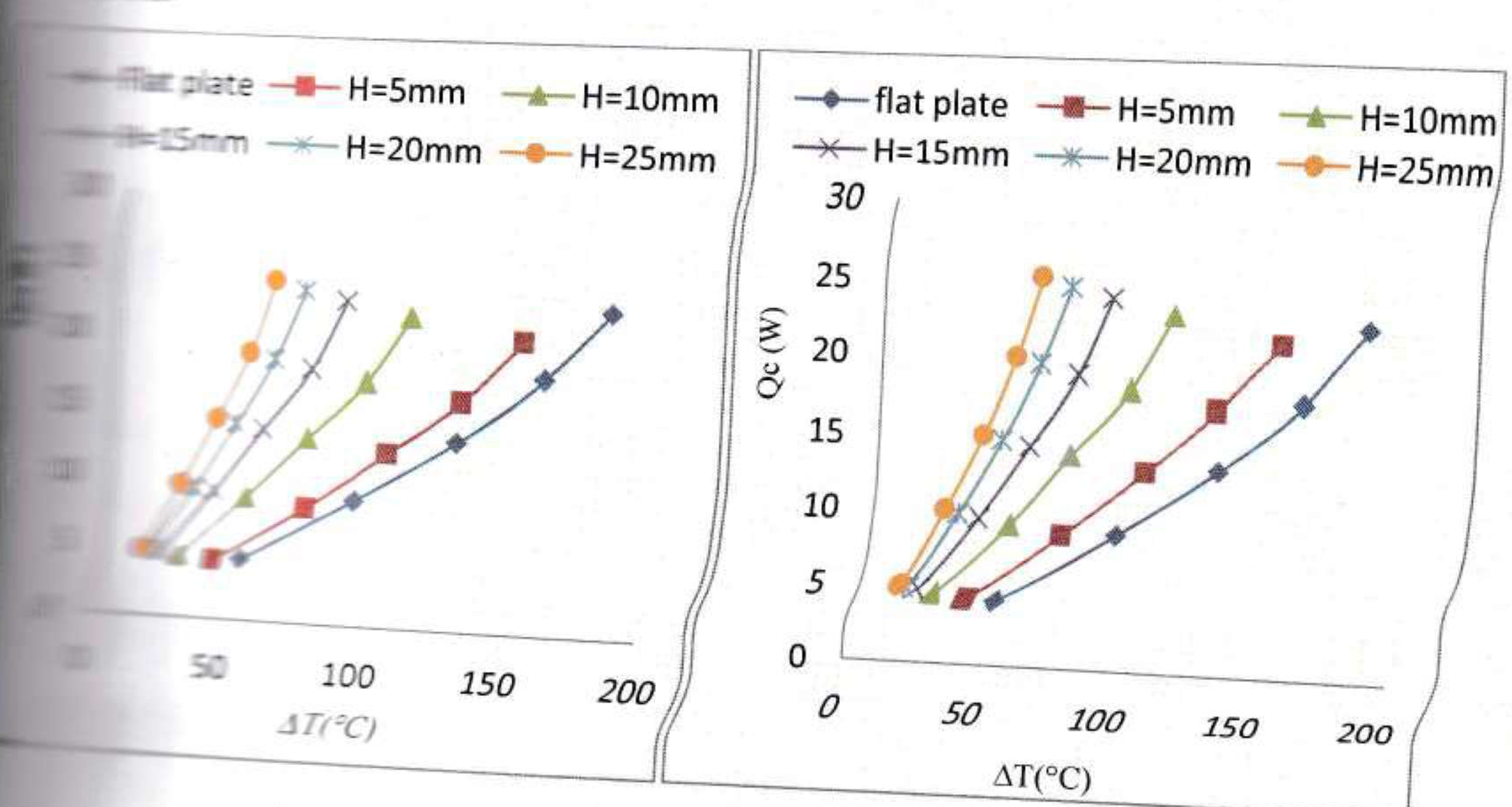
The experimental data obtained from twenty five different heat sink configurations are presented in this chapter. The results are useful to reveal the effect of geometric parameters such as fin spacings, fin height and effects of temperature difference on steady state heat transfer rates from the heat sink. The results and discussion are divided into three parts viz. vertical plate heat sink, inclined plate heat sink and mixed convection vertical plate heat sink.

5.2 Vertical Plate Heat Sink

The results obtained from vertical plate heat sink for temperature difference, various fin height and fin spacings are given below.

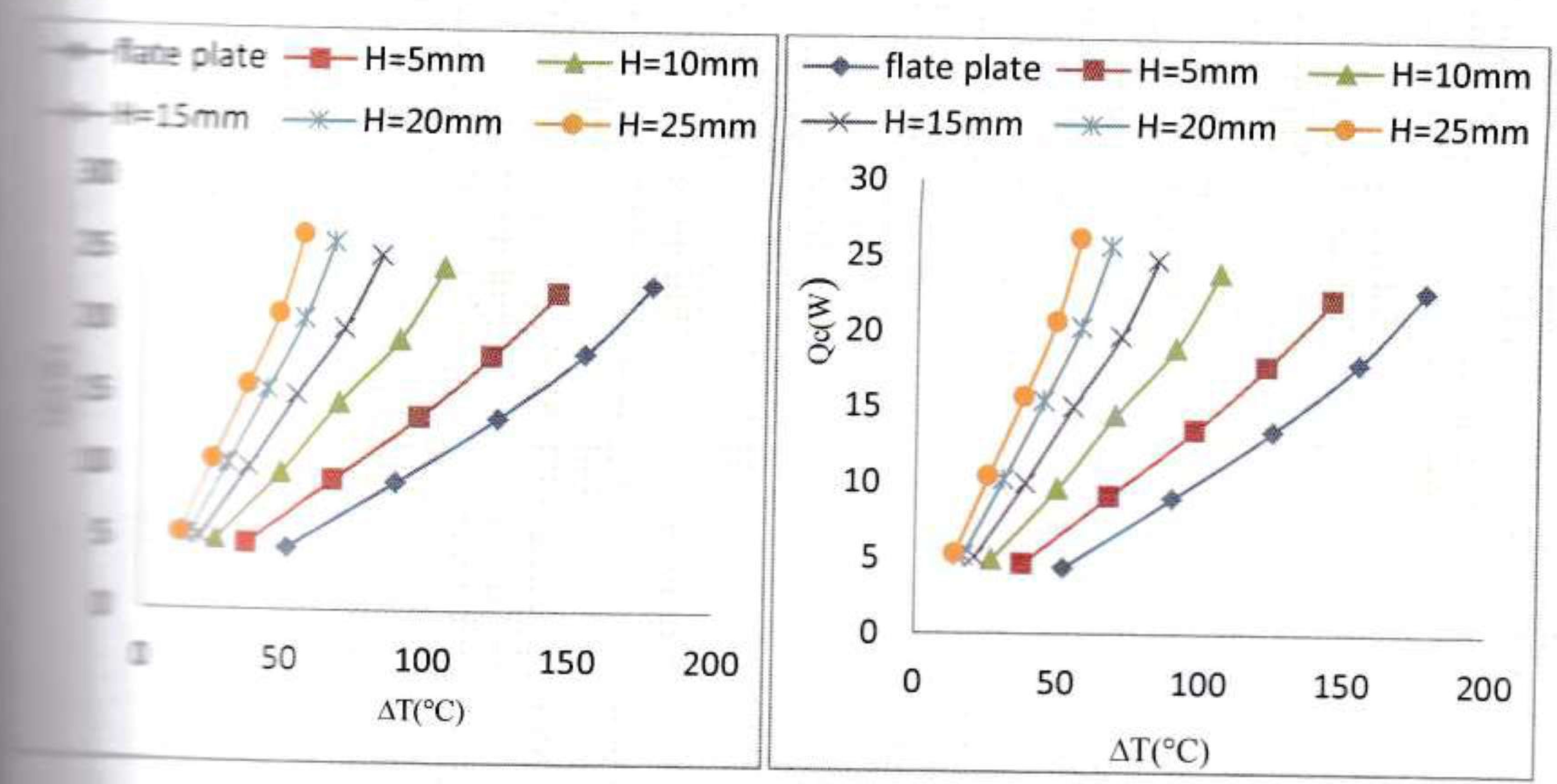
5.2.1 Effect of Temperature Difference on Convective Heat Transfer Rate

The convective heat transfer rate of the heat sink and vertical flat plate are plotted as a function of temperature difference at different fin spacings at S=5.5mm,7mm,9.5 mm, 15.5 mm and 17 mm respectively. The results of all fin heights and for vertical flat plate are compared which is shown in figure 5.1(a, b, c, d, e). At each value of fin height, variations in convective heat transfer rate vs. temperature difference are observed.



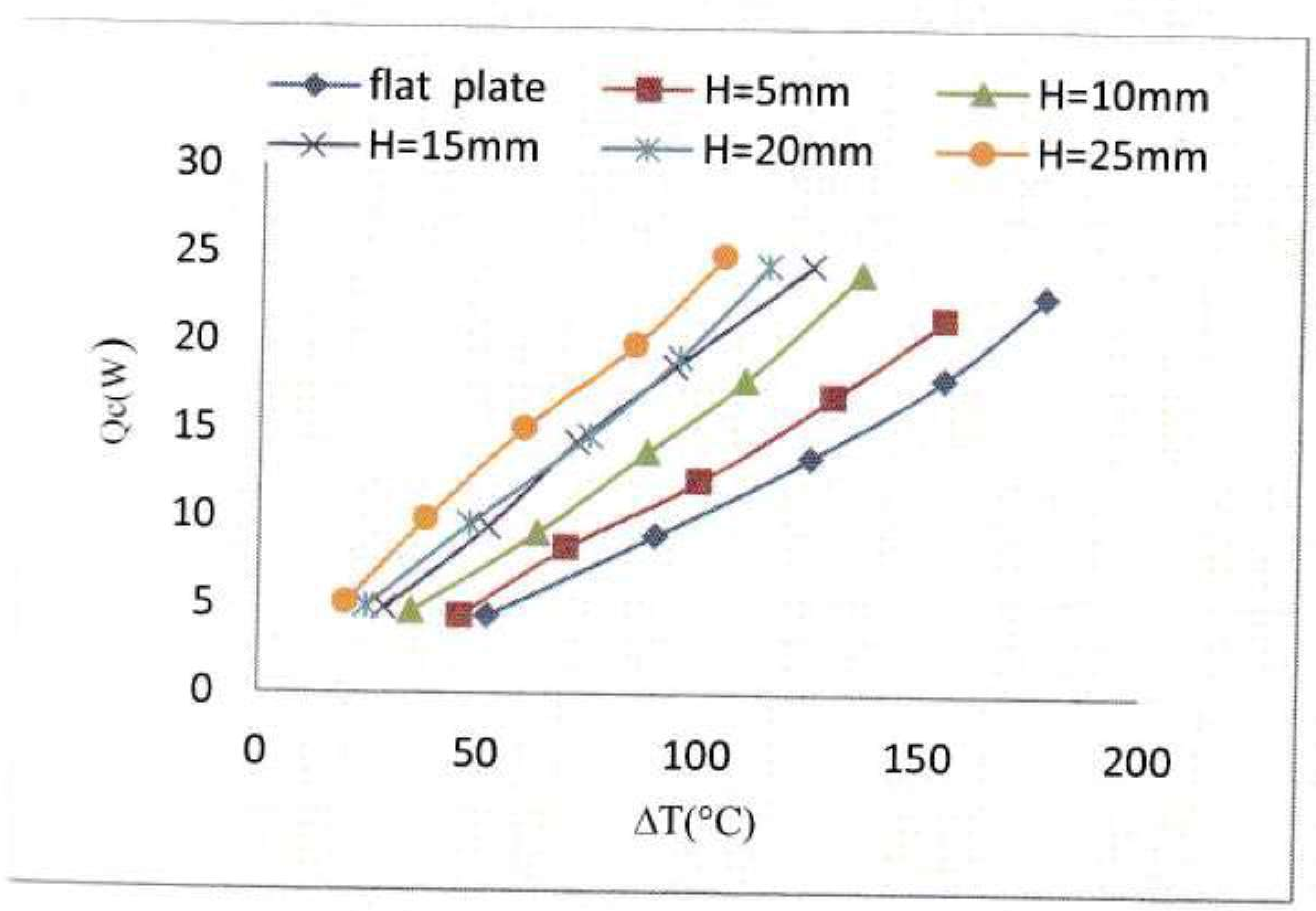
(a) (b)

Figure 5.1 Variation of Convection Heat Transfer Rate with Temperature Difference at Fin Spacing of a) S=5.5mm (b) S= 7mm



(c) (d)

Figure 5.1 Variation of Convection Heat Transfer Rate with Temperature Difference at Fin Spacing of c) S=9.5mm (d) S= 13.5mm



(e)

Figure 5.1 Variation of Convection Heat Transfer Rate with Temperature Difference at Fin Spacing of S=17mm

... from these figures that heat transfer rate increases with increase in fin ... temperature difference. The trend of change in temperature difference with ... height at fin spacing 5.5 mm is almost similar in case of H=10 mm to 25 ... change is observed for flat plate and plate with H=5mm as shown ... (a), that means, temperature difference is of large magnitude with H= ... flat plate against rest of the height. It reveals from the figure 5.1 (b) that ... all thickness viz.from flat plate to H=25 are same. For fin spacing of 9.5 ... in figure 5.1 (c), these samples of all heights are almost similar. It is ... the convective heat transfer rates from the plate heat sink depends on fin height, fin spacing and base to ambient temperature difference. The heat transfer rate is higher in case of all plate heat sink than the vertical flat plate for same temperature difference, which is shown in figure 5.1(e) for fin spacing of 17 mm.

5.2.2 Effect of Fin Spacing on Convective Heat Transfer Rate

The figure 5.2 (a, b, c, d and e) shows the variation in convective hat transfer rate with the change in fin spacing at different fin heights. The heat input is varied from 10 W to 50 W.

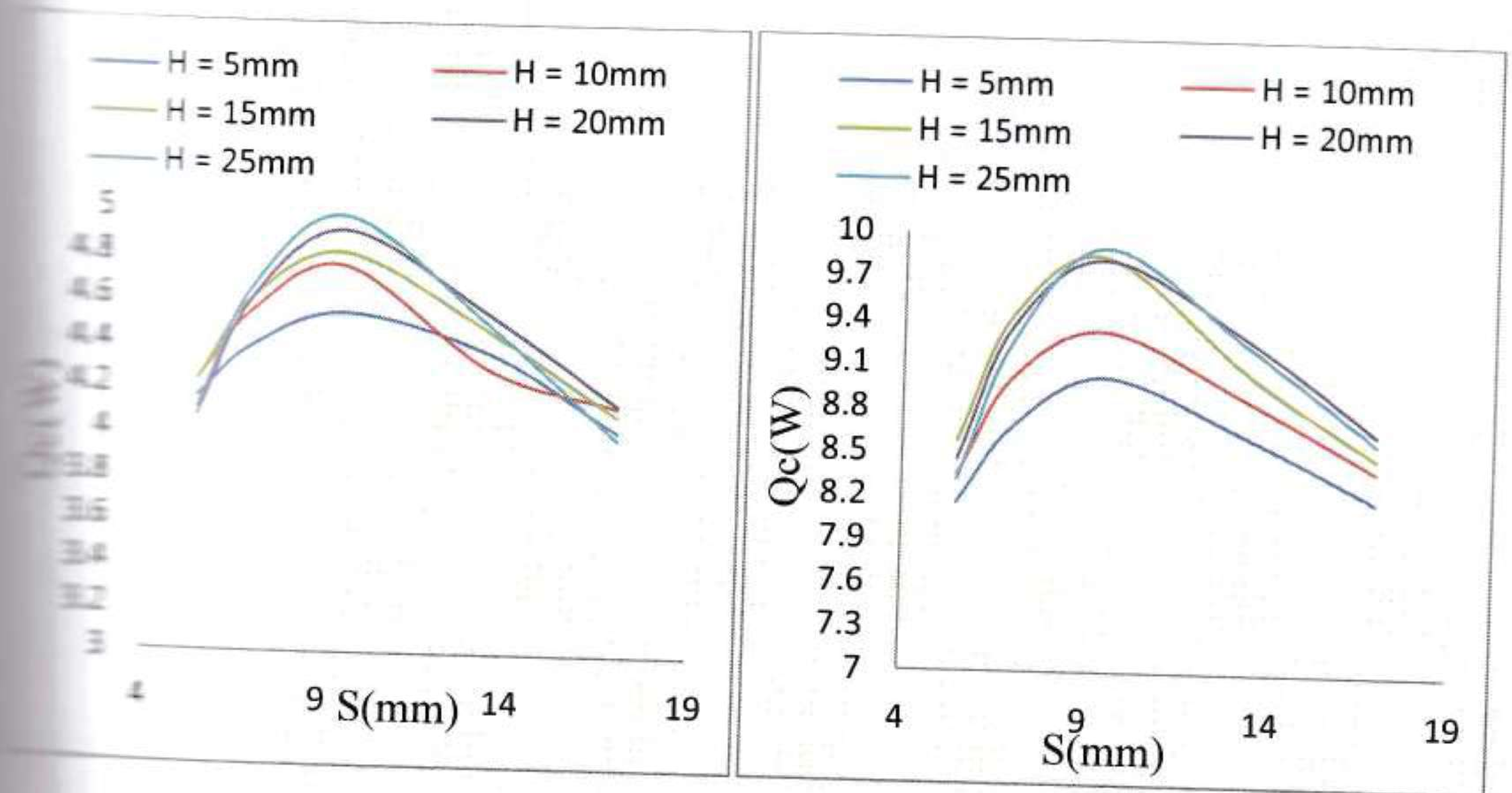


Figure 5.2 Variation of Convection Heat Transfer Rate with Fin Spacing for Different Height at a) 10W and b) 20W

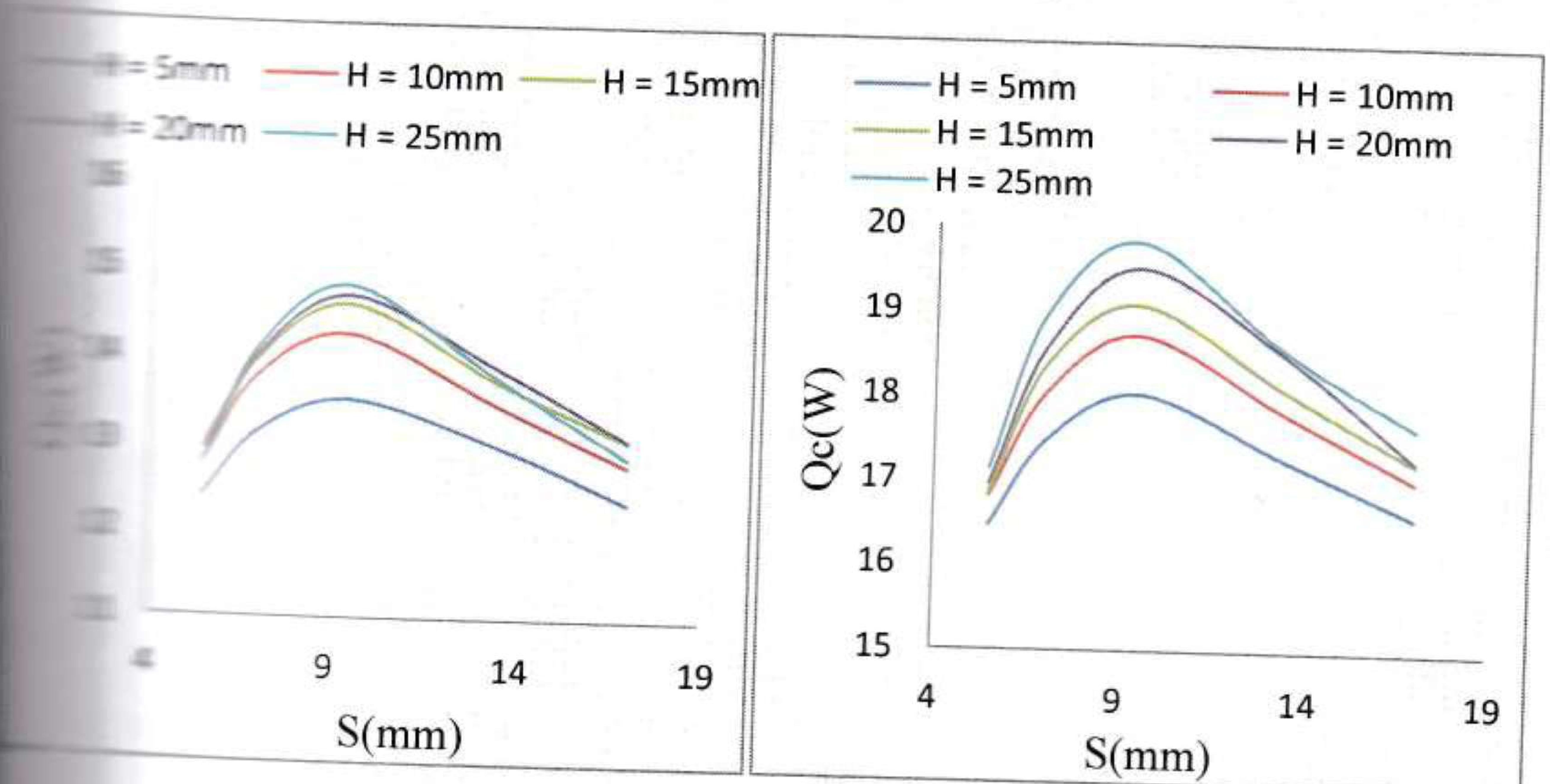
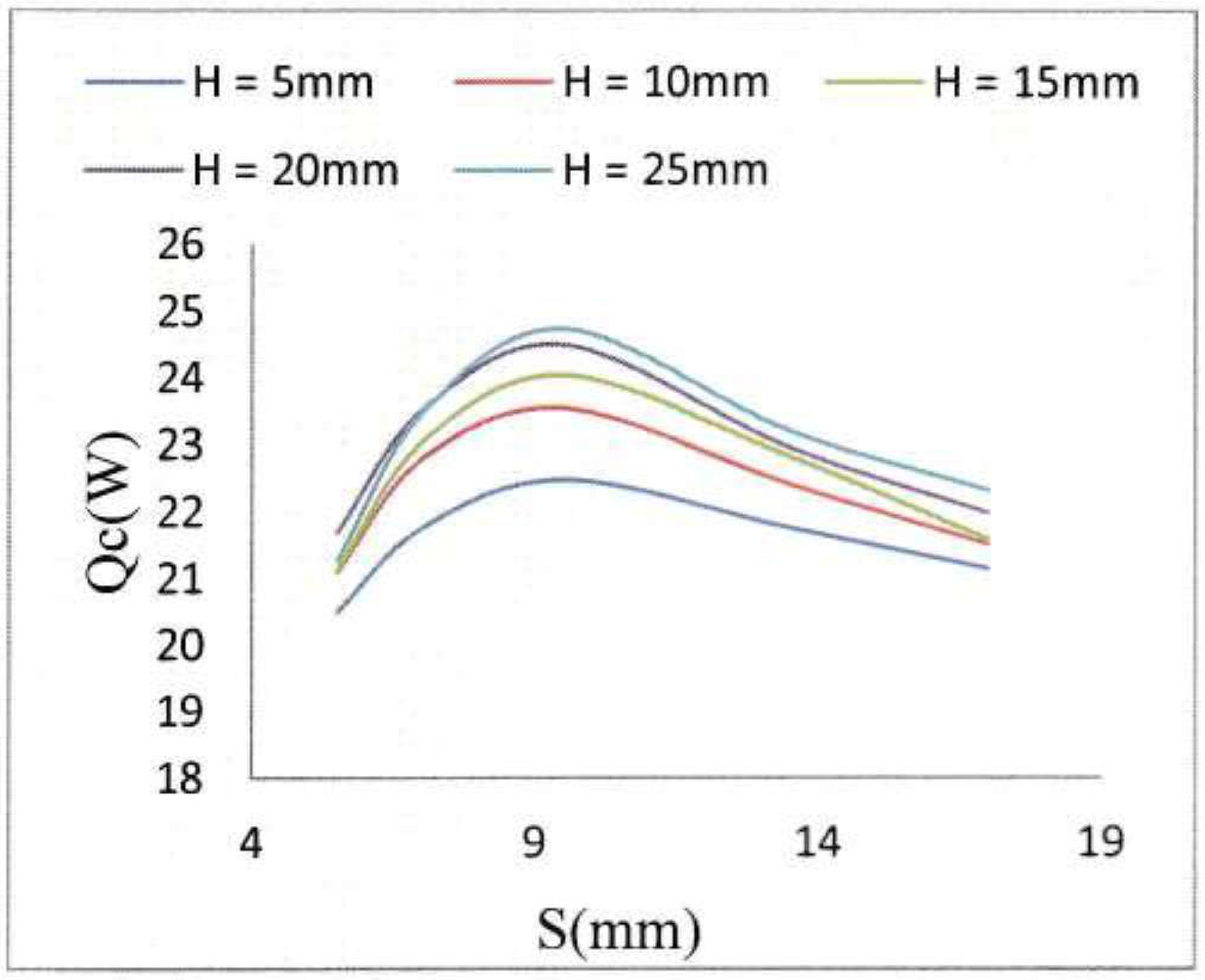


Figure 5.2 Variation of Convection Heat Transfer Rate with Fin Spacing for Different Height at a) 30W and b) 40W



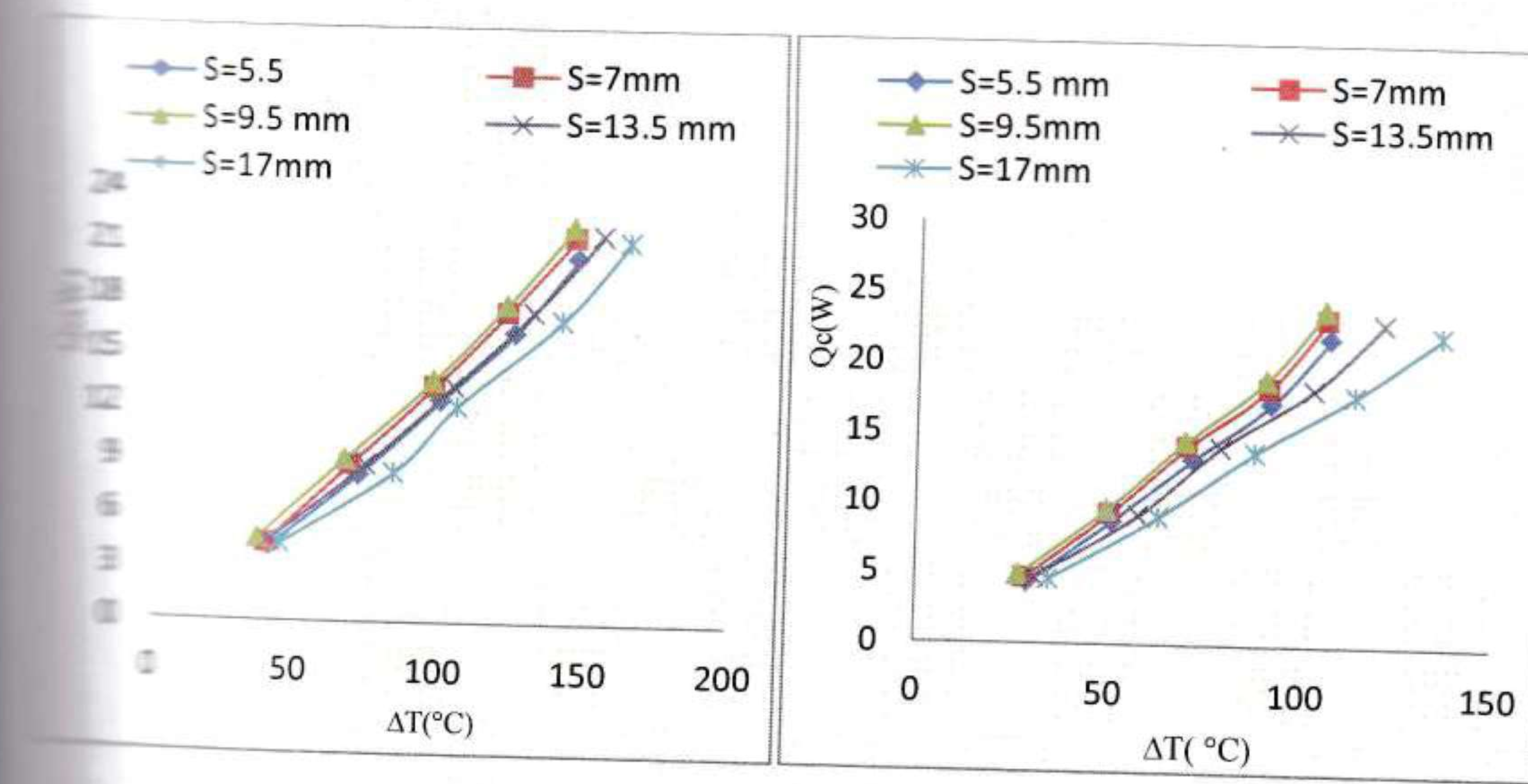
(e)

Figure 5.2 Variation of Convection Heat Transfer Rate with Fin Spacing for Different Height at 50W

...erved that the convection heat transfer rate is maximum in between the fin ... 7 mm to 9.5mm.So it is optimum fin spacing. Figure 5.2(a) reveals that when ... spacing is increased from optimum value, the convective heat transfer rate ... Moreover if the fin spacing decreases from optimum value, the convective ...fer rate also decreases as shown in figure 5.2 (b). Figure 5.2 (c) reveals that ... of fin height viz. H=5mm to H=25mm, the nature of these plots is almost ... those in figure 5.2 (a).A heat sink with closely packed fins will have greater ... area for heat transfer but a smaller heat transfer coefficient because of the ...ance of the additional fins introduce to fluid flow through the inter fin ... A heat sink with closely packed fins will have grater surface area fro heat ... a smaller heat transfer coefficient because of the extra resistance ... fin introduced to fluid flow through interfin passage. A heat sink with ... fins on the other hand, will have a higher heat transfer coefficient but a ... area. Therefore, there is need to find an optimum spacing that ... the natural convection heat transfer from the heat sink for a given base ... shown in figure 5.2 (d) and figure 5.2(e). It would be appropriate to ... the heat sink with aforementioned fin height and spacing.

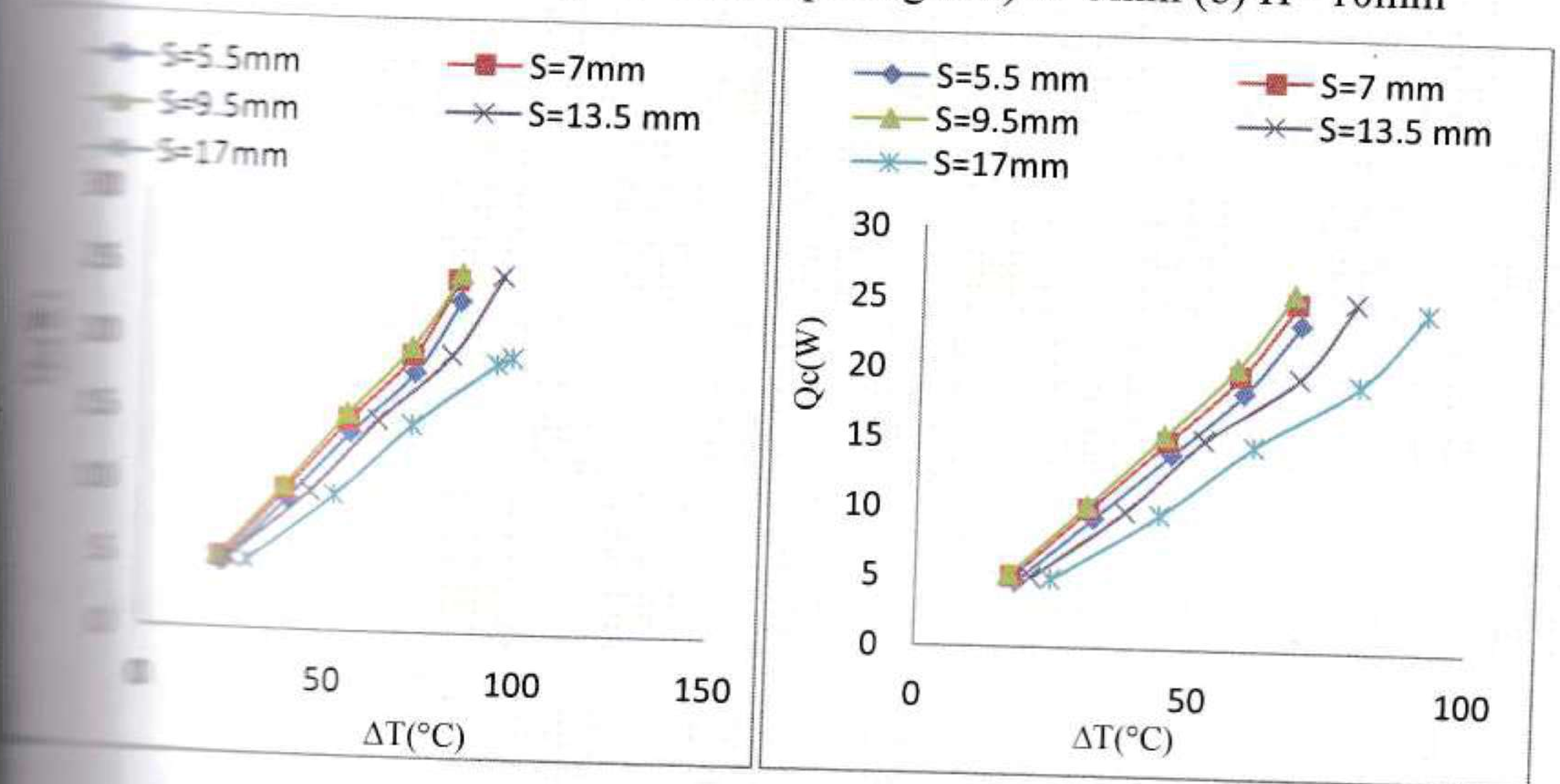
5.2.3 Effect of Temperature Difference on Convective Heat Transfer Rate

It is important to know the effect of temperature difference on convective heat transfer rate, because these effect are prevalent on the surface of fins. The study of temperature difference will helpful to know the flow separation phenomenon, hence at different fin spacing the convective heat transfer rate against temperature difference are plotted in figure 5.3 (a, b, c ,d and e).



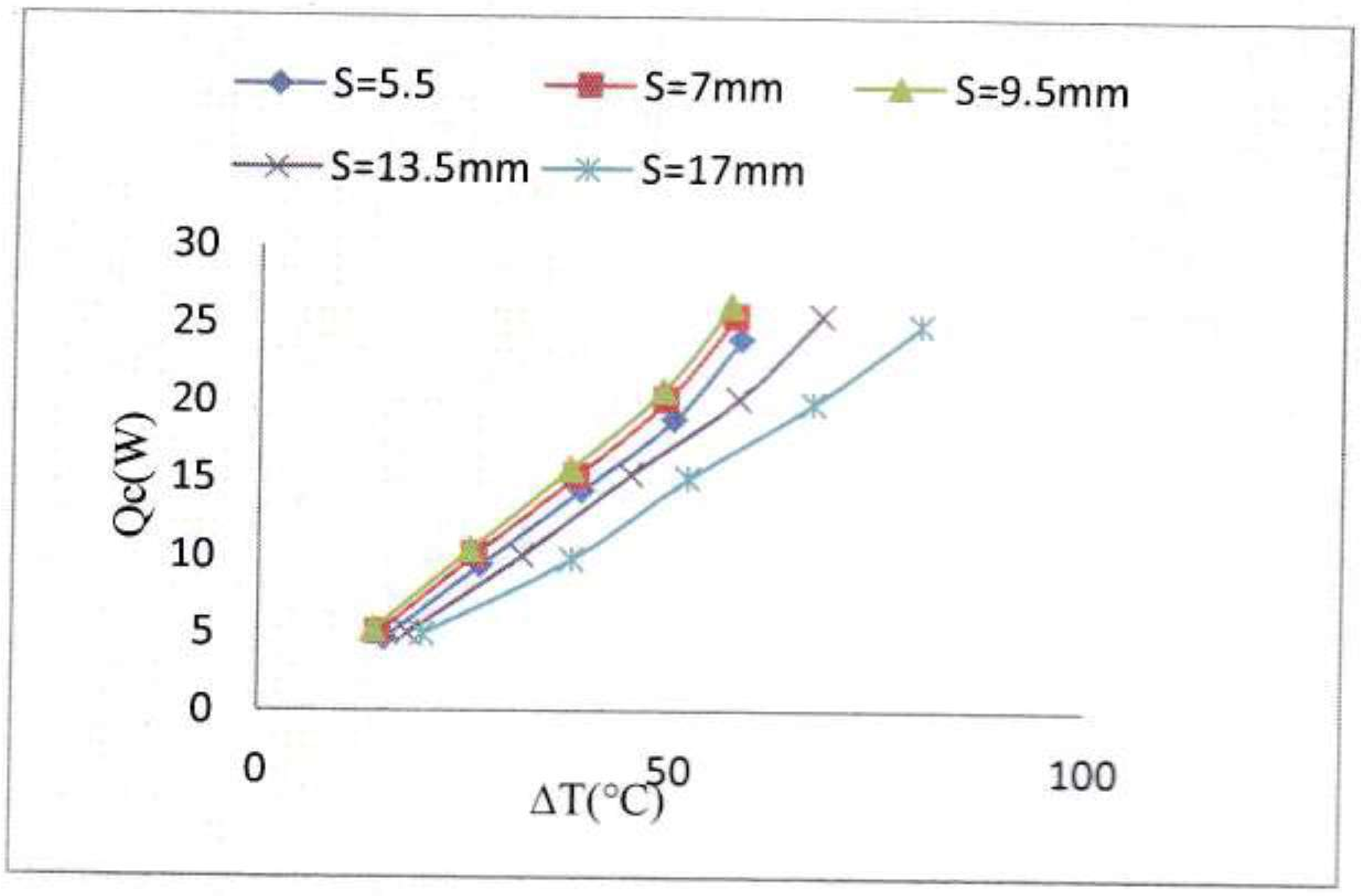
(a) (b)

Figure 5.3 Variation of Qc with Fin Spacing at a) H=5mm (b) H= 10mm



(c) (d)

Figure 5.3 Variation of Qc with Fin Spacing at a) H=15mm (b) H= 20mm



(e)

Figure 5.3 Variation of Qc with Fin Spacing at H=25mm

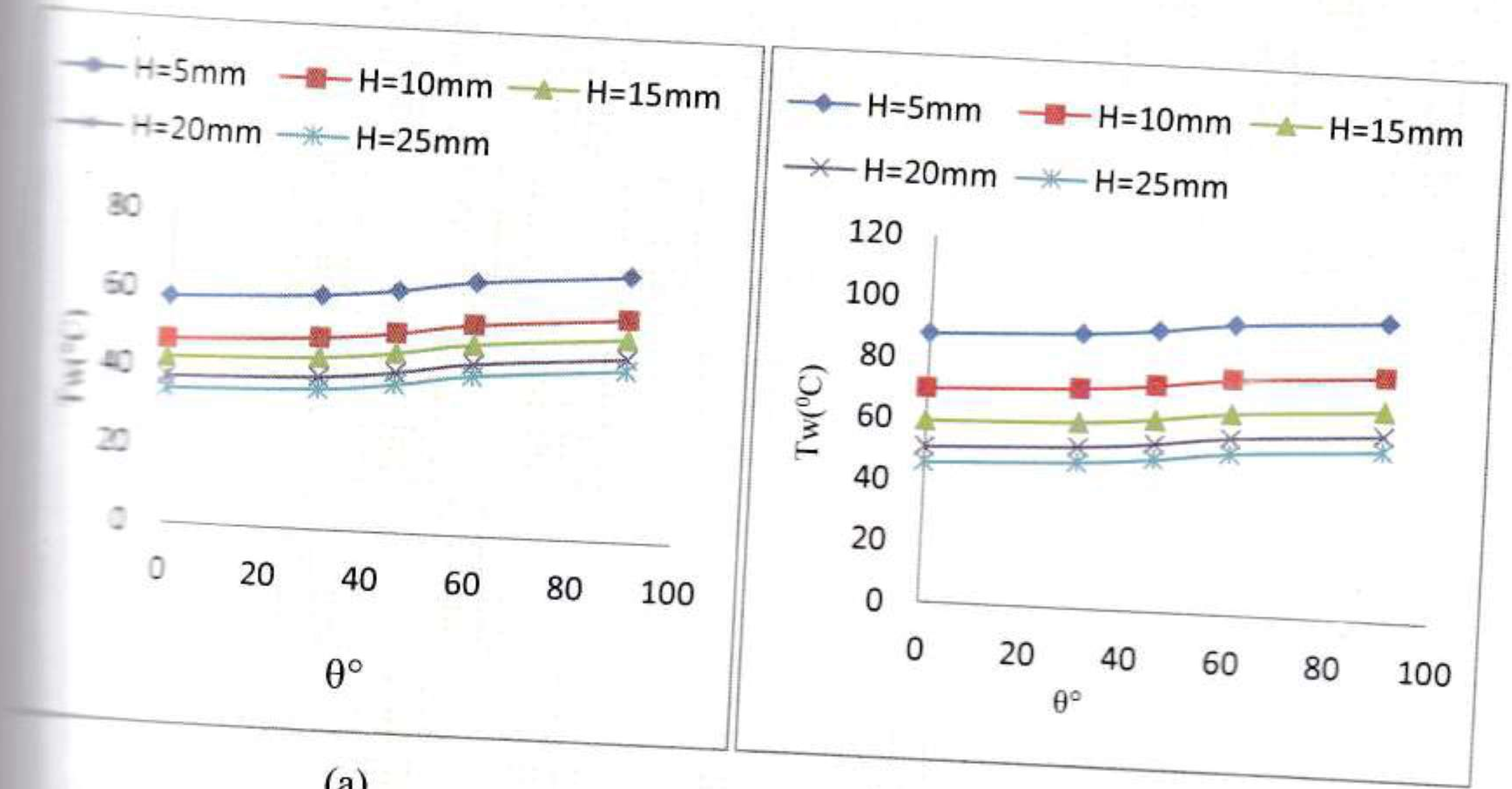
It is observed that at low heat inputs, the convection heat transfer rate of heat sink are closer than those at high value of heat inputs, regardless of variation in fin spacing and fin height. It is interesting to note that the convective heat transfer rate for heat sink at fin spacing, S = 9.5 mm are greater than those of remaining fin spacings. For a given temperature difference and fin height similar type of behavior is observed by earlier researchers also.

5.3 Inclined Plate Heat Sink

To carry out the experiments on vertical plate heat sink, for base to ambient temperature difference on various fin heights and at different fin spacing. Optimum range of fin spacing are identified in between 7mm to 9.5mm.It was decided to study the only fifteen heat sink samples i.e. fin spacing within 7mm to 9.5mm.Out of twenty three heat sink samples for inclined orientation experimentation. The results obtained from inclined plate heat sink performance are mentioned below.

5.3.1 Effect of Angle of Inclination on Average Base Temperature

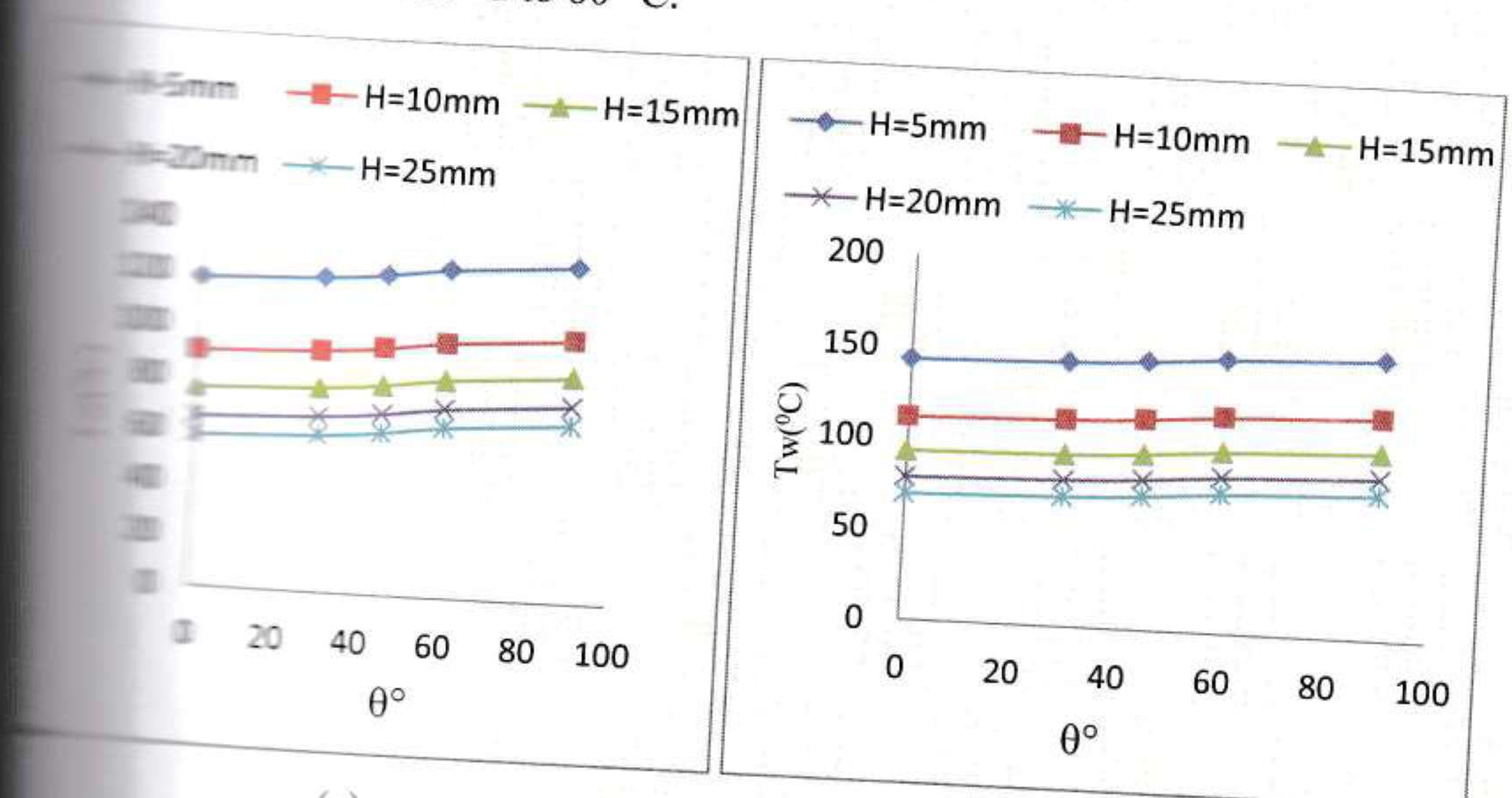
Effect of angle of inclination for different fin height on the average base temperature and fin spacing S=9.5mm is shown in figure 5.4 (a, b, c, d and e).



(a) (b)

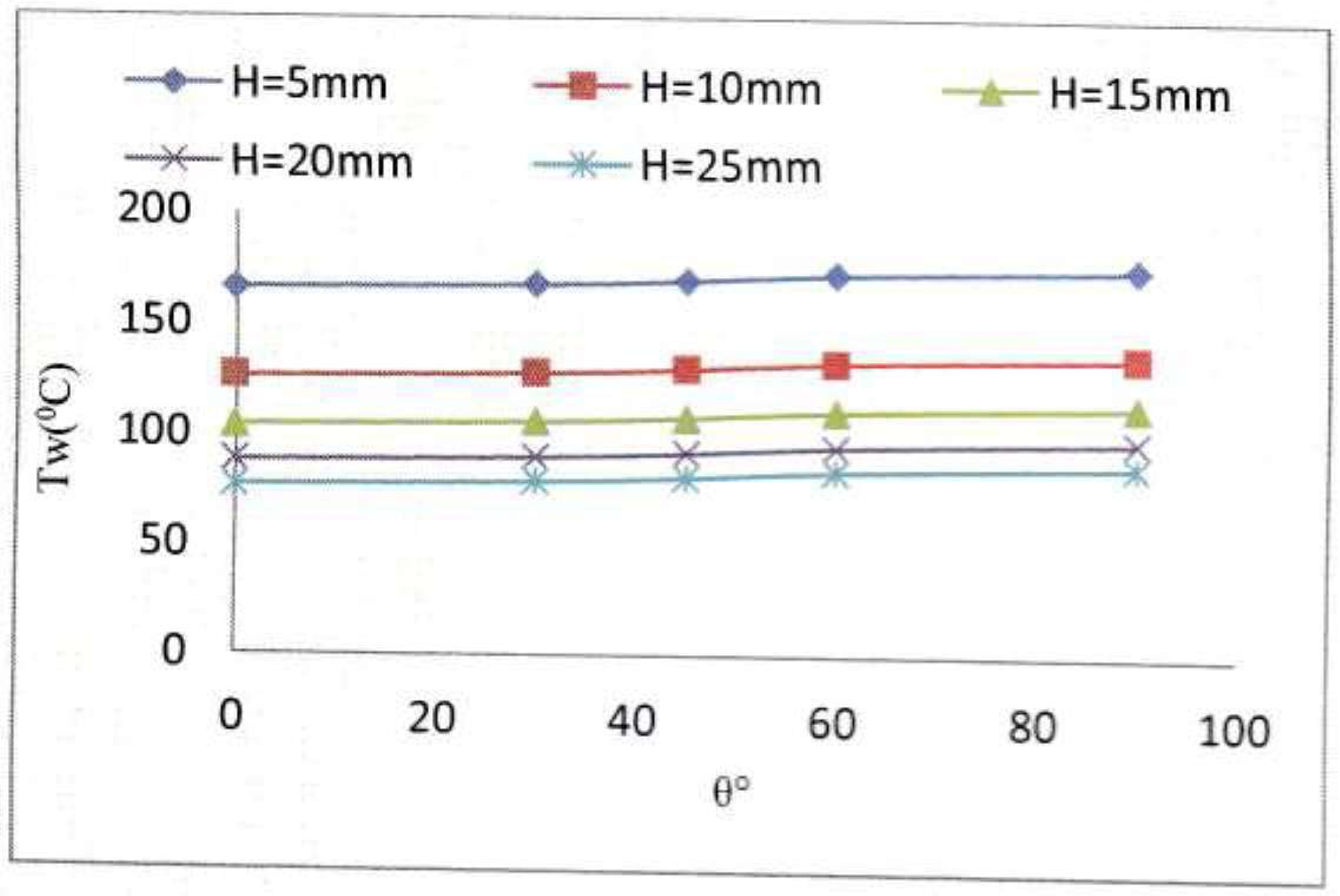
Figure 5.4 Variation of Average Base Temperature with Angle of Inclination at a) 10W at b) 20W

When average base temperature was plotted as a function of angle of inclination, then it is observed that at each heat input, value of average base temperature increases as angle of inclination increases as shown in figure 5.4(a,b,c,d). Figure 5.4 (a) and (b) indicates that the temperature difference increases with increase in heat input. At 20 W heat input the temperature difference was approximately 50°C to 90 °C while for 10 W, it is in between 35°C to 60 °C.



(c) (d)

Figure 5.4 Variation of Average Base Temperature with Angle of Inclination at a) 30W at b) 40W



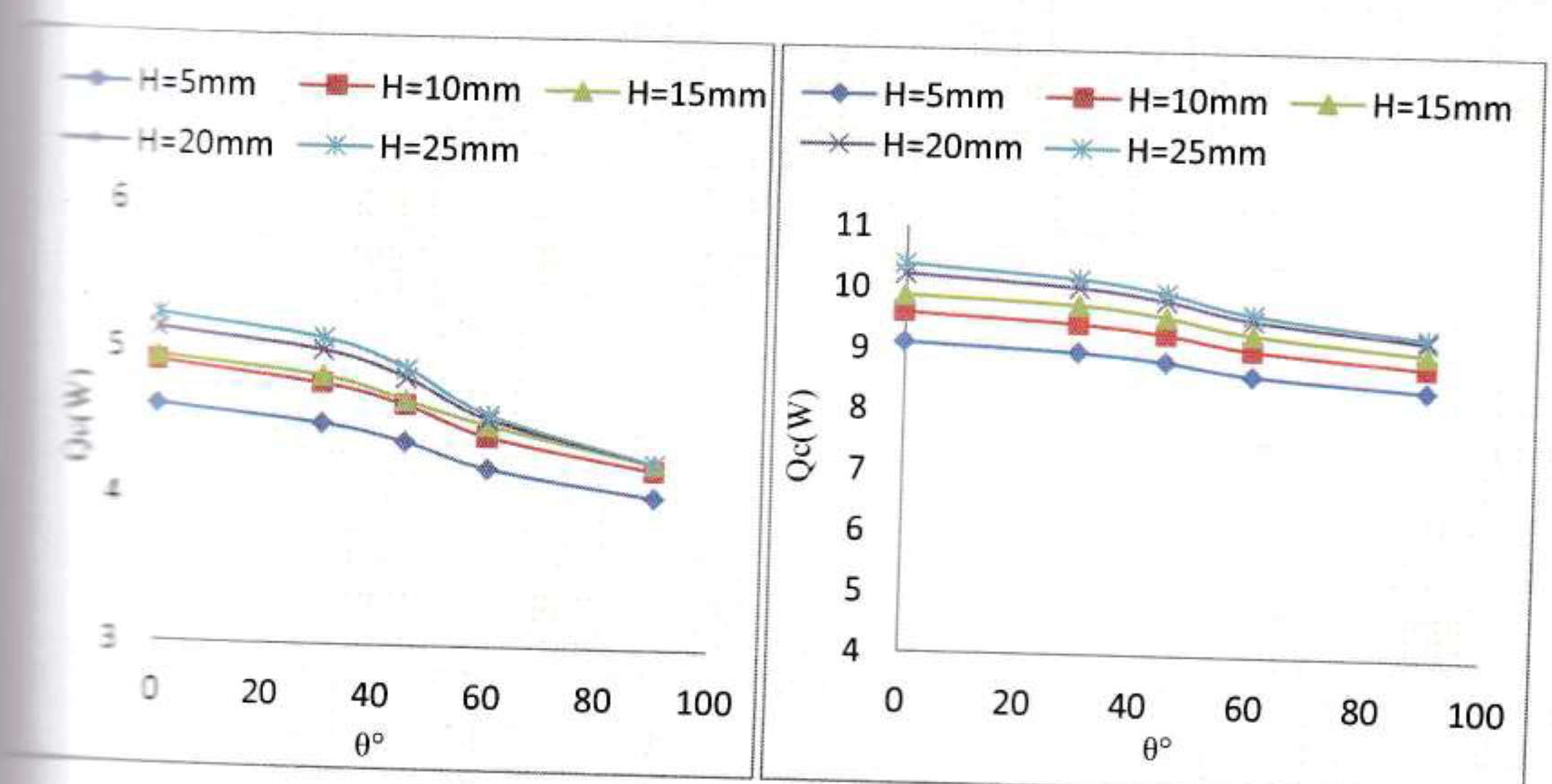
(e)

Figure 5.4 Variation of Average Base Temperature with Angle of Inclination at e) 50W

From figure 5.4 (a, b, c d and e), it is observed that heat transfer rate is almost same for 0° to 30° and for 60° to 90°.but it can be seen that there is trend of increase in temperature for an angle of 30° to 60°.This is due to diversion of flow of air from the base of the heat sink. It was found that for a constant fin height and angle of inclination Average Base Temperature increases when heat input was increased.

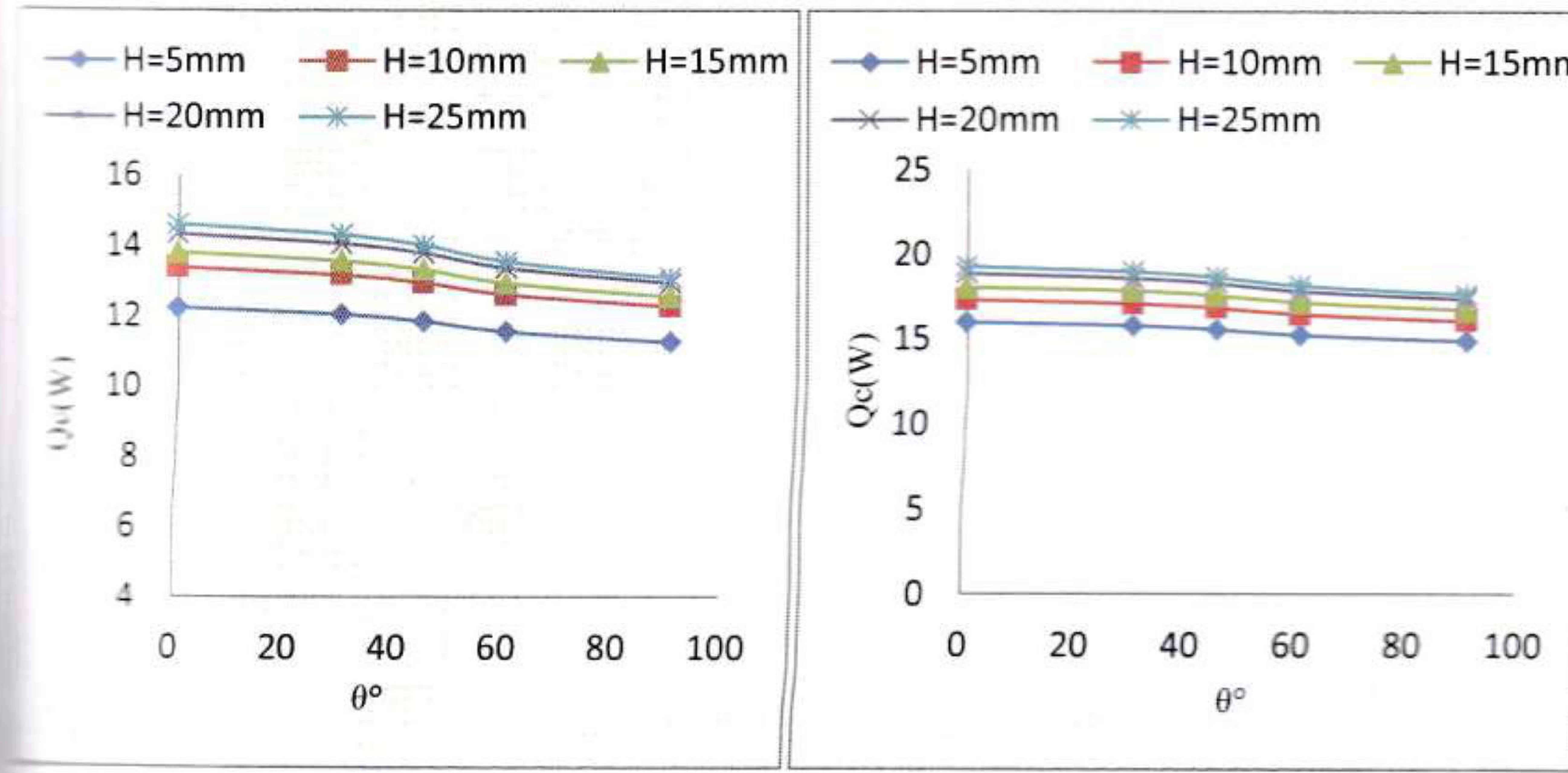
2 Effect of Angle of Inclination on Convective Heat Transfer Rate

Variation of heat transfer rate with respect to angle of inclination for vertical heat sink at various heights shown in figure 5.5(a,b,c,d,e)



(a) (b)

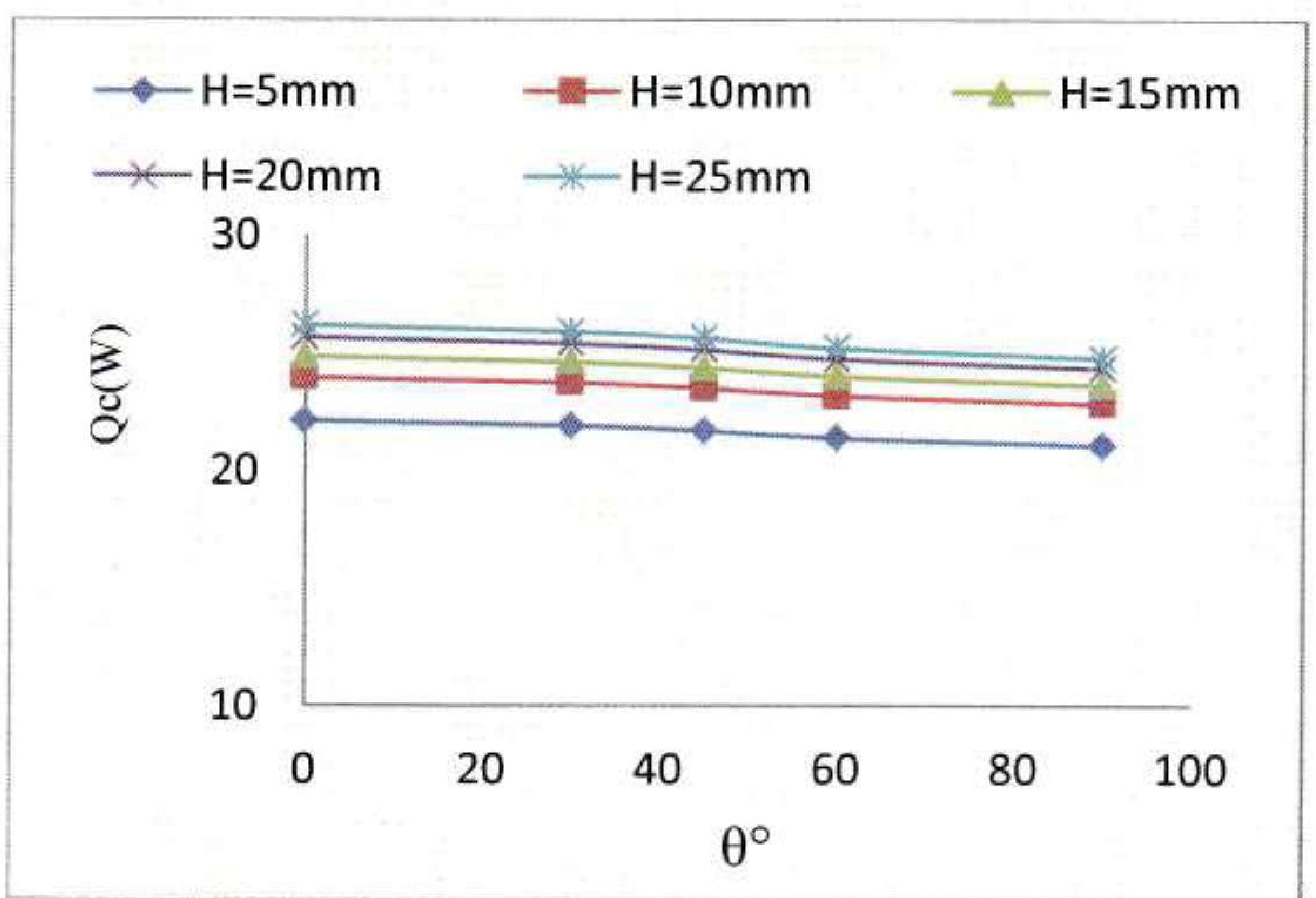
Figure 5.5 Variations of Qc with Respect to Angle of Inclination at a) 10W at b) 20W



(c) (d)

Figure 5.5 Variations of Qc with Respect to Angle of Inclination at a) 30W at b) 40W

All three plots show the similar trends of gradual increase in inclination. However in figure 5.5 (a) at 5 mm fin height, there is drop in convective heat transfer rate drastically. Convective heat transfer rate decreases as angle of inclination increases for a constant fin height which is shown in first three plots viz. figure 5.5(a, b, c).



(e)

Figure 5.5 Variations of Qc with Respect to Angle of Inclination at e) 50W

It can be seen from figure 5.5(d,e),both as inclination increases convective heat transfer rate decreases very little (as a matter of fact almost remain straight) for all fin heights. This is because of slight change is observed from, vertical position to 30° and to 90° horizontal position. The reason behind is an air flow characteristic seems quiet identical for slightly inclined fin base from either vertical or horizontal position.

5.4 Mixed Convection

The results were discussed for vertical and inclined plate heat sinks. On optimum fin spacings in between 7 mm to 9.5mm at fin height H=25mm and heat input Q=50W gives best results on convective heat transfer rate and overall performance of heat sinks. This is much desirable. The future observations under mixed convection concept are recorded only for selected five heat sink, which is at optimum fin spacing mentioned. The experiments were performed at different velocities from 0.8 to 1.2 m/s under assisting mode of mixed convection. This selection of range of velocity was done for the fact that the application of such a fins in electronic circuits, where the velocities normally do not exceed 4m/s.

5.4.1 Effect of Fin Spacing on Convective Heat Transfer Rate

The figure 5.6 shows the convective heat transfer rate Vs. fin spacing for the maximum heat input i.e.50W at air velocity 0.8 to 1.2 m/s.

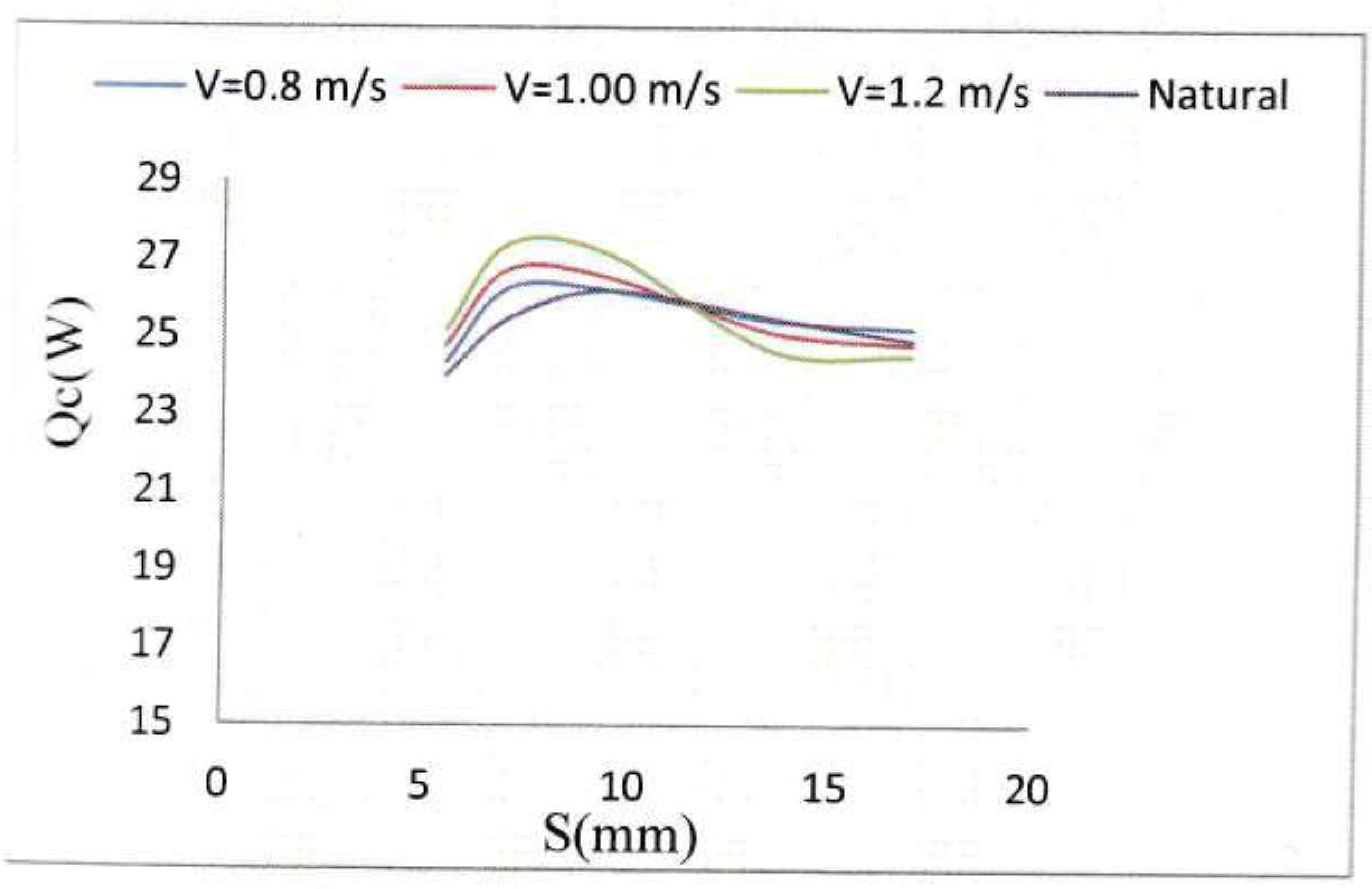


Figure 5.6 Variation of Convection Heat Transfer Rate with Fin Spacing

It is seen that convective heat transfer rate is normal in case of natural convection phenomenon. As velocity of air increases the convective heat transfer rate also increases it is obvious. It is also observed that as spacing of heat sink beyond optimum value i.e. more than 9.5mm, the convective heat transfer rate decreases. The optimum samples of heat sink are desirable and indicate that only this type of sample is used to dissipate heat to which it is exposed.

5.4.2 Effect of Fin Spacing on Convective Heat Transfer Coefficient

Figure 5.7 shows convective heat transfer coefficient with different fin spacing. It is observed that at given flow rate the convective heat transfer coefficient increases first at optimum fin spacing level value and then decrease drastically. This is because of at smaller fin spacing boundary layers starts to develop at lower ends of opposing surfaces and eventually merge at the midplane, if plates are vertical and sufficiently long. The results obtained from the present experiments and the revelations are considerably in agreement with the findings of other researchers reported in literature.

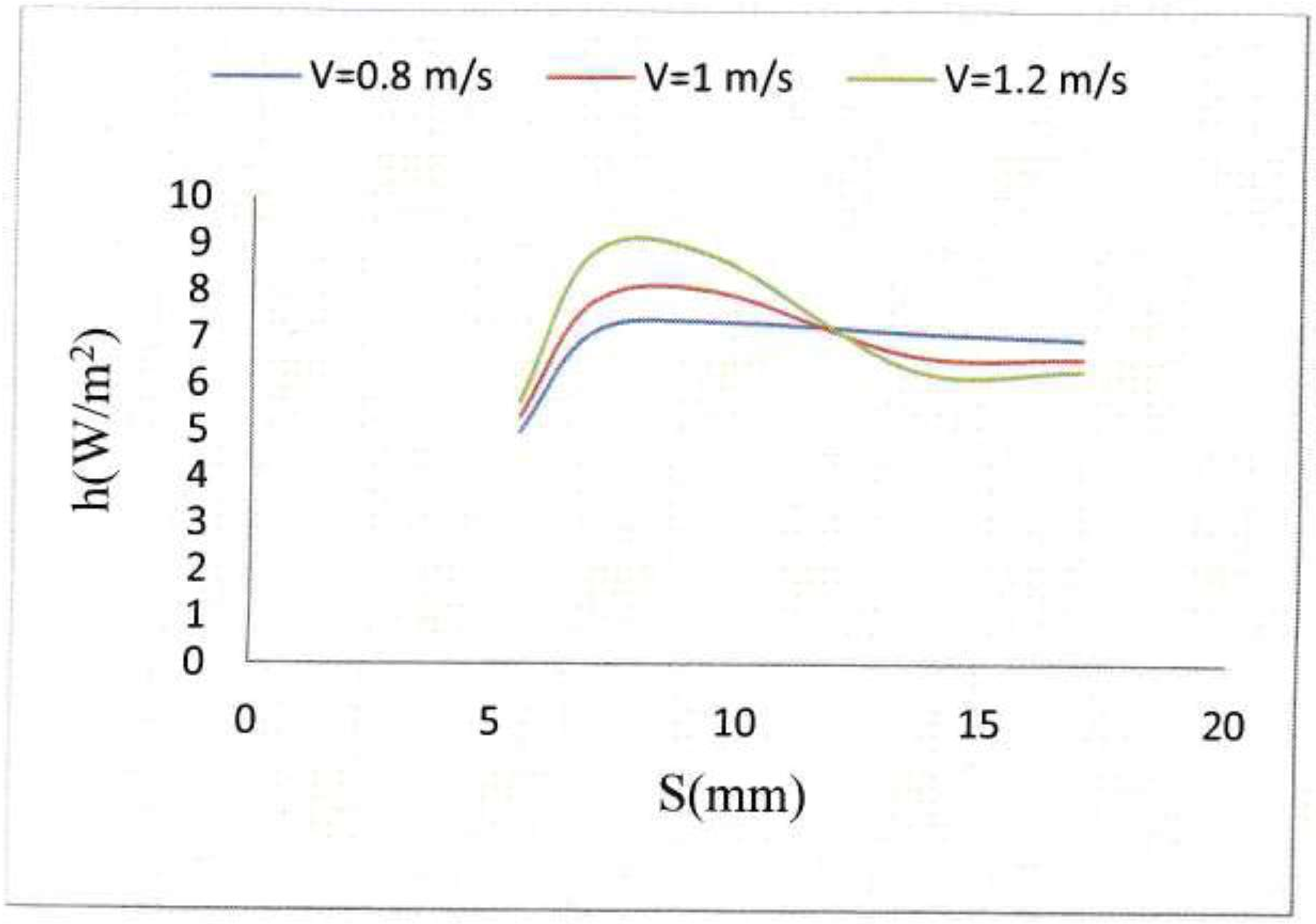


Figure 5.7 Variation of Convection Heat Transfer Coefficient with Fin Spacing

5.4.3 Variation of Average base Temperature with Fin Spacing

The average temperatures of plate heat sink are plotted against fin spacing as shown in Figure 5.8. It is observed that when the fin spacing is increased the average temperatures of the heat sink increase rapidly. Moreover if the fin spacing is increased from the optimum value, average temperatures of the fin arrays again increased.

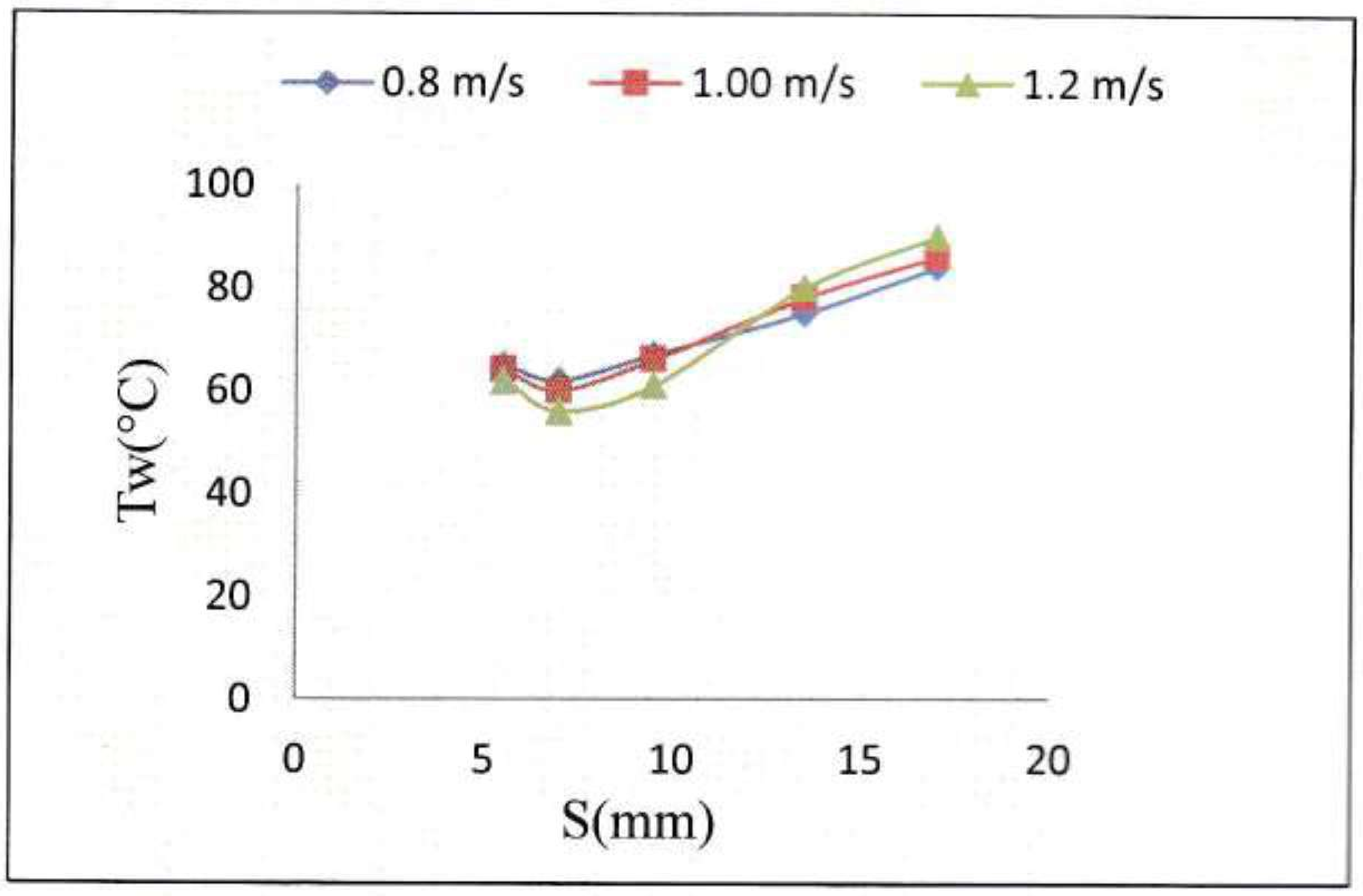


Figure 5.8 Variation of Average Base Temperature with Fin Spacing

It is observed that average temperature is maintained at optimum fin spacings in between 7mm to 9.5mm.

Computational Fluid Dynamics (CFD)

Introduction

It seems from previous research work, CFD is better for air-flow visualization. One of the most useful advantages of CFD is its ability to visualize the flow easily. In this section, temperature distribution along the fin length is studied. The temperature values at a particular node can be easily obtained in this diagram, and also study velocity profile diagram, for examining the nature of flow.

Heat Sink Model

A simplified model is created to simulate the experimental study .The model consists of concrete block, a base plate for heat generation and heat sink configuration. In the model 200×120×50mm concrete block is used as insulator on which heat sink model is mounted.

Analysis Report

Discretization is essential step in CFD analysis.Discretization is carried out by meshing. Different types of grids like structured and unstructured grids are used for meshing. Finite volume approach is more feasible for heat transfer and fluid flow analysis. The domain is kept smaller to decrease the mesh size and computational time. Numbers of optimized element are 277324 which will give significant results. Mesh structure are as shown in figure 5.9.

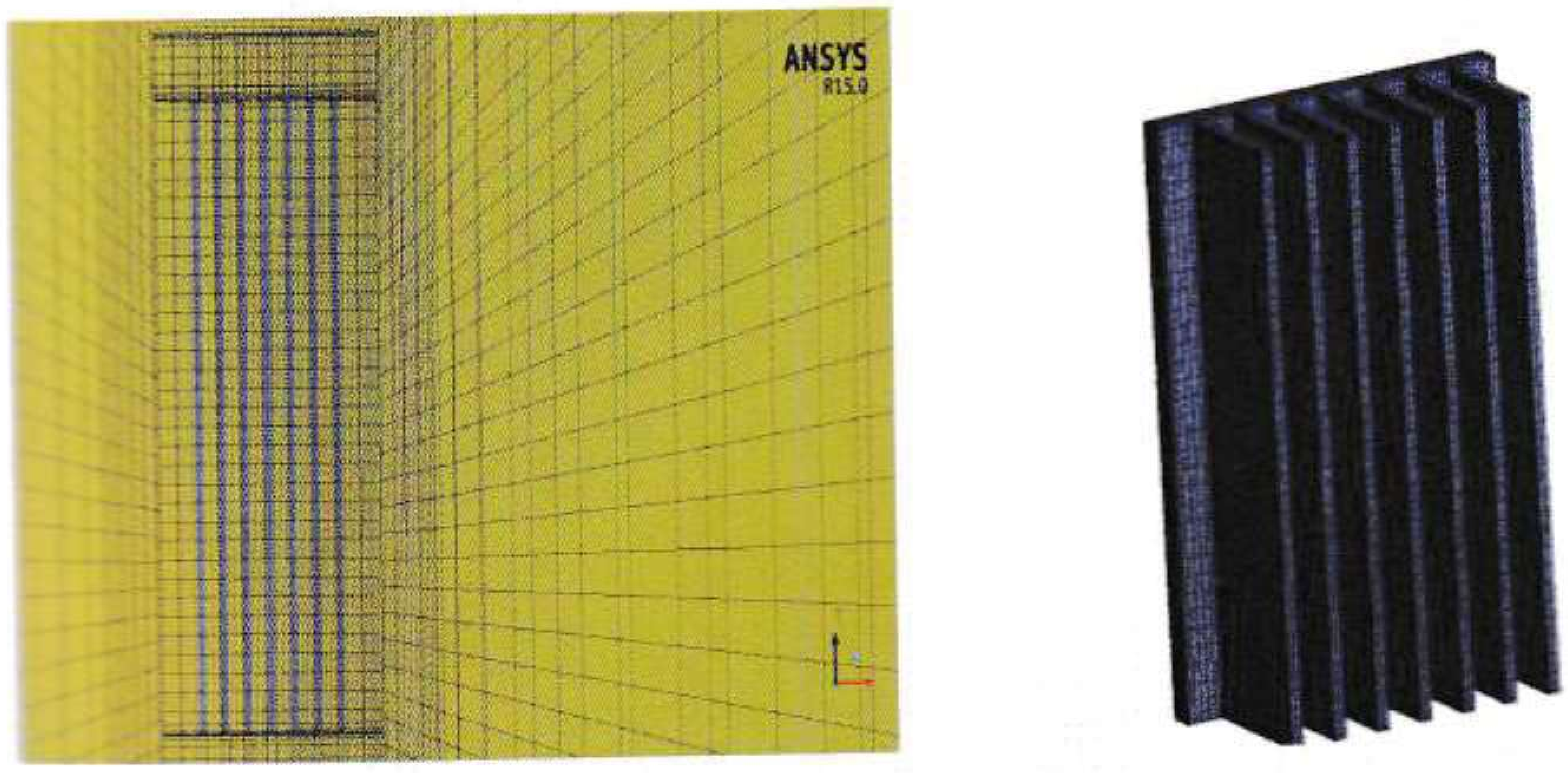
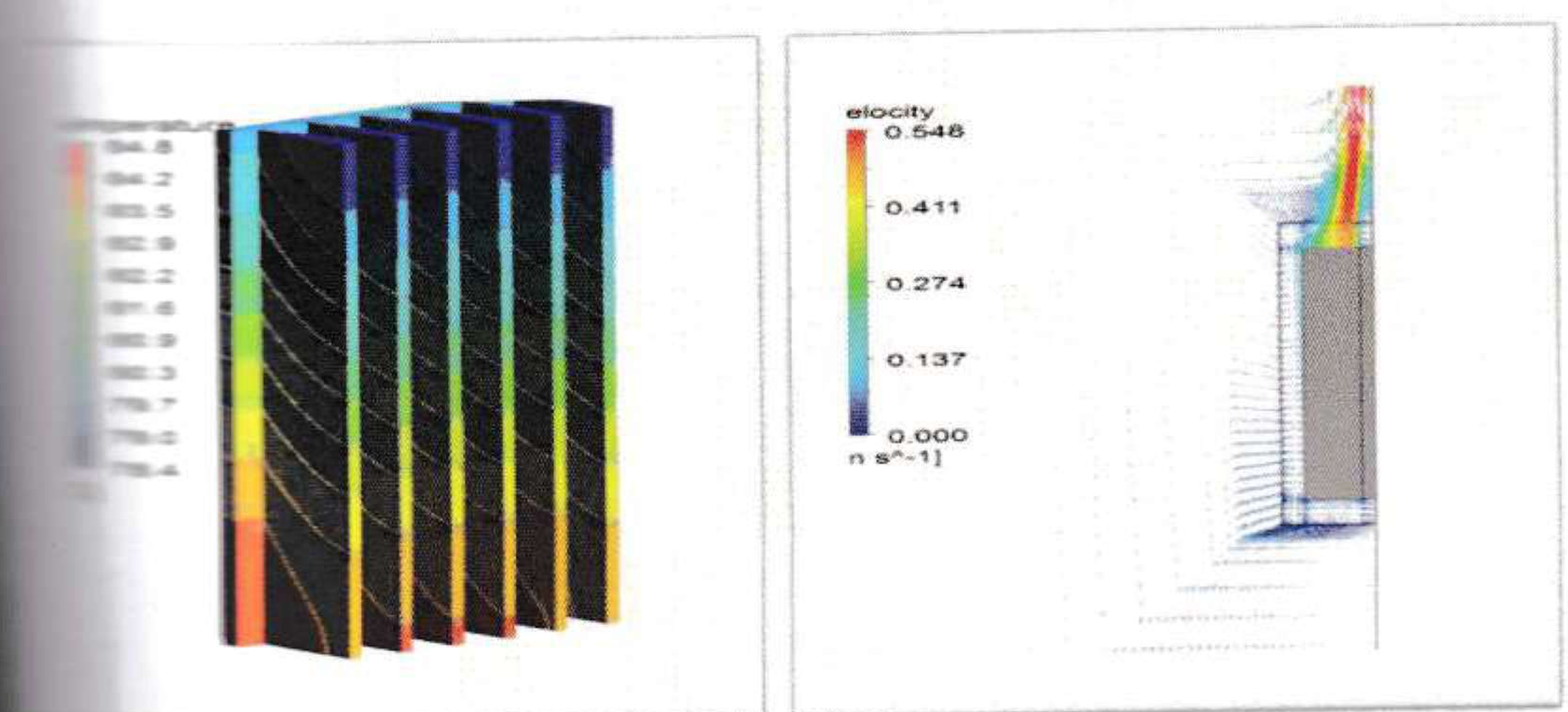


Figure 5.9 Meshing Representation of Heat Sink

5.3.1 Temperature and Velocity Distribution for Vertical Heat Sink

Figures 5.18(a) shows temperature distribution. The heated base images which has red colour shows the highest temperature. Away from the base the colour becomes yellow first and then blue which shows reduction in temperature. The difference in flow structure affects the convective heat transfer rate.



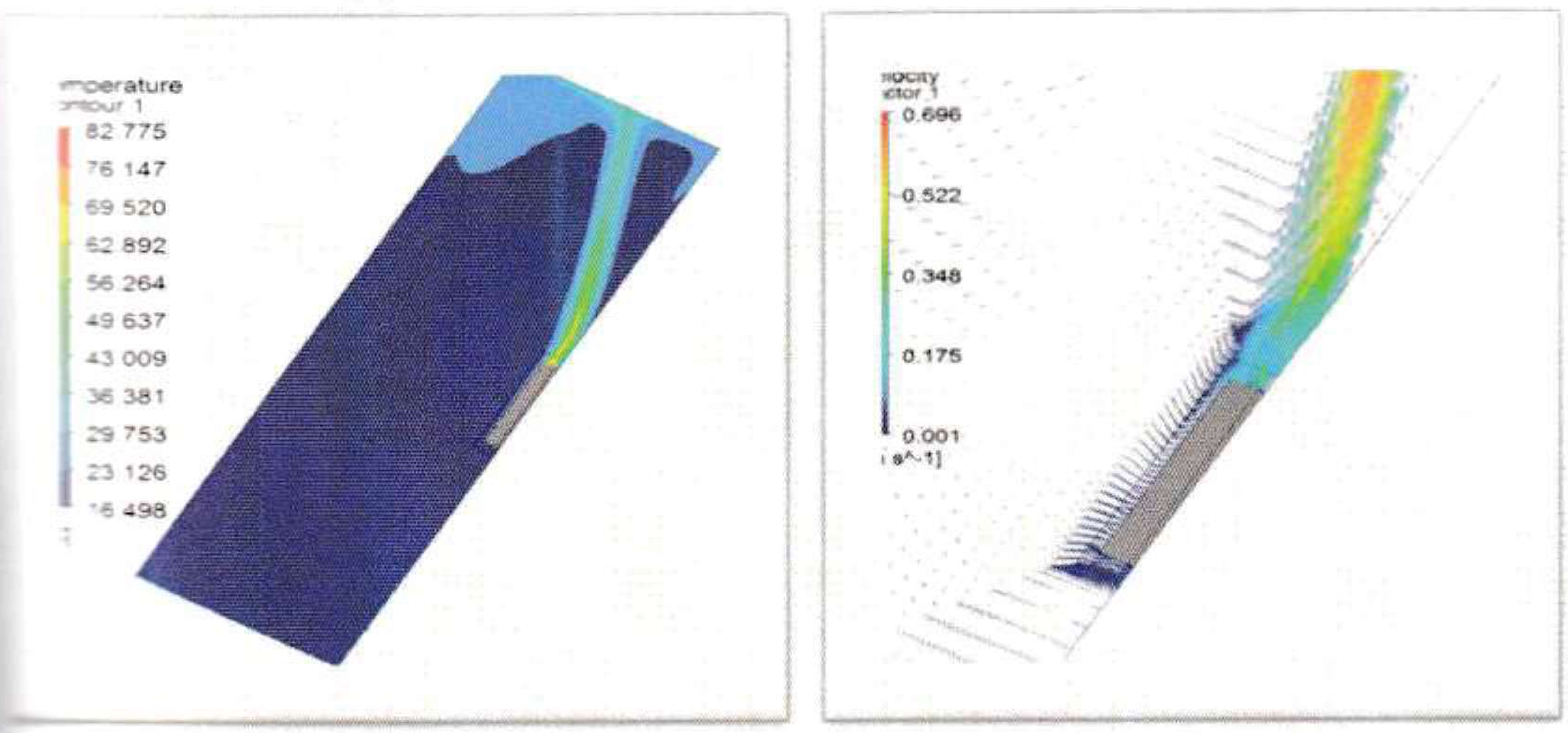
(a) (b)

Figure 5.10 Temperature and Velocity Images for Vertical Plate Heat Sink

Figure 5.10 (b) shows the velocity distribution. It is observed that more air enters from the open side of the heat sink throughout its length. The increase in velocity from bottom to the top side of heat sink is due to density difference. Red colour shows the maximum velocity while blue colour shows minimum velocity.

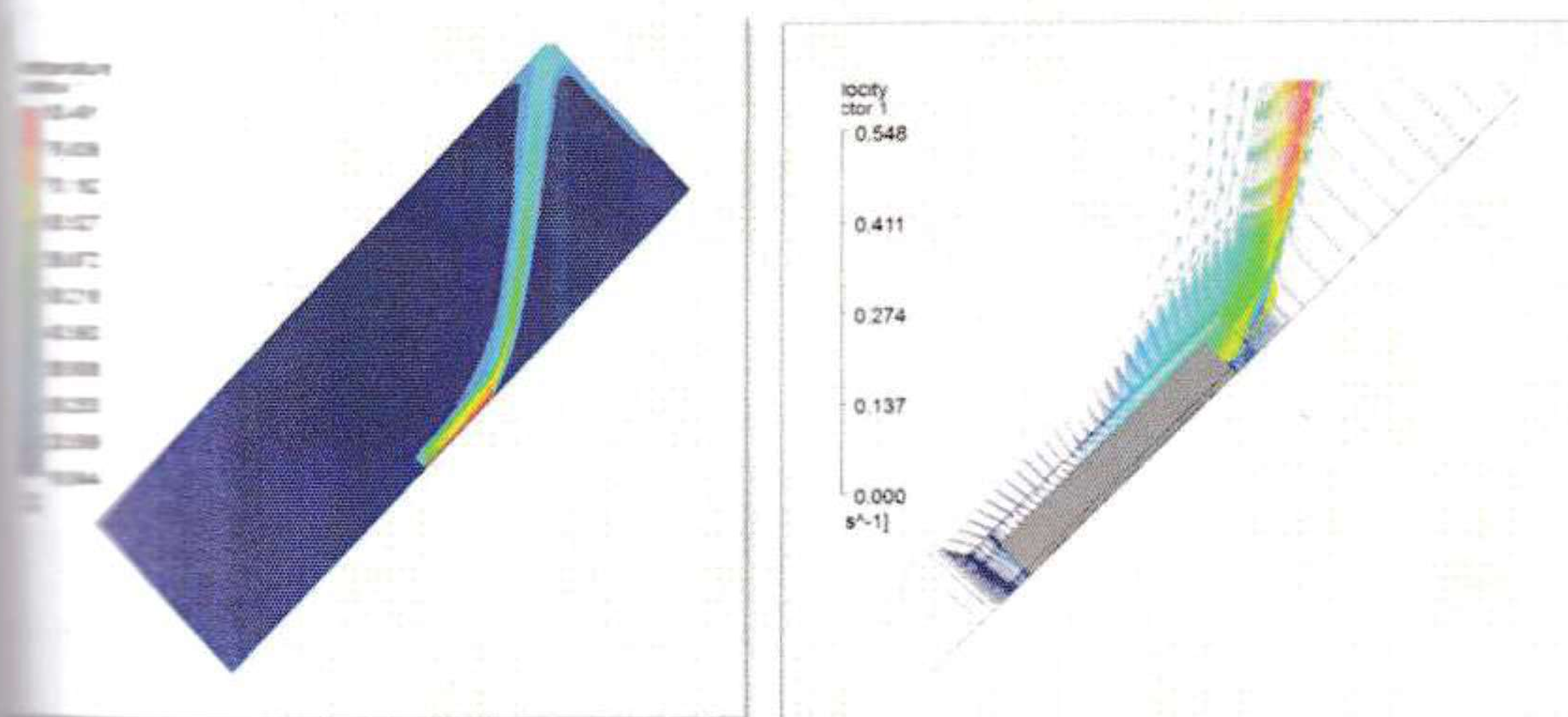
5.5.3.2 Temperature and Velocity Distribution for Inclined Heat Sink

The temperature and velocity images for inclined heat sink at an inclination of 30^0,45^0,60^0 and 90^0as shown in figure 5.11 (a, b, c, d, e, f, g and h).When a heat sink is inclined from the vertical upward orientation as the average base temperature is higher than ambient air temperature, cold air entering from the bottom side or top side close to horizontal of the heat sink. A plume of air rises from the heat sink at a location that depends on the inclination. The heat sink base is visible (red in color) due to its higher temperature. When the figures a, b, c, d, e, f, g and h are compared, it is observed that as average base temperature increases with increasing angle of inclination, indicating lower heat transfer rates at higher inclination.



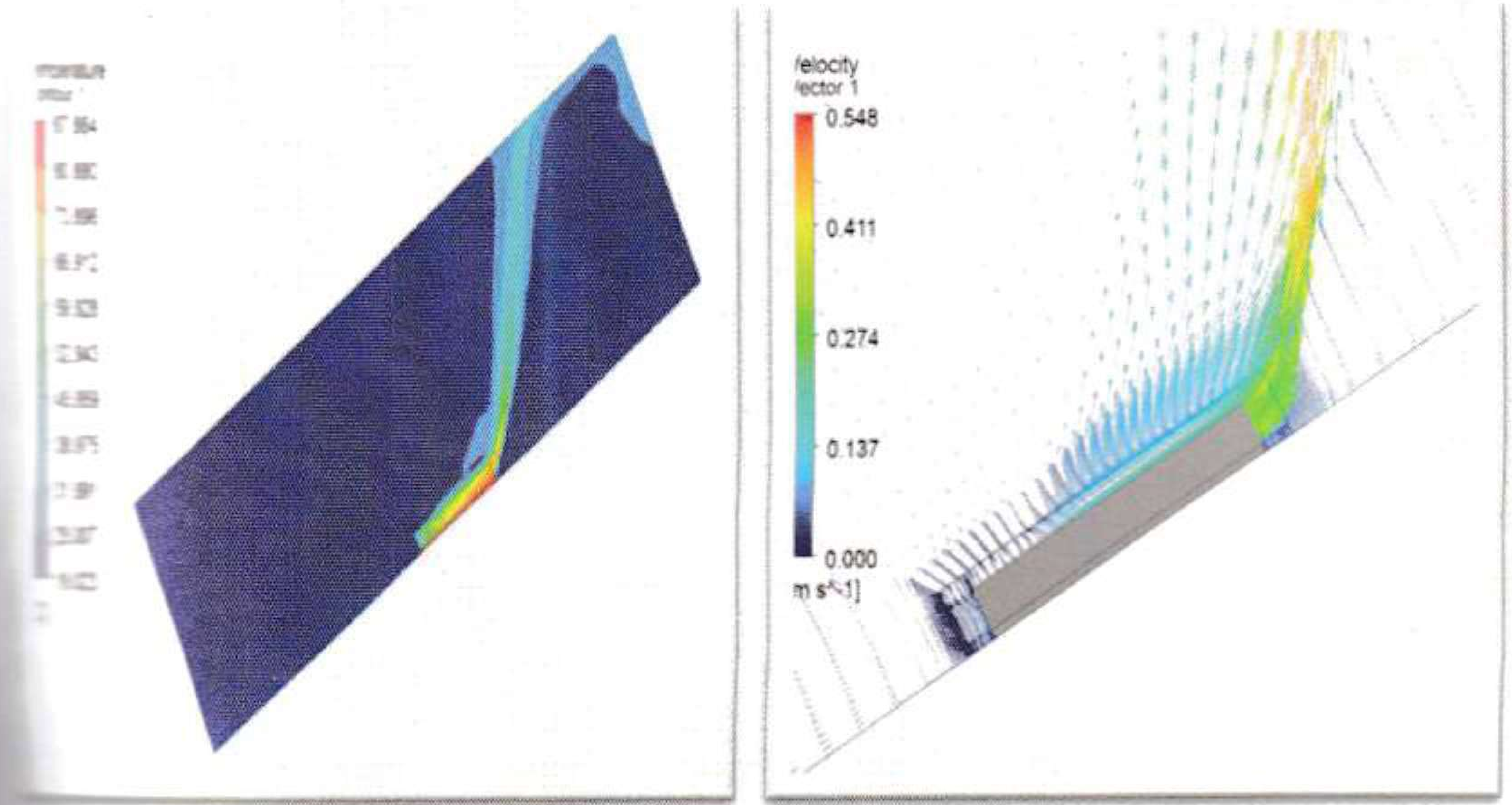
(a) (b)

Figure 5.11 Temperature and Velocity Images for 30° inclination



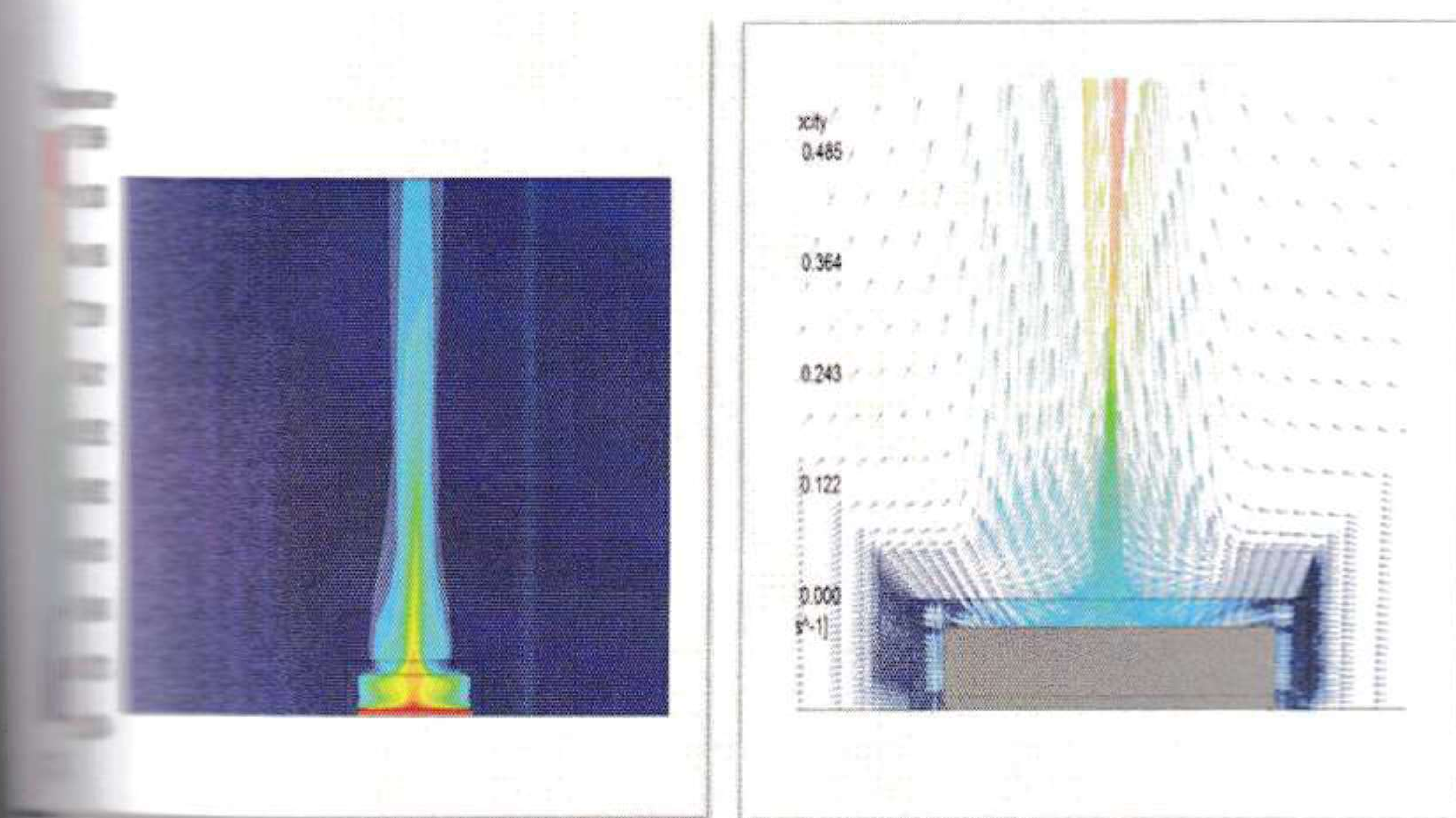
(c) (d)

Figure 5.11 Temperature and Velocity Images for 45° Inclination



(e) (f)

Figure 5.11 Temperature and Velocity Images for 60° Inclination



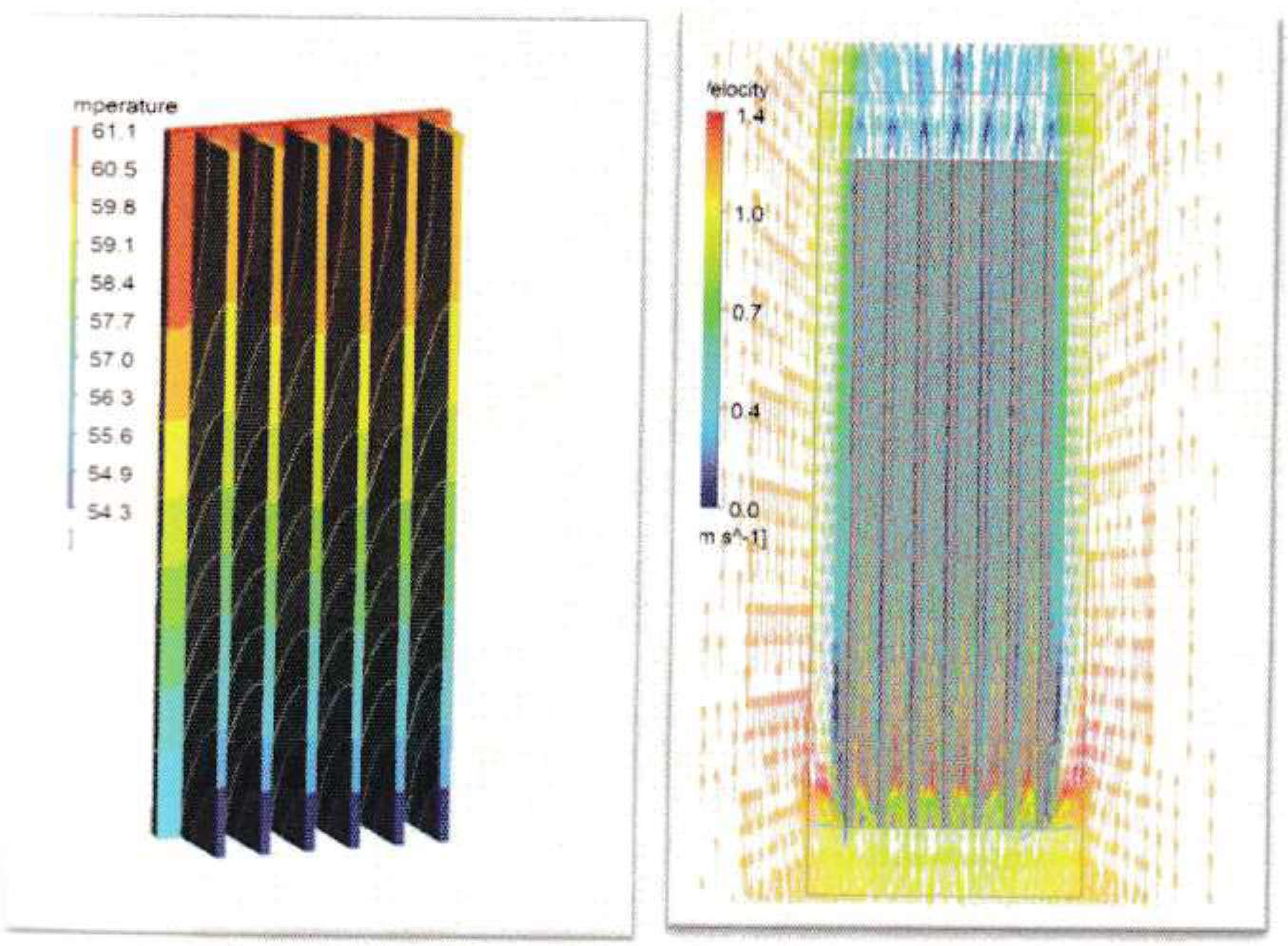
(g) (h)

Figure 5.11 Temperature and Velocity Images for Horizontal Position (90°)

...inclination, the density of fluid changes with the fluid temperature As a result, ...buoyancy driven flow structures are formed. Fluid temperature contours at ... angles of 30^0,45^0,60^0,90^0 are shown in figure 5.11 (a, b, c, d, e, f, g and ... of inclination over streamline flow and thereby on natural convection heat ... can be observed. As inclination increases, flow velocities at the exit of the heat sink reduces. It is observed that the separation location starts to move from the tip towards the centre after 60^0 of inclination. At 90^0, the flow is symmetric around the center of the heat sink as shown in figure 5.11(g and h).

5.5.3.3 Temperature and Velocity Distribution for Mixed Convection

The distribution of temperature and velocity for vertical plate heat sink are shown in figure 5.12 with for air flow velocity of 1.2 m/s. It is observed that as air is flowing from bottom side of the plate more heat is dissipated from the bottom side of heat sink. The upper portion which is sharpen (orange in color) shows highest temperature while colour gets lighter away from heated base (blue) shows minimum temperature.



(a) (b)

Figure 5.12 Temperature and Velocity Images for Mixed Convection

Temperature and velocity images for vertical plate heat sink, inclined plate heat sink and mixed convection at different spacing are shown in Appendix D.

Simulation Results

The simulation study is carried out for heat sink having H=25mm L=200mm and ... heat input is 50W for vertical plate heat sink, inclined heat sink and mixed convection phenomenon.

5.6.1 Validation of Experimental result with CFD for Vertical Plate Heat Sink

The convective heat transfer rate from experimentation and CFD are shown in figure 5.13

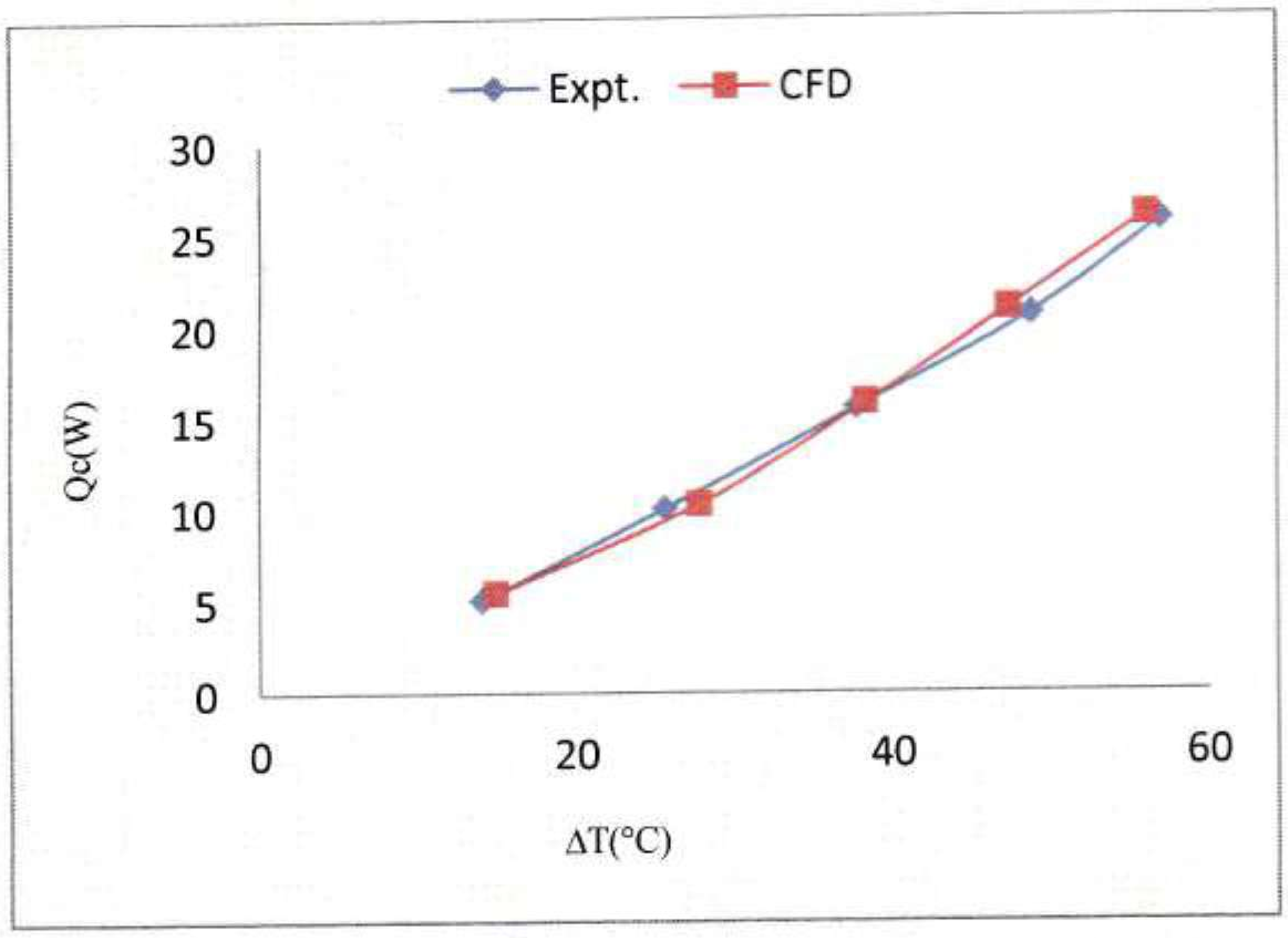


Figure 5.13 Validation of Experimental and CFD Results for Vertical Plate Heat Sink

The convective heat transfer rate indicates the satisfactory trends both in experimental and CFD work. It is also seen that experimentally calculated heat transfer rate and value obtained from CFD are in good agreement.

5.6.2 Validation of Experimental result with CFD for Inclined Plate Heat Sink

The convective heat transfer rate from experimentation and CFD are shown in figure 5.14

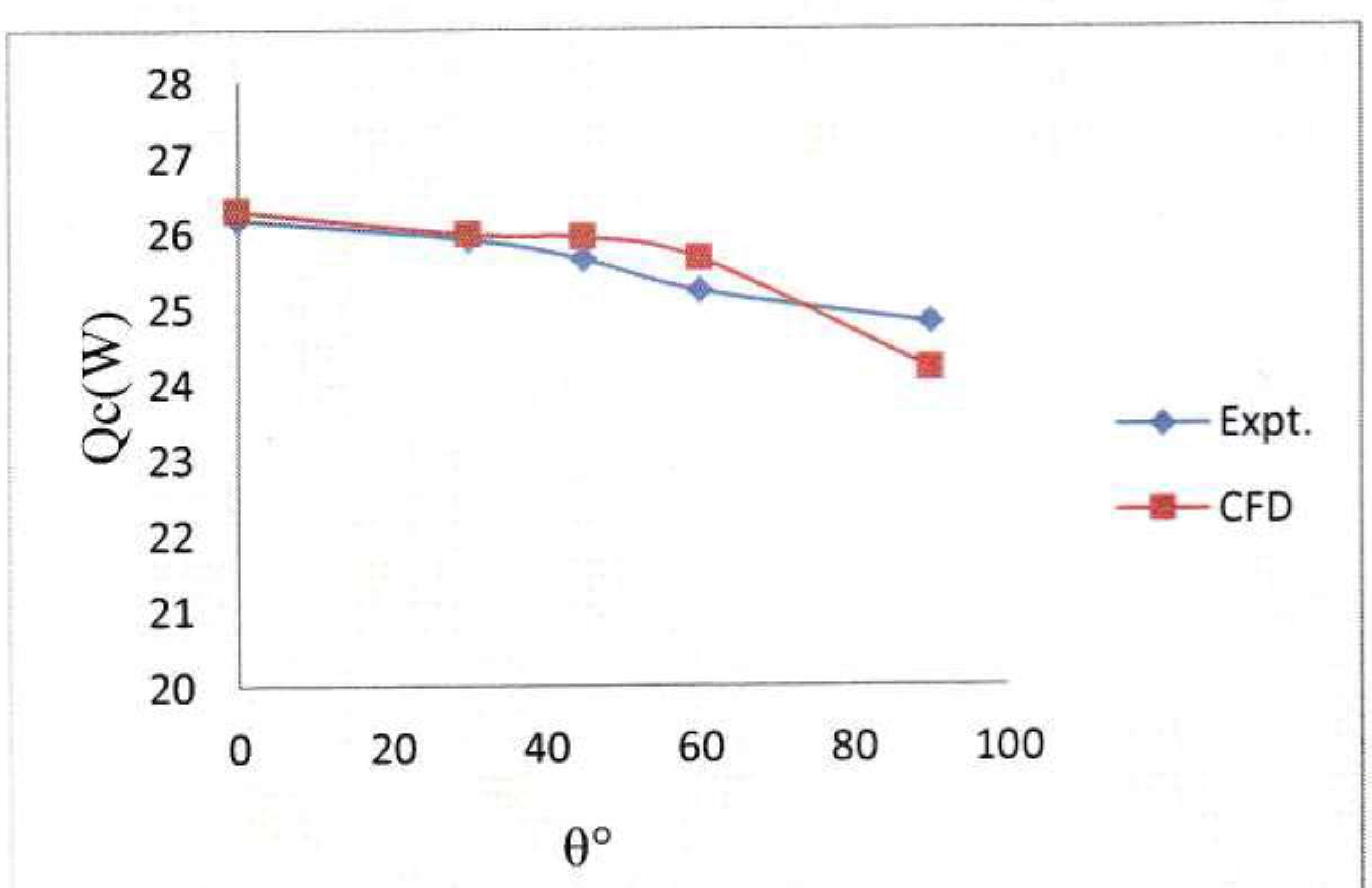


Figure 5.14 Validation of Experimental and CFD Results for Inclined Plate Heat Sink

It is observed that as angle of inclination increases heat transfer rate decreases. Up to 30° angle of inclination the result obtained from experiment and simulation work is perfectly close in agreement. A little deviation obtained at higher inclinations. This is due to uncertainty in experiment. So we can neglect this type of degree of error. Over all results obtained with experimental work and simulation are quite in agreement.

5.6.3 Validation of Experimental result with CFD for Mixed Convection

From figure 5.15, it is clear that at higher velocity the convective heat transfer rate increases. It is also seen that both experimental and simulation trends have the degree of error. This is because of turbulence and eddies are formed at higher velocity.

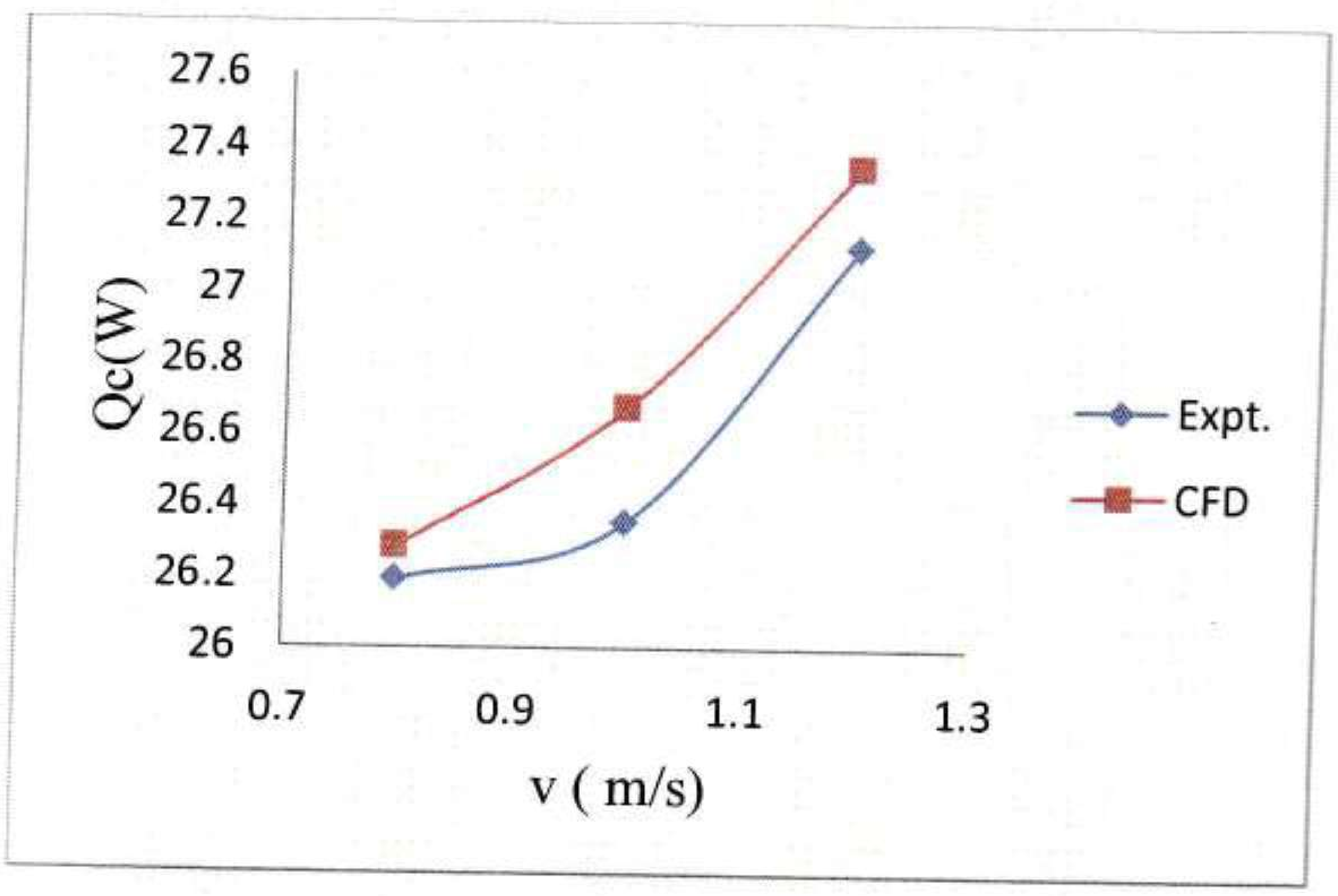


Figure 5.15 Validation of Experimental and CFD Results for Mixed Convection

This degree of error can be found out in terms of error coefficient with the help of numerical methods like curve fittings. So the results obtained with experimental work and simulations are nearer to close in agreement.

5.7 Validation of RSM and ANN Results

Response surface methodology (RSM) and artificial neural network (ANN) methods are successfully used together for modeling as well as an optimization in numerous heat transfer problems. The investigational outcome, response surface methodology simulation outcome and artificial neural network outcome were compared to estimate responses. ANN and RSM techniques were compared for their predictive capabilities. The comparison of the RSM and ANN methods for vertical plate heat sink, inclined plate heat sink and mixed convection for vertical plate heat sink is analyzed.

5.7.1 Vertical Plate Heat Sink

The error of convective heat transfer rate and temperature difference for RSM and ANN for vertical plate heat sink in natural convection is as shown in figure 5.16 and 5.17 From figure 5.16, it is seen that at experiment number 26,33,54,80 percentages of error increases, this is due to uncertainties in the experimentation. Rest of the number of experiments shows little peak values of error, so we can neglect this type of percentage error.

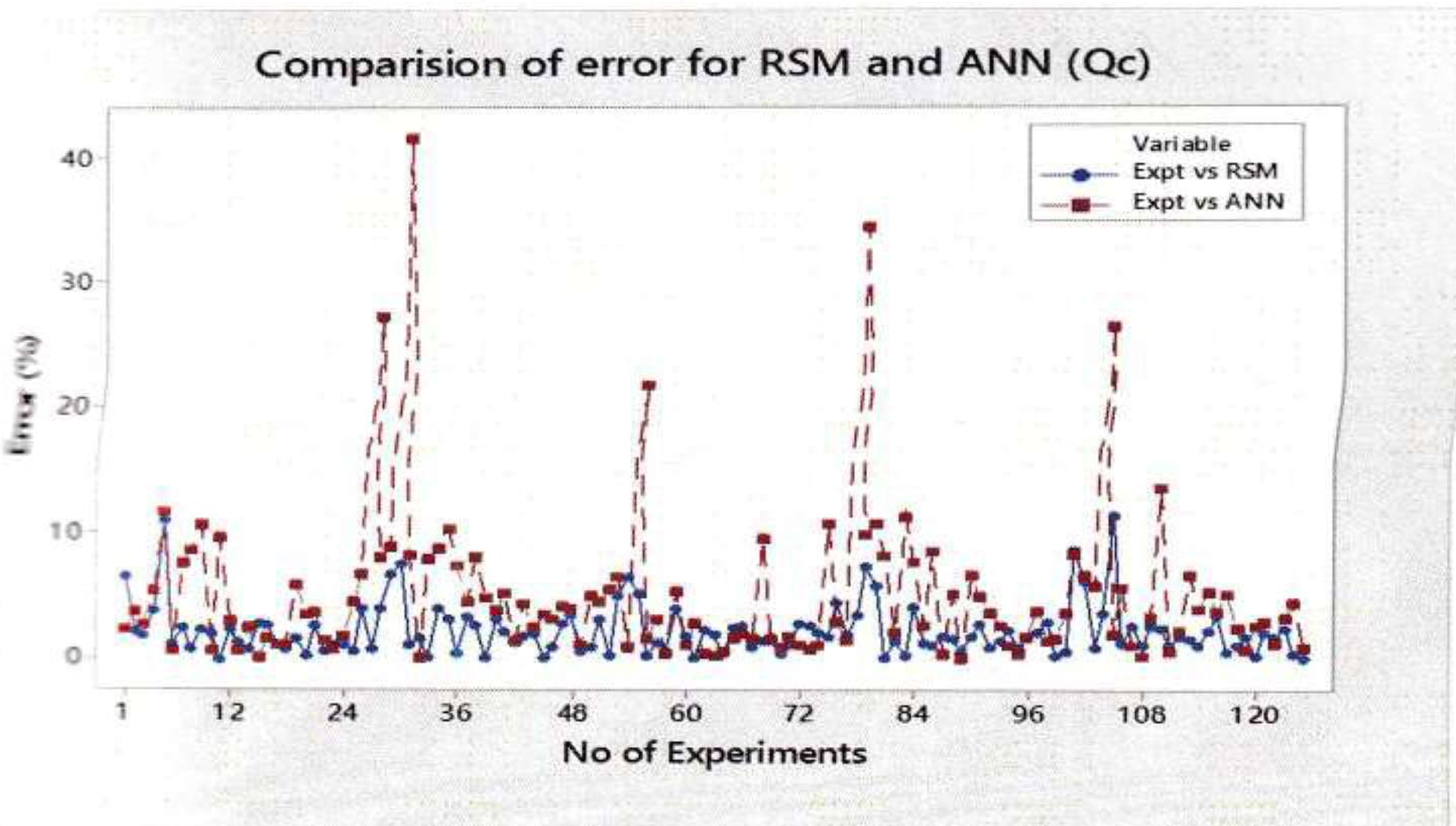


Figure 5.16 Validation of RSM and ANN Errors of Qc for Vertical Plate Heat Sink

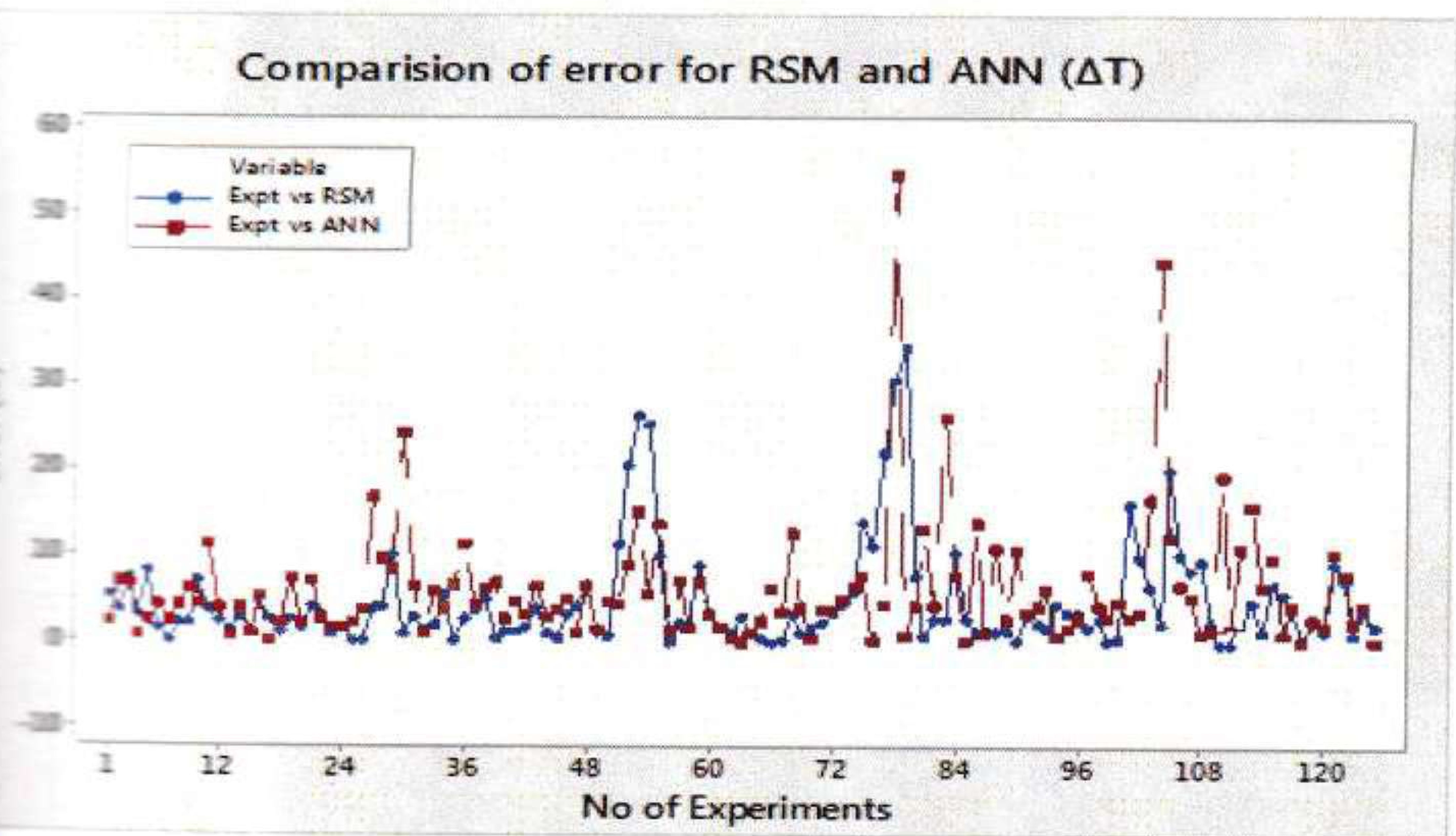


Figure 5.17 Validation of RSM and ANN Errors of ΔT for Vertical Plate Heat Sink

The average percentage errors between experimental results and predicted values of the RSM model for vertical plate heat sink are 4.71% for temperature difference and 2.29% for convective heat transfer rate. The average percentage error between experimental results and predicted values by ANN model for vertical plate heat sink are 6.16% for temperature difference and 5.10% for convective heat transfer rate.

5.7.2 Inclined Plate Heat Sink

The error of convective heat transfer rate and temperature difference for RSM and ANN for inclined plate heat sink in natural convection is as shown in figure 5.18 and 5.19.

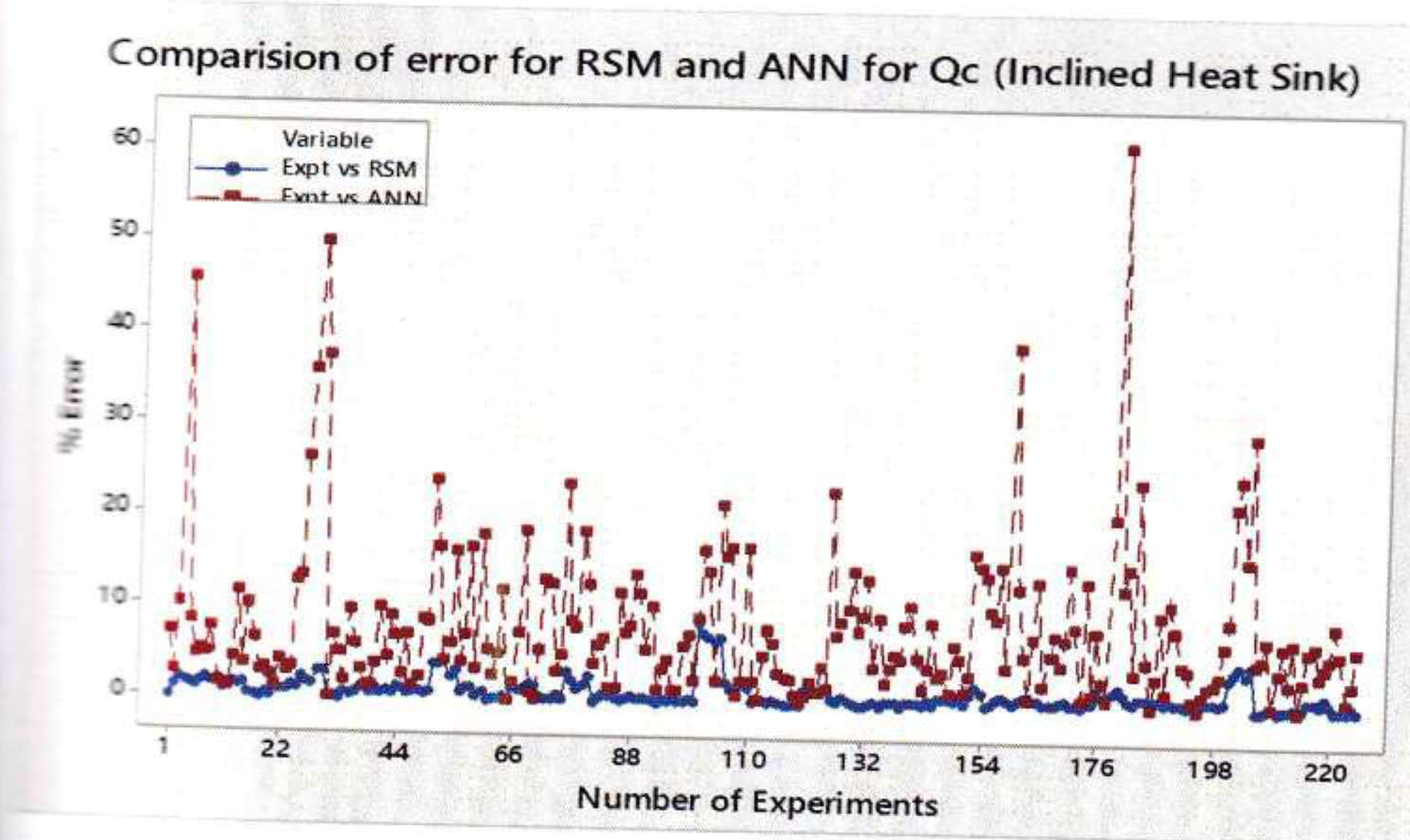


Figure 5.18 Validation of RSM and ANN Errors of Qc for Inclined Plate Heat Sink

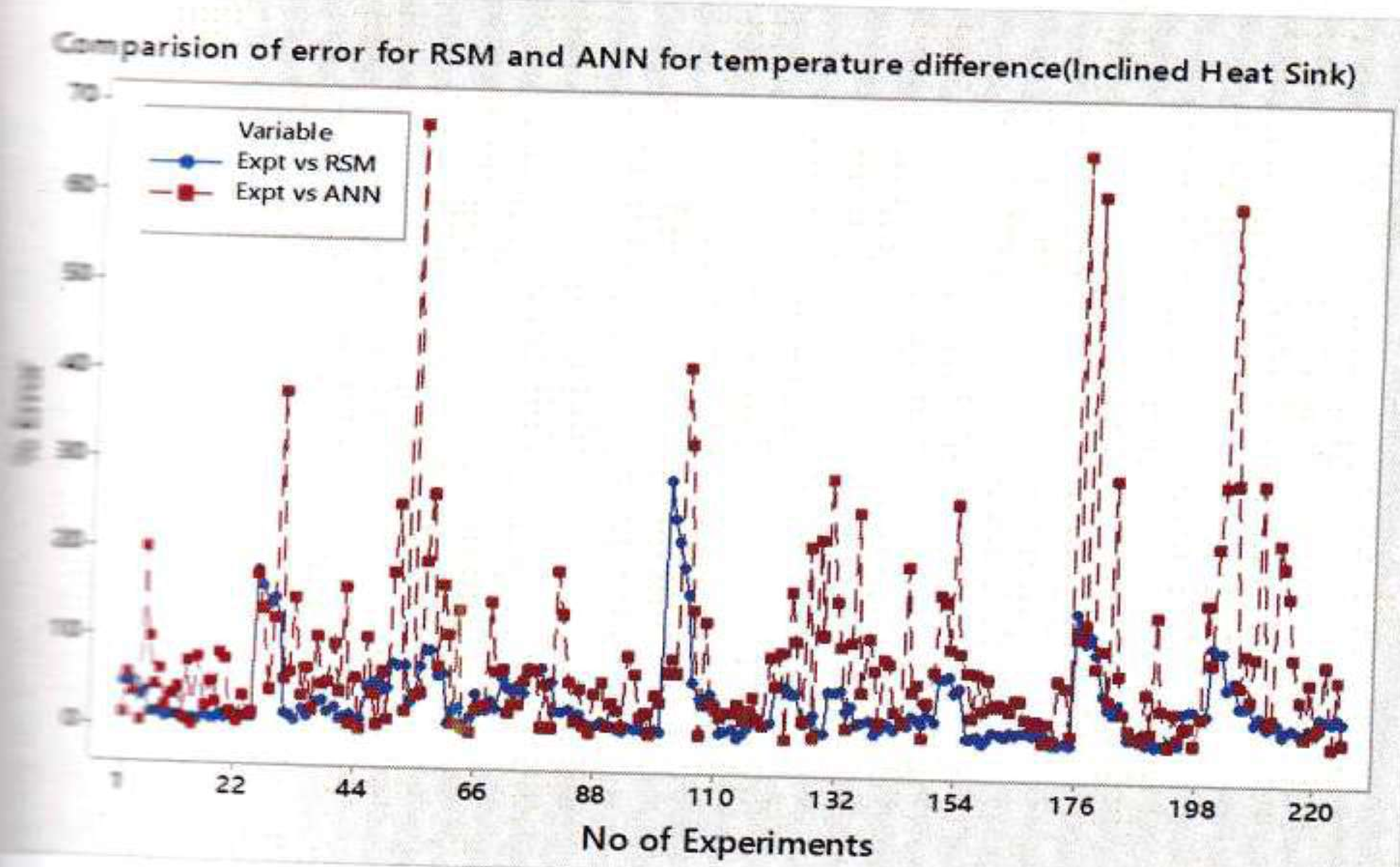


Figure 5.19 Validation of RSM and ANN Errors of ΔT for Inclined Plate Heat Sink

Figure 5.19 shows that experiment number 50, 88, 188 and 200 shows high peak values of percentage of error. This type of rise of error is not admissible to compensate for these error will have to take care of calibration of experiments, during performance, so that it can be eliminate. Rest of readings shows quite in good agreement. For inclined plate fin heat sink the average error are 3.74% for temperature difference and 1.19% for convective heat transfer rate.

5.7.3 Mixed Convection for Vertical Plate Heat Sink

The error of convective heat transfer rate and for RSM and ANN for assisting flow mixed convection plate heat sink is as shown in figure 5.20. The experiment number 1, 6 and 11 shows high values of % error while rest of the experiment number shows less percentage of error. The average error is 1.21%.

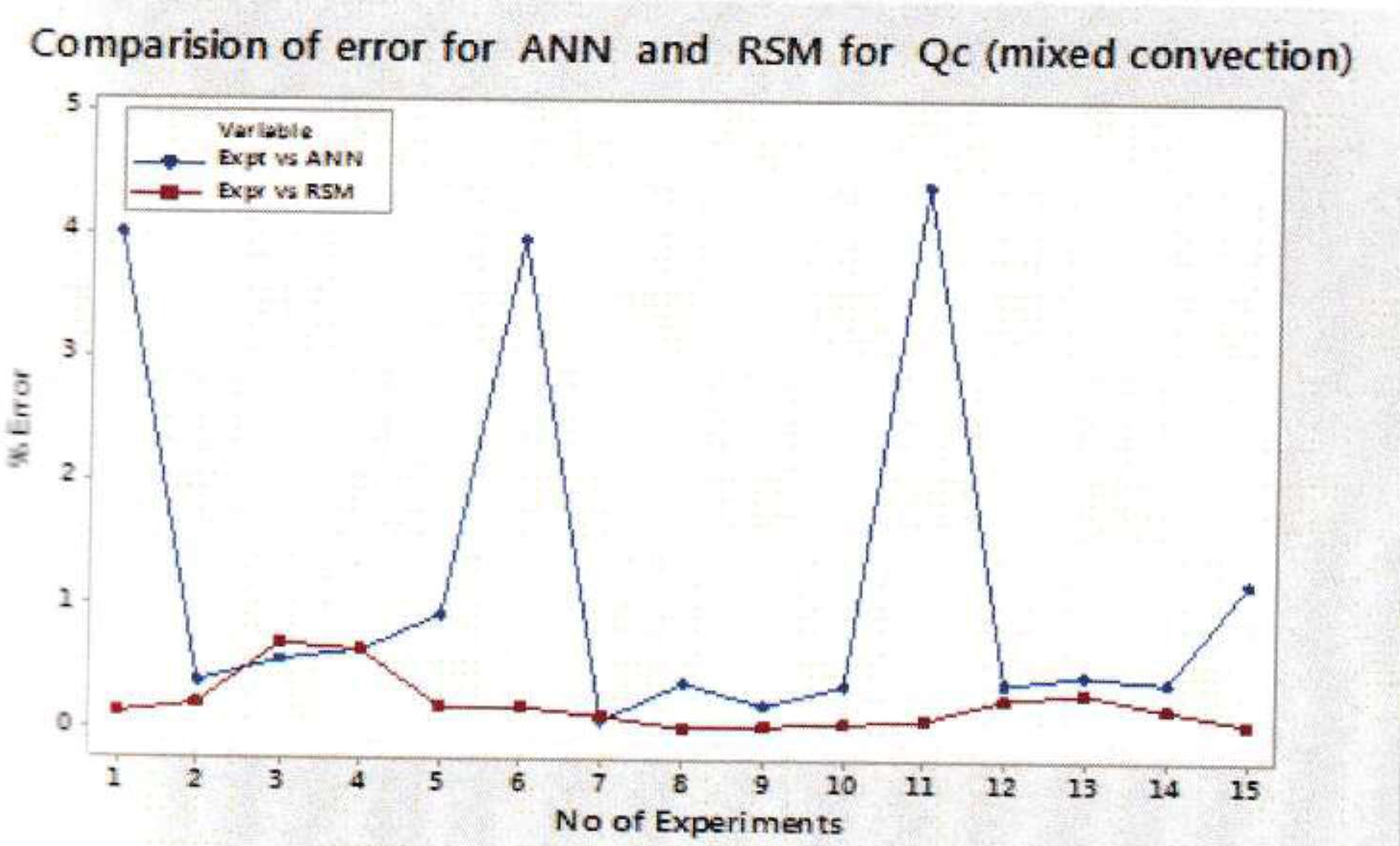


Figure 5.20 Validation of RSM and ANN Errors of Qc for Mixed Convection

Good agreement is seen between the actual experimental results and predicted values based on RSM model and ANN model. The results showed that the models could be used proficiently for forecasting the heat transfer rate. The percentage of errors is less than 5% in RSM and less than 10% in ANN.

CHAPTER 6

CONCLUSIONS

Various samples of heat sink were experimentally tested to evaluate their characteristics, using air as flowing fluid. Twenty five samples used for first phase of experimentation i.e. vertical plate heat sink. Among the samples, convective heat transfer rate is find out considering base to ambient temperature difference for different fin height and fin spacings. The primary reason to study all heat sinks is to find out optimum range of fin spacing to provide necessary information from application point of view, i.e. electronic cooling and other thermal system. Only optimum range of heat sink samples were selected for second phase .i.e. inclined orientation heat sink, of experimentation. The mixed flow convection heat transfer rate has been investigated for different fin spacings for low velocities in third phase of experimentation. Heat sink samples are tested in the lab were analyzed in RSM and simulated in ANN and CFD.

On the basis of studies carried out the following conclusions have been drawn.

- Experimental results show that the convective heat transfer rate for all heat sinks is greater than that for vertical flat plate. This shows that good enhancement can be achieved by mountings plate fins to vertical surfaces.
- For a given fin spacing, heat transfer rate increases with fin height and base to ambient temperature. At low base to ambient temperature differences, the increase in convective heat transfer rate with fin height is not significant but at higher temperature differences the convective heat transfer rate increases with fin height.
- Effect of fin spacing on heat transfer rate was found more dominant than other geometrical parameters. It was observed that during performance of heat sink configurations that the convective heat transfer rate first increases with increase in spacing up to certain limit, then reaches to maximum at a certain value of spacing known as an optimum spacing ,which decreases with further increase in spacing. However, the effect of fin height and base to ambient temperature with optimum fin spacing but this parameter not affecting significantly.

- As fin spacing is decreased, the total surface area of heat sink increases, which enhances the heat transfer rate. However, more closer fins causes resistance to flow, the boundary layers start to interfere and after a certain value further increase in the area starts to decrease the heat transfer rate. So the spacing should be kept at optimum value.
- Effect of angle of inclination over natural convective heat transfer rate was verified. The examined inclination angle range includes five angles at different orientation. It is observed that natural convective heat transfer rate is maximum for vertical orientation of plate heat sink and it goes on decreasing as we inclined the heat sink from vertical to horizontal. Therefore for better heat transfer vertical rectangular heat sink should prefer than horizontal.
- An experimental result also shows that the larger fin height results in higher heat transfer rate at constant fin spacing and fin length. It is conclude that decrement in heat transfer rate is more for large fin height, as compared with smaller height as heat sink inclined from vertical (0°) to horizontal (90°) position.
- It is found that, within small inclinations plate heat sink from vertical position to 30° inclination and from horizontal position to 30° of inclination, the inclination does not reduce the convection heat transfer rate. The convective heat transfer rate remains almost same. It is because an air flow characteristic seems quiet identical for slightly inclined fin base from either vertical or horizontal position.
- When average base temperature was studied as a function of angle of inclination, then it was observed that the average base temperature increases as angle of inclination increases also indicating lower heat transfer rates at higher angle.
- It is observed that the angle of inclination have negligible effect on the optimum fin spacing.
- The mixed flow convection heat transfer rate has been investigated for different fin spacings for low velocities. It is observed that the optimum fin spacing in mixed convection is slightly less than that of natural convection. The experimental result also shows improvement in convective heat transfer rate as compared with natural convection.
- A mathematical model was studied using response surface methodology to predict the convective heat transfer rate and to find optimum fin spacings. ANOVA test

also carried out to check the capability of the model. The predictions of the model matched well with the experimental results.

- In order to validate the response surface methodology (RSM) based regression model, artificial neural network (ANN) is used to predict the responses. The results of these methodologies were compared for their predictive capability. It is noticed that the results of ANN model showed close matching between RSM model output and experimental results. It has been confirmed numerically that the results from the derived modeling equation are consistent with the experimental results. Experimental results are also validated with CFD which shows good agreement.
- Enhanced convective heat transfer rate can be achieved at optimized geometrical parameters. It is concluded from the experimentation that the optimum fin spacings is found in between 7 mm to 9.5mm for all three cases for maximum convective heat transfer rate. RSM based desirability approach was used to optimize the fin spacing. The optimized value found from RSM is 8.28 mm for vertical plate heat sink, 8.44 mm for inclined heat sink and 7.93 mm for vertical plate heat sink in mixed convection.
- This research confirms that convective heat transfer rate is superior at optimum fin spacing. This is important input for designer and researches in the field of electronics systems. The design of electronics component based on optimum fin spacing will results into more life span, less failure rate and compact size. It will also reduce the overall cost of the electronics component without affecting its performance.

Future Scope

The current work has demonstrate the capabilities of experimental study of vertical, inclined and mixed convection vertical plate heat sink for optimization of fin spacings. There are some extensions of present work for future scope.

- The numerical investigation can be carried in future study to obtain the correlation for fin spacing.
- Mixed convection study is carried out on limited number of heat sink. This can be studied widely with various fluid velocities.

- The study has been done assuming the flow regime to be laminar. Therefore, the present study can be extended by considering turbulent flows. The forced convection study can be implemented.
- The study has been done at study state conditions. it can be extended for unsteady natural convective heat transfer from heat sink.

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APPENDIX B

Observation Tables

Table B1 Observation Table of Vertical Plate Heat Sink

Q=10W H=5mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	33	0.309	62	63	62	61	63	62.2	20
7	33	0.309	59	61	61	61	62	60.8	20
9.5	33	0.309	58	58	57	58	58	57.8	20
13.5	33	0.309	61	61	62	62	63	61.8	20
17	33	0.309	68	66	66	65	65	66	20

Q=20W H=5mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	53	0.377	94	93	93	92	92	92.8	20
7	53	0.377	91	91	90	89	89	90	20
9.5	53	0.377	90	89	89	87	87	88	20
13.5	53	0.377	96	95	95	95	95	95.2	20
17	53	0.378	106	105	104	104	104	104.8	20

Q=30W H=5mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	63	0.479	122	122	120	120	119	120.6	20
7	63	0.479	120	118	118	118	118	118.4	20
9.5	63	0.479	119	119	118	117	116	117.8	20
13.5	63	0.479	126	125	125	125	124	125	20
17	63	0.479	135	134	133	132	132	133.2	20

Q=40W H=5mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	71	0.564	148	147	146	145	144	146	20
7	71	0.564	145	144	144	144	144	143.2	20
9.5	71	0.564	144	143	142	142	143	142.8	20
13.5	71	0.564	153	152	152	152	151	152	20
17	71	0.564	163	162	162	162	161	162	20

Q=50W H=5mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	80	0.628	168	167	167	167	167	167.2	20
7	80	0.628	168	166	165	166	167	166.4	20
9.5	80	0.628	167	166	165	165	165	165.6	20
13.5	80	0.628	177	176	175	175	175	175.6	20
17	80	0.628	186	186	185	185	184	185	20

Q=10W H=10mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	33	0.309	50	50	49	49	49	49.4	20
7	33	0.309	49	49	49	48	48	48.5	20
9.5	33	0.309	48	47	47	47	46	47	20
13.5	33	0.309	53	52	51	50	50	51.2	20
17	33	0.309	56	55	55	55	54	55	20

Q=20W H=10mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	53	0.377	72	72	71	71	70	71.2	20
7	53	0.377	71	71	71	70	70	70.6	20
9.5	53	0.377	70	70	70	70	69	69.8	20
13.5	53	0.377	79	79	78	78	76	78	20
17	53	0.378	84	84	83	83	82	83.2	20

Q=30W H=10mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	63	0.479	92	92	92	93	91	92	20
7	63	0.479	91	91	91	90	90	90.5	20
9.5	63	0.479	91	91	90	89	89	90	20
13.5	63	0.479	100	99	99	99	98	99	20
17	63	0.479	109	108	108	108	107	108	20

Q=40W H=10mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	71	0.564	113	112	112	112	112	112.2	20
7	71	0.564	112	112	111	111	110	111.5	20
9.5	71	0.564	111	111	111	111	110	110.8	20
13.5	71	0.564	124	123	123	123	122	123	20
17	71	0.564	134	134	134	134	133	133.8	20

Q=50W H=10mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	80	0.628	128	127	127	127	127	127.2	20
7	80	0.628	127	127	126	126	126	126.4	20
9.5	80	0.628	126	126	125	126	126	125.9	20
13.5	80	0.628	142	141	141	141	140	141	20
17	80	0.628	157	156	156	156	156	156.2	20

Q=10W H=15mm										
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	33	0.309	43	43	42	42	42	42.4	20
7	33	0.309	42	42	42	42	41	41.8	20
9.5	33	0.309	41	41	41	41	40	41	20
13.5	33	0.309	45	44	44	44	43	44	20
17	33	0.309	49	49	49	49	48	48.9	20

Q=20W H=15mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	53	0.377	60	60	59	59	59	59.5	20
7	53	0.377	60	59	59	59	58	59	20
9.5	53	0.377	59	59	58	58	58	58.5	20
13.5	53	0.377	66	66	65	65	65	65.5	20
17	53	0.378	73	72	72	72	71	72	20

Q=30W H=15mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	63	0.479	77	76	76	76	75	76	20
7	63	0.479	76	76	75	75	75	75.5	20
9.5	63	0.479	76	75	75	75	74	75	20
13.5	63	0.479	84	83	83	83	82	83	20
17	63	0.479	93	92	92	92	91	92	20

Q=40W H=15mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	71	0.564	93	93	92	92	92	92.5	20
7	71	0.564	93	92	92	92	91	92	20
9.5	71	0.564	92	92	91	91	91	91.5	20
13.5	71	0.564	103	102	102	102	101	102	20
17	71	0.564	115	114	114	114	113	114	20

Q=50W H=15mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	80	0.628	105	104	104	104	103	104	20
7	80	0.628	104	104	103	103	103	103.4	20
9.5	80	0.628	106	105	105	105	104	105	20
13.5	80	0.628	121	120	120	120	119	120	20
17	80	0.628	123	122	122	122	121	122	20

Q=10W H=20mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	33	0.309	39	39	38	38	37	38.2	20
7	33	0.309	38	38	38	37	37	37.6	20
9.5	33	0.309	38	37	37	37	36	37	20
13.5	33	0.309	42	41	41	41	40	41	20
17	33	0.309	45	44	45	44	44	44.6	20

Q=20W H=20mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	53	0.377	53	52	52	52	52	52.2	20
7	53	0.377	52	52	51	51	51	51.4	20
9.5	53	0.377	52	51	51	51	50	51	20
13.5	53	0.377	59	58	58	58	57	58	20
17	53	0.378	65	64	64	64	64	64.2	20

Q=30W H=20mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	63	0.479	67	67	66	65	66	66.1	20
7	63	0.479	66	66	65	65	65	65.4	20
9.5	63	0.479	65	65	65	64	64	64.8	20
13.5	63	0.479	73	72	72	72	71	72	20
17	63	0.479	82	81	81	81	80	81	20

Q=40W H=20mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	71	0.564	80	79	79	79	78	79	20
7	71	0.564	79	79	78	78	78	78.3	20
9.5	71	0.564	78	78	78	77	77	77.6	20
13.5	71	0.564	90	89	89	89	88	89	20
17	71	0.564	101	100	100	100	99	100	20

Q=50W H=20mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	80	0.628	90	89	89	89	89	89.1	20
7	80	0.628	89	89	88	88	88	88.4	20
9.5	80	0.628	88	88	88	88	87	87.8	20
13.5	80	0.628	100	99	99	99	98	99	20
17	80	0.628	113	112	112	112	111	112	20

Q=10W H=25mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	33	0.309	36	36	35	35	35	35.4	20
7	33	0.309	35	35	35	35	34	34.8	20
9.5	33	0.309	35	34	34	34	34	34.1	20
13.5	33	0.309	39	38	38	38	38	38.2	20
17	33	0.309	41	40	40	40	39	40	20

Q=20W H=25mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	53	0.377	48	47	47	47	46	47	20
7	53	0.377	47	46	46	46	46	46.3	20
9.5	53	0.377	46	46	46	45	45	45.7	20
13.5	53	0.3775	53	52	52	52	51	52	20
17	53	0.378	59	58	58	58	57	58	20

Q=30W H=25mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	63	0.479	60	59	59	59	59	59.1	20
7	63	0.479	59	59	58	58	58	58.5	20
9.5	63	0.479	58	58	58	58	57	57.8	20
13.5	63	0.479	66	65	65	65	64	65	20
17	63	0.479	73	72	72	72	71	72	20

Q=40W H=25mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	71	0.564	71	70	70	70	70	70.2	20
7	71	0.564	70	70	69	69	69	69.3	20
9.5	71	0.564	69	69	69	69	68	68.8	20
13.5	71	0.564	79	78	78	78	77	78	20
17	71	0.564	88	87	87	87	86	87	20

Q=50W H=25mm									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	80	0.628	79	79	78	78	77	78.2	20
7	80	0.628	78	78	78	77	77	77.6	20
9.5	80	0.628	78	77	77	77	76	77	20
13.5	80	0.628	89	88	88	88	87	88	20
17	80	0.628	101	100	100	100	99	100	20

Table B2 Observation Table for Inclined Plate Heat Sink

Q=10W, H=5mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	33	0.309	60.4	60.7	61	61.2	61.7	61	20
30	33	0.309	62.4	62.8	62.7	63.4	63.7	63	20
45	33	0.309	64	64.9	65.2	65.4	65.5	65	20
60	33	0.309	67.4	67.9	68.1	68.2	68.4	68	20
90	33	0.309	68.1	69.7	71.5	72.2	73.5	71	20

Q=20W, H=5mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	53	0.377	87.9	88.5	89.4	91.6	92.6	90	20
30	53	0.377	89.6	90.6	91.7	93.4	94.7	92	20
45	53	0.377	92.1	93.2	93.9	94.7	96.1	94	20
60	53	0.377	95.2	96.4	96.8	97.9	98.7	97	20
90	53	0.377	97.8	99.1	99.9	101.1	102.1	100	20

Q=30W, H=5mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	63	0.479	115.2	116.7	117.6	119.2	121.3	118.5	20
30	63	0.479	117.6	118.4	119.4	121.5	123.1	120	20
45	63	0.479	118.9	121.1	122.3	123.2	124.5	122	20
60	63	0.479	121.3	122.8	124.2	126.8	129.9	125	20
90	63	0.479	124.4	126.2	127.2	129.1	133.1	128	20

Q=40W, H=5mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	71	0.564	140.7	141.2	143.9	144.6	146.1	143.3	20
30	71	0.564	141.4	143.5	145.6	146.6	147.9	145	20
45	71	0.564	143.6	145.9	146.9	148.5	150.1	147	20
60	71	0.564	147.1	148.1	149.3	152.1	153.4	150	20
90	71	0.564	150.2	151.4	152.3	154.2	156.9	153	20

Q=50W, H=5mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	80	0.628	162.9	165.3	166.4	167.8	170.1	166.5	20
30	80	0.628	164.2	166.9	168.2	169.3	171.4	168	20
45	80	0.628	165.7	168.5	170.6	171.6	173.6	170	20
60	80	0.628	168.5	172.2	173.2	174.2	176.9	173	20
90	80	0.628	171.2	175.2	175.8	177.2	180.6	176	20

Q=10W, H=10mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	33	0.309	46.9	47.6	48.6	49.5	49.9	48.5	20
30	33	0.309	47.2	49.5	50.6	51.1	51.6	50	20
45	33	0.309	50.1	51.6	52.4	52.8	53.1	52	20
60	33	0.309	53.1	54	54.9	55.9	57.1	55	20
90	33	0.309	55.9	56.6	57.8	59.1	60.6	58	20

Q=20W, H=10mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	53	0.377	67.9	69.1	70.5	71.9	73.1	70.5	20
30	53	0.377	68.5	70.6	71.8	73.6	75.5	72	20
45	53	0.377	70.1	72.6	73.8	75.8	77.7	74	20
60	53	0.377	73.1	75.8	76.9	78.8	80.4	77	20
90	53	0.377	76.1	79	80	81.8	83.1	80	20

Q=30W, H=10mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	63	0.479	87.9	88.9	90.7	91.9	93.1	90.5	20
30	63	0.479	89.5	90.5	91.9	93.4	94.7	92	20
45	63	0.479	91.9	93.5	93.7	94.4	96.5	94	20
60	63	0.479	95.2	96.4	96.8	97.9	98.7	97	20
90	63	0.479	97.6	99	100.1	101.2	102.1	100	20

Q=40W, H=10mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	71	0.564	109.3	110.2	111.2	112.9	113.9	111.5	20
30	71	0.564	110.8	111.4	112.5	114.1	116.2	113	20
45	71	0.564	112.3	113.2	114.2	116.8	118.5	115	20
60	71	0.564	114.9	116.7	117.8	119.5	121.1	118	20
90	71	0.564	117.5	120.2	121.4	122.2	123.7	121	20

Q=50W, H=10mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	80	0.628	122.8	124.9	126.7	127.9	130.2	126.5	20
30	80	0.628	124.8	126.2	127.1	129.1	132.8	128	20
45	80	0.628	126.8	127.5	128.7	132.5	134.5	130	20
60	80	0.628	129.6	130.2	133.1	134.9	137.2	133	20
90	80	0.628	131.4	133.3	136.9	138.9	139.5	136	20

Q=10W, H=15mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	33	0.309	40.5	41.2	41.8	42.9	43.6	42	20
30	33	0.309	41.9	43.5	43.9	44.5	46.2	44	20
45	33	0.309	43.3	45.8	46	46.1	48.8	46	20
60	33	0.309	46.2	47.5	48.9	50.5	51.9	49	20
90	33	0.309	50.2	51.5	52.5	52.7	53.1	52	20

Q=20W, H=15mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	53	0.377	57.1	58.1	59.4	59.7	60.7	59	20
30	53	0.377	59.9	60.5	61.6	61.3	61.7	61	20
45	53	0.377	61.2	62.9	62.8	63.5	64.6	63	20
60	53	0.377	63.4	64.9	66	66.8	68.9	66	20
90	53	0.377	65.6	66.9	69.2	70.1	73.2	69	20

Q=30W, H=15mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	63	0.479	71.5	74.6	75.8	76.9	78.7	75.5	20
30	63	0.479	73.1	75.8	76.9	78.8	80.4	77	20
45	63	0.479	74.9	77.3	78.6	81.3	82.9	79	20
60	63	0.479	77.9	80.9	81.9	83.9	85.5	82	20
90	63	0.479	81.1	83.6	89.8	86.9	88.6	85	20

Q=40W, H=15mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	71	0.564	88.9	90.9	91.8	93.7	94.7	92	20
30	71	0.564	90.5	93.3	94.3	95.1	96.8	94	20
45	71	0.564	92.1	95.7	96.8	96.5	98.9	96	20
60	71	0.564	95.6	98.6	98.9	99.6	102.3	99	20
90	71	0.564	98.2	100.7	101.9	103.6	105.6	102	20

Q=50W, H=15mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	80	0.628	98.5	101.9	103.9	105.3	107.9	103.5	20
30	80	0.628	99.9	103.4	104.9	107.9	108.9	105	20
45	80	0.628	102.1	105.9	107.8	108.9	110.3	107	20
60	80	0.628	105.1	108.3	110.8	112.1	113.7	110	20
90	80	0.628	108.1	112.1	113.9	114.6	116.3	113	20

Q=10W, H=20mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	33	0.309	36.9	37.3	37.9	38.3	39.1	37.9	20
30	33	0.309	37.5	38.2	38.8	39.4	41.1	39	20
45	33	0.309	39.9	40.2	40.9	41.1	42.9	41	20
60	33	0.309	41.8	43.6	43.8	44.6	46.2	44	20
90	33	0.309	44.9	46.1	46.9	47.6	49.5	47	20

Q=20W, H=20mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	53	0.377	49.5	51.3	51.7	52.1	52.9	51.5	20
30	53	0.377	50.9	51.9	52.7	53.9	55.6	53	20
45	53	0.377	52.3	52.5	55.4	56.5	58.3	55	20
60	53	0.377	54.4	55.9	58.6	60.1	61	58	20
90	53	0.377	58.7	60.5	61.6	61.3	62.9	61	20

Q=30W, H=20mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	63	0.479	63.4	64.5	65.5	66.2	67.9	65.5	20
30	63	0.479	64.9	65.9	66.9	67.7	69.6	67	20
45	63	0.479	65.6	66.9	69.2	70.1	73.2	69	20
60	63	0.479	68.5	70.6	71.8	73.6	75.5	72	20
90	63	0.479	71.5	73.9	75.2	76.1	78.3	75	20

Q=40W, H=20mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	71	0.564	16.8	17.5	18.2	18.6	19.2	18.06	20
30	71	0.564	16.7	17.2	17.9	18.6	18.7	17.81	20
45	71	0.564	16.3	17	17.5	18.1	18.5	17.48	20
60	71	0.564	15.9	16.4	16.9	17.8	17.8	16.96	20
90	71	0.564	15.7	16.1	16.5	16.7	17.2	16.44	20

Q=50W, H=20mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	80	0.628	85.9	86.8	88.6	89.7	91.5	88.5	20
30	80	0.628	87.3	88.4	90.1	91.3	92.9	90	20
45	80	0.628	88.9	90.9	91.8	93.7	94.7	92	20
60	80	0.628	91.9	93.6	95.4	96.3	97.8	95	20
90	80	0.628	94.9	96.9	97.7	98.9	101.6	98	20

Q=10W, H=25mm, S=7mm										
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	33	0.309	33.8	34.5	35.1	35.4	36.2	35	20
30	33	0.309	35.9	36.5	37.1	37.4	38.1	37	20
45	33	0.309	37.5	38.1	38.9	39.3	41.2	39	20
60	33	0.309	40.5	41.2	41.8	42.9	43.6	42	20
90	33	0.309	42.5	44.1	44.8	46.1	47.5	45	20

Q=20W, H=25mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	53	0.377	43.9	45.9	46.5	47.4	48.8	46.5	20
30	53	0.377	45.9	46.5	47.6	49.5	50.5	48	20
45	53	0.377	46.7	48.9	49.8	51.8	52.8	50	20
60	53	0.377	50.5	51.9	52.8	53.9	55.9	53	20
90	53	0.377	53.1	54.9	55.9	57.3	58.8	56	20

Q=30W, H=25mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	63	0.479	54.4	57.2	59.3	60.3	61.3	58.5	20
30	63	0.479	57.5	59.2	59.9	60.9	62.5	60	20
45	63	0.479	58.9	60.9	62.1	63.4	64.7	62	20
60	63	0.479	62.6	64.1	65.1	65.9	67.3	65	20
90	63	0.479	65.3	66.9	67.9	69.3	70.6	68	20

Q=40W, H=25mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	71	0.564	65.6	67.9	69.6	70.9	73.5	69.5	20
30	71	0.564	68.6	69.1	71.6	72.6	73.1	71	20
45	71	0.564	70.4	71.2	73.5	74.3	75.6	73	20
60	71	0.564	72.1	74.6	76.9	77.9	78.5	76	20
90	71	0.564	74.9	77.3	78.6	81.3	82.9	79	20

Q=50W, H=25mm, S=7mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	80	0.628	73.9	76.3	77.9	78.8	80.6	77.5	20
30	80	0.628	74.8	77.6	78.2	81.5	82.9	79	20
45	80	0.628	76.9	79.2	81.7	83.1	84.1	81	20
60	80	0.628	79.2	83.7	84.9	85.6	86.6	84	20
90	80	0.628	81.5	88.2	88.1	88.1	89.1	87	20

Q=10W, H=5mm, S=9.5mm										
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	33	0.309	54.4	57.2	58.6	59.5	60.3	58	20
30	33	0.309	57.5	59.2	59.9	60.9	62.5	60	20
45	33	0.309	58.7	61.1	62.1	63.4	64.7	62	20
60	33	0.309	62.8	64.2	65.2	65.6	67.2	65	20
90	33	0.309	65.4	66.9	67.8	69.2	70.7	68	20

Q=20W, H=5mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	53	0.377	85.1	86.9	87.8	89.1	91.1	88	20
30	53	0.377	87.4	88.3	90.1	91.3	92.9	90	20
45	53	0.377	88.9	90.9	91.8	93.7	94.7	92	20
60	53	0.377	91.7	93.8	95.4	96.3	97.8	95	20
90	53	0.377	94.7	97.1	97.9	98.7	101.6	98	20

Q=30W, H=5mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	63	0.479	114.9	116.7	117.8	119.5	121.1	118	20
30	63	0.479	116.8	118.4	119.5	121.6	123.7	120	20
45	63	0.479	118.7	120.1	121.2	123.7	126.3	122	20
60	63	0.479	120.6	123.5	125.1	126.9	128.9	125	20
90	63	0.479	124.3	126.1	127.9	130.1	131.6	128	20

Q=40W, H=5mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	71	0.564	138.5	141.6	143.5	144.5	146.9	143	20
30	71	0.564	140.6	143.4	145.6	146.7	148.7	145	20
45	71	0.564	142.7	145.2	147.7	148.9	150.5	147	20
60	71	0.564	144.8	148.6	150.6	152.4	153.6	150	20
90	71	0.564	148.1	152.6	153.4	154.6	156.3	153	20

Q=50W, H=5mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	80	0.628	161.7	163.9	165.8	168.9	169.7	166	20
30	80	0.628	163.5	165.9	167.4	171.1	172.1	168	20
45	80	0.628	165.3	167.9	169	173.3	174.5	170	20
60	80	0.628	167.5	171.6	173.5	175.5	176.9	173	20
90	80	0.628	170.8	174.8	176.9	177.7	179.8	176	20

Q=10W, H=10mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	33	0.309	43.8	45.8	46.9	48.6	49.9	47	20
30	33	0.309	46.3	47.4	48.9	50.5	51.9	49	20
45	33	0.309	49.1	50.8	51.1	51.7	52.3	51	20
60	33	0.309	51.9	52.6	53.3	55.1	57.1	54	20
90	33	0.309	54.7	54.4	55.5	58.5	61.9	57	20

Q=20W, H=10mm, S= 9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	53	0.377	65.6	68.8	70.6	71.5	73.5	70	20
30	53	0.377	68.4	70.7	71.7	73.7	75.5	72	20
45	53	0.377	71.2	72.6	72.8	75.9	77.5	74	20
60	53	0.377	74.2	75.8	77.4	78.1	79.5	77	20
90	53	0.377	77.2	79	80.2	81.5	82.1	80	20

Q=30W, H=10mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	63	0.479	87.4	88.3	89.9	91.5	92.9	90	20
30	63	0.479	88.9	90.8	91.9	93.6	94.8	92	20
45	63	0.479	90.6	93.2	94.3	95.1	96.8	94	20
60	63	0.479	93.4	96.7	96.9	98.1	99.9	97	20
90	63	0.479	96.5	99.1	100.1	101.1	103.2	100	20

Q=40W, H=10mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	71	0.564	105.8	109.1	112.8	113.2	114.1	111	20
30	71	0.564	108.1	112.1	113.9	114.6	116.3	113	20
45	71	0.564	110.4	115.1	115.1	115.9	118.5	115	20
60	71	0.564	113.6	116.5	118.9	119.6	121.4	118	20
90	71	0.564	116.8	117.9	122.7	123.3	124.3	121	20

Q=50W, H=10mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	80	0.628	121.5	124.6	126.5	127.8	129.6	126	20
30	80	0.628	124.3	126.1	127.9	130.1	131.6	128	20
45	80	0.628	127.1	127.6	129.3	132.4	133.6	130	20
60	80	0.628	129.9	130.6	133.2	135.1	136.2	133	20
90	80	0.628	132.7	133.6	137.1	137.8	138.8	136	20

Q=10W, H=15mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	33	0.309	40.6	41.8	42.6	43.4	44.1	42.5	20
30	33	0.309	41.8	43.6	43.8	44.6	46.2	44	20
45	33	0.309	43.9	45.4	45.9	46.5	48.3	46	20
60	33	0.309	45.4	47.5	47.9	48.8	50.4	48	20
90	33	0.309	47.3	50.5	51.6	52.1	53.5	51	20

Q=20W, H=15mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	53	0.377	55.3	58.8	60.5	61.1	61.8	59.5	20
30	53	0.377	58.5	59.9	60.7	62.4	63.5	61	20
45	53	0.377	60.9	61.8	62.8	63.9	65.6	63	20
60	53	0.377	63.3	64.9	65.9	67.1	68.8	66	20
90	53	0.377	65.7	68	69	70.3	72	69	20

Q=30W, H=15mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	63	0.479	72.2	74.5	76.9	77.9	78.5	76	20
30	63	0.479	74.1	76.9	78.4	79.5	81.1	78	20
45	63	0.479	77.2	79	80.2	81.5	82.1	80	20
60	63	0.479	78.9	82.7	83.5	84.4	85.5	83	20
90	63	0.479	80.6	86.2	87.1	87.5	88.6	86	20

Q=40W, H=15mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	71	0.564	89.9	91.1	92.3	94.1	95.1	92.5	20
30	71	0.564	90.5	93.3	94.4	95.1	96.7	94	20
45	71	0.564	92.2	95.1	96.8	97.1	98.9	96	20
60	71	0.564	94.8	97.9	98.9	100.9	102.5	99	20
90	71	0.564	96.8	100.3	102.9	104.9	105.1	102	20

Q=50W, H=15mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	80	0.628	99.4	102.6	103.8	106.4	107.8	104	20
30	80	0.628	102.1	104.6	105.8	107.9	109.6	106	20
45	80	0.628	104.8	106.6	107.8	109.4	111.4	108	20
60	80	0.628	107.5	108.9	111.1	112.9	114.6	111	20
90	80	0.628	110.2	111.2	114.4	116.4	117.8	114	20

Q=10W, H=20mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	33	0.309	36.3	36.8	37.2	38.1	39.1	37.5	20
30	33	0.309	37.6	38.1	38.7	39.5	41.1	39	20
45	33	0.309	39.9	40.1	40.8	41.1	43.1	41	20
60	33	0.309	41.9	43.4	43.8	44.7	46.2	44	20
90	33	0.309	44.9	46.1	46.9	47.5	49.6	47	20

Q=20W, H=20mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	53	0.377	49.1	50.8	51.1	51.7	52.3	51	20
30	53	0.377	50.9	51.6	52.8	54.6	55.1	53	20
45	53	0.377	51.9	53.2	55.6	57.2	57.1	55	20
60	53	0.377	54.5	56.8	58.4	59.8	60.5	58	20
90	53	0.377	57.1	60.4	61.2	62.4	63.9	61	20

Q=30W, H=20mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	63	0.479	18.5	19.1	19.8	21.5	22.4	20.27	20
30	63	0.479	18.1	18.8	19.6	21.4	22.3	20.03	20
45	63	0.479	17.7	18.5	19.4	21.3	22.1	19.79	20
60	63	0.479	17.3	18.1	19.1	20.7	21.9	19.43	20
90	63	0.479	16.9	17.8	18.7	20.2	21.6	19.05	20

Q=40W, H=20mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	71	0.564	74.2	76.8	78.5	79.4	74.2	78	20
30	71	0.564	77.3	78.9	80.2	81.5	77.3	80	20
45	71	0.564	79.1	82.3	83.7	84.4	79.1	82	20
60	71	0.564	81.1	85.7	87.1	87.5	81.1	85	20
90	71	0.564	83.3	85.9	88.8	90.5	83.3	88	20

Q=50W, H=20mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	80	0.628	84.9	86.9	87.8	89.3	91.1	88	20
30	80	0.628	57.2	88.5	90.1	91.3	92.9	90	20
45	80	0.628	88.9	90.9	91.8	93.6	94.8	92	20
60	80	0.628	91.7	93.8	95.3	96.3	97.9	95	20
90	80	0.628	94.2	97.3	97.9	98.9	101.7	98	20

Q=10W, H=25mm, S=9.5mm										
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	33	0.309	32.3	33.6	34.9	35.6	36.1	34.5	20
30	33	0.309	34.2	35.6	35.9	36.8	37.5	36	20
45	33	0.309	36.9	37.5	37.9	38.4	39.3	38	20
60	33	0.309	39.9	40.1	40.7	41.1	43.2	41	20
90	33	0.309	41.9	43.6	43.8	44.5	46.2	44	20

Q=20W, H=25mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	53	0.377	43.8	45.5	45.8	46.4	48.3	46	20
30	53	0.377	45.4	47.6	47.8	48.8	50.4	48	20
45	53	0.377	47.3	50.6	51.5	52.1	53.5	50	20
60	53	0.377	50.8	51.7	52.8	54.6	55.1	53	20
90	53	0.377	52.1	54.9	56.9	57.8	58.3	56	20

Q=30W, H=25mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	63	0.479	54.6	56.7	58.4	59.8	60.5	58	20
30	63	0.479	57.3	59.4	59.9	60.9	62.5	60	20
45	63	0.479	58.9	60.7	62.3	63.4	64.7	62	20
60	63	0.479	62.6	64.4	65.1	65.6	67.3	65	20
90	63	0.479	65.3	66.9	67.8	69.4	70.6	68	20

Q=40W, H=25mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	71	0.564	65.1	67.1	69.5	70.4	72.9	69	20
30	71	0.564	68.6	69.3	71.4	72.6	73.1	71	20
45	71	0.564	70.4	71.2	73.2	74.6	75.6	73	20
60	71	0.564	72.1	74.8	76.7	77.9	78.5	76	20
90	71	0.564	74.8	77.4	78.6	81.3	82.9	79	20

Q=50W, H=25mm, S=9.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	80	0.628	73.2	76.1	77.5	78.1	80.1	77	20
30	80	0.628	74.9	77.5	78.2	81.5	82.9	79	20
45	80	0.628	76.9	79.3	81.2	83.5	84.1	81	20
60	80	0.628	79.3	83.7	84.8	85.7	86.5	84	20
90	80	0.628	81.3	88.2	88.1	88.1	89.3	87	20

Q=10W, H=5mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	33	0.309	58.8	60.8	62.3	63.3	64.8	62	20
30	33	0.309	62.1	63.2	64.2	64.1	66.4	64	20
45	33	0.309	65.4	65.6	66.1	64.7	68.2	66	20
60	33	0.309	67.2	67.9	68.9	69.5	71.5	69	20
90	33	0.309	69.1	70.2	71.6	74.3	74.8	72	20

Q=20W, H=5mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	53	0.377	91.5	93.8	95.5	96.4	97.8	95	20
30	53	0.377	93.1	95.9	97.2	98.7	100.1	97	20
45	53	0.377	94.7	97.9	98.9	101.1	102.4	99	20
60	53	0.377	97.1	100.8	102.8	103.9	105.4	102	20
90	53	0.377	99.5	103.7	106.7	106.7	108.4	105	20

Q=30W, H=5mm, S= S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	63	0.479	120.5	123.4	125.6	126.7	128.8	125	20
30	63	0.479	123.2	125.4	126.9	128.9	130.6	127	20
45	63	0.479	125.9	127.4	128.2	131.1	132.4	129	20
60	63	0.479	128.6	130.6	131.7	133.9	135.2	132	20
90	63	0.479	131.3	133.8	134.8	136.9	138.2	135	20

Q=40W, H=5mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	71	0.564	146.2	151.5	152.3	154.1	155.9	152	20
30	71	0.564	148.6	153.4	154.6	155.6	157.8	154	20
45	71	0.564	151.2	155.3	156.7	157.1	159.7	156	20
60	71	0.564	154.8	157.9	158.9	160.8	162.6	159	20
90	71	0.564	157.9	160.8	161.9	163.8	165.6	162	20

Q=50W, H=5mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	80	0.628	170.8	173.8	174.9	176.6	178.9	175	20
30	80	0.628	172.6	175.9	176.4	178.9	181.2	177	20
45	80	0.628	174.4	177.5	178.4	181.2	183.5	179	20
60	80	0.628	176.4	180.4	182.3	184.6	186.2	182	20
90	80	0.628	178.9	182.7	185.5	187.8	190.1	185	20

Q=10W, H=10mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	33	0.309	49.3	50.4	51.3	51.7	52.3	51	20
30	33	0.309	50.9	51.7	52.8	54.7	54.9	53	20
45	33	0.309	51.8	53.2	55.6	57.2	57.2	55	20
60	33	0.309	54.2	56.9	58.5	59.7	60.7	58	20
90	33	0.309	57.2	60.6	61.5	62.3	63.4	61	20

Q=20W, H=10mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	53	0.377	73.1	76.2	77.4	78.1	80.2	77	20
30	53	0.377	75.1	77.5	78.2	81.3	82.9	79	20
45	53	0.377	76.9	79.1	81.2	83.5	84.3	81	20
60	53	0.377	79.5	83.7	84.8	85.7	86.3	84	20
90	53	0.377	85.3	86.9	88.2	88.9	90.7	87	20

Q=30W, H=10mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	63	0.479	94.9	97.7	98.7	101.1	102.6	99	20
30	63	0.479	96.7	99.3	101.4	103.4	104.2	101	20
45	63	0.479	98.6	101.3	103.1	105.3	106.7	103	20
60	63	0.479	99.9	103.5	104.8	107.9	108.9	106	20
90	63	0.479	104.9	107.8	109.3	110.9	112.1	109	20

Q=40W, H=10mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	71	0.564	118.7	120.1	121.2	123.7	126.3	122	20
30	71	0.564	119.3	122.6	124.4	125.8	127.9	124	20
45	71	0.564	119.9	125.1	127.6	127.9	129.5	126	20
60	71	0.564	125.9	127.2	128.2	131.1	132.6	129	20
90	71	0.564	128.6	130.6	131.7	133.9	135.2	132	20

Q=50W, H=10mm , S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	80	0.628	136.3	138.6	140.2	141.3	143.6	140	20
30	80	0.628	138.5	140.4	142.1	143.2	145.8	142	20
45	80	0.628	140.6	142.3	144.4	145.2	147.5	144	20
60	80	0.628	142.7	145.3	147.7	148.9	150.4	147	20
90	80	0.628	144.8	148.6	150.6	152.4	153.6	150	20

Q=10W, H=15mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	33	0.309	41.7	43.5	43.9	44.5	46.4	44	20
30	33	0.309	43.8	45.6	45.8	46.5	48.3	46	20
45	33	0.309	45.4	47.6	47.8	48.6	50.6	48	20
60	33	0.309	47.3	50.6	51.5	52.3	53.3	51	20
90	33	0.309	50.8	51.7	52.6	54.6	55.3	54	20

Q=20W, H=15mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	53	0.377	62.9	64.5	65.3	66.3	68.5	65.5	20
30	53	0.377	66.3	66.4	67.5	65.6	69.2	67	20
45	53	0.377	67.2	67.9	68.9	69.5	71.5	69	20
60	53	0.377	69.2	70.9	71.2	73.6	75.1	72	20
90	53	0.377	71.2	73.9	73.5	77.7	78.7	75	20

Q=30W, H=15mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	63	0.479	79.1	82.5	83.3	84.6	85.5	83	20
30	63	0.479	80.9	83.6	85.7	86.9	87.9	85	20
45	63	0.479	82.7	84.7	88.1	89.2	90.3	87	20
60	63	0.479	85.1	87.9	90.9	92.4	93.7	90	20
90	63	0.479	87.9	90.9	93.9	95.8	96.5	93	20

Q=40W, H=15mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	71	0.564	97.3	100.6	102.8	103.9	105.4	102	20
30	71	0.564	99.2	103.2	104.8	105.9	106.9	104	20
45	71	0.564	101.1	105.8	106.8	107.9	108.4	106	20
60	71	0.564	104.9	107.8	109.3	110.9	112.1	109	20
90	71	0.564	108.2	110.6	112.2	113.8	115.2	112	20

Q=50W, H=15mm, S= S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	80	0.628	110.5	113.6	115.6	116.8	118.5	115	20
30	80	0.628	112.7	115.6	117.6	118.6	120.5	117	20
45	80	0.628	114.9	117.6	119.6	120.4	122.5	119	20
60	80	0.628	117.8	120.3	122.7	123.9	125.3	122	20
90	80	0.628	120.8	123.3	125.9	126.8	128.2	125	20

Q=10W, H=20mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	33	0.309	37.9	39.4	39.9	40.9	41.9	40	20
30	33	0.309	54.4	57.2	58.6	59.5	60.3	58	20
45	33	0.309	57.3	58.4	60.3	61.5	62.5	60	20
60	33	0.309	60.2	61.8	63.6	64.1	65.3	63	20
90	33	0.309	63.1	65.2	66.9	66.7	68.1	66	20

Q=20W, H=20mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	53	0.377	54.5	57.3	58.7	59.3	60.2	58	20
30	53	0.377	57.1	58.5	60.4	61.5	62.5	60	20
45	53	0.377	58.9	60.7	62.3	63.3	64.8	62	20
60	53	0.377	62.6	64.4	64.9	65.8	67.3	65	20
90	53	0.377	65.3	66.9	67.7	69.5	70.6	68	20

Q=30W, H=20mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	63	0.479	69.2	70.9	71.2	73.6	75.1	72	20
30	63	0.479	71.2	72.7	72.8	75.8	77.5	74	20
45	63	0.479	72.3	73.8	75.9	78.1	79.9	76	20
60	63	0.479	74.3	77.8	79.7	80.9	82.3	79	20
90	63	0.479	76.3	81.8	83.5	83.7	84.7	82	20

Q=40W, H=20mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	71	0.564	84.5	87.1	89.3	91.1	92.8	89	20
30	71	0.564	86.1	89.6	91.6	93.4	94.3	91	20
45	71	0.564	87.9	90.9	93.9	95.8	96.5	93	20
60	71	0.564	90.6	94.6	96.8	98.6	99.4	96	20
90	71	0.564	93.3	98.3	99.7	101.4	102.3	99	20

Q=50W, H=20mm, S= S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	80	0.628	93.1	98.6	99.7	101.5	102.1	99	20
30	80	0.628	96.6	99.6	101.9	102.6	104.3	101	20
45	80	0.628	100.1	100.6	104.1	103.7	106.5	103	20
60	80	0.628	103.6	101.6	106.3	104.8	108.7	106	20
90	80	0.628	104.9	107.8	109.3	110.9	112.1	109	20

Q=10W, H=25mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	33	0.309	34.9	36.4	37.2	37.4	39.1	37	20
30	33	0.309	37.4	38.3	38.7	39.3	41.3	39	20
45	33	0.309	39.9	40.2	40.2	41.2	43.5	41	20
60	33	0.309	41.9	43.4	43.7	44.5	46.5	44	20
90	33	0.309	45.1	46.1	46.7	47.5	49.6	47	20

Q=20W, H=25mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	53	0.377	49.7	51.7	51.9	52.8	53.9	52	20
30	53	0.377	51.8	52.4	53.3	55.3	57.2	54	20
45	53	0.377	54.1	54.5	56.1	58.5	61.8	56	20
60	53	0.377	55.2	57.1	58.1	60.5	64.1	59	20
90	53	0.377	57.4	60.2	61.5	63.4	67.5	62	20

Q=30W, H=25mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	63	0.479	62.9	63.7	64.9	65.8	67.8	65	20
30	63	0.479	64.9	66.2	66.9	67.8	69.2	67	20
45	63	0.479	66.9	68.7	68.5	69.8	71.1	69	20
60	63	0.479	69.2	70.9	71.2	73.6	75.1	72	20
90	63	0.479	71.2	73.9	73.5	77.7	78.7	75	20

Q=40W, H=25mm, S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	71	0.564	72.5	75.9	77.6	78.7	80.3	78	20
30	71	0.564	74.3	77.8	79.7	80.9	82.3	80	20
45	71	0.564	76.3	81.8	83.5	83.7	84.7	82	20
60	71	0.564	80.9	83.6	85.7	86.9	87.9	85	20
90	71	0.564	84.1	86.5	88.6	89.9	90.9	88	20

Q=50W, H=25mm, S= S=13.5mm									
θ°	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
0	80	0.628	84.1	86.3	88.1	90.3	91.2	88	20
30	80	0.628	85.1	87.9	90.9	92.4	93.7	90	20
45	80	0.628	86.1	89.5	93.7	94.5	96.2	92	20
60	80	0.628	88.7	93.4	96.5	97.2	99.3	95	20
90	80	0.628	92.4	96.5	98.8	99.9	102.1	98	20

Table B3 Observation Table of Vertical Plate Heat Sink in Mixed Convection

v=0.8 m/s H=25mm,Q=50W									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	80	0.628	64	63	65	66	67	65	20
7	80	0.628	61	62	63	61	63	62	20
9.5	80	0.628	67	68	66	65	69	67	20
13.5	80	0.628	75	76	74	74	76	75	20
17	80	0.628	85	83	84	82	86	84	20

v=1.00 m/s H=25mm,Q=50W									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	80	0.628	64	65	63	62	66	64	20
7	80	0.628	61	62	59	58	60	60	20
9.5	80	0.628	68	67	63	63	69	66	20
13.5	80	0.628	79	78	76	76	81	78	20
17	80	0.628	86	87	85	84	88	86	20

v=1.2 m/s H=25mm,Q=50W									
S(mm)	V(volt)	I(Amp)	T_1(°C)	T_2 °C)	T_3(°C)	T_4(°C)	T_5(°C)	Tw(°C)	Ta(°C)
5.5	80	0.628	64	62	61	59	64	62	20
7	80	0.628	56	57	55	54	58	56	20
9.5	80	0.628	61	62	60	59	63	61	20
13.5	80	0.628	82	80	79	78	81	80	20
17	80	0.628	90	92	88	87	93	90	20

APPENDIX C

Artificial Neural Network

C1 Development of ANN Model for Inclined Plate Heat Sink

The regression plots represent the training, validation, and testing data. The solid line represents the best-fit linear regression line between outputs and targets. The R-value is 0.9859, approaching to 1 shows training data indicates a good fit.

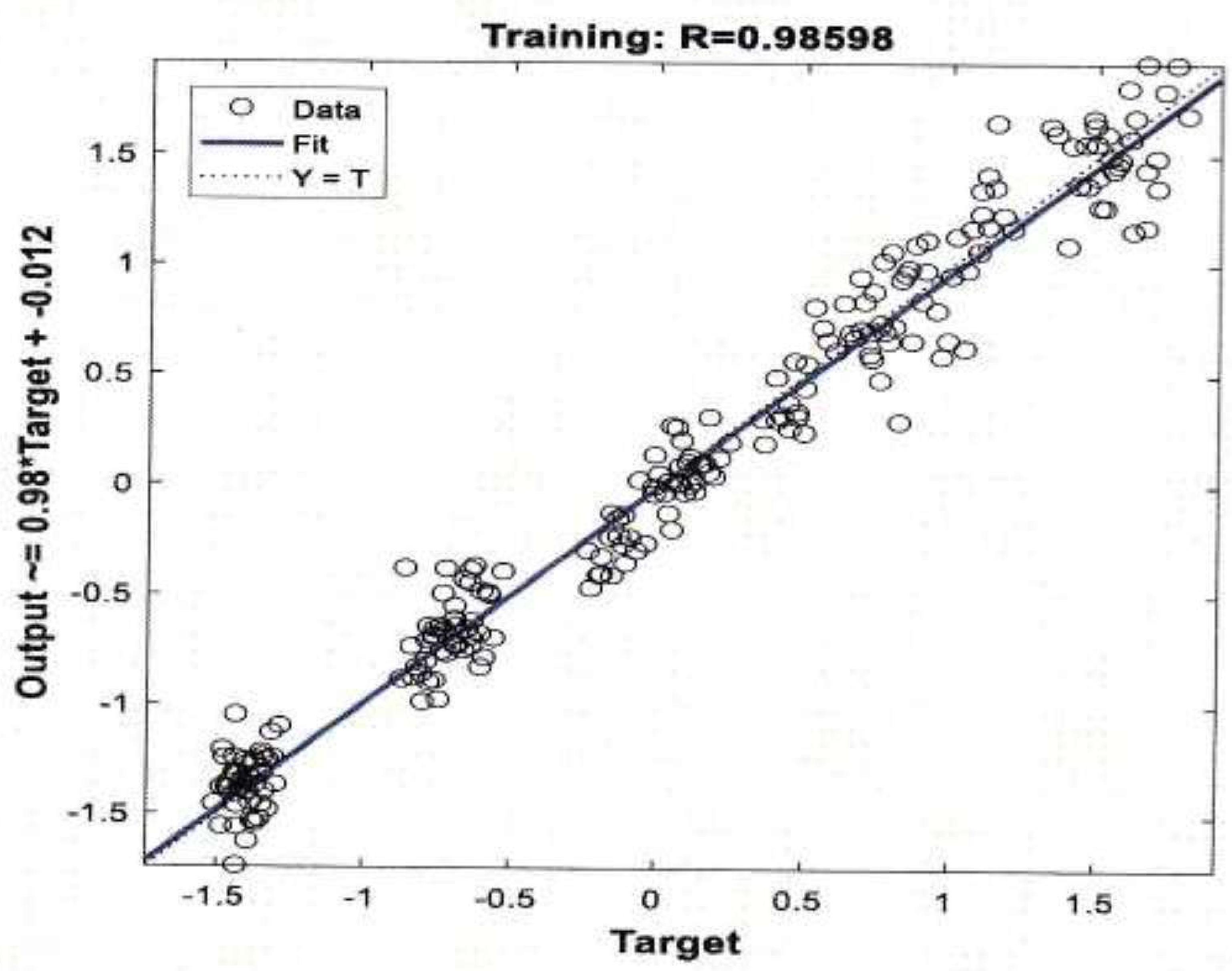


Figure C1 Regression Plot of Convective Heat Transfer Rate

The percentage error between the experimental results and ANN predicted values for Qc and ΔT is in shown in figure C2 and C3 respectively.

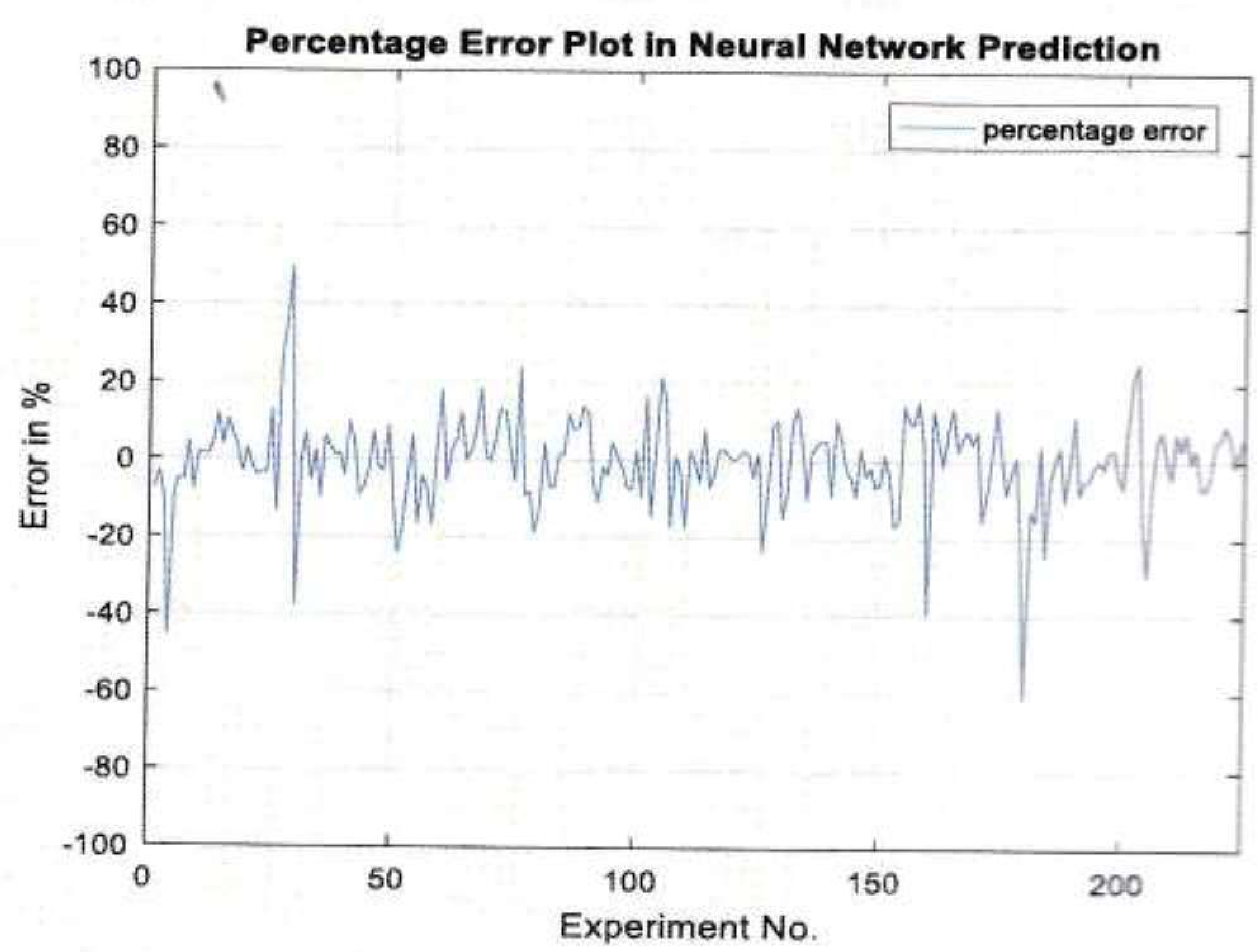


Figure C2 Percentage Error of Convective Heat Transfer Rate

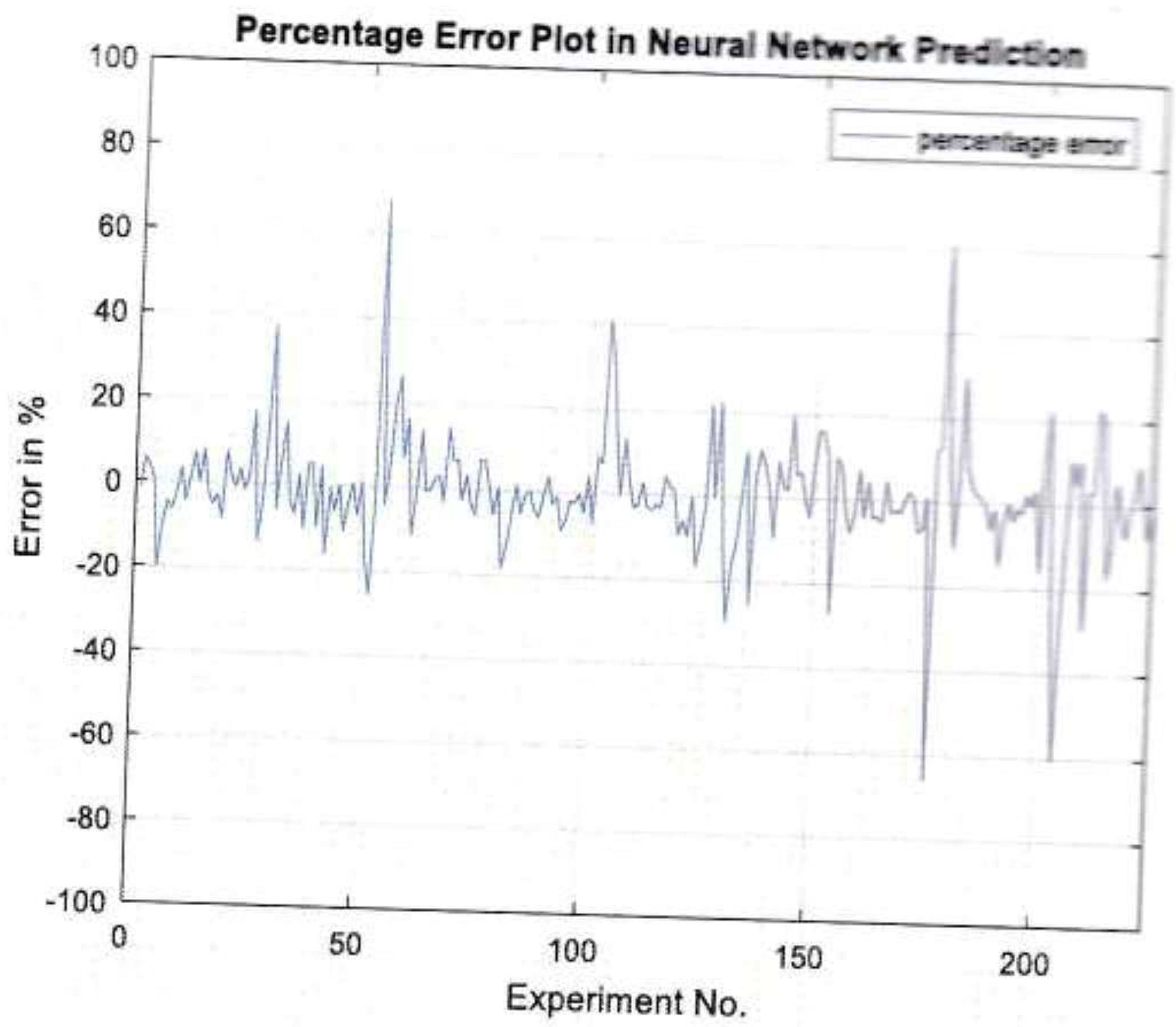


Figure C3 Percentage Error of Average Base to Ambient Temperature difference

C2 Comparison of Experimental and ANN Results for ΔT and QC for Inclined Plate Heat Sink

The predicted values by using ANN model and the experimental value of QC and ΔT for inclined plate heat sink are shown in figure C4 and C5.

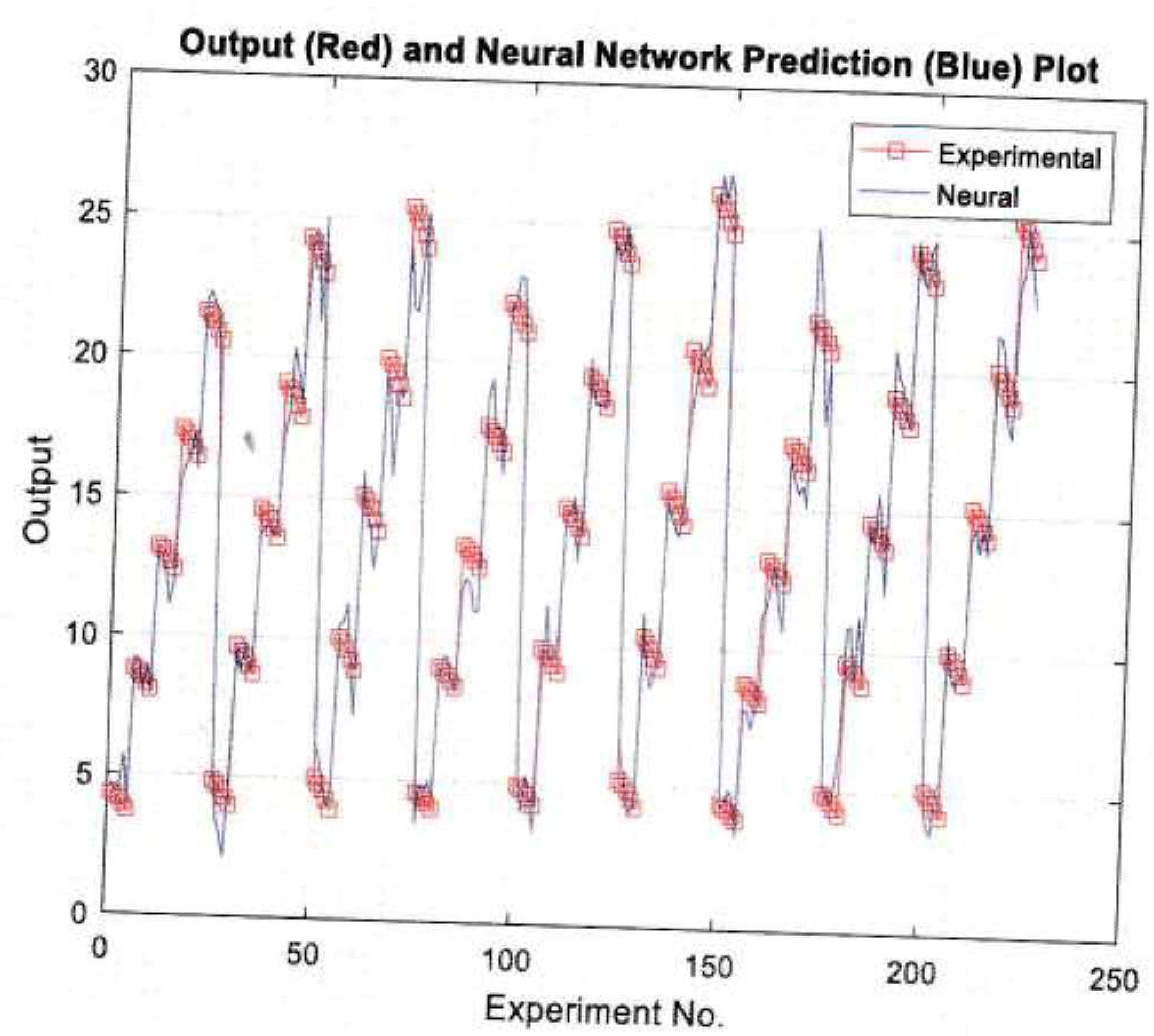


Figure C4 Comparison of Expt.and ANN Results for Convective Heat Transfer Rate

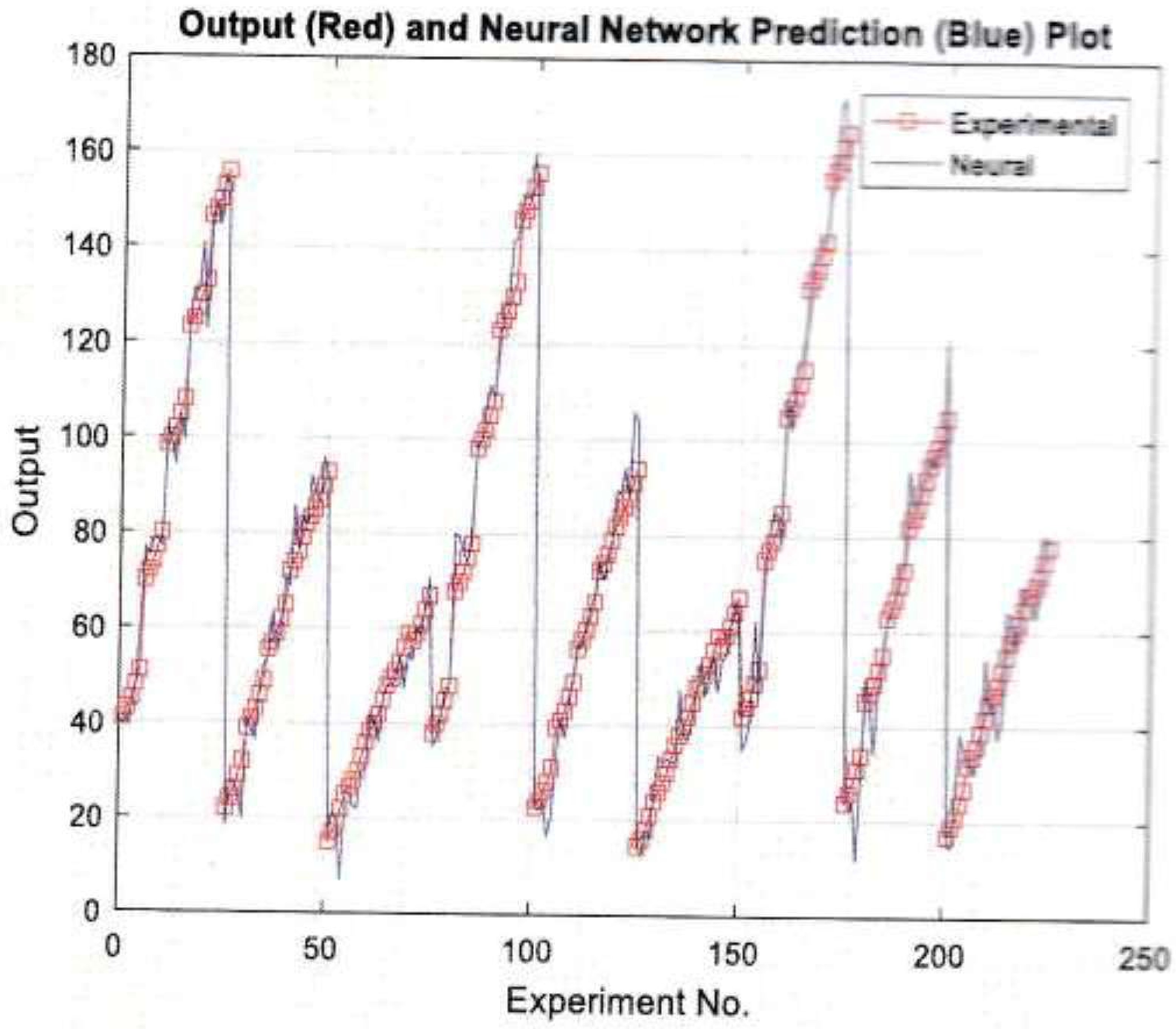


Figure C5 Comparison of Expt.and ANN Results for Average Base to Ambient Temperature difference

C3 Development of ANN Model for Vertical Plate Heat Sink in Mixed Convection

The regression plots represent the training, validation, and testing data. The dashed line in figure C6, represents the perfect result – outputs = targets. The solid line represents the best-fit linear regression line between outputs and targets.

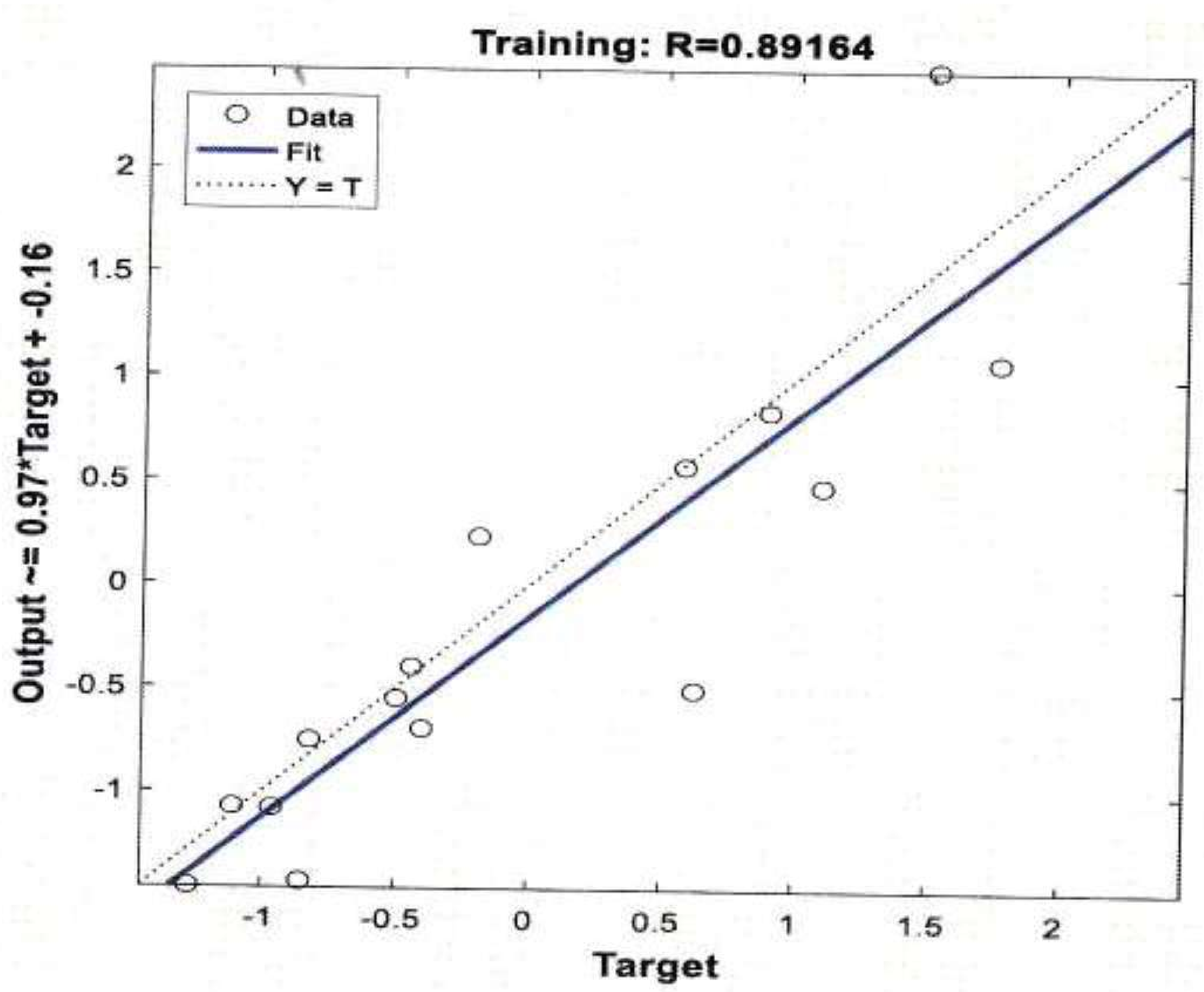


Figure C6 Regression Plot for Nusselt Number

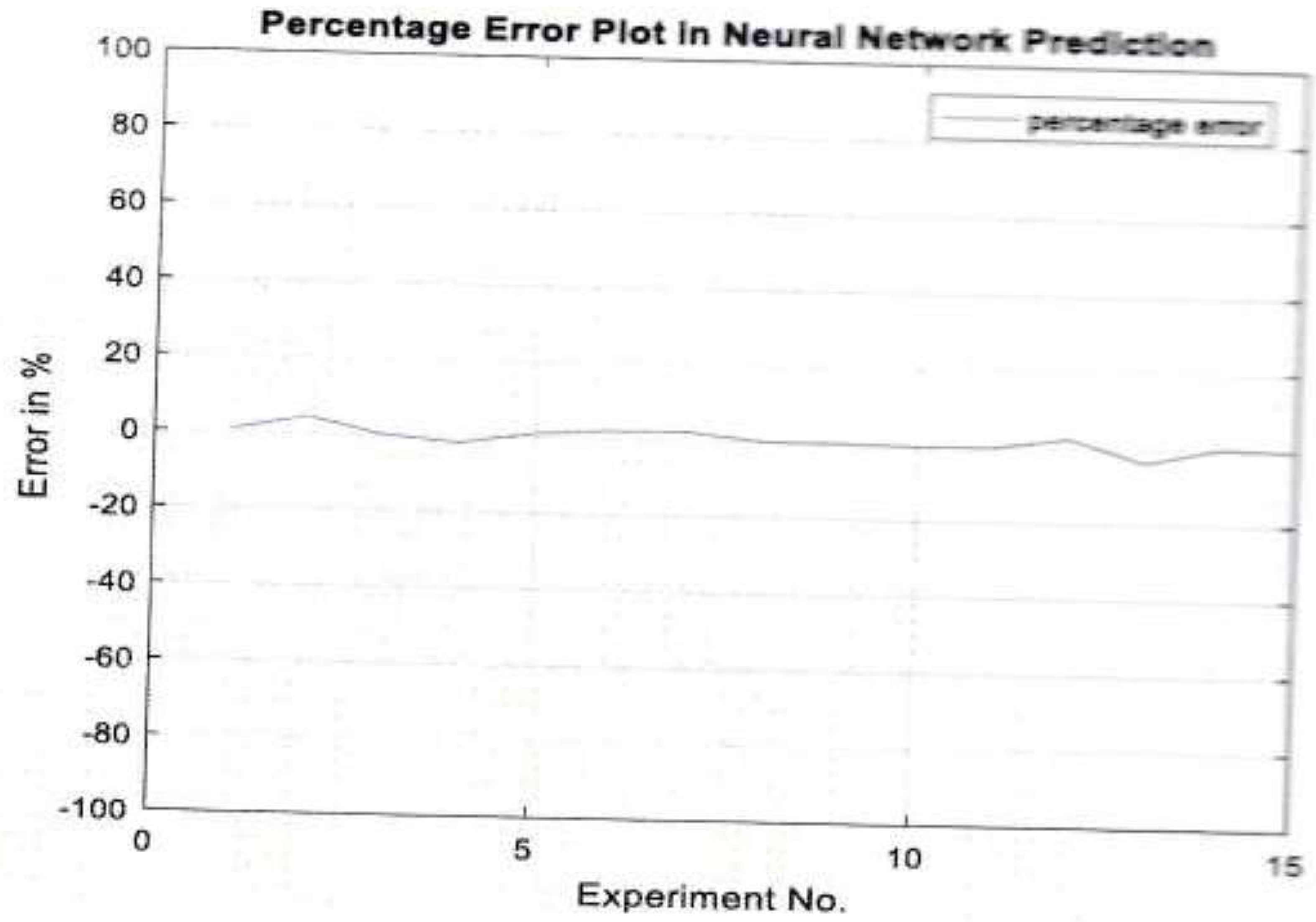


Figure C7 Percentage Error of Convective Heat Transfer Rate

C4 Comparison of Experimental and ANN Results for ΔT and QC for Mixed Convection

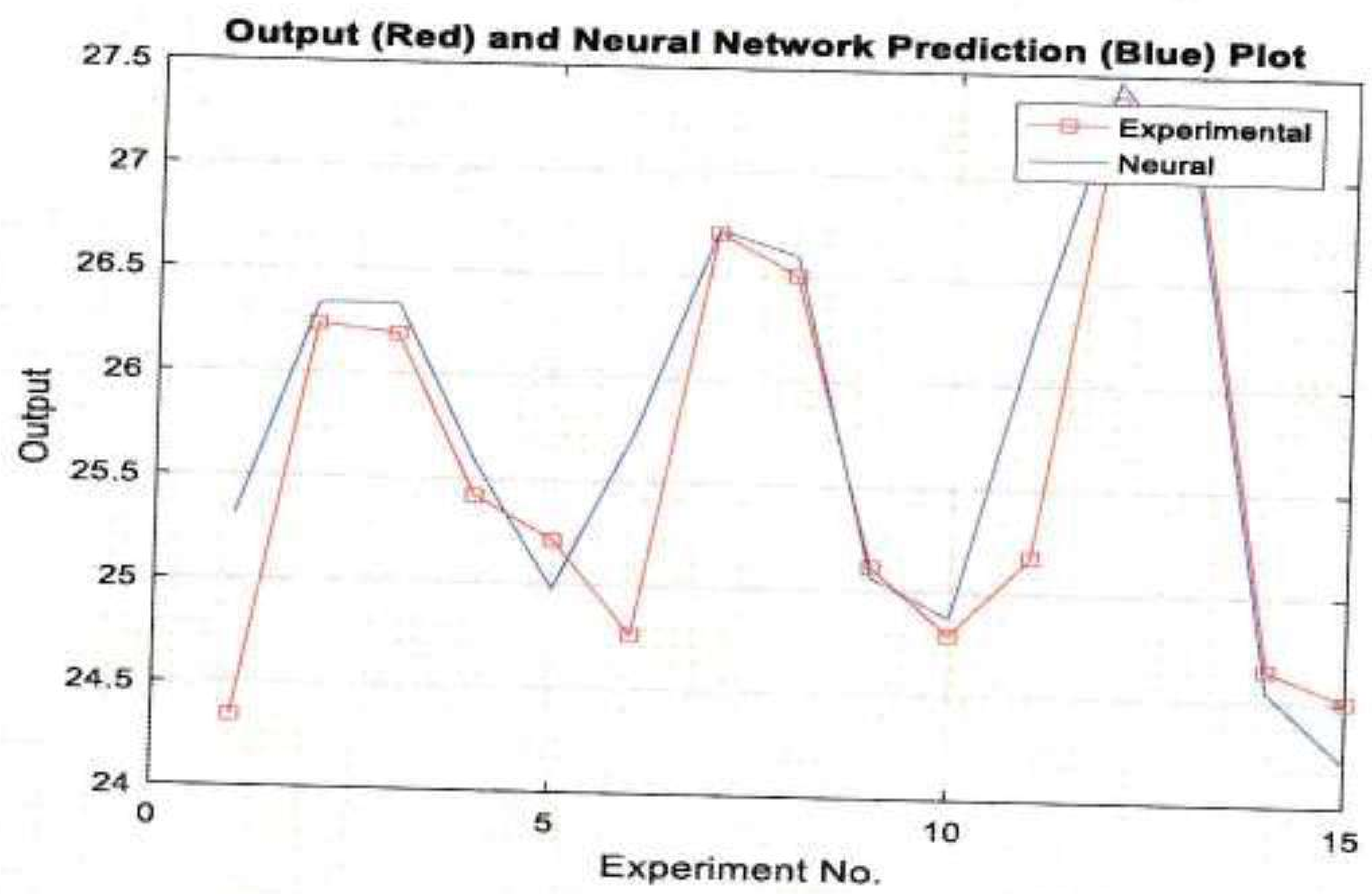


Figure C8 Comparison of Expt.and ANN Results for Convective Heat Transfer Rate

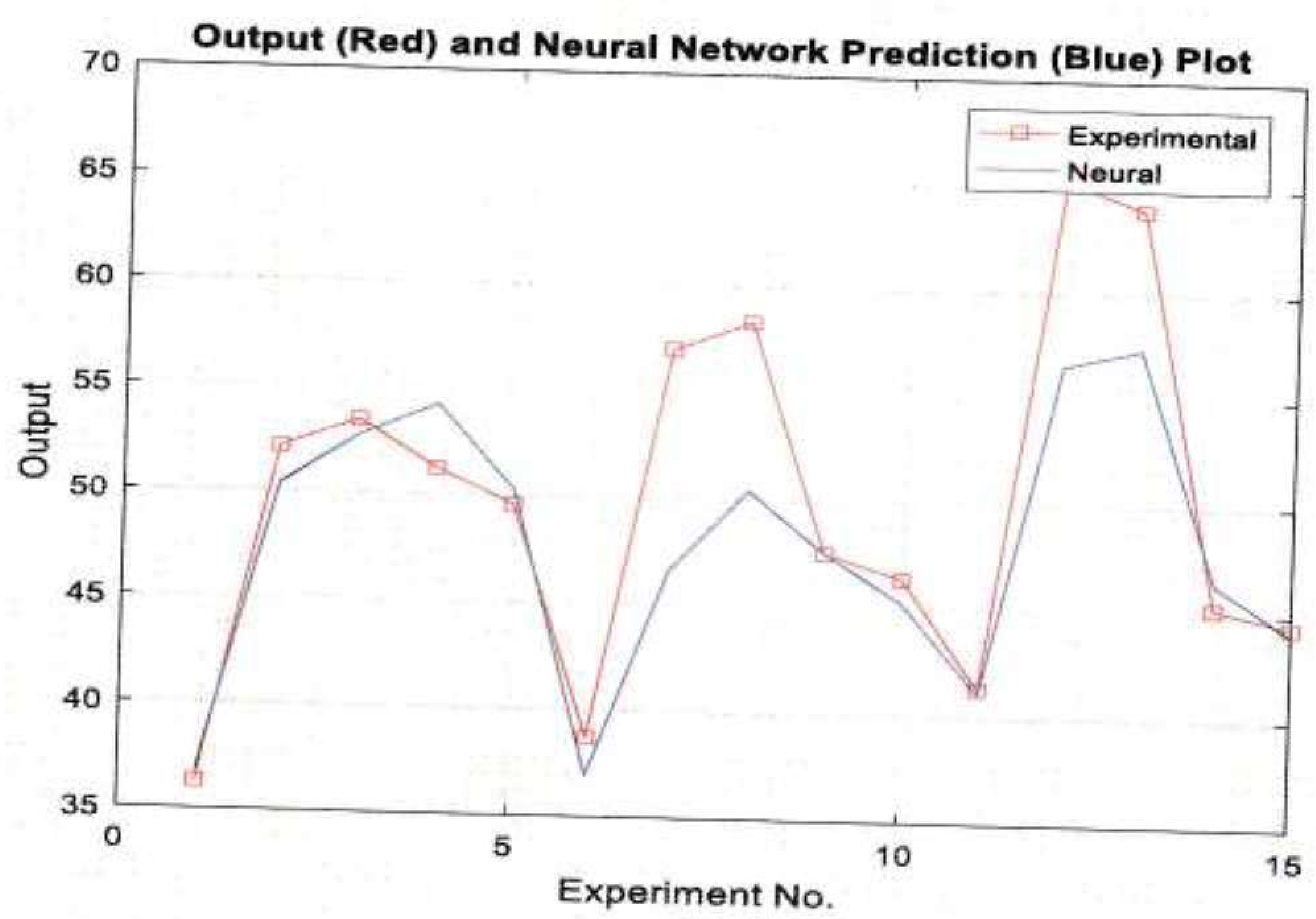


Figure C9 Comparison of Expt.and ANN Results for Nusselt number

Table C1 Percentage Error of ΔT using RSM and ANN for Inclined Plate Heat Sink

Total run	cosθ	H(mm)	S(mm)	Q(W)	ΔT_{Expt} (°C)	ΔT_{RSM} (°C)	%Error RSM	ΔT_{ANN} (°C)	%Error ANN
1	1	5	7	10	41	42.94	4.74	41.50	1.21
2	0.866	5	7	10	43	45.05	4.76	40.44	5.95
3	0.707	5	7	10	45	47.23	4.97	43.25	3.88
4	0.5	5	7	10	48	49.58	3.29	47.71	0.61
5	0	5	7	10	51	52.89	3.70	61.20	20.01
6	1	5	7	20	70	71.05	1.50	76.87	9.81
7	0.866	5	7	20	72	73.16	1.61	75.22	4.48
8	0.707	5	7	20	74	75.35	1.82	78.67	6.31
9	0.5	5	7	20	77	77.70	0.90	78.79	2.33
10	0	5	7	20	80	81.01	1.27	77.20	3.50
11	1	5	7	30	98.5	97.24	1.28	102.73	4.30
12	0.866	5	7	30	100	99.35	0.65	98.89	1.11
13	0.707	5	7	30	102	101.54	0.45	94.46	7.39
14	0.5	5	7	30	105	103.89	1.05	104.75	0.24
15	0	5	7	30	108	107.22	0.72	99.54	7.83
16	1	5	7	40	123.3	121.51	1.45	126.03	2.21
17	0.866	5	7	40	125	123.62	1.10	131.18	4.95
18	0.707	5	7	40	127	125.82	0.93	130.47	2.73
19	0.5	5	7	40	130	128.17	1.41	140.86	8.36
20	0	5	7	40	133	131.51	1.12	122.87	7.61
21	1	5	7	50	146.5	143.85	1.81	143.98	1.72
22	0.866	5	7	50	148	145.97	1.37	149.05	0.71
23	0.707	5	7	50	150	148.17	1.22	144.80	3.46
24	0.5	5	7	50	153	150.53	1.61	154.78	1.16
25	0	5	7	50	156	153.88	1.36	153.10	1.86
26	1	15	7	10	22	18.10	17.74	18.19	17.31
27	0.866	15	7	10	24	20.20	15.84	27.20	13.33
28	0.707	15	7	10	26	22.38	13.92	27.11	4.25
29	0.5	15	7	10	29	24.72	14.77	25.41	12.36
30	0	15	7	10	32	28.01	12.46	19.96	37.63
31	1	15	7	20	39	38.32	1.75	41.21	5.68
32	0.866	15	7	20	41	40.42	1.42	38.45	6.23
33	0.707	15	7	20	43	42.61	0.92	36.69	14.67
34	0.5	15	7	20	46	44.95	2.29	47.78	3.87
35	0	15	7	20	49	48.25	1.52	52.31	6.76
36	1	15	7	30	55.5	56.62	2.01	54.19	2.36
37	0.866	15	7	30	57	58.72	3.02	62.96	10.45
38	0.707	15	7	30	59	60.91	3.24	56.03	5.03
39	0.5	15	7	30	62	63.26	2.03	58.78	5.20
40	0	15	7	30	65	66.57	2.42	71.23	9.58
41	1	15	7	40	72	73.00	1.38	68.84	4.39
42	0.866	15	7	40	74	75.10	1.49	85.82	15.98
43	0.707	15	7	40	76	77.30	1.71	76.50	0.66
44	0.5	15	7	40	79	79.65	0.82	83.56	5.77

45	0	15	7	40	82	82.97	1.19	81.73	0.33
46	1	15	7	50	83.5	87.45	4.74	92.17	10.39
47	0.866	15	7	50	85	89.57	5.37	88.34	3.93
48	0.707	15	7	50	87	91.76	5.47	86.33	0.77
49	0.5	15	7	50	90	94.12	4.57	96.02	6.69
50	0	15	7	50	93	97.45	4.79	91.83	1.26
51	1	25	7	10	15	16.14	7.59	17.66	17.75
52	0.866	25	7	10	17	18.24	7.27	21.28	25.20
53	0.707	25	7	10	19	20.41	7.45	19.44	2.32
54	0.5	25	7	10	22	22.75	3.39	7.07	67.84
55	0	25	7	10	25	26.03	4.12	26.02	4.09
56	1	25	7	20	26.5	28.47	7.44	25.33	4.40
57	0.866	25	7	20	28	30.57	9.18	22.67	19.03
58	0.707	25	7	20	30	32.75	9.17	22.04	26.53
59	0.5	25	7	20	33	35.09	6.33	30.59	7.29
60	0	25	7	20	36	38.38	6.62	30.09	16.41
61	1	25	7	30	38.5	38.88	0.99	42.73	10.99
62	0.866	25	7	30	40	40.98	2.46	40.37	0.93
63	0.707	25	7	30	42	43.17	2.79	36.30	13.56
64	0.5	25	7	30	45	45.51	1.14	45.25	0.55
65	0	25	7	30	48	48.81	1.70	48.02	0.04
66	1	25	7	40	49.5	47.37	4.30	48.26	2.51
67	0.866	25	7	40	51	49.48	2.98	49.45	3.03
68	0.707	25	7	40	53	51.67	2.51	54.63	3.07
69	0.5	25	7	40	56	54.01	3.55	47.74	14.75
70	0	25	7	40	59	57.33	2.84	54.99	6.80
71	1	25	7	50	57.5	53.95	6.18	53.42	7.09
72	0.866	25	7	50	59	56.05	4.99	60.40	2.37
73	0.707	25	7	50	61	58.25	4.52	59.01	3.27
74	0.5	25	7	50	64	60.59	5.32	66.03	3.17
75	0	25	7	50	67	63.92	4.60	70.95	5.90
76	1	5	9.5	10	38	40.76	7.27	35.34	7.01
77	0.866	5	9.5	10	40	42.88	7.19	37.14	7.15
78	0.707	5	9.5	10	42	45.07	7.32	41.70	0.71
79	0.5	5	9.5	10	45	47.43	5.40	47.54	5.65
80	0	5	9.5	10	48	50.77	5.77	47.64	0.75
81	1	5	9.5	20	68	69.72	2.53	80.33	18.13
82	0.866	5	9.5	20	70	71.83	2.62	79.35	13.35
83	0.707	5	9.5	20	72	74.03	2.83	76.16	5.78
84	0.5	5	9.5	20	75	76.40	1.86	73.80	1.60
85	0	5	9.5	20	78	79.75	2.24	82.00	5.13
86	1	5	9.5	30	98	96.76	1.27	98.94	0.96
87	0.866	5	9.5	30	100	98.87	1.13	99.85	0.15
88	0.707	5	9.5	30	102	101.08	0.90	106.58	4.49
89	0.5	5	9.5	30	105	103.44	1.48	111.21	5.91
90	0	5	9.5	30	108	106.80	1.11	109.03	0.95
91	1	5	9.5	40	123	121.87	0.92	118.56	3.61
92	0.866	5	9.5	40	125	123.99	0.81	128.46	2.77

93	0.707	5	9.5	40	127	126.20	0.63	128.23	0.97
94	0.5	5	9.5	40	130	128.57	1.10	141.69	8.99
95	0	5	9.5	40	133	131.94	0.80	142.23	6.94
96	1	5	9.5	50	146	145.07	0.64	148.83	1.94
97	0.866	5	9.5	50	148	147.19	0.55	151.65	2.46
98	0.707	5	9.5	50	150	149.40	0.40	150.30	0.20
99	0.5	5	9.5	50	153	151.78	0.80	160.03	4.60
100	0	5	9.5	50	156	155.16	0.54	149.92	3.90
101	1	15	9.5	10	22.5	16.05	28.67	24.12	7.19
102	0.866	15	9.5	10	24	18.16	24.34	21.92	8.65
103	0.707	15	9.5	10	26	20.35	21.73	24.13	7.18
104	0.5	15	9.5	10	28	22.70	18.92	16.45	41.24
105	0	15	9.5	10	31	26.03	16.03	20.90	32.58
106	1	15	9.5	20	39.5	37.12	6.03	33.91	14.15
107	0.866	15	9.5	20	41	39.23	4.32	41.10	0.23
108	0.707	15	9.5	20	43	41.43	3.66	37.43	12.95
109	0.5	15	9.5	20	46	43.78	4.82	44.28	3.74
110	0	15	9.5	20	49	47.12	3.84	50.44	2.93
111	1	15	9.5	30	56	56.27	0.48	57.34	2.39
112	0.866	15	9.5	30	58	58.38	0.66	56.36	2.82
113	0.707	15	9.5	30	60	60.58	0.97	61.61	2.68
114	0.5	15	9.5	30	63	62.94	0.10	65.36	3.74
115	0	15	9.5	30	66	66.29	0.44	67.41	2.14
116	1	15	9.5	40	72.5	73.49	1.37	74.62	2.92
117	0.866	15	9.5	40	74	75.61	2.18	70.66	4.52
118	0.707	15	9.5	40	76	77.81	2.39	74.44	2.05
119	0.5	15	9.5	40	79	80.18	1.49	77.86	1.44
120	0	15	9.5	40	82	83.54	1.88	89.42	9.05
121	1	15	9.5	50	84	88.80	5.72	88.94	5.89
122	0.866	15	9.5	50	86	90.92	5.72	94.21	9.54
123	0.707	15	9.5	50	88	93.13	5.83	88.03	0.03
124	0.5	15	9.5	50	91	95.50	4.94	105.99	16.47
125	0	15	9.5	50	94	98.87	5.18	104.14	10.79
126	1	25	9.5	10	14.5	14.23	1.89	14.80	2.06
127	0.866	25	9.5	10	16	16.33	2.07	12.57	21.44
128	0.707	25	9.5	10	18	18.52	2.89	18.02	0.13
129	0.5	25	9.5	10	21	20.87	0.64	16.33	22.22
130	0	25	9.5	10	24	24.18	0.76	26.81	11.69
131	1	25	9.5	20	26	27.41	5.41	33.57	29.13
132	0.866	25	9.5	20	28	29.51	5.41	32.34	15.48
133	0.707	25	9.5	20	30	31.71	5.69	33.14	10.46
134	0.5	25	9.5	20	33	34.06	3.20	32.55	1.36
135	0	25	9.5	20	36	37.38	3.84	32.05	10.98
136	1	25	9.5	30	38	38.67	1.75	47.61	25.28
137	0.866	25	9.5	30	40	40.78	1.94	37.84	5.39
138	0.707	25	9.5	30	42	42.97	2.32	37.23	11.36
139	0.5	25	9.5	30	45	45.33	0.73	41.48	7.83
140	0	25	9.5	30	48	48.66	1.38	47.08	1.91

141	1	25	9.5	40	49	48.01	2.03	53.50	9.18
142	0.866	25	9.5	40	51	50.12	1.72	46.61	8.61
143	0.707	25	9.5	40	53	52.32	1.28	51.24	3.33
144	0.5	25	9.5	40	56	54.68	2.36	54.85	2.05
145	0	25	9.5	40	59	58.03	1.65	47.49	19.51
146	1	25	9.5	50	57	55.43	2.76	53.79	5.64
147	0.866	25	9.5	50	59	57.54	2.47	55.30	6.27
148	0.707	25	9.5	50	61	59.75	2.06	61.29	0.47
149	0.5	25	9.5	50	64	62.11	2.95	66.78	4.34
150	0	25	9.5	50	67	65.47	2.29	61.75	7.83
151	1	5	13.5	10	42	45.00	7.14	35.09	16.46
152	0.866	5	13.5	10	44	47.12	7.10	37.07	15.75
153	0.707	5	13.5	10	46	49.34	7.26	41.23	10.37
154	0.5	5	13.5	10	49	51.72	5.54	62.07	26.68
155	0	5	13.5	10	52	55.11	5.98	46.84	9.92
156	1	5	13.5	20	75	75.31	0.42	69.05	7.93
157	0.866	5	13.5	20	77	77.44	0.57	79.08	2.70
158	0.707	5	13.5	20	79	79.66	0.83	85.01	7.60
159	0.5	5	13.5	20	82	82.04	0.05	84.84	3.46
160	0	5	13.5	20	85	85.44	0.52	78.91	7.17
161	1	5	13.5	30	105	103.71	1.23	109.23	4.03
162	0.866	5	13.5	30	107	105.84	1.09	102.42	4.28
163	0.707	5	13.5	30	109	108.06	0.86	113.38	4.02
164	0.5	5	13.5	30	112	110.44	1.39	116.11	3.67
165	0	5	13.5	30	115	113.86	0.99	120.57	4.84
166	1	5	13.5	40	132	130.18	1.38	125.69	4.78
167	0.866	5	13.5	40	134	132.32	1.26	137.74	2.79
168	0.707	5	13.5	40	136	134.54	1.07	138.88	2.12
169	0.5	5	13.5	40	139	136.93	1.49	142.67	2.64
170	0	5	13.5	40	142	140.35	1.16	142.22	0.15
171	1	5	13.5	50	155	154.73	0.17	151.48	2.27
172	0.866	5	13.5	50	157	156.87	0.08	156.08	0.59
173	0.707	5	13.5	50	159	159.10	0.06	170.20	7.04
174	0.5	5	13.5	50	162	161.49	0.31	172.41	6.43
175	0	5	13.5	50	165	164.93	0.04	163.29	1.04
176	1	15	13.5	10	24	20.50	14.59	39.82	65.90
177	0.866	15	13.5	10	26	22.62	12.99	22.93	11.80
178	0.707	15	13.5	10	28	24.83	11.32	24.26	13.37
179	0.5	15	13.5	10	31	27.20	12.25	11.97	61.38
180	0	15	13.5	10	34	30.58	10.05	31.08	8.58
181	1	15	13.5	20	45.5	42.92	5.66	50.38	10.72
182	0.866	15	13.5	20	47	45.05	4.15	44.59	5.12
183	0.707	15	13.5	20	49	47.26	3.54	34.51	29.57
184	0.5	15	13.5	20	52	49.64	4.54	47.89	7.91
185	0	15	13.5	20	55	53.03	3.58	53.04	3.57
186	1	15	13.5	30	63	63.43	0.68	61.87	1.79
187	0.866	15	13.5	30	65	65.56	0.86	64.40	0.92
188	0.707	15	13.5	30	67	67.78	1.16	67.55	0.83

189	0.5	15	13.5	30	70	70.16	0.22	74.11	5.88
190	0	15	13.5	30	73	73.56	0.76	74.06	1.46
191	1	15	13.5	40	82	82.02	0.02	93.83	14.42
192	0.866	15	13.5	40	84	84.15	0.18	87.36	4.00
193	0.707	15	13.5	40	86	86.37	0.43	85.95	0.06
194	0.5	15	13.5	40	89	88.75	0.28	92.45	3.88
195	0	15	13.5	40	92	92.16	0.18	92.97	1.05
196	1	15	13.5	50	95	98.68	3.88	96.99	2.09
197	0.866	15	13.5	50	97	100.82	3.94	94.81	2.26
198	0.707	15	13.5	50	99	103.04	4.08	99.34	0.35
199	0.5	15	13.5	50	102	105.43	3.36	98.69	3.25
200	0	15	13.5	50	105	108.85	3.67	121.66	15.87
201	1	25	13.5	10	17	18.89	11.11	15.42	9.29
202	0.866	25	13.5	10	19	21.01	10.57	14.78	22.19
203	0.707	25	13.5	10	21	23.21	10.54	27.13	29.21
204	0.5	25	13.5	10	24	25.58	6.59	38.46	60.26
205	0	25	13.5	10	27	28.95	7.22	34.90	29.28
206	1	25	13.5	20	32	33.43	4.46	34.21	6.91
207	0.866	25	13.5	20	34	35.55	4.56	30.48	10.35
208	0.707	25	13.5	20	36	37.76	4.88	34.07	5.35
209	0.5	25	13.5	20	39	40.13	2.90	35.00	10.24
210	0	25	13.5	20	42	43.51	3.59	54.32	29.32
211	1	25	13.5	30	45	46.05	2.32	43.70	2.90
212	0.866	25	13.5	30	47	48.17	2.49	45.48	3.24
213	0.707	25	13.5	30	49	50.38	2.82	37.82	22.82
214	0.5	25	13.5	30	52	52.76	1.46	41.50	20.20
215	0	25	13.5	30	55	56.15	2.09	64.39	17.07
216	1	25	13.5	40	58	56.74	2.17	63.85	10.09
217	0.866	25	13.5	40	60	58.87	1.88	56.82	5.30
218	0.707	25	13.5	40	62	61.09	1.47	62.78	1.25
219	0.5	25	13.5	40	65	63.47	2.36	69.80	7.38
220	0	25	13.5	40	68	66.87	1.67	69.34	1.98
221	1	25	13.5	50	68	65.52	3.64	66.29	2.51
222	0.866	25	13.5	50	70	67.65	3.35	63.41	9.41
223	0.707	25	13.5	50	72	69.87	2.96	71.80	0.27
224	0.5	25	13.5	50	75	72.26	3.66	80.64	7.52
225	0	25	13.5	50	78	75.67	2.99	78.54	0.70

Table C2 Percentage Error of Qc using RSM and ANN for Vertical Plate Heat Sink

Total run	cosθ	H(mm)	S(mm)	Q(W)	Qc_{Expt} (W)	Qc_{RSM} (W)	%Error Qc_{RSM}	Qc_{ANN} (W)	%Error Qc_{ANN}
1	1	5	7	10	4.35	4.34	0.12	4.67	7.28
2	0.866	5	7	10	4.23	4.18	1.17	4.35	2.91
3	0.707	5	7	10	4.1	4.02	2.05	4.52	10.21
4	0.5	5	7	10	3.92	3.85	1.77	5.71	45.72
5	0	5	7	10	3.73	3.68	1.34	4.04	8.41
6	1	5	7	20	8.78	8.67	1.25	9.20	4.76
7	0.866	5	7	20	8.64	8.49	1.72	9.09	5.23
8	0.707	5	7	20	8.49	8.31	2.12	8.08	4.82
9	0.5	5	7	20	8.27	8.12	1.79	8.91	7.70
10	0	5	7	20	8.05	7.90	1.90	7.91	1.71
11	1	5	7	30	13.16	13.03	1.02	12.97	1.47
12	0.866	5	7	30	13.03	12.83	1.52	12.87	1.26
13	0.707	5	7	30	12.86	12.63	1.76	12.28	4.48
14	0.5	5	7	30	12.6	12.42	1.40	11.13	11.70
15	0	5	7	30	12.34	12.14	1.59	11.87	3.81
16	1	5	7	40	17.32	17.41	0.52	15.52	10.39
17	0.866	5	7	40	17.15	17.20	0.31	16.01	6.67
18	0.707	5	7	40	16.96	16.99	0.16	16.43	3.14
19	0.5	5	7	40	16.67	16.75	0.50	17.22	3.27
20	0	5	7	40	16.37	16.42	0.31	15.93	2.72
21	1	5	7	50	21.55	21.83	1.28	21.88	1.54
22	0.866	5	7	50	21.39	21.60	1.00	22.28	4.15
23	0.707	5	7	50	21.17	21.37	0.94	21.81	3.03
24	0.5	5	7	50	20.83	21.11	1.37	21.56	3.53
25	0	5	7	50	20.5	20.73	1.11	17.87	12.83
26	1	15	7	10	4.85	4.96	2.26	5.50	13.44
27	0.866	15	7	10	4.68	4.77	1.90	3.45	26.36
28	0.707	15	7	10	4.5	4.57	1.61	2.88	35.89
29	0.5	15	7	10	4.24	4.37	2.97	2.13	49.80
30	0	15	7	10	3.97	4.10	3.18	5.46	37.59
31	1	15	7	20	9.66	9.69	0.30	9.68	0.21
32	0.866	15	7	20	9.46	9.48	0.25	8.80	7.00
33	0.707	15	7	20	9.27	9.27	0.00	9.75	5.13
34	0.5	15	7	20	8.97	9.04	0.79	8.77	2.25
35	0	15	7	20	8.67	8.72	0.54	9.53	9.92
36	1	15	7	30	14.57	14.45	0.84	13.67	6.16
37	0.866	15	7	30	14.41	14.23	1.27	13.93	3.32
38	0.707	15	7	30	14.19	14.00	1.36	14.00	1.35
39	0.5	15	7	30	13.86	13.75	0.83	13.61	1.77
40	0	15	7	30	13.52	13.37	1.13	14.05	3.89
41	1	15	7	40	19.08	19.24	0.82	17.14	10.15
42	0.866	15	7	40	18.84	19.00	0.86	17.93	4.80
43	0.707	15	7	40	18.6	18.75	0.83	20.30	9.16
44	0.5	15	7	40	18.23	18.48	1.37	19.52	7.08

Total run	cosθ	H(mm)	S(mm)	Q(W)	Qc_{Expt} (W)	Qc_{RSM} (W)	%Error Qc_{RSM}	Qc_{ANN} (W)	%Error Qc_{ANN}
45	0	15	7	40	17.85	18.05	1.11	18.35	2.80
46	1	15	7	50	24.25	24.05	0.81	22.47	7.33
47	0.866	15	7	50	24.05	23.81	1.02	24.44	1.63
48	0.707	15	7	50	23.79	23.54	1.05	24.43	2.68
49	0.5	15	7	50	23.4	23.24	0.67	21.29	9.00
50	0	15	7	50	22.99	22.76	1.01	24.98	8.66
51	1	25	7	10	5.041	4.84	3.90	6.25	23.99
52	0.866	25	7	10	4.821	4.63	4.03	5.63	16.87
53	0.707	25	7	10	4.598	4.40	4.33	4.80	4.49
54	0.5	25	7	10	4.257	4.15	2.49	3.99	6.33
55	0	25	7	10	3.908	3.78	3.22	4.54	16.26
56	1	25	7	20	10.07	9.98	0.93	10.49	4.21
57	0.866	25	7	20	9.888	9.74	1.45	10.62	7.36
58	0.707	25	7	20	9.646	9.50	1.52	11.27	16.82
59	0.5	25	7	20	9.275	9.23	0.49	8.94	3.60
60	0	25	7	20	8.896	8.81	1.01	7.29	18.08
61	1	25	7	30	15.14	15.14	0.01	15.98	5.57
62	0.866	25	7	30	14.95	14.89	0.39	14.54	2.78
63	0.707	25	7	30	14.68	14.63	0.34	13.91	5.26
64	0.5	25	7	30	14.28	14.34	0.40	12.54	12.22
65	0	25	7	30	13.86	13.86	0.00	13.85	0.05
66	1	25	7	40	20.03	20.33	1.50	19.58	2.24
67	0.866	25	7	40	19.81	20.07	1.31	18.34	7.43
68	0.707	25	7	40	19.53	19.79	1.33	15.87	18.75
69	0.5	25	7	40	19.09	19.48	2.02	18.89	1.05
70	0	25	7	40	18.64	18.94	1.63	18.71	0.35
71	1	25	7	50	25.45	25.55	0.40	24.00	5.68
72	0.866	25	7	50	25.22	25.28	0.23	21.87	13.30
73	0.707	25	7	50	24.92	24.98	0.24	21.74	12.74
74	0.5	25	7	50	24.45	24.64	0.79	23.63	3.37
75	0	25	7	50	23.98	24.06	0.32	25.22	5.19
76	1	5	9.5	10	4.615	4.76	3.21	3.52	23.78
77	0.866	5	9.5	10	4.5	4.60	2.32	4.90	8.98
78	0.707	5	9.5	10	4.384	4.45	1.42	4.74	8.08
79	0.5	5	9.5	10	4.207	4.29	1.96	4.99	18.64
80	0	5	9.5	10	4.027	4.14	2.81	4.55	12.93
81	1	5	9.5	20	9.091	9.08	0.12	8.70	4.34
82	0.866	5	9.5	20	8.956	8.91	0.55	9.52	6.34
83	0.707	5	9.5	20	8.819	8.73	0.99	9.45	7.12
84	0.5	5	9.5	20	8.611	8.55	0.68	8.47	1.67
85	0	5	9.5	20	8.4	8.35	0.61	8.27	1.59
86	1	5	9.5	30	13.47	13.43	0.32	11.87	11.89
87	0.866	5	9.5	30	13.31	13.24	0.53	12.28	7.74
88	0.707	5	9.5	30	13.15	13.05	0.79	12.06	8.33
89	0.5	5	9.5	30	12.91	12.84	0.51	11.11	13.93
90	0	5	9.5	30	12.66	12.59	0.58	11.16	11.83

Total run	cosθ	H(mm)	S(mm)	Q(W)	Qc_{Expt} (W)	Qc_{RSM} (W)	%Error Qc_{RSM}	Qc_{ANN} (W)	%Error Qc_{ANN}
91	1	5	9.5	40	17.73	17.80	0.41	18.76	5.79
92	0.866	5	9.5	40	17.55	17.60	0.29	19.40	10.53
93	0.707	5	9.5	40	17.37	17.39	0.12	17.63	1.50
94	0.5	5	9.5	40	17.09	17.17	0.45	17.72	3.68
95	0	5	9.5	40	16.81	16.85	0.27	16.04	4.59
96	1	5	9.5	50	22.11	22.21	0.45	21.81	1.36
97	0.866	5	9.5	50	21.91	21.99	0.38	22.22	1.41
98	0.707	5	9.5	50	21.7	21.77	0.30	23.10	6.44
99	0.5	5	9.5	50	21.39	21.52	0.60	23.00	7.53
100	0	5	9.5	50	21.07	21.15	0.39	20.52	2.59
101	1	15	9.5	10	4.942	5.38	8.87	5.40	9.29
102	0.866	15	9.5	10	4.824	5.19	7.69	4.02	16.74
103	0.707	15	9.5	10	4.664	5.01	7.31	5.34	14.45
104	0.5	15	9.5	10	4.502	4.81	6.78	4.39	2.56
105	0	15	9.5	10	4.254	4.56	7.15	3.33	21.74
106	1	15	9.5	20	9.864	10.10	2.40	8.28	16.01
107	0.866	15	9.5	20	9.731	9.90	1.74	11.39	17.07
108	0.707	15	9.5	20	9.552	9.69	1.48	9.45	1.05
109	0.5	15	9.5	20	9.279	9.47	2.09	9.52	2.63
110	0	15	9.5	20	9	9.17	1.89	10.54	17.10
111	1	15	9.5	30	14.9	14.85	0.33	14.51	2.61
112	0.866	15	9.5	30	14.7	14.64	0.44	14.76	0.41
113	0.707	15	9.5	30	14.5	14.41	0.61	15.27	5.34
114	0.5	15	9.5	30	14.2	14.17	0.22	13.03	8.22
115	0	15	9.5	30	13.88	13.81	0.49	14.83	6.82
116	1	15	9.5	40	19.56	19.63	0.36	20.24	3.49
117	0.866	15	9.5	40	19.4	19.40	0.01	18.80	3.07
118	0.707	15	9.5	40	19.18	19.16	0.11	18.64	2.84
119	0.5	15	9.5	40	18.84	18.89	0.29	18.60	1.26
120	0	15	9.5	40	18.49	18.48	0.04	18.44	0.25
121	1	15	9.5	50	24.85	24.44	1.65	24.59	1.03
122	0.866	15	9.5	50	24.61	24.20	1.68	23.94	2.71
123	0.707	15	9.5	50	24.37	23.94	1.77	24.02	1.45
124	0.5	15	9.5	50	24.01	23.65	1.50	25.00	4.12
125	0	15	9.5	50	23.63	23.18	1.89	23.17	1.93
126	1	25	9.5	10	5.231	5.27	0.68	6.46	23.42
127	0.866	25	9.5	10	5.082	5.05	0.54	5.47	7.64
128	0.707	25	9.5	10	4.881	4.83	0.98	4.43	9.16
129	0.5	25	9.5	10	4.574	4.59	0.44	4.09	10.51
130	0	25	9.5	10	4.26	4.25	0.33	4.88	14.67
131	1	25	9.5	20	10.38	10.39	0.10	11.23	8.16
132	0.866	25	9.5	20	10.17	10.16	0.06	9.17	9.84
133	0.707	25	9.5	20	9.948	9.93	0.23	8.58	13.76
134	0.5	25	9.5	20	9.613	9.66	0.53	9.20	4.25
135	0	25	9.5	20	9.27	9.26	0.10	10.16	9.56
136	1	25	9.5	30	15.61	15.54	0.43	15.21	2.53

Total run	cosθ	H(mm)	S(mm)	Q(W)	Qc_{Expt} (W)	Qc_{RSM} (W)	%Error Qc_{RSM}	Qc_{ANN} (W)	%Error Qc_{ANN}
137	0.866	25	9.5	30	15.37	15.30	0.44	14.72	4.22
138	0.707	25	9.5	30	15.13	15.05	0.55	14.29	5.55
139	0.5	25	9.5	30	14.77	14.76	0.05	14.00	5.19
140	0	25	9.5	30	14.39	14.31	0.58	15.68	8.93
141	1	25	9.5	40	20.64	20.73	0.42	18.36	11.03
142	0.866	25	9.5	40	20.38	20.47	0.45	19.29	5.35
143	0.707	25	9.5	40	20.12	20.20	0.39	20.51	1.95
144	0.5	25	9.5	40	19.73	19.89	0.82	20.58	4.31
145	0	25	9.5	40	19.33	19.38	0.26	21.09	9.11
146	1	25	9.5	50	26.18	25.94	0.92	25.32	3.27
147	0.866	25	9.5	50	25.91	25.67	0.93	26.88	3.74
148	0.707	25	9.5	50	25.64	25.38	1.02	26.06	1.63
149	0.5	25	9.5	50	25.22	25.05	0.67	26.91	6.70
150	0	25	9.5	50	24.79	24.49	1.23	26.15	5.50
151	1	5	13.5	10	4.474	4.45	0.61	4.40	1.60
152	0.866	5	13.5	10	4.361	4.30	1.47	4.52	3.56
153	0.707	5	13.5	10	4.248	4.15	2.32	4.96	16.87
154	0.5	5	13.5	10	4.076	4.01	1.71	4.70	15.39
155	0	5	13.5	10	3.9	3.89	0.25	3.34	14.34
156	1	5	13.5	20	8.8	8.75	0.57	7.88	10.51
157	0.866	5	13.5	20	8.667	8.59	0.94	7.83	9.67
158	0.707	5	13.5	20	8.532	8.42	1.31	7.22	15.40
159	0.5	5	13.5	20	8.327	8.25	0.87	7.95	4.56
160	0	5	13.5	20	8.119	8.08	0.43	11.31	39.36
161	1	5	13.5	30	13.21	13.08	0.97	11.48	13.13
162	0.866	5	13.5	30	13.06	12.90	1.20	12.33	5.57
163	0.707	5	13.5	30	12.9	12.72	1.39	13.03	0.97
164	0.5	5	13.5	30	12.66	12.53	1.00	11.68	7.71
165	0	5	13.5	30	12.42	12.31	0.90	10.72	13.69
166	1	5	13.5	40	17.34	17.44	0.60	16.89	2.59
167	0.866	5	13.5	40	17.16	17.25	0.53	16.16	5.84
168	0.707	5	13.5	40	16.98	17.05	0.42	15.65	7.86
169	0.5	5	13.5	40	16.7	16.84	0.85	15.91	4.71
170	0	5	13.5	40	16.42	16.56	0.87	15.18	7.52
171	1	5	13.5	50	21.74	21.84	0.44	25.08	15.36
172	0.866	5	13.5	50	21.54	21.63	0.41	23.47	8.95
173	0.707	5	13.5	50	21.34	21.41	0.34	21.11	1.09
174	0.5	5	13.5	50	21.03	21.18	0.71	18.13	13.80
175	0	5	13.5	50	20.71	20.85	0.66	20.36	1.70
176	1	15	13.5	10	4.965	5.07	2.05	5.39	8.52
177	0.866	15	13.5	10	4.818	4.89	1.50	4.97	3.16
178	0.707	15	13.5	10	4.669	4.71	0.90	4.62	1.01
179	0.5	15	13.5	10	4.443	4.53	1.89	5.37	20.76
180	0	15	13.5	10	4.212	4.31	2.35	6.79	61.28
181	1	15	13.5	20	9.622	9.77	1.57	10.87	12.97
182	0.866	15	13.5	20	9.496	9.58	0.90	10.96	15.46

Total run	cosθ	H(mm)	S(mm)	Q(W)	Qc_{Expt} (W)	Qc_{RSM} (W)	%Error Qc_{RSM}	Qc_{ANN} (W)	%Error Qc_{ANN}
183	0.707	15	13.5	20	9.326	9.39	0.64	8.95	4.00
184	0.5	15	13.5	20	9.067	9.18	1.23	11.30	24.66
185	0	15	13.5	20	8.803	8.91	1.20	9.25	5.07
186	1	15	13.5	30	14.64	14.51	0.90	14.61	0.23
187	0.866	15	13.5	30	14.46	14.30	1.08	13.95	3.53
188	0.707	15	13.5	30	14.27	14.09	1.26	15.72	10.19
189	0.5	15	13.5	30	13.98	13.86	0.85	14.23	1.82
190	0	15	13.5	30	13.68	13.54	1.05	12.10	11.56
191	1	15	13.5	40	19.13	19.27	0.76	20.80	8.74
192	0.866	15	13.5	40	18.92	19.05	0.71	19.87	5.00
193	0.707	15	13.5	40	18.71	18.82	0.61	19.56	4.54
194	0.5	15	13.5	40	18.38	18.57	1.04	18.60	1.21
195	0	15	13.5	40	18.05	18.19	0.80	18.03	0.09
196	1	15	13.5	50	24.3	24.07	0.95	24.73	1.77
197	0.866	15	13.5	50	24.07	23.84	0.97	23.42	2.72
198	0.707	15	13.5	50	23.84	23.59	1.06	23.14	2.93
199	0.5	15	13.5	50	23.48	23.31	0.71	24.39	3.86
200	0	15	13.5	50	23.12	22.88	1.04	24.75	7.06
201	1	25	13.5	10	5.143	4.96	3.63	4.65	9.67
202	0.866	25	13.5	10	4.961	4.75	4.19	3.86	22.10
203	0.707	25	13.5	10	4.776	4.54	4.89	3.57	25.23
204	0.5	25	13.5	10	4.495	4.32	3.96	5.23	16.41
205	0	25	13.5	10	4.207	4.00	4.88	5.47	29.92
206	1	25	13.5	20	10.05	10.07	0.16	10.56	5.09
207	0.866	25	13.5	20	9.85	9.85	0.02	9.30	5.57
208	0.707	25	13.5	20	9.644	9.62	0.25	8.91	7.63
209	0.5	25	13.5	20	9.331	9.37	0.44	9.29	0.44
210	0	25	13.5	20	9.012	9.00	0.10	9.40	4.31
211	1	25	13.5	30	15.25	15.21	0.29	14.16	7.13
212	0.866	25	13.5	30	15.03	14.97	0.38	14.56	3.12
213	0.707	25	13.5	30	14.81	14.73	0.56	13.70	7.48
214	0.5	25	13.5	30	14.47	14.46	0.09	14.49	0.14
215	0	25	13.5	30	14.12	14.03	0.61	13.66	3.24
216	1	25	13.5	40	20.13	20.37	1.21	21.45	6.58
217	0.866	25	13.5	40	19.89	20.13	1.19	21.32	7.18
218	0.707	25	13.5	40	19.65	19.86	1.09	20.42	3.92
219	0.5	25	13.5	40	19.27	19.57	1.57	18.33	4.89
220	0	25	13.5	40	18.89	19.09	1.08	17.80	5.78
221	1	25	13.5	50	25.48	25.57	0.37	23.08	9.41
222	0.866	25	13.5	50	25.22	25.31	0.36	23.63	6.31
223	0.707	25	13.5	50	24.95	25.03	0.33	25.25	1.19
224	0.5	25	13.5	50	24.55	24.72	0.68	23.79	3.10
225	0	25	13.5	50	24.14	24.18	0.19	22.49	6.84

Table C3 Percentage Error in Qc using RMS and ANN in Mixed Convection.

Total runs	v (m/s)	S (mm)	Tw (^{0}C)	Qc $_{Expt.}$ (W)	Qc$_{RSM}$ (W)	Error Expt Vs RSM %	Qc $_{ANN}$ (W)	Error Expt Vs. ANN %
1	0.8	5.5	66	24.34	24.37	0.13	25.31	4.00
2	0.8	7	62.8	26.23	26.28	0.20	26.33	0.38
3	0.8	9.5	67	26.19	26.01	0.68	26.34	0.56
4	0.8	13.5	75	25.42	25.58	0.64	25.58	0.64
5	0.8	17	85	25.21	25.17	0.17	24.98	0.92
6	1.0	5.5	64	24.76	24.71	0.18	25.74	3.96
7	1.0	7	60	26.71	26.74	0.10	26.72	0.06
8	1.0	9.5	64	26.51	26.51	0.02	26.60	0.37
9	1.0	13.5	78	25.11	25.12	0.03	25.07	0.19
10	1.0	17	88	24.79	24.80	0.05	24.88	0.35
11	1.2	5.5	62	25.17	25.15	0.08	26.28	4.39
12	1.2	7	56	27.37	27.44	0.25	27.48	0.38
13	1.2	9.5	61	27.12	27.04	0.31	27.00	0.44
14	1.2	13.5	80	24.65	24.70	0.18	24.55	0.40
15	1.2	17	90	24.50	24.49	0.06	24.21	1.20

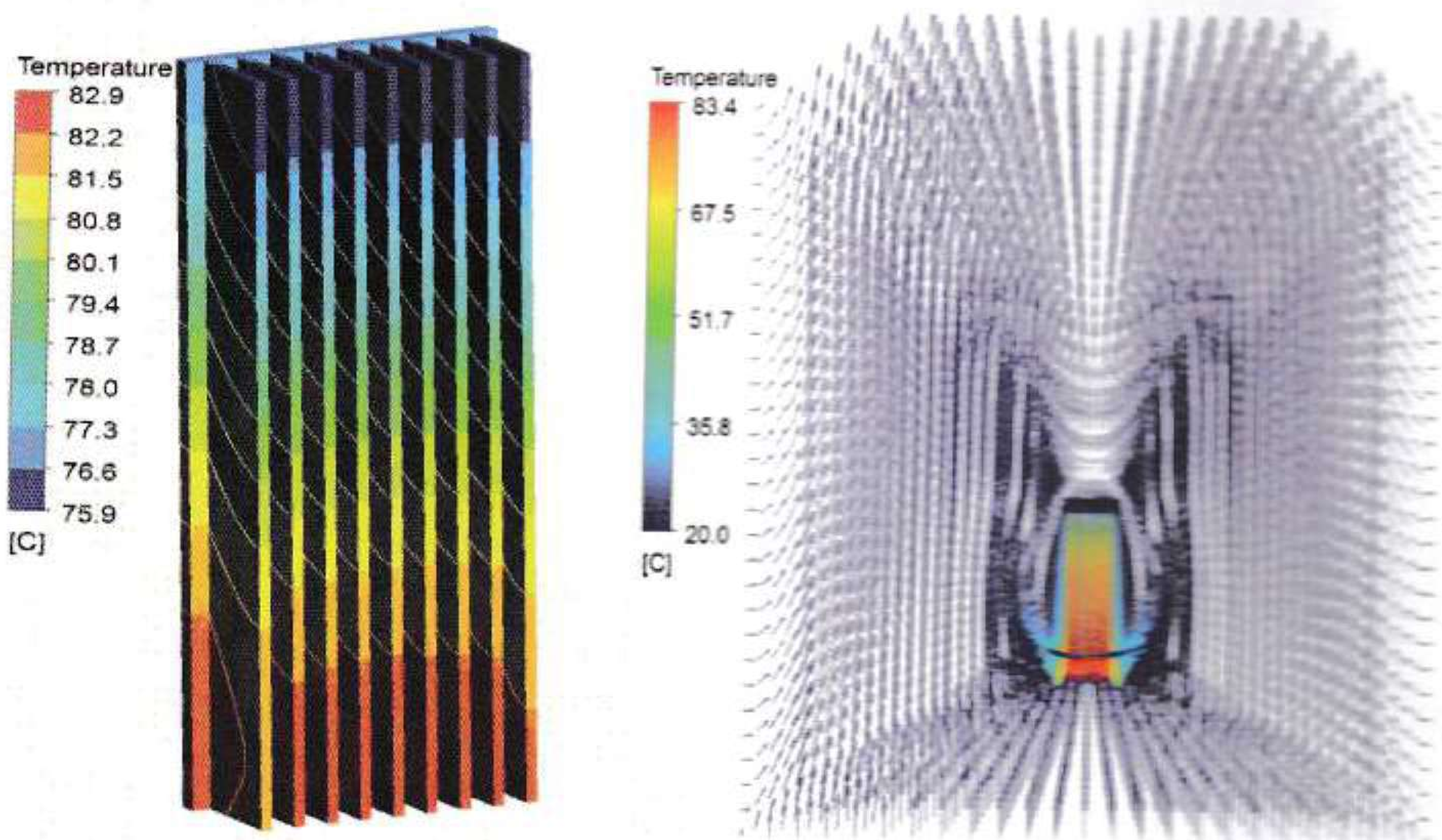
Table C 4 Percentage Error in Nusselt Number using RMS and ANN in Mixed Convection

Total runs	v (m/s)	S (mm)	Tw (^{0}C)	Nu $_{Expt}$	Nu $_{RSM}$	% Error Expt Vs RSM	Nu$_{ANN}$	% Error Expt Vs. ANN
1	0.8	5.5	66	36.28	35.48	2.19	36.84	1.54
2	0.8	7	62.8	52.16	51.58	1.11	50.41	3.37
3	0.8	9.5	67	53.46	52.18	2.39	52.77	1.29
4	0.8	13.5	75	51.23	50.96	0.53	54.27	5.93
5	0.8	17	85	49.59	47.99	3.22	50.28	1.40
6	1.0	5.5	64	38.69	37.59	2.84	36.91	4.59
7	1.0	7	60	57.04	56.10	1.65	46.61	18.29
8	1.0	9.5	64	58.37	57.10	2.17	50.45	13.56
9	1.0	13.5	78	47.54	47.09	0.94	47.57	0.06
10	1.0	17	88	46.43	45.66	1.64	45.31	2.41
11	1.2	5.5	62	41.32	40.82	1.20	41.09	0.55
12	1.2	7	56	65.30	64.41	1.36	56.59	13.34
13	1.2	9.5	61	63.98	63.20	1.22	57.44	10.23
14	1.2	13.5	80	45.28	43.76	3.34	46.44	2.58
15	1.2	17	90	44.46	43.62	1.89	44.12	0.76

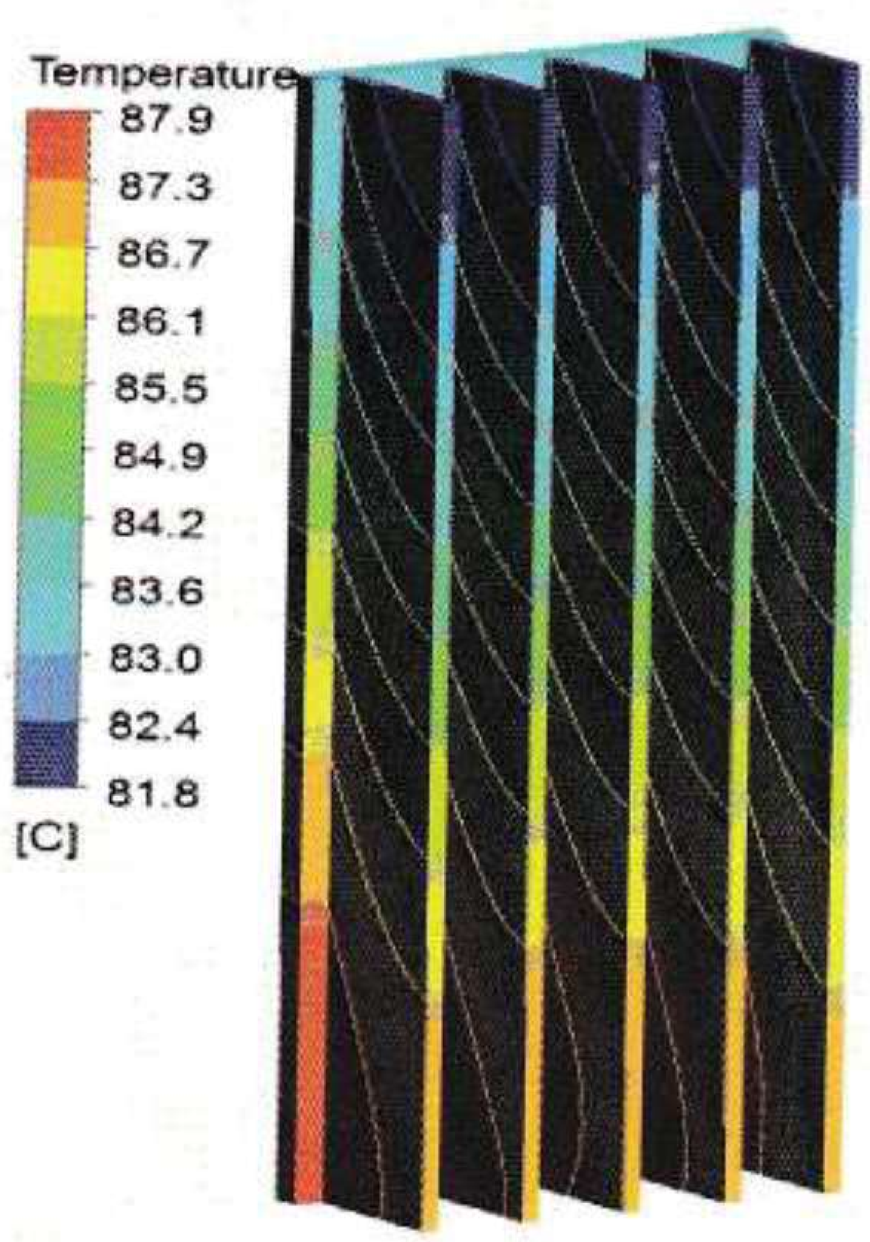
APPENDIX D

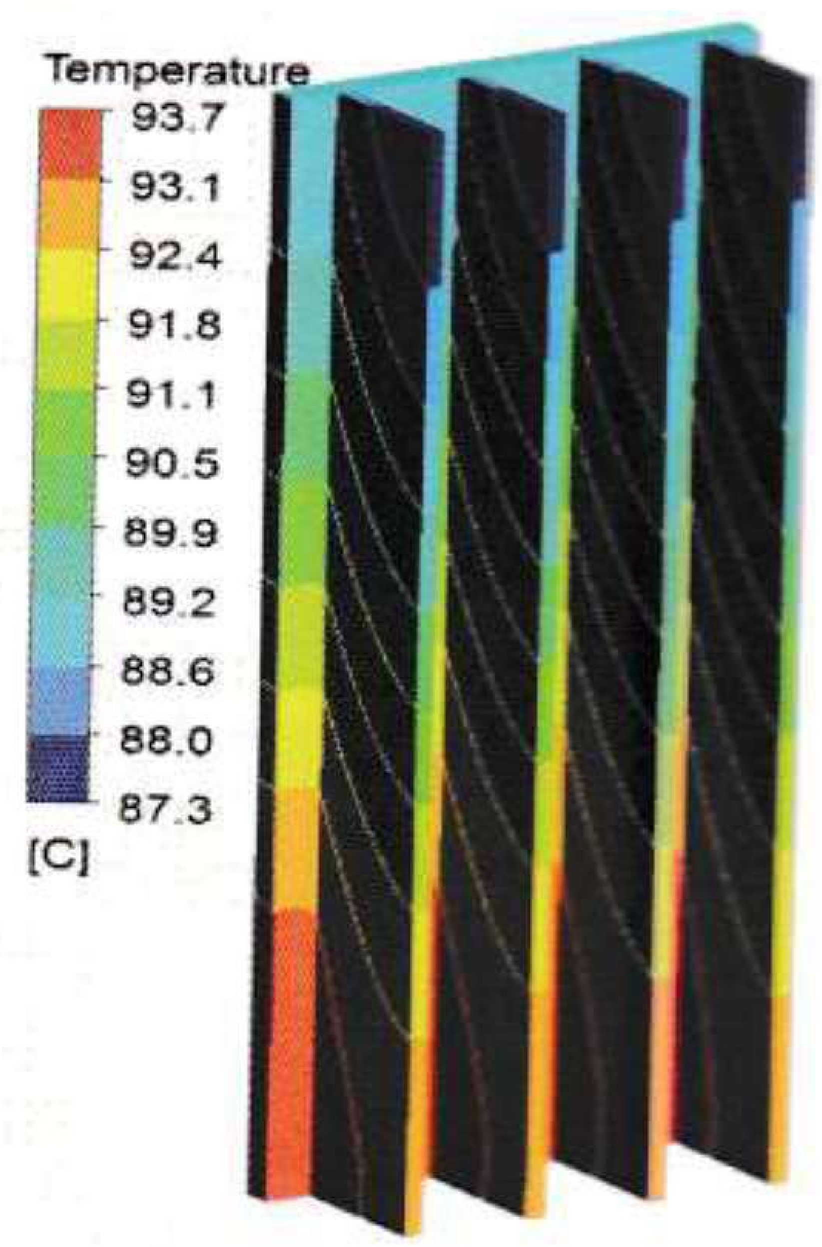
CFD Simulation Images

D1 CFD Simulation Images for Temperature Distribution for Vertical Plate Heat Sink



(a) For Fin Spacing S=5.5mm

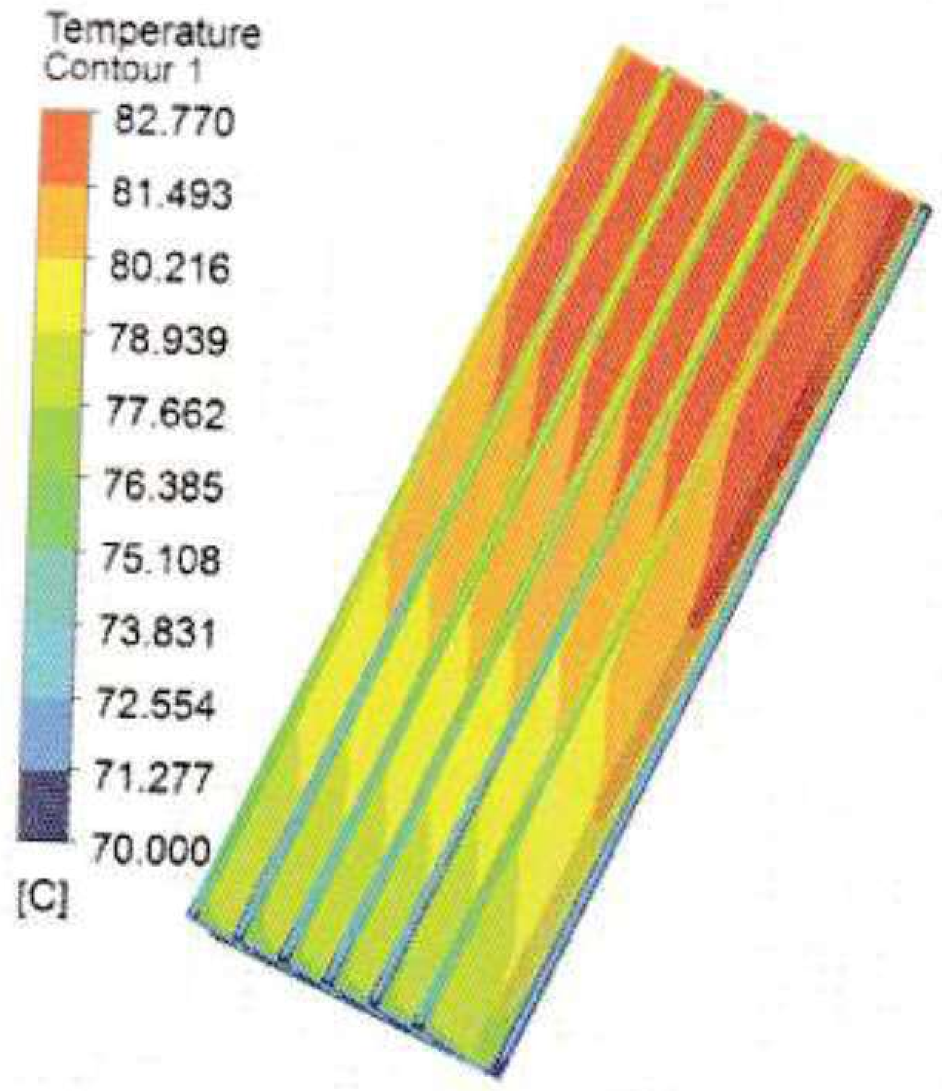




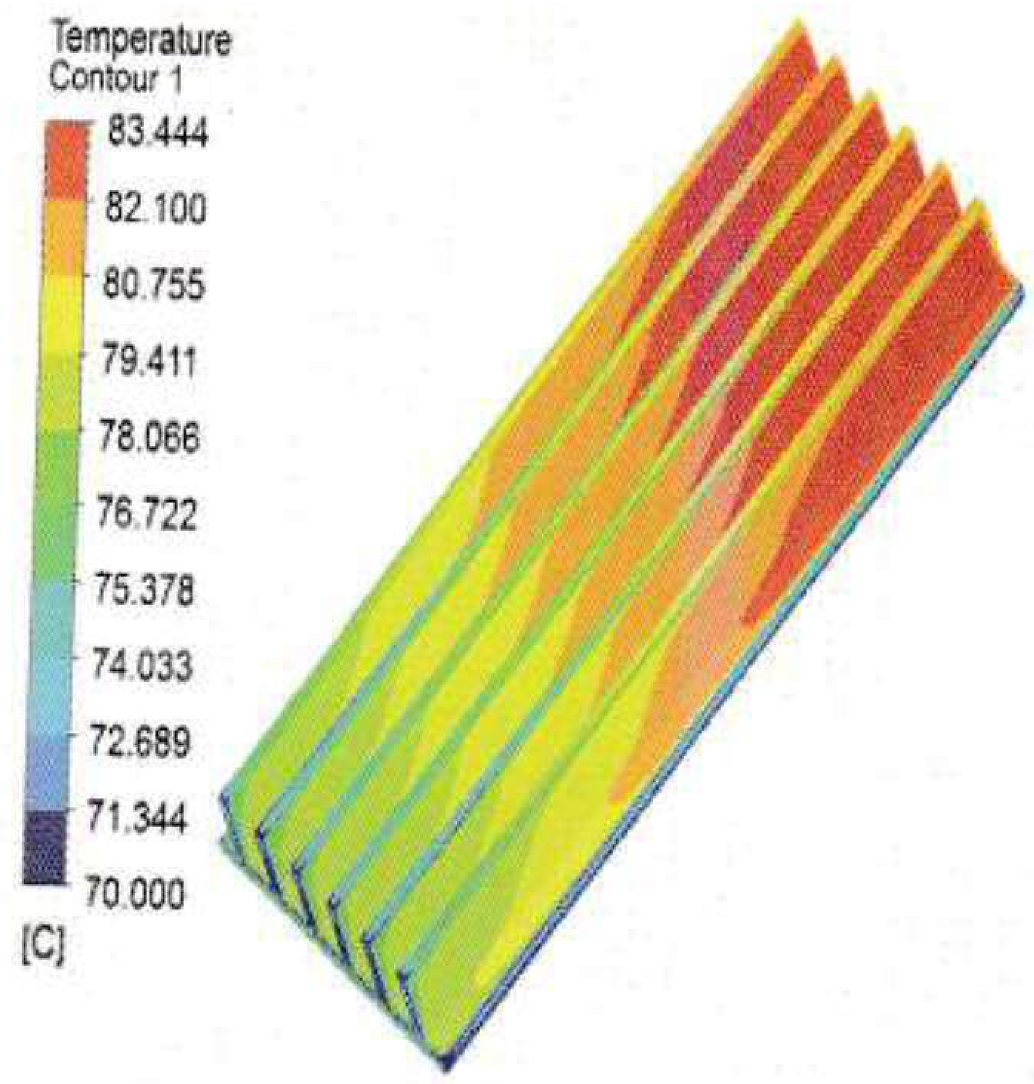
(b) For Fin Spacing S=13.5 mm (c) For Fin Spacing S=17mm

Figure D.1 Temperature Distribution for Different Fin Spacing of Vertical Plate Heat Sink

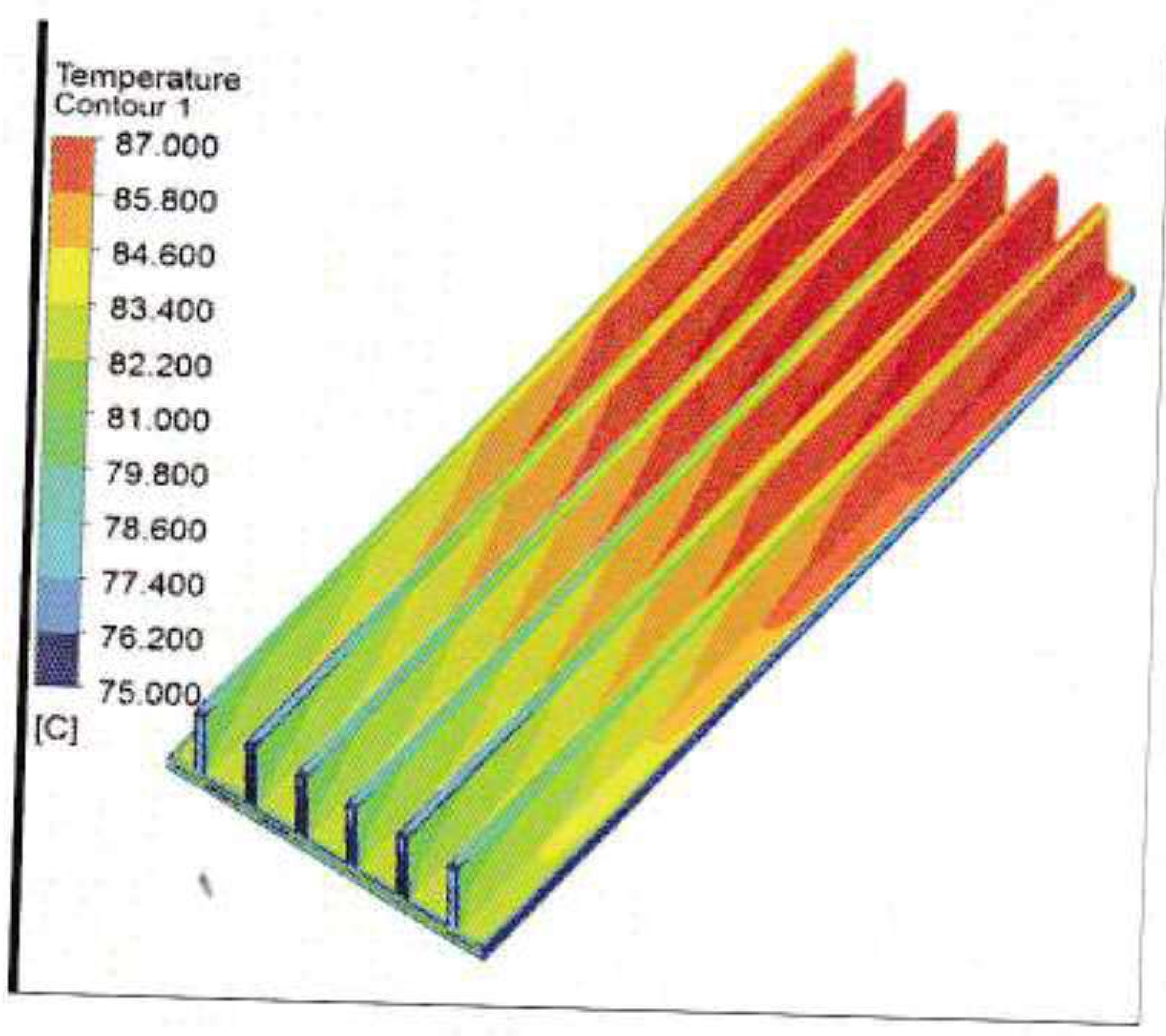
D2 CFD Simulation Images for Temperature Distribution for Inclined Heat Sink



(a) For Angle of Inclination=30°



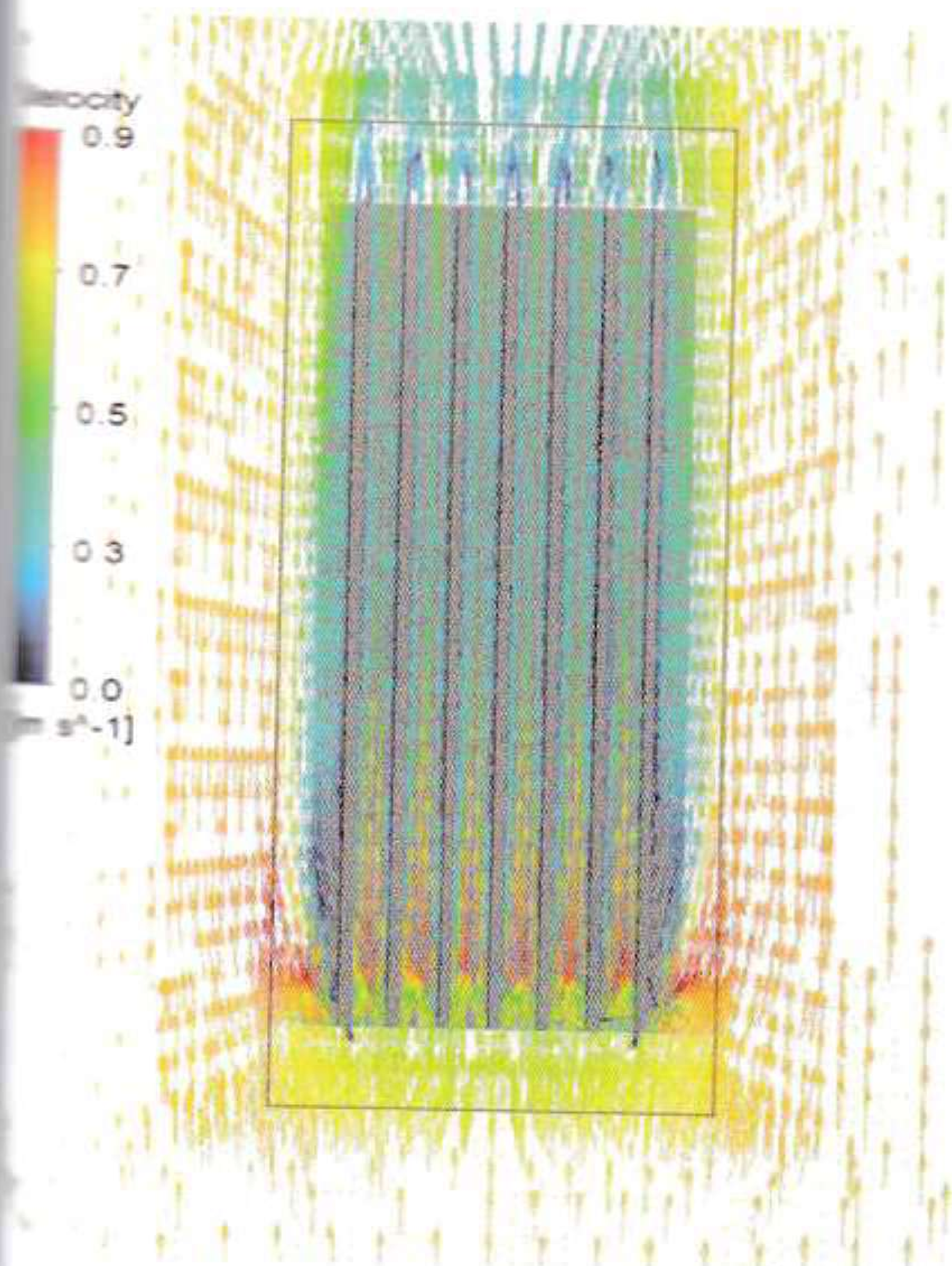
(b) For Angle of Inclination=45°



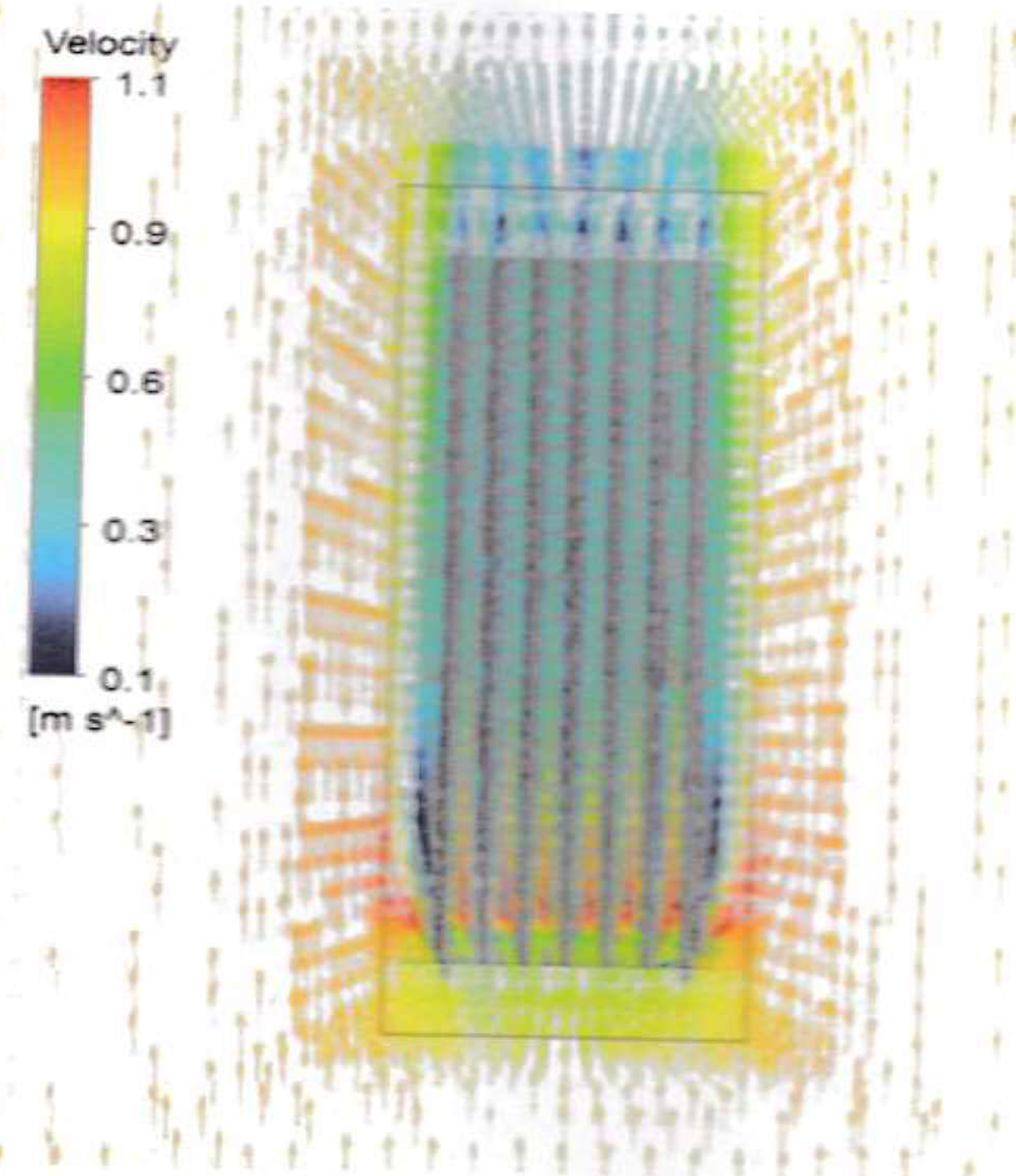
(c) For Angle of Inclination=60°

Figure D2 Temperature Distribution for Different Fin Spacing of Inclined Plate Heat Sink

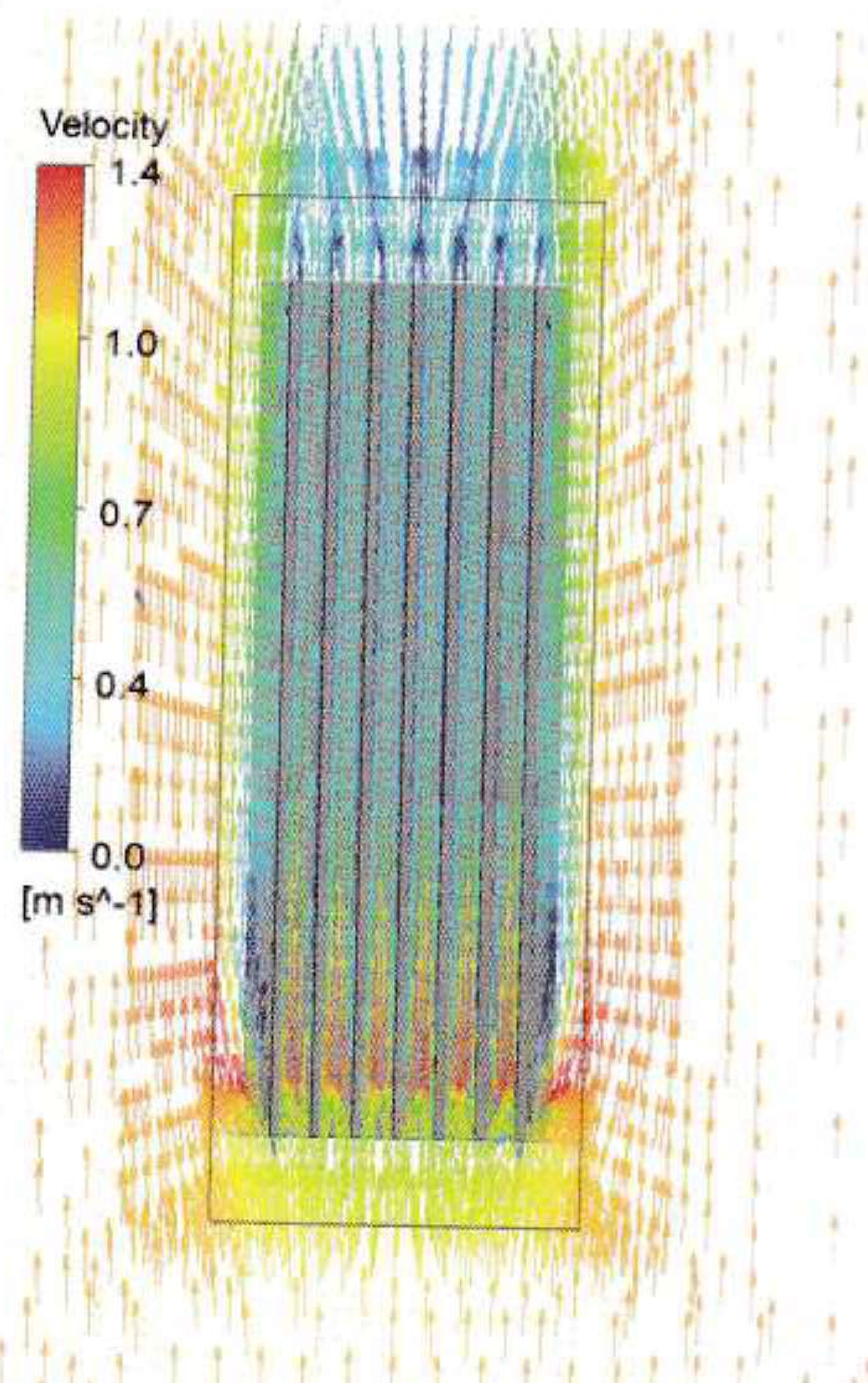
D3 CFD Simulation Images of Temperature Distribution for Vertical Heat Sink In Mixed Convection



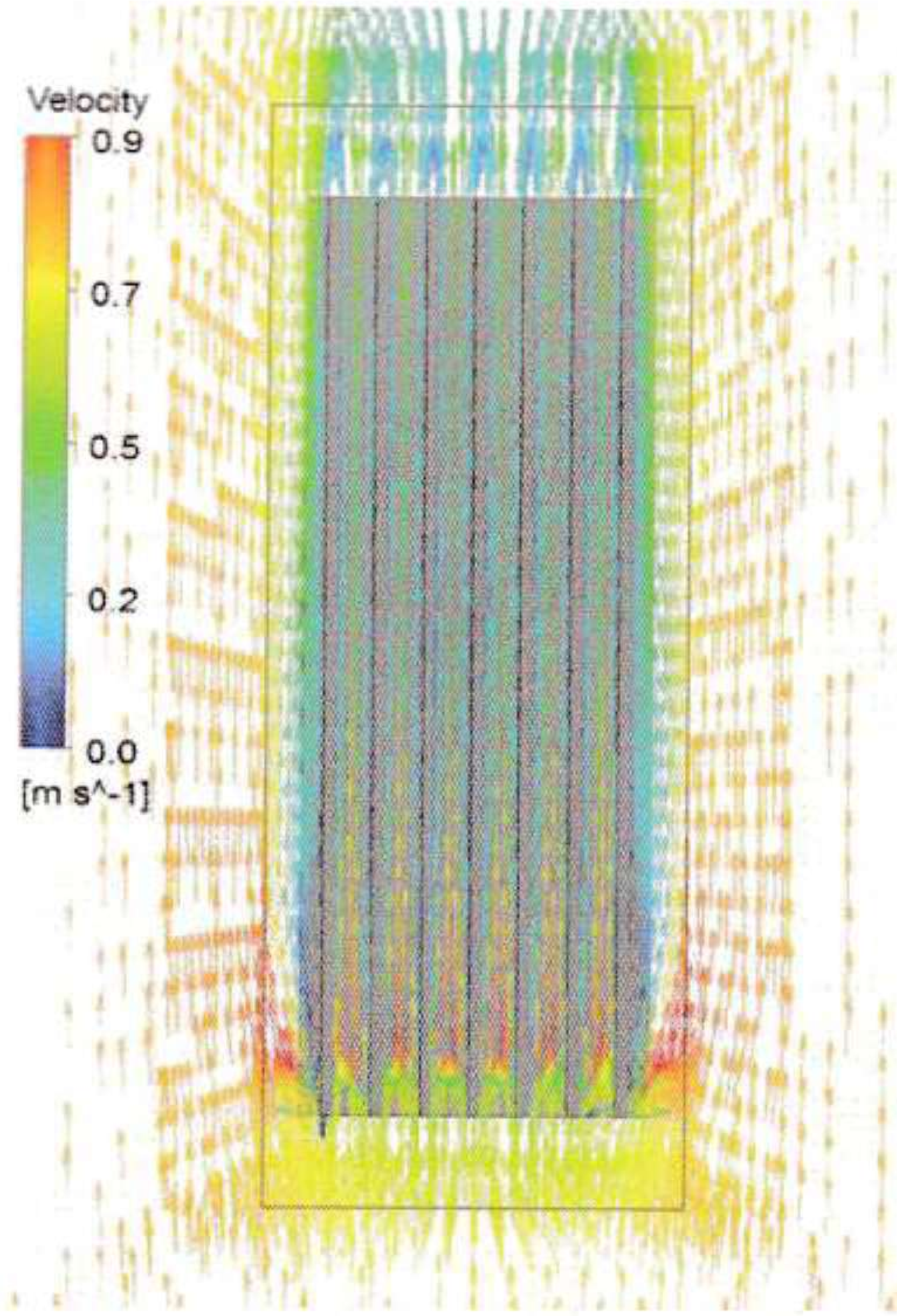
(a) For Spacing S=7.5mm and v=0.8m/s

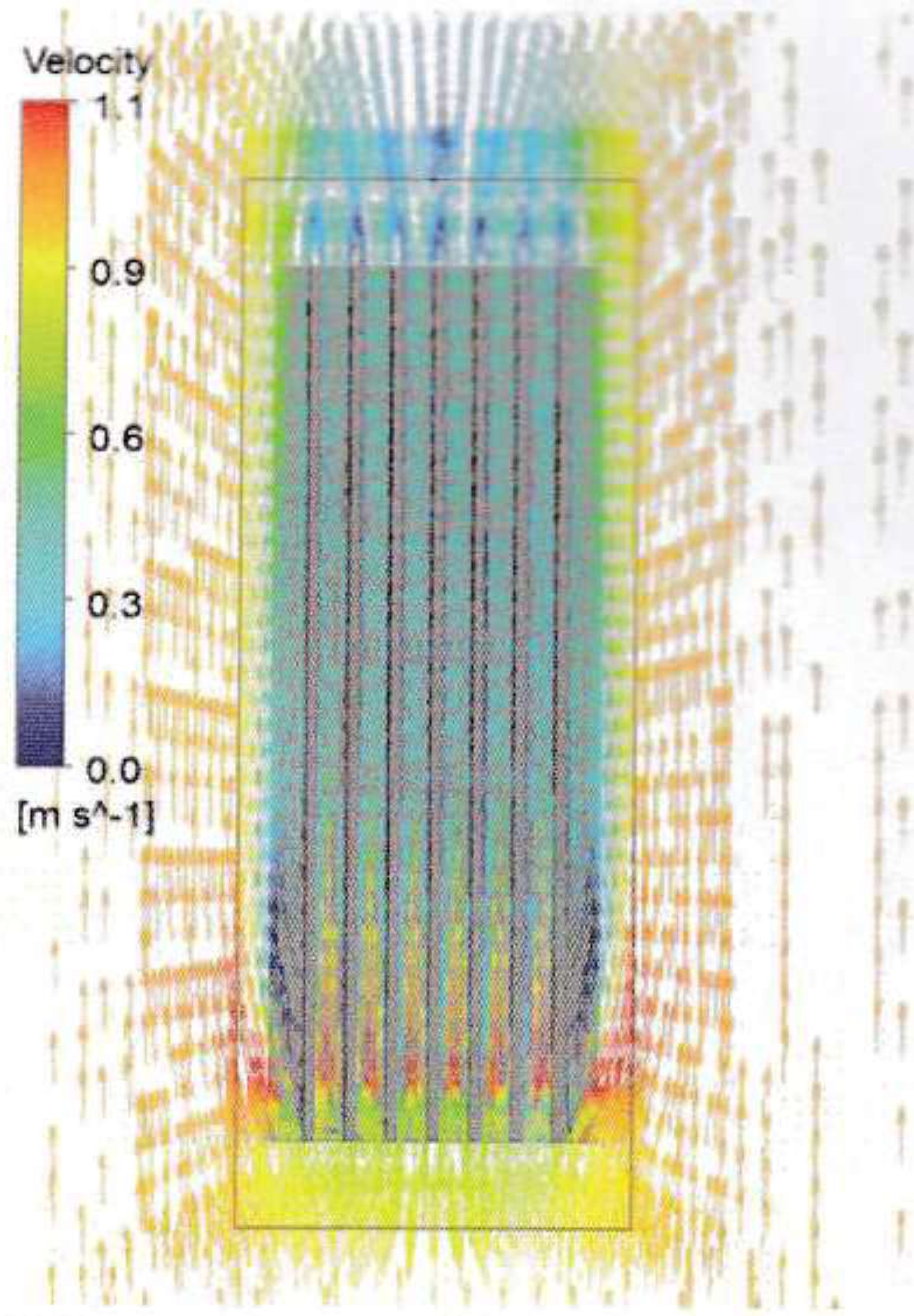


(b) For Spacing S=7.5mm and v=1m/s

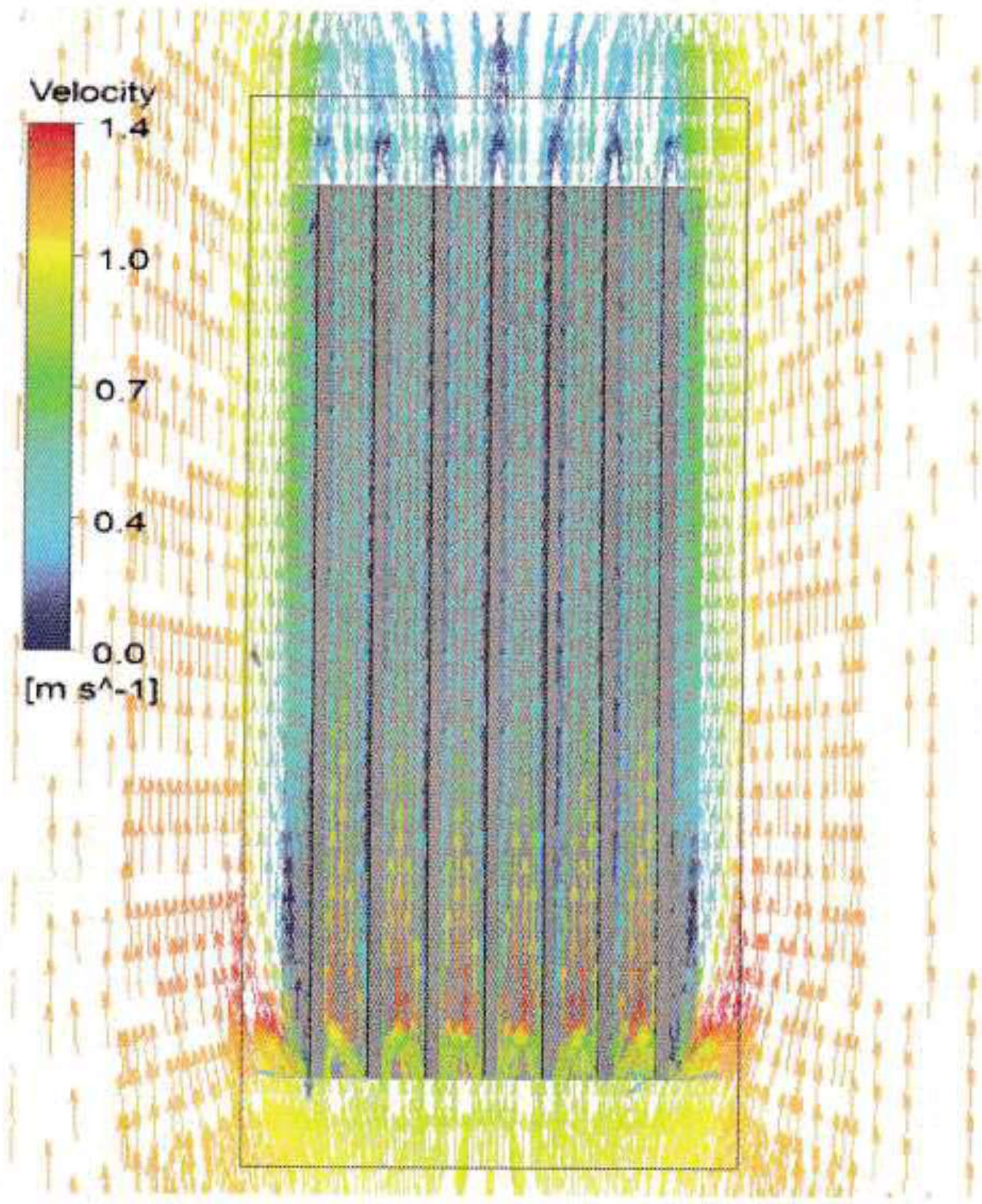


(c) For Spacing S=7.5mm and v=1.2m/s





(d) For Spacing S=8mm and v=1.2 m/s (e) For Spacing S=8mm and v=1.2 m/s



(f) For Spacing S=8mm and v=1.2 m/s

Figure D3 Velocity Distribution for Different Fin Spacing of Vertical Plate Heat Sink in Mixed Convection