THERMAL PERFORMANCE ANALYSIS OF DIFFERENT FIN ARRAYS WITH VARIOUS PERFORATIONS UNDER TURBULENT FLOW REGIME

A THESIS SUBMITTED TO THE DEPARTMENT OF "MECHANICAL ENGINEERING" IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

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A thesis submitted to the Department of Mechanical Engineering, Military Institute of Science and Technology, Dhaka, in December, 2017 in partial fulfilment of the requirements for the degree of Bachelor of Science in Mechanical Engineering.

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SUPERVISOR CERTIFICATION

This is to certify that **Imtiaz Taimoor**, Student no: 201418071; **Nazneen Sultana Aankhy**, Student no:201418085; **Muzahid Bin Khalid** Student no: 201418122 have completed their undergraduate thesis report on **“THERMAL PERFORMANCE ANALYSIS OF DIFFERENT FIN ARRAYS WITH VARIOUS PERFORATIONS UNDER TURBULENT FLOW REGIME”** under my supervision. To the best of my knowledge, the report is their original work and was not submitted elsewhere for other purpose.

I wish their ever success in life.

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STUDENT DECLARATION

This is to certify that the thesis entitled**, "THERMAL PERFORMANCE ANALYSIS OF DIFFERENT FIN ARRAYS WITH VARIOUS PERFORATIONS UNDER TURBULENT FLOW REGIME"** is an outcome of the investigation carried out by the author under the supervision of **Brig Gen Md Lutfor Rahman,** PhD, Adjunct Professor and Former Head and Dean, Faculty of Mechanical Engineering, MIST. This thesis or any part of it has not been submitted to elsewhere for the award of any other degree or diploma or other similar title or prize.

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ABSTRACT

Heat transfer enhancement has been a major concern in modern days in designing heat generating equipment. In the present study an experimental study has been investigated to analyze the thermal performance of plate fin arrays and pin fin arrays for solid, circular and hexagonal perforations along the length of the fin in the turbulent flow regime under steady state forced convection. The air velocity was varied ranging from $4ms^{-1}$ to $12ms^{-1}$ and data are recorded after a certain period of time at a constant heat flux. The performance of plate fin and pin fin as heat sink was tested and best result was found in case of pin fin with hexagonal perforation heat sink.Convective heat transfer co-efficient, fin effectiveness, fin efficiency seem to increase in hexagonal perforation both for plate fin and pin fin arrays. Thermal resistance seems to decrease in hexagonal perforation than circular perforation and solid fins. This study suggests that most important parameter that governs the performance of fin is the fin geometry and varied cross section i.e. perforations.

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NOMENCLATURE

A_{front}	Total area restricting the air flow (m^2)
A	Cross-sectional area of the duct (m^2)
A_s	Total heat transfer area (m^2)
A_b	Total base area (m^2)
A_{fin}	Total heat transfer area (m^2)
$A_{un\ fin}$	Total heat transfer area of the unfinned portion (m^2)
$A_{no\ fin}$	Total heat transfer area when there are no fins (m^2)
D	Fin diameter (m)
d_h	Hydraulic diameter of the duct (m)
F	Correction factor
h	Convective heat transfer coefficient (W/m^2 k)
N_L	Number of row
S_T	Transverse pitch (m)
S_D	Diagonal pitch (m)
S_L	Longitudinal pitch (m)
V	Approach velocity (m/s)
V_{max}	Maximum velocity (m/s)
v_{avg}	Average effective air flow velocity (m/s)
T_s	Average surface temperature of fin array (°C)
T_{surr}	Average temperature of the surroundings (°C)
T_∞	Average temperature of bulk air flow (°C)
T_b	Average base temperature (°C)
Δp	Pressure drop across the fin array (Pa)
Δp^*	Dimensionless pressure drop across the fin array (-)

Q_T Total heat supplied (W)

Q_{loss} Total heat loss from setup (W)

Q_{rad} Total heat radiated from fin array (W)

Q_{conv} total convection heat from fin array (W)

R_{th} Thermal resistance of the fin (K/W)

Re Reynolds number (-)

Nu Nusselt number (-)

Pr Prandtl number at film temperature (-)

Pr_s Prandtl number at average surface temperature of fin array (-)

K Thermal conductivity of air (W/m.K)

K_{ins} Thermal conductivity of insulation tape (W/m.K)

GREEK SYMBOLS

η_{fin} Fin efficiency (%)

ε_{fin} Fin effectiveness (-)

ρ Density of air (kg/m^3)

ν kinematic viscosity of air (kg/m^3)

ε Emissivity of heater material (-)

σ Stefan-Boltzmann constant (-)

CHAPTER ONE

INTRODUCTION

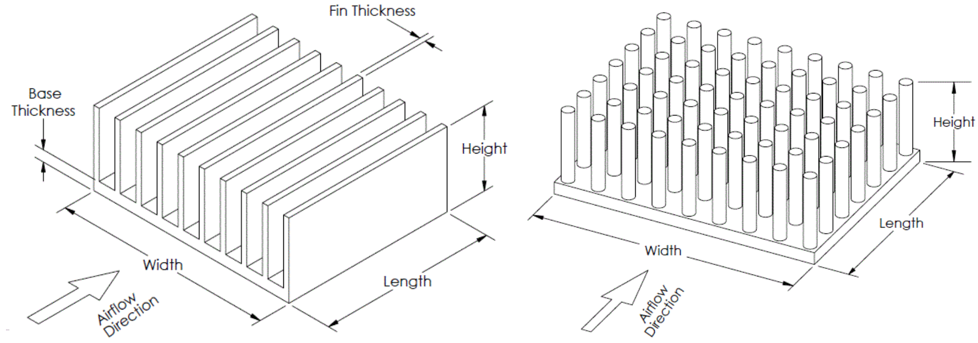
1.1 Introduction

Extended Surface (fin) is used in a large number of applications to increase the heat transfer from surfaces. Typically, the fin material has a high thermal conductivity. The fin is exposed to a flowing fluid, which cools or heat sit, with the high thermal conductivity allowing increased heat being conducted from the wall through the fin. Fins are used to enhance convective heat transfer in a wide range of engineering applications and offer practical means for achieving a large total heat transfer surface area without the use of an excessive amount of primary surface area.

Fins are commonly applied for heat management in electrical appliances such as computer power supplies or substation transformers. According to Chu [1], heat generation is an irreversible process and heat must be removed to maintain continuous operation and to avoid detrimental consequences due to burning and overheating. Removal of heat is done by making heat sink arrangements by means of fins. The most common type of heat sink is metal arrangement with many fins. The high thermal conductivity of metal along with its large surface area result in the rapid transfer of thermal energy to the encircling cooler air. A fan may improve the transfer of heat energy from the heat sink to the air. Other applications of fins include IC engine cooling; such as fins in a car radiator. Fins are widely used in the trailing edges of gas-turbine blades, in electronic cooling and in the aerospace industry.

Two most common types of fins widely used are plate fins and pin fins [2]. The plate fins have a rectangular cross section and the pin fins have circular cross section. These fins are connected to a base plate which is to be cooled. Aluminum alloy plate fins along with heat sinks have been used in the aircraft industry for more than 60 years and adopted into the cryogenic air separation industry around the time of the second world war and shortly afterwards into cryogenic processes in chemical plants such as Natural Gas Processing. They are also used in railway engines and motor cars [3].

Pin fins and pin fin heat sinks are used in many devices nowadays and works excellently with LEDs compared to other techniques [4]. Among the different types of heat sinks, pin fin heat sinks are gaining a lot of popularity among people.



(a) (b)

Figure 1.1: Common configuration of (a) plate fins and (b) pin fins

From the previous investigation it has been understood that factors affecting the heat transfer rate from fins include the velocity of fluid flow [5], the thermal properties of the fluid, types of fins (plate or pin fin) [6], cross sectional shape of the fins like perforations [7], types of perforations, the formation/arrangement of pin fins (staggered or in line) [8]. In existing studies, the parameters affecting heat transfer like the velocity of fluid flow, types of fins i.e. plate and pin fins, the cross-sectional shape of the fins like perforation, types of perforation like circular and hexagonal have been investigated under turbulent flow condition. In addition, pressure drop across the fin arrays have also been experimented.

1.2 Energy Transfer Theories applied in Fin

Heat transfer enhancement by fins is a very simple mechanism but it associates a number of heat transfer, fluid mechanics and thermodynamic principles. Basic conduction and convection along with a negligible effect of radiation are applicable here. The surrounding fluid velocity, the nature of the surrounding fluid very much affects the fin performance and these factors are directly related with fluid mechanics. As our experiment was conducted within a wind tunnel which is nothing but a control volume, several thermodynamic principles are also applicable here.

1.2.1 Heat Transfer Theories

Actually conduction is the transfer of energy from more energetic particles of a substance to the adjacent less energetic ones as a result of interactions between particles [9]. Atfirst heat is transferred by conduction from the base plate which is to be cooled to the fins or the extended surfaces. These fins are exposed to the environment. Then heat is transferred to the environment by free convection or forced convection. In free convection any fluid motion is caused by natural means such as buoyancy effect [10]. On the other hand, in forced convection the fluid is forced to flow by an external means such as a pump or a blower.

1.2.2 Fluid Mechanics Theories

The velocity of the moving fluid affects fin performance. This velocity controls the Reynolds Number. Reynolds number determines whether the flow is laminar, transient or turbulent. Reynolds Number is also affected by the hydraulic diameter of the test section and kinematic viscosity of the fluid.

1.2.3 Thermodynamic Theories

Wind tunnel test section is modeled as control volume. Most control volumes are analyzed under steady operating conditions. The total energy content of a control volume during a steady flow process remains constant. Thus the amount of energy entering in control volume in the form of heat for a steady flow process must be equal to the amount of energy leaving it[10]. The term steady means no change with time at a specified location.

1.3 Assumptions Made During Calculation of Fin

Some assumptions are made while applying governing equations and doing related calculations. With the change in assumption governing equations and scenario changes at a great extent. The assumptions are listed below:

a. Steady state heat transfer while calculating fin performance parameters. Temperature is not changed with time.
b. Constant material properties (independent of temperature).
c. No internal heat generation from fins.
d. One dimensional conduction

e. Uniform convection across the surface area.

1.4 Factors Affecting the Performance of Fin

There are some factors which control the performance of fin. Some of them are direct properties of fin such as fin material and design and some are surrounding properties.

1.4.1 Design and Geometry of Fin

Plate fin and pin fin have got different geometry and their performance is also not same. In case of plate fin H/w [7] control the performance of fin at a great extent. Likewise, in pin fin H/D ratio and S_{y}, S_{L} and S_{D} greatly affect the performance of fin [8].

1.4.2 Varying Cross Section

We can vary the cross section by doing perforation in the fin. It increases the heat transfer by the fin a lot [7]. Various types of perforations can be done i.e. circular, square, hexagonal. The size of the perforation has also an effect on heat transfer. The higher the size of the perforation the higher the rate of heat transfer [7,8]

1.4.3 Fin Materials

Fin material should be selected in such a way that it has got high thermal conductivity, less mass, reduced cost and it is not affected by humid condition. When it comes to material selection the preferable one would be the material which can absorb heat at a higher rate and also dissipate it to the air passing through it really fast. Aluminium is an ideal material which possesses this quality. It is also chosen for good heat conductivity, high malleability, easily casting capability, corrosion resistance, light weight than other metal, abundant availability and easily recyclable [11]

1.4.4 Surrounding Conditions

The temperature of the surrounding environment of the fin affect the heat transfer rate and performance of fin. If the surrounding fluid is air and then it is forced to flow by a fan or a blower, then heat transfer will increase and so on the fin performance**.**

1.5 Objectives

The main objectives of this thesis are:

a. To understand steady heat transfer.
b. Importance of plate fin and pin fin heat sink.
c. To understand plate fin and pin fin functions and suitability
d. To compare convective heat transfer co-efficient of fins without perforation, fins with circular perforation and fins with hexagonal perforation at different Reynolds Number
e. To compare Nusselt Number of fins without perforation, fins with circular perforation and fins with hexagonal perforation at different Reynolds Number
f. To compare fin efficiencies of fins without perforation, fins with circular perforations and fins with hexagonal perforations at different Reynolds Number.
g. To compare fin effectiveness fins without perforation, fins with circular perforations and fins with hexagonal perforations at different Reynolds Number
h. To compare thermal resistance of fins without perforation, fins with circular perforations and fins with hexagonal perforations at different Reynolds Number.
i. To compare pressure drop across fin arrays for fins without perforation, fins with circular perforations and fins with hexagonal perforations at different Reynolds Number
j. To find out the overall performance of plate fin and pin fin

CHAPTER TWO

LITERATURE REVIEW

2.1 Review of Literatures

There have been many investigation regarding heat transfer and pressure drop of channels with pin fins have been done by the following researchers considering the different factors for heat transfer.

In the year 2008 **B.Sahin** and **A.Demir**[12] studied the heat transfer enhancement and the corresponding pressure drop over a flat surface equipped with square cross-sectional perforated pin fins in a rectangular channel. The experimental results showed that the use of the square pin fins may lead to heat transfer enhancement. Enhancement efficiencies varied between 1.1 and 1.9 depending on the clearance ratio and inter-fin spacing ratio. Both lower clearance ratio and lower inter-fin spacing ratio and comparatively lower Reynolds numbers are suggested for higher thermal performance. In this study, the overall heat transfer, friction factor and the effect of the various design parameters on the heat transfer and friction factor for the heat exchanger equipped with square cross-sectional perforated pin fins were investigated experimentally.

R. Karthikeyan and **R. Rathnasamy2007**[13] studied the heat transfer and friction characteristics of convective heat transfer through a rectangular channel with cylindrical and square cross-section pin-fins attached over a rectangular duralumin flat surface. The pin-fins were arranged in in-line and a staggered manner

O.N. Saraet al 2002[14] reported another way to improve heat transfer rate is to employ attachments with (i) perforations, (ii) a certain degree of porosity or (iii) slots which allow the flow to go through the blocks. In the case of perforated attachments, the improvement in the flow (thus the enhancement in the heat transfer) is brought about by the multiple jet-like flows through the perforations.

Essa et al. [15] and **Zan et al**. [16] found that the perforation of fins enhances the heat dissipation rates and at the same time decreases the expenditure for fin materials.

M. R. Shaeri and **M. Yaghoubi2009**[17] conducted numerical study of turbulent fluid flow and convective heat transfer over an array of solid and perforated fins. According to their study temperature drop form fin base to fin top surface increases with additions of perforations and perforated fins have higher fin effectiveness than solid fin that rises remarkably by adding more perforations. They also found that the form drag was the highest and the average friction drag was lowest for solid fin compared to perforated fins and drag decreases with increase of perforations [7].

Bhuiyan et al. 2012, 2013, 2014[18,19,20] studied thermal and hydraulic performance of plate fin, wavy fin and tube heat exchanger for transitional and turbulent flow regime. They found that the heat transfers and pressure drop performance increase with the decrease in the longitudinal, transverse pitch and the increase in fin pitch.

Iyengar and Bar-Cohen 1998[21] tried to compare optimized plate-fin and pin-fin array with least material method. In many cases, however, thermal performance itself is usually more important than the amount of material. Therefore, there may be other practical constraints to compare plate-fin and pin-fin heat sinks.

Tzer-Ming Jeng and **Sheng-Chung Tzeng 2009**[22] studied the pressure drop and heat transfer of a square pin-fin array in a rectangular channel. The variable parameters are the relative longitudinal pitch, the relative transverse pitch and the arrangement (inline or staggered). The result shows that the in-line square pin-fin array has smaller pressure drop than the in-line circular pin-fin array at high transverse pitch but at an equivalent or slightly higher pressure drop at low transverse pitch. Additionally, the staggered square pin fin array has the largest pressure drop of the three pin fin arrays (in-line circular pin-fins, in-line square pin-fins and staggered square pin-fins). Most in-line square pin-fin arrays have poorer heat transfer than an in-line circular pin fin array, but a few, as when longitudinal pitch = 2.8, exhibit excellent heat transfer at high Reynolds number.

Giovanni Tanda 2001[23] studied heat transfer and pressure drop experiments were performed for a rectangular channel equipped with arrays of diamond-shaped elements.

2.2 Motivation for Present Study

Early works and investigations on fin mainly included how fin geometry affects heat transfer. It has been seen that in some cases plate fins are most effective and in some cases pin fins are most effective. Pin fins are found mainly in two formations i.e. in-line and staggered. From some experimental studies it has been concluded that staggered arrangement increase the heat transfer at a great extent than the in-line arrangement. When investigation was conducted in a forced convection environment the effect of staggered arrangement was more than the in-line arrangement. Transverse pitch and longitudinal pitch were changed to observe the increase or decrease of heat transfer.

The comparison between plate fin and pin fin was made by keeping the surface area same. The cross-sectional area of the fin was varied by making different perforations i.e. square, circular. The size of the perforation was also varied to increase heat transfer and make the fin much more effective. But the effect of hexagonal perforation on the fin is not yet investigated. Hexagonal perforations have got the highest surface/perimeter ratio compared to other polygons and other geometrical shapes. So we will have more surface area which is very much convenient to increase heat transfer. Hexagonal perforation also decreases the mass of the fin models.

2.3 Governing Equations

While doing the experiment for plate fin, it has been seen that the total air flow doesn't strike the model. So in this case we have to use the effective velocity. It is calculated by using effective fluid flow area [7].

$$V_{avg} = \frac{V}{A-A_{front}}\text{[m/s]} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.1)$$

The flow regime depends mainly on the ratio of the inertia forces to viscous forces in the fluid. This ratio is called the Reynolds number [22], which is a dimensionless quantity, and is expressed for external flow as:

$$\text{Re} = \frac{V_{avg} d_h}{\nu} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.2)$$

laminar - when Re < 2300,

transient - when 2300 < Re < 4000

turbulent - when Re > 4000

The total heat input $\dot{Q}_T$ is calculated from the potential and the current passing through the wire. It is equal to the summation of the conduction heat loss$\dot{Q}_{cond}$, convection heat loss$\dot{Q}_{conv}$ and radiation heat loss$\dot{Q}_{rad}$.

$$\dot{Q}_T = \dot{Q}_{cond} + \dot{Q}_{conv} + \dot{Q}_{rad} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

Heat loss due to conduction is given by,

$$\dot{Q}_{cond} = \frac{T_x - T_y}{R_1 + R_2} [\text{W}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.4)$$

Heat loss by radiation is given by,

$$\dot{Q}_{rad} = \varepsilon A_s \sigma (T_s^4 - T_\infty^4) [\text{W}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.5)$$

Convective heat transfer co-efficient, h is calculated by

$$\text{h} = \frac{\dot{Q}_{conv}}{A_s (T_s - T_\infty)} \qquad [\frac{W}{m^2.K}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.6)$$

Thermal resistance is a measure of the temperature difference by which a material resists heat flow. Thermal conduction is a material property. Thermal resistance is the temperature difference across a system when heat flows through it.

$$R_{th} = \frac{1}{h \, . \, A_s} \qquad [\frac{K}{W}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.7)$$

Fin efficiency, η_{fin} is defined as the ratio of actual heat transfer rate from the fin to the ideal heat transfer rate from the fin if the entire fin were at base temperature.

$$\eta_{fin} = \frac{h \, A_s \, (T_s - T_\infty)}{h \, A_s \, (T_b - T_\infty)} \times 100 \qquad [\%] \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.8)$$

Fin effectiveness, ε_{fin} is the ratio of heat transfer from fin to heat transfer from fin base without fin as,

$$\varepsilon_{fin} = \frac{h \left(A_{un-fin} + \eta_{fin} A_{fin}\right) (T_b - T_\infty)}{h \, A_{no-fin} \, (T_b - T_\infty)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.9)$$

The dimensionless pressure drop, Δp^* is defined as,

$$\Delta P^* = \frac{\Delta P}{\frac{1}{2} \, . \, \rho \, . \, V_{Avg}^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.10)$$

Nusselt Number equation for flat plate,

$$Nu = \frac{h\,L}{K} \quad \text{..................................} (2.11)$$

Maximum velocity for flow across the tube banks,

$$V_{max} = \frac{S_T}{2(S_D - D)} V \quad [m/s] \text{........................} (2.12)$$

Nusselt Number equation for flow across the tube banks,

$$Nu = F \times [0.35 (\frac{S_T}{S_L})^{0.2} \times (Re)^{0.6} \times (Pr)^{0.36} \times (\frac{Pr}{Pr_s})^{0.25}] \text{........} (2.13)$$

Bulk temperature,

$$T_\infty = \frac{T_i + T_0}{2} \quad [°C] \text{..............................} (2.14)$$

Film temperature,

$$T_f = \frac{T_s - T_\infty}{2} \quad [°C] \text{..............................} (2.15)$$

CHAPTER THREE

METHODLOGY AND EXPERIMENTAL SET-UP

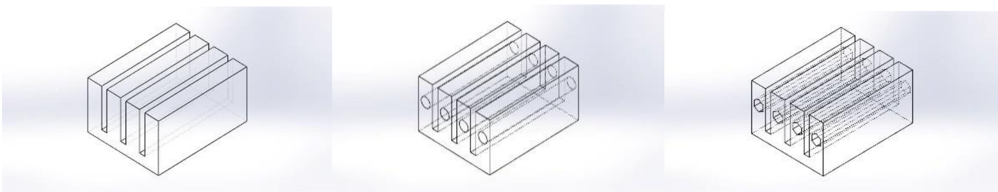
3.1 Outline of Methodology

There are six fin models. Among them three are plate fins and three are pin fins. The isometric views of the fin models are shown in Figure 3.1, Figure 3.2. The plate fin models consist of plate fin without perforation, plate fin with circular perforation, plate fin with hexagonal perforation. Same goes for the pin fins. The fins have been machined in CNC machine from solid aluminium bar. A heater box which dimension is 201mm×170mm×47mm has been constructed. The box was filled with glass wool and asbestos and on the top of this insulators two aluminum plates of size 120mm×100mm are bolted together. Between these aluminium plates a heating coil of 440W is placed. The heater box with the help of a shat is clamped into the three component balance of the wind tunnel. The fin models are tested one by one. Along the length of every fin model six K-type thermocouples are attached. The thermocouples give output in the KKK displays. The fin model with attached thermocouples is placed on the heater box which is clamped by the three component balance. The air velocity is set manually according to the purpose. The heater is plugged in to the power supply. The voltage output is 220V and the ampere is measured by a clamp-on meter.

The experimental procedure is given below:

a. At first the heater box is clamped via three component balance in the test section of the AF100 subsonic wind tunnel.
b. K-type thermocouples are attached with the fin along the fin length.
c. The heater is plugged into main supply line and the air velocity is set at $4ms^{-1}$.
d. Two temperature measuring sensors are placed at the inlet and outlet of the test section respectively to measure the inlet and outlet air temperature.
e. The heat is allowed to increase. After every 30 sec temperatures are recorded.
f. After a certain period of time, the temperature is seen not be increased further. Then we can say that steady state condition is achieved. The temperatures are noted down at this stage.

g. After the achievement of steady state condition, the heater box is unplugged from the main supply line and the base plate of the fin model is allowed to cool.
h. As the fin model is exposed to forced convection heat transfer situation it will dissipate heat to the environment and thus will do the cooling of the base plate.
i. As the temperature is changing with time, we call it transient condition
j. After a period of time the base plate temperature will be equal to the environment temperature or will be slightly higher than the environment temperature.
k. The same procedure is repeated for the same model for $6ms^{-1}$, $8ms^{-1}$, $10ms^{-1}$, $12ms^{-1}$.
l. In this way data are recorded for the six fin models.



(a) (b) (c)

Figure 3.1: Plate Fin (a) without perforation (b) circular perforation (c) hexagonal perforation

(a) (b) (c)

Figure 3.2: Pin Fin (a) without perforation (b) circular perforation (c) hexagonal perforation

3.2 General Aspect

For collection of data, an experimental set up is made and installed. Apparatus used and experimental procedures are described in this chapter. The equipment used in this experiment are as follows:

3.2.1 Fins

(i) Solid plate fin
(ii) Plate fin with circular perforation
(iii) Plate fin with hexagonal perforation
(iv) Solid pin fin
(v) Pin fin with circular perforation
(vi) Pin fin with hexagonal perforation

3.2.2 Machines and Materials Used for Making Fins

(i) CNC machine
(ii) LATHE machine
(iii) Grinding machine
(iv) Aluminium

3.2.3 Measuring Equipment

(i) Thermocouple
(ii) Clamp on meter
(iii) Multimeter
(iv) Digital display

3.2.4 Heating Equipment

(i) Electric heater
(ii) Thermostat

3.2.5 Materials for Insulation

(i) Glass wool
(ii) Asbestos

3.2.6 Subsonic Wind Tunnel

3.2.7 Other Equipment

(i) Vise

(ii) Hacksaw blade

(iii) Power strip

(iv) Super glue

(v) Fire extinguisher

3.3 Capsulization of Experimental Setup

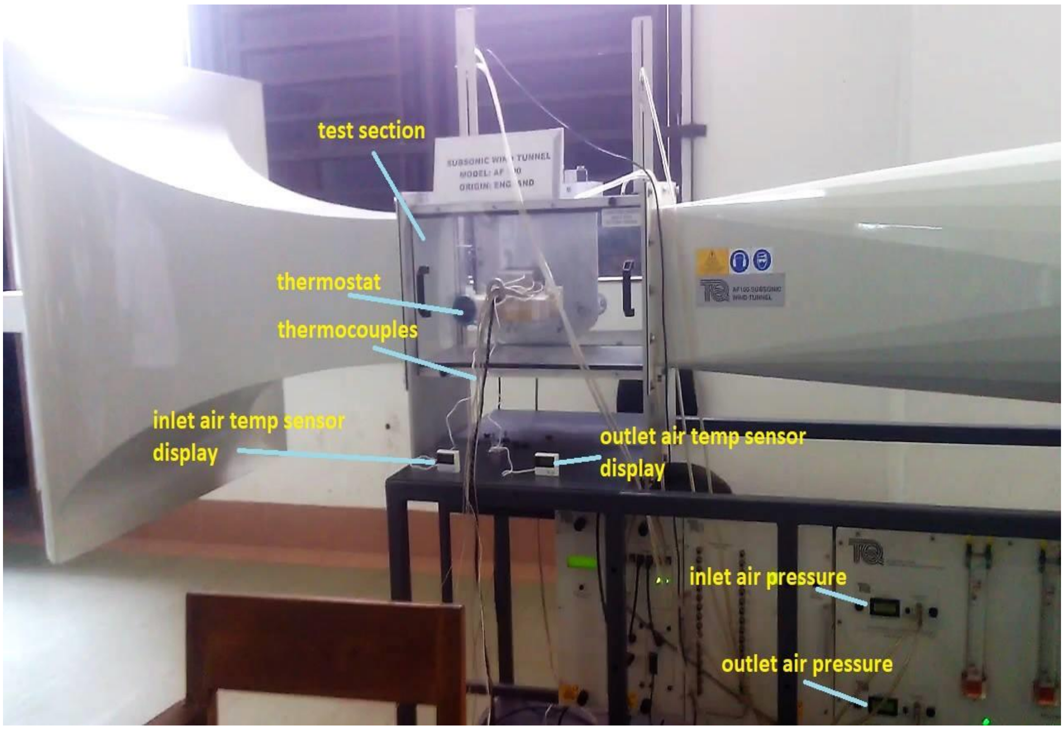


Figure 3.3: Capsulization of experimental setup

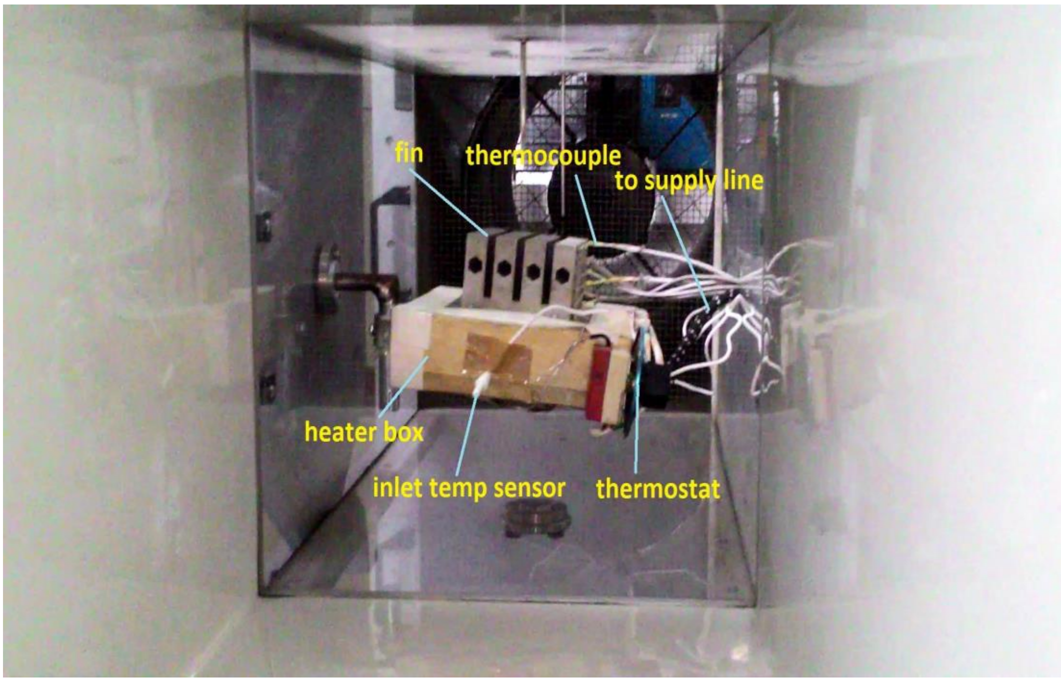


Figure 3.4: Heater box with fin

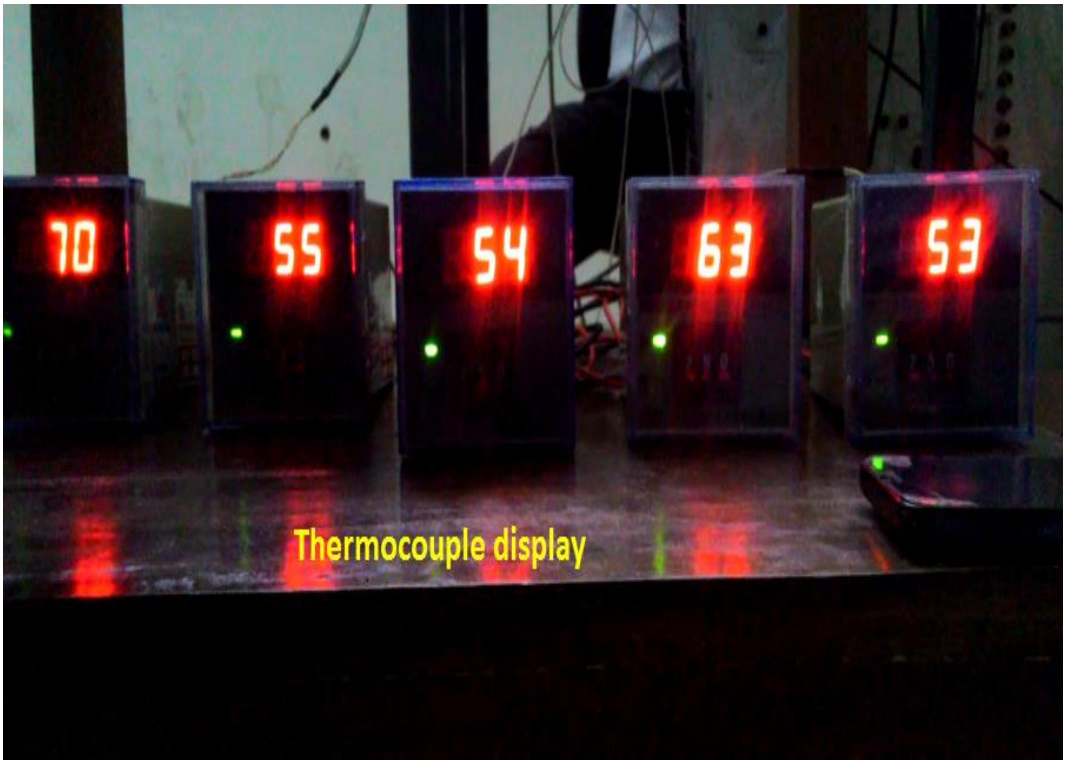


Figure 3.5: Thermocouple display

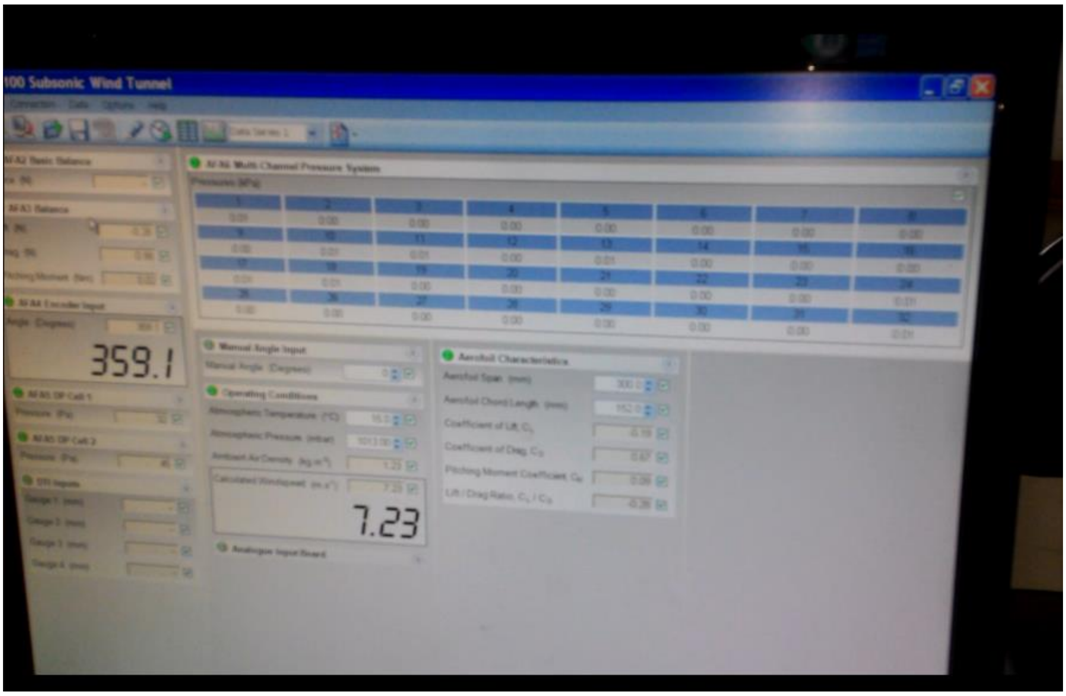


Figure 3.6: Air velocity display

3.4 Fabrication of Fin

3.4.1 Solid Plate Fin:

It is made of cutting rectangular groove in the solid aluminium block**.**

Figure 3.7: Solid plate fin

3.4.2 Plate Fin with Circular Perforation

Circular perforation is made with the help of CNC machine.

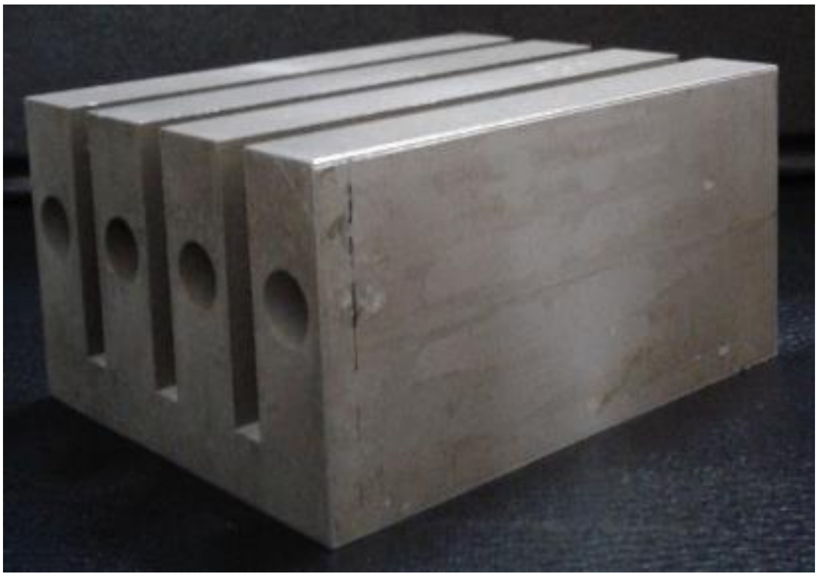


Figure 3.8: Plate fin with circular perforation

3.4.3 Plate Fin with hexagonal Perforation

Hexagonal perforation is made with the help of CNC machine.

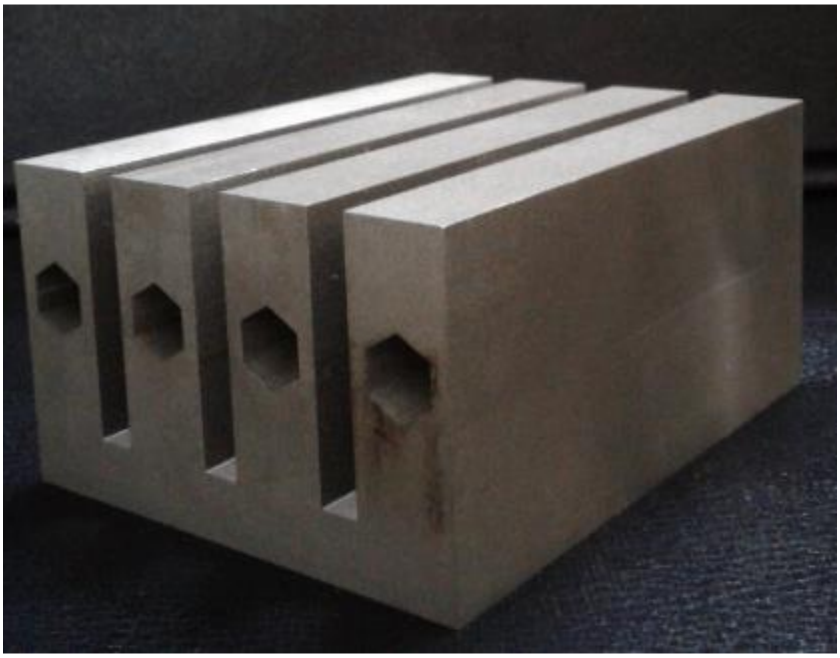


Figure 3.9: Plate fin with hexagonal perforation

3.4.4 Solid Pin Fin

It is made of using aluminium rod and bar and base plate.

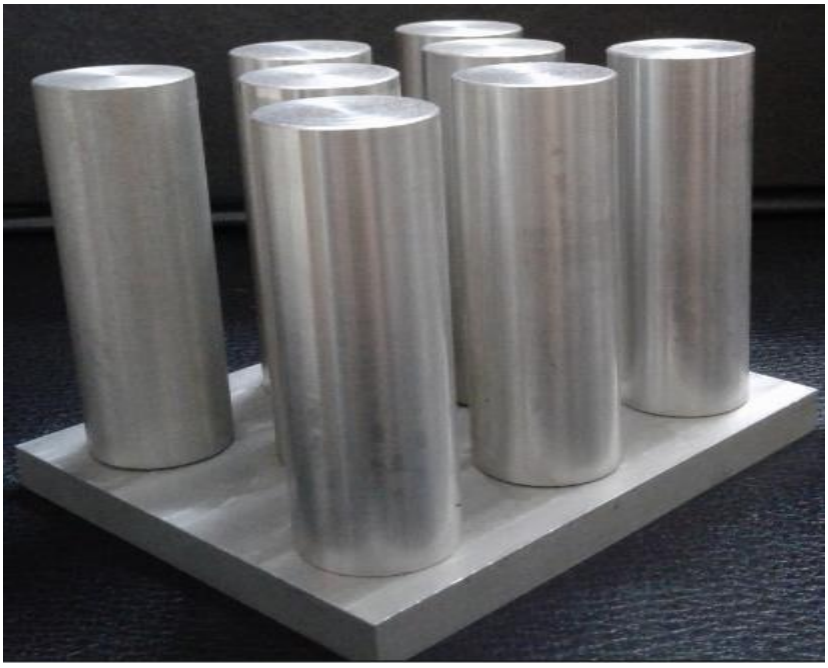


Figure 3.10: Solid pin fin

3.4.5 Pin Fin with Circular Perforation

Circular perforation is made with the help of CNC machine.

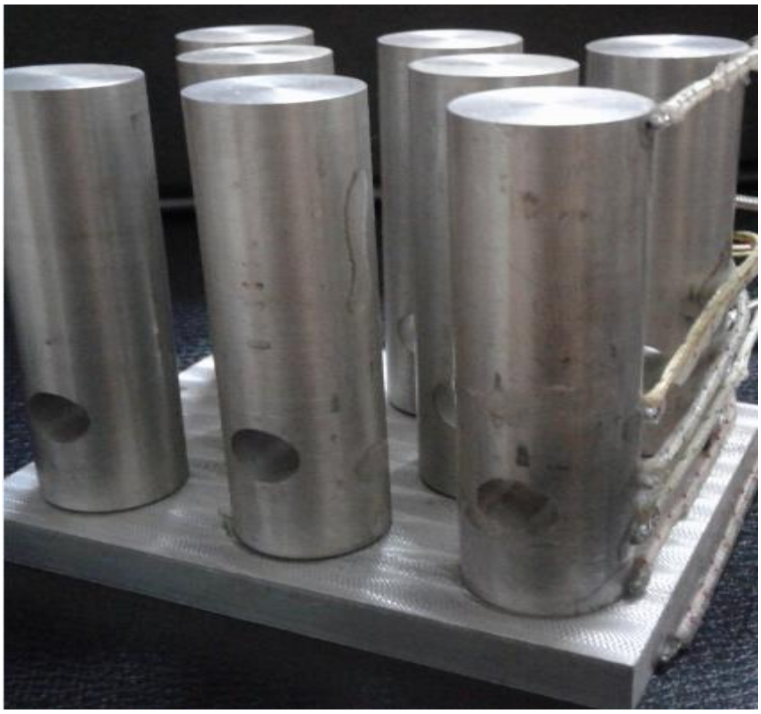


Figure 3.11: Pin fin with circular perforation

3.4.6 Pin Fin with Hexagonal Perforation

Hexagonal perforation is made with the help of CNC machine.

Figure 3.12: Pin fin with hexagonal perforation

3.5 Machines and Materials Used for Making Fins

3.5.1 CNC Machine

CNC Machining is a process used in the manufacturing sector that involves the use of computers to control machine tools. Tools that can be controlled in this manner include lathes, mills, routers and grinders. The CNC in CNC Machining stands for Computer Numerical Control.

A CNC or computer numerical control machine is a high precision tool that's computer-controlled and makes repeated, accurate movements. It does so by taking computer-generated code and converting it with software to electrical signals.

Figure 3.13: CNC Machine

3.5.2 LATHE Machine

A lathe is a tool that rotates the work piece about an axis of rotation to perform various actions as cutting, sanding, knurling, drilling, deformation, facing, turning, with tools that are applied to the work piece to create an object with symmetry about that axis.

Lathes are used in woodturning, metalworking, metal spinning, thermal spraying, parts reclamation, and glass-working. Lathes can be used to shape pottery, the best-known design being the potter's wheel. Most suitably equipped metalworking lathes can also be used to produce most solids of revolution, plane surfaces and screw threads or helices. Ornamental lathes can produce three-dimensional solids of incredible complexity. The work piece is usually held in place by either one or two *centers*, at least one of which can typically be moved horizontally to accommodate varying work piece lengths. Other work-holding methods include clamping the work about the axis of rotation using a chuck or cullet, or to a faceplate, using clamps or dogs.

Examples of objects that can be produced on a lathe include candlestick holders, gun barrels, cue sticks, table legs, bowls, baseball bats, musical instruments (especially woodwind instruments), crankshafts, and camshafts.

Figure 3.14: LATHE Machine

3.5.3 Grinding Machine

A grinding machine, often shortened to grinder, is any of various power tools or machine tools used for grinding, which is a type of machining using an abrasive wheel as the cutting tool. Each grain of abrasive on the wheel's surface cuts a small chip from the work piece via shear deformation.

Grinding is used to finish work pieces that must show high surface quality (e.g., low surface roughness) and high accuracy of shape and dimension. As the accuracy in dimensions in grinding is of the order of 0.000025 mm, in most applications it tends to be a finishing operation and removes comparatively little metal, about 0.25 to 0.50 mm depth. However, there are some roughing applications in which grinding removes high volumes of metal quite rapidly. Thus, grinding is a diverse field.

Figure 3.15: Grinding machine

3.5.4 Aluminium

Aluminium is a chemical element with symbol Al and atomic number 13. It is a silvery-white, soft, nonmagnetic, ductile metal in the boron group. By mass, aluminium makes up about 8% of the Earth's crust; it is the third most abundant element after oxygen and silicon and the most abundant metal in the crust, though it is less common in the mantle below. The chief ore of aluminium is bauxite. Aluminium metal is so chemically reactive that native specimens are rare and limited to extreme reducing environments. Instead, it is found combined in over 270 different minerals.

Figure 3.16: Aluminium rod

Aluminium is remarkable for its low density and its ability to resist corrosion through the phenomenon of passivation. Aluminium and its alloys are vital to the aerospace industry and important in transportation and building industries, such as building facades and window frames. The oxides and sulfates are the most useful compounds of aluminium.

Despite its prevalence in the environment, no known form of life uses aluminium salts metabolically, but aluminium is well tolerated by plants and animals. Because of these salts' abundance, the potential for a biological role for them is of continuing interest, and studies continue.

3.6 Measuring Equipment

3.6.1 Thermocouple

A thermocouple is an electrical device consisting of two dissimilar electrical conductors forming electrical junctions at differing temperatures. A thermocouple produces a temperature-dependent voltage as a result of the thermoelectric effect, and this voltage can be interpreted to measure temperature. Thermocouples are a widely used type of temperature sensor.

Commercial thermocouples are inexpensive, interchangeable, are supplied with standard connectors, and can measure a wide range of temperatures. In contrast to most other methods of temperature measurement, thermocouples are self-powered and require no external form of excitation. The main limitation of thermocouples is accuracy; system errors of less than one degree Celsius (°C) can be difficult to achieve.

Figure 3.17: Thermocouple

3.6.2 Clamp Meter

A clamp meter is an electrical test tool that combines a basic digital multi meter with a current sensor.

Figure 3.18: Clamp meter

Clamps measure current. Probes measure voltage. Having a hinged jaw integrated into an electrical meter allows technicians to clamp the jaws around a wire, cable or other conductor at any point in an electrical system, then measure current in that circuit without disconnecting/de energizing it.

Beneath their plastic moldings, hard jaws consist of ferrite iron and are engineered to detect, concentrate and measure the magnetic field being generated by current as it flows through a conductor.

3.6.3 Multimeter

A multimeter is also known as to engineers VOM (volt-ohm-milliammeter), is an electronic measuring instrument that combines several measurement functions in one unit. A typical multimeter can measure voltage, current, and resistance. Analog multimeters use a micrometer with a moving pointer to display readings. Digital multimeters (DMM, DVOM) have a numeric display, and may also show a graphical bar representing the measured value. Digital multimeters are now far more common due to their cost and precision, but analog multimeters are still preferable in some cases, for example when monitoring a rapidly varying value.

Figure 3.19: Multimeter

3.6.4 Digital Display

A display device is an output device for presentation of information in visual or tactile form (the latter used for example in tactile electronic displays for blind people). When the input information that is supplied has an electrical signal, the display is called an electronic display. Some displays can show only digits or alphanumeric characters. They are called segment displays, because they are composed of several segments that switch on and off to give appearance of desired glyph. The segments are usually single LEDs or liquid crystals. They are mostly used in digital watches and pocket calculators. There are several types:

- Seven-segment display (most common, digits only)
- Fourteen-segment display
- Sixteen-segment display

- HD44780 LCD controller a widely accepted protocol for LCDs.

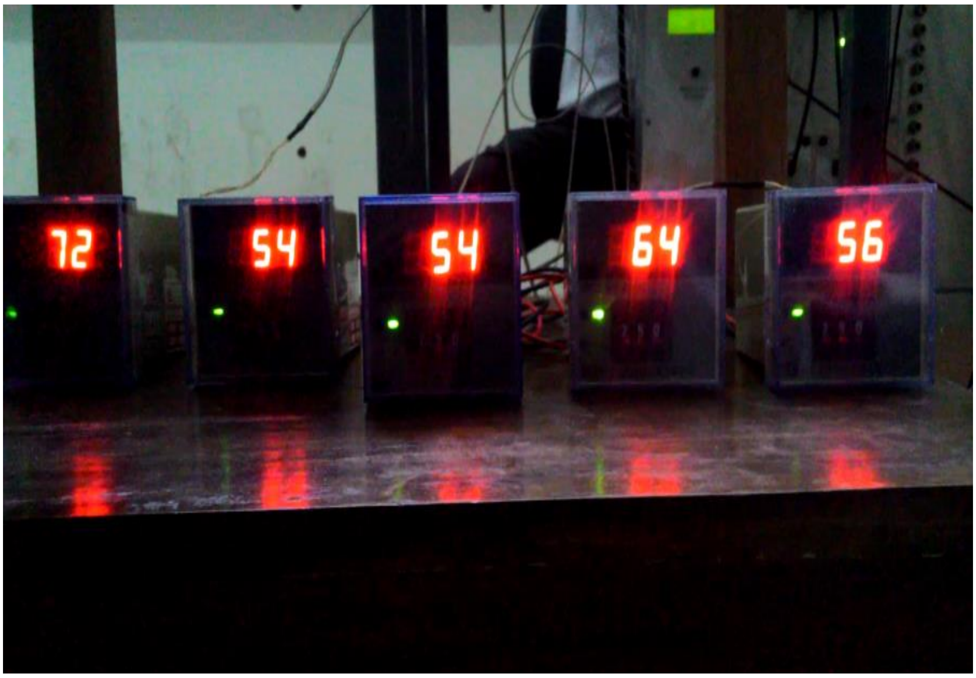


Figure 3.20: Digital temperature display

3.7 Heating Equipment

3.7.1 Electric Heater

A heater is made by using wood, asbestos, glass wool, aluminium, heater coil so that it can heat the surface of the fin.

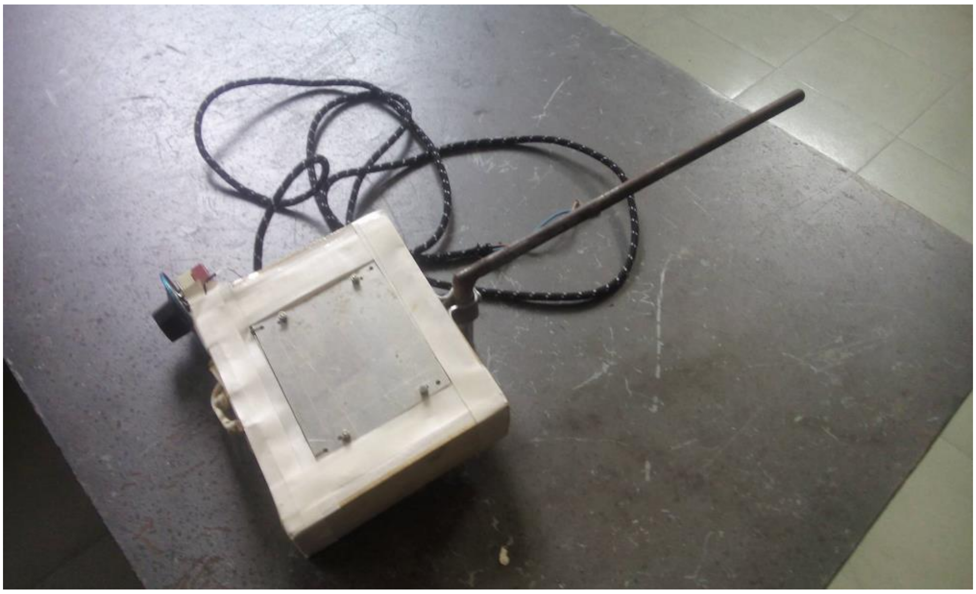


Figure 3.21: Electric heater

3.7.2 Thermostat

A thermostat is a component which senses the temperature of a system so that the system's temperature is maintained near a desired set point. Thermostats are used in any device or system that heats or cools to a set-point temperature, examples include building heating, central heating, air conditioners, HVAC systems, water heaters, as well as kitchen equipment including ovens and refrigerators and medical and scientific incubators. In scientific literature, these devices are often broadly classified as thermostatically controlled loads (TCLs). Thermostatically controlled loads comprise roughly 50% of the overall electricity demand in the United States.

Figure 3.22: Thermostat

A thermostat operates as a "closed loop" control device, as it seeks to reduce the error between the desired and measured temperatures. Sometimes a thermostat combines both the sensing and control action elements of a controlled system, such as in an automotive thermostat.

3.8 Materials for Insulation

3.8.1 Glass Wool

Glass wool is an insulating material made from fibers of glass arranged using a binder into a texture similar to wool. The process traps many small pockets of air between the glass, and these small air pockets result in high thermal insulation properties. Glass wool is produced in rolls or in slabs, with different thermal and mechanical properties. It may also be produced as a material that can be sprayed or applied in place, on the surface to be insulated.

3.8.2 Asbestos

Asbestos is a set of six naturally occurring silicate minerals, [1] which all have in common their eponymous asbestos form habit: i.e. long (roughly 1:20 aspect ratio), thin fibrous crystals, with each visible fiber composed of millions of microscopic "fibrils" that can be released by abrasion and other processes

3.9 Subsonic Wind Tunnel

A wind tunnel is a tool used in aerodynamic research to study the effects of air moving past solid objects. A wind tunnel consists of a tubular passage with the object under test mounted in the middle. Air is made to move past the object by a powerful fan system or other means. The test object, often called a wind tunnel model, is instrumented with suitable sensors to measure aerodynamic forces, pressure distribution, or other aerodynamic-related characteristics.

The earliest wind tunnels were invented towards the end of the 19th century, in the early days of aeronautic research, when many attempted to develop successful heavier-than-air flying machines. The wind tunnel was envisioned as a means of reversing the usual paradigm: instead of the air standing still and an object moving at speed through it, the same effect would be obtained if the object stood still and the air moved at speed past it. In that way a stationary observer could study the flying object in action, and could measure the aerodynamic forces being imposed on it.

The development of wind tunnels accompanied the development of the airplane. Large wind tunnels were built during World War II. Wind tunnel testing was considered of strategic importance during the Cold War development of supersonic aircraft and missiles.

Figure 3.23: Subsonic wind tunnel

3.10 Other Equipment

3.10.1 Vise

A vise (American English) or vice (British English) is a mechanical apparatus used to secure an object to allow work to be performed on it. Vices have two parallel jaws, one fixed and the other movable, threaded in and out by a screw and lever.

An engineer's vice, also known as a *metalworking vice* or *machinists vice,* is used to clamp metal instead of wood. It is used to hold metal when filing or cutting. It is sometimes made of cast steel or malleable cast iron, but most are made of cast iron. However, most heavy duty vices are 55,000 psi cast steel or 65,000 psi ductile iron. Some vices have a cast iron body but a steel channel bar. Cast iron is popular because it is typically 30ksi grey iron which is rigid, strong and inexpensive. The jaws are often separate and replaceable, usually engraved with serrated or diamond teeth. Soft jaw covers made of aluminum, copper, wood (for woodworking) or plastic may be used to protect delicate work. The jaw opening of an engineer's vice is almost always the same size as the jaw width, if not bigger.

Figure 3.24: Vise

3.10.2 Hacksaw Blade

A hacksaw is a fine-toothed saw, originally and mainly made for cutting metal.

Most hacksaws are hand saws with a C-shaped frame that holds a blade under tension. Such hacksaws have a handle, usually a pistol grip, with pins for attaching a narrow disposable blade. The frames may also be adjustable to accommodate blades of different sizes. A screw or other mechanism is used to put the thin blade under tension.

On hacksaws, as with most frame saws, the blade can be mounted with the teeth facing toward or away from the handle, resulting in cutting action on either the push or pull stroke. In normal use, cutting vertically downwards with work held in a bench vice, hacksaw blades are set to be facing forward.

Figure 3.25: Hacksaw blade

3.10.3 Power Strip

A power strip (also known as an extension block, power board, power bar, plug board, trailing gang, trailing socket, plug bar, trailer lead, multi-socket, multiple socket, multiple outlet, poly socket and by many other variations) is a block of electrical sockets that attaches to the end of a flexible cable (typically with a mains plug on the other end), allowing multiple electrical devices to be powered from a single electrical socket.

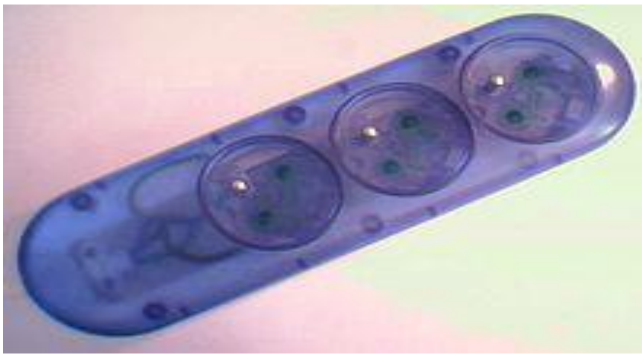


Figure 3.26: Power strip

3.10.4 Super Glue

Cyanoacrylate glue has a low shearing strength, which has led to its use as a temporary adhesive in cases where the piece needs to be sheared off later. Common examples include mounting a work piece to a sacrificial glue block on a lathe, and tightening pins and bolts. It is also used in conjunction with another, slower, but more resilient adhesive as way of rapidly forming a joint, which then holds the pieces in the appropriate configuration until the second adhesive has set.

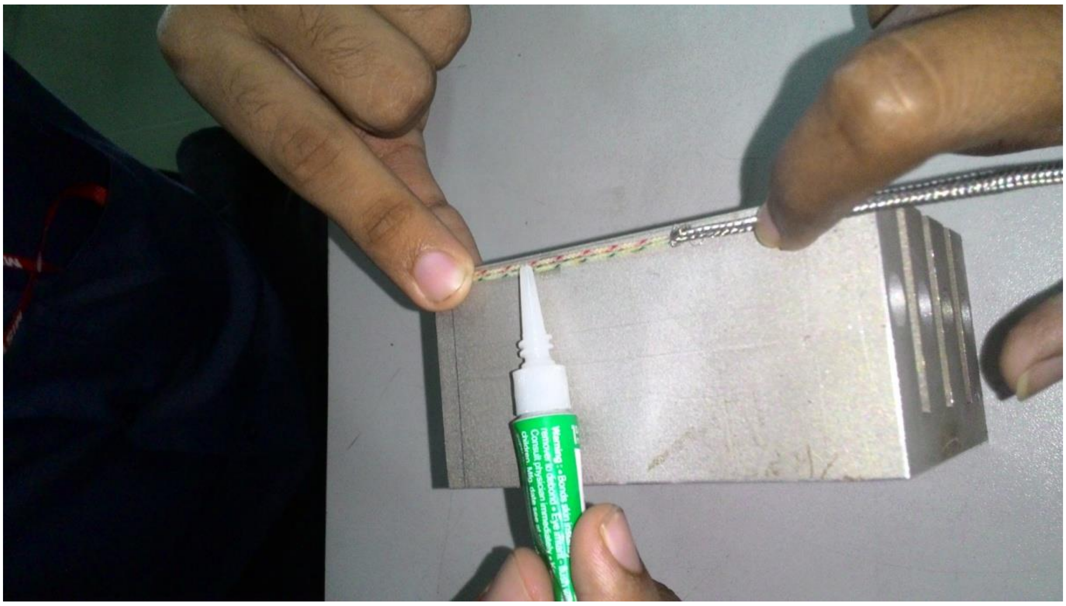


Figure 3.27: Super glue

3.10.5 Fire Extinguisher

A fire extinguisher is an active fire protection device used to extinguish or control small fires, often in emergency situations. It is not intended for use on an out-of-control fire, such as one which has reached the ceiling, endangers the user (i.e., no escape route, smoke, explosion hazard, etc.), or otherwise requires the expertise of a fire department. Typically, a fire extinguisher consists of a hand-held cylindrical pressure vessel containing an agent which can be discharged to extinguish a fire. Fire extinguishers manufactured with non-cylindrical pressure vessels also exist, but are less common.

Figure 3.28: Fire extinguisher

3.11 Solid Works designs of the Fin and Heater

3.11.1 Solid Plate Fin

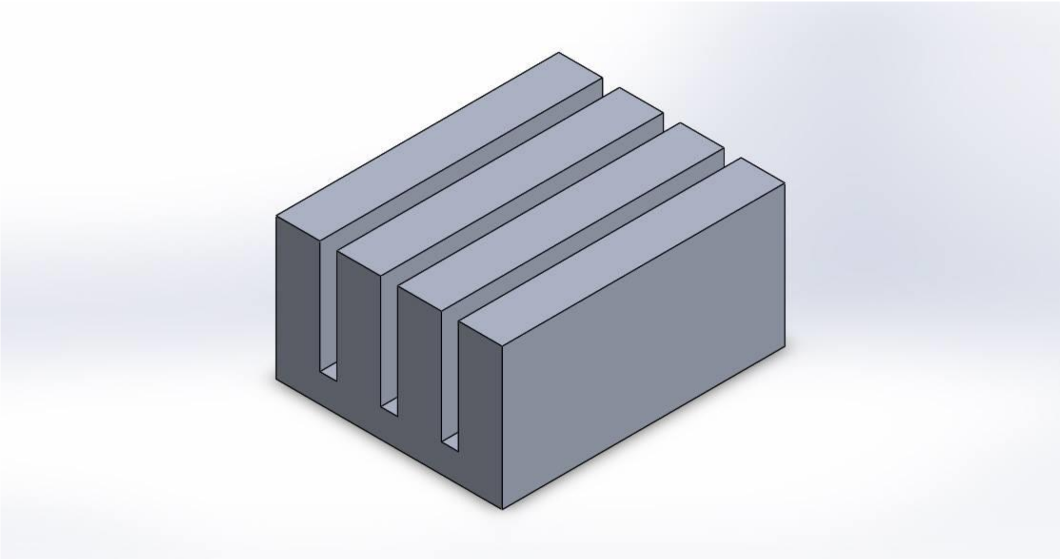


Figure 3.29: Solid works design of solid plate fin

3.11.2 Plate Fin with Circular Perforation

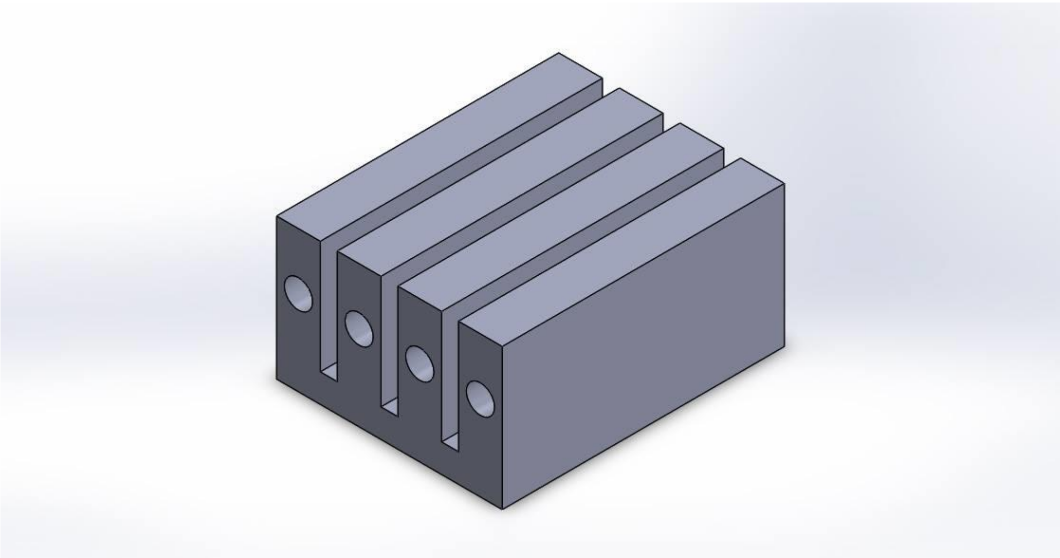


Figure 3.30: Solid works design of plate fin with circular perforation

3.11.3 Plate Fin with Hexagonal Perforation

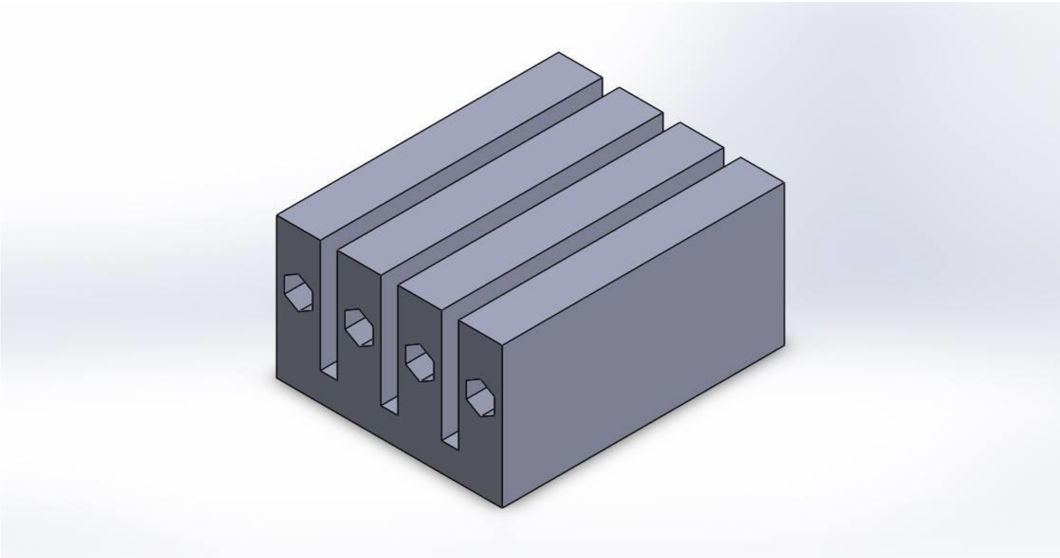


Figure 3.31: Solid works design of plate fin with hexagonal perforation

3.11.4 Solid Pin Fin

Figure 3.32: Solid works design of solid pin fin

3.11.5 Pin Fin with Circular Perforation

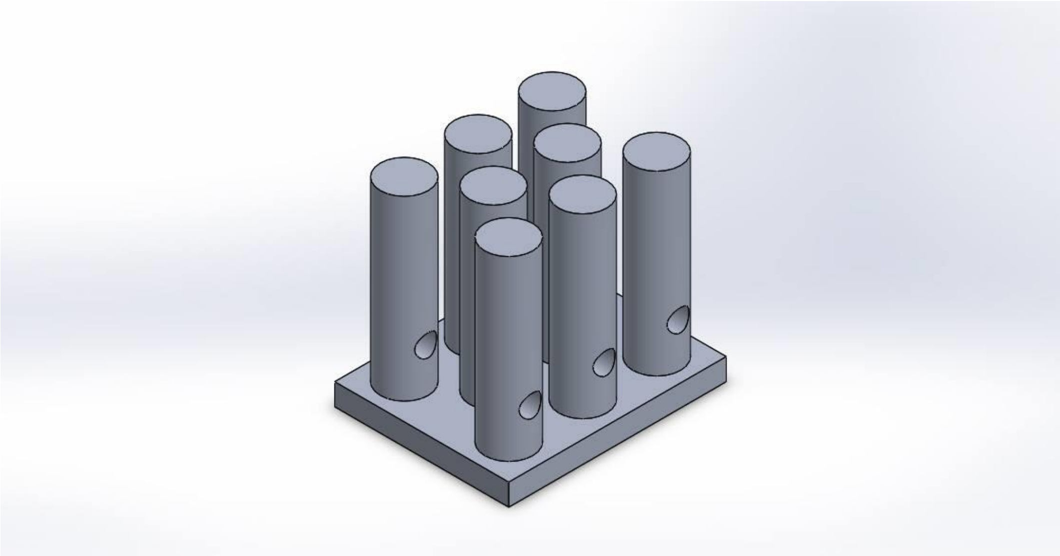


Figure 3.33: Solid works design of pin fin with circular perforation

3.11.6 Pin Fin with Hexagonal Perforation

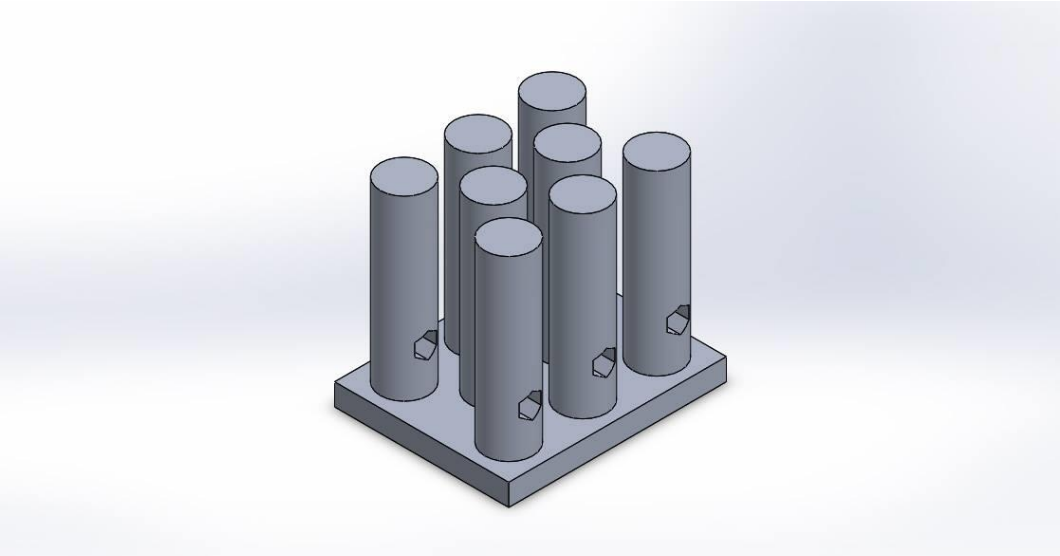


Figure 3.34: Solid works design of pin fin with hexagonal peroration

3.11.7 Heater box

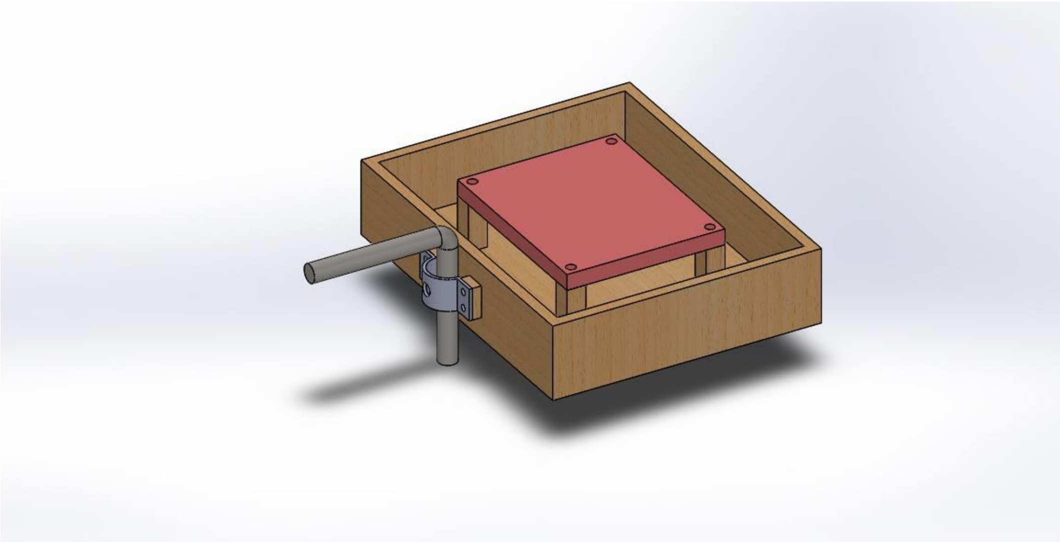


Figure 3.35: Solid works design of heater box

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Variation of cooling time for different plate fins for different air velocity

With the increase of air velocity, time needed for cooling is decreasing. Because increasing air velocity is assisting the cooling process.

4.1.1 Temperature Vs Time Graph for Cooling of Solid Plate Fin at 4m/s

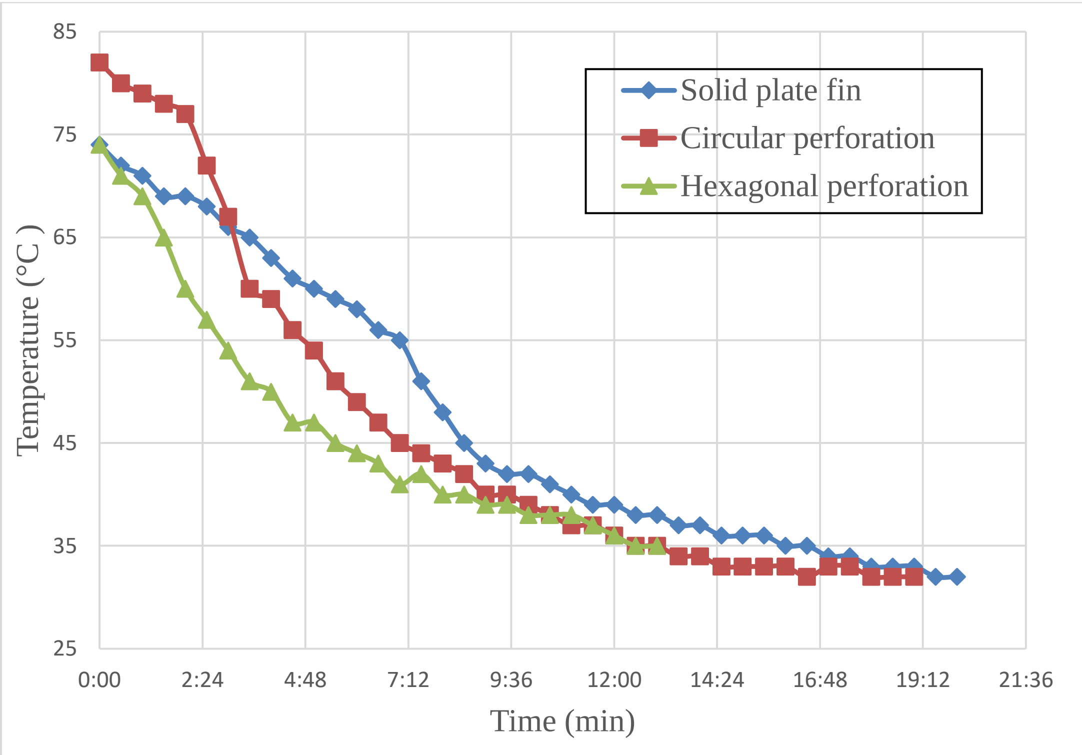


Figure 4.1: Variation of cooling time for different plate fins for 4m/s air velocity

At 4m/s, from the graph, we get the result that solid plate fin without any perforation takes almost 20 minutes for reaching at room temperature; plate fin with circular perforation needs almost 18 minutes, plate fin with hexagonal perforation needs 13 minutes. As circular perforation makes more surface area than no perforation, the heat is transferred at a higher rate and cooling occurs more quickly in it than solid plate fin. On the other hand, hexagonal perforation makes more surface area than circular perforation, so the heat is transferred at a higher rate and cooling occurs more quickly in it than plate fin with circular perforation.

4.1.2 Temperature Vs Time Graph for the Cooling of Plate Fins at 6 m/s

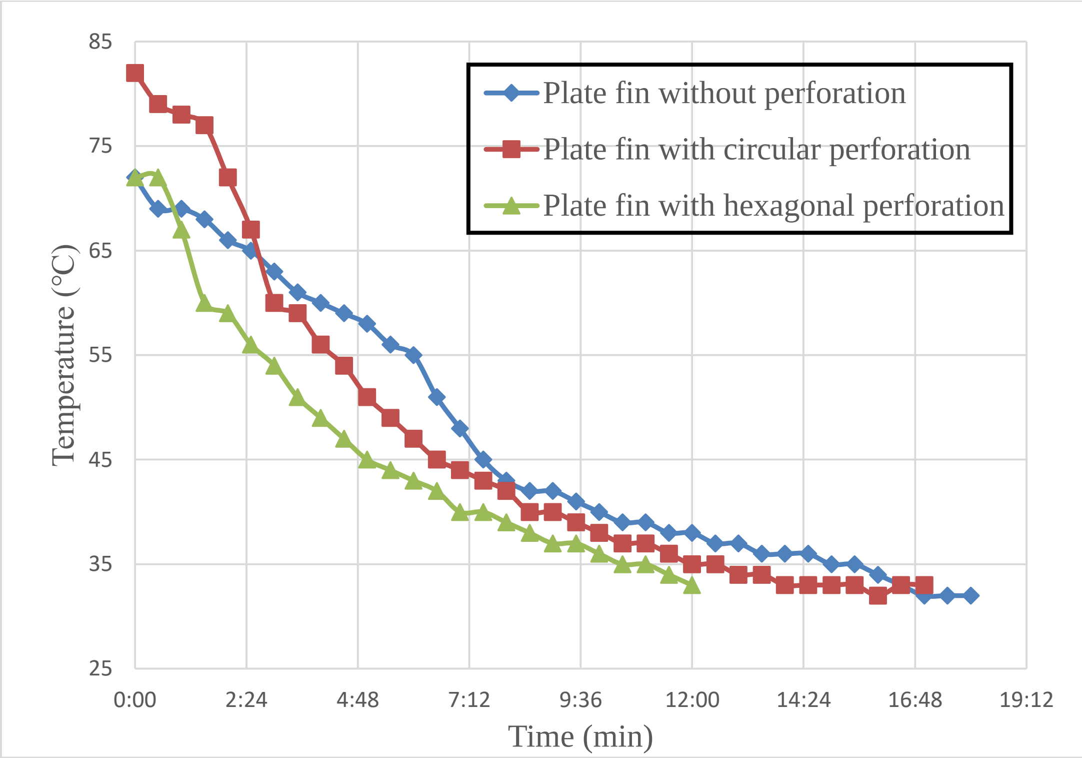


Figure 4.2: Variation of cooling time for different plate fins for 6m/s air velocity

At 6m/s, from the graph, we get the result that solid plate fin without any perforation takes almost 17minutes for reaching at room temperature; plate fin with circular perforation needs almost 16 minutes, plate fin with hexagonal perforation needs 12 minutes. As circular perforation makes more surface area than no perforation, the heat is transferred at a higher rate and cooling occurs more quickly in it than solid plate fin. On the other hand, hexagonal perforation makes more surface area than circular perforation, so the heat is transferred at a higher rate and cooling occurs more quickly in it than plate fin with circular perforation. At 6m/s, all the respective fins take less time for cooling than at 4m/s. Because, more velocity of air causing more quick heat transfer.

4.1.3 Temperature Vs Time Graph for the Cooling of Plate Fins at 8 m/s

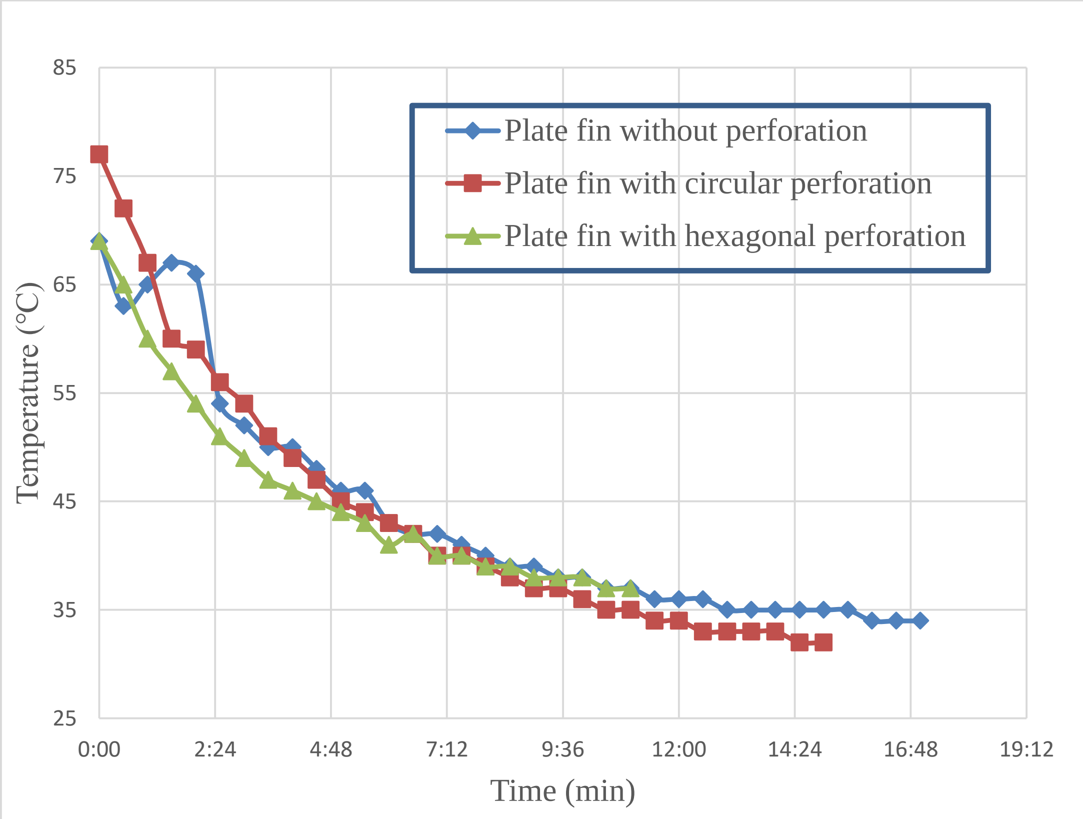


Figure 4.3: Variation of cooling time for different plate fins for 8m/s air velocity

At 8m/s, from the graph, we get the result that solid plate fin without any perforation takes almost 17 minutes for reaching at room temperature; plate fin with circular perforation needs almost 15 minutes, plate fin with hexagonal perforation needs 11 minutes. As circular perforation makes more surface area than no perforation, the heat is transferred at a higher rate and cooling occurs more quickly in it than solid plate fin. On the other hand, hexagonal perforation makes more surface area than circular perforation, so the heat is transferred at a higher rate and cooling occurs more quickly in it than plate fin with circular perforation. At 8m/s, all the respective fins take less time for cooling than at 4m/s and 6m/s. Because, more velocity of air causing more quick heat transfer

4.1.4 Temperature Vs Time Graph for the Cooling of Plate Fins at 10 m/s

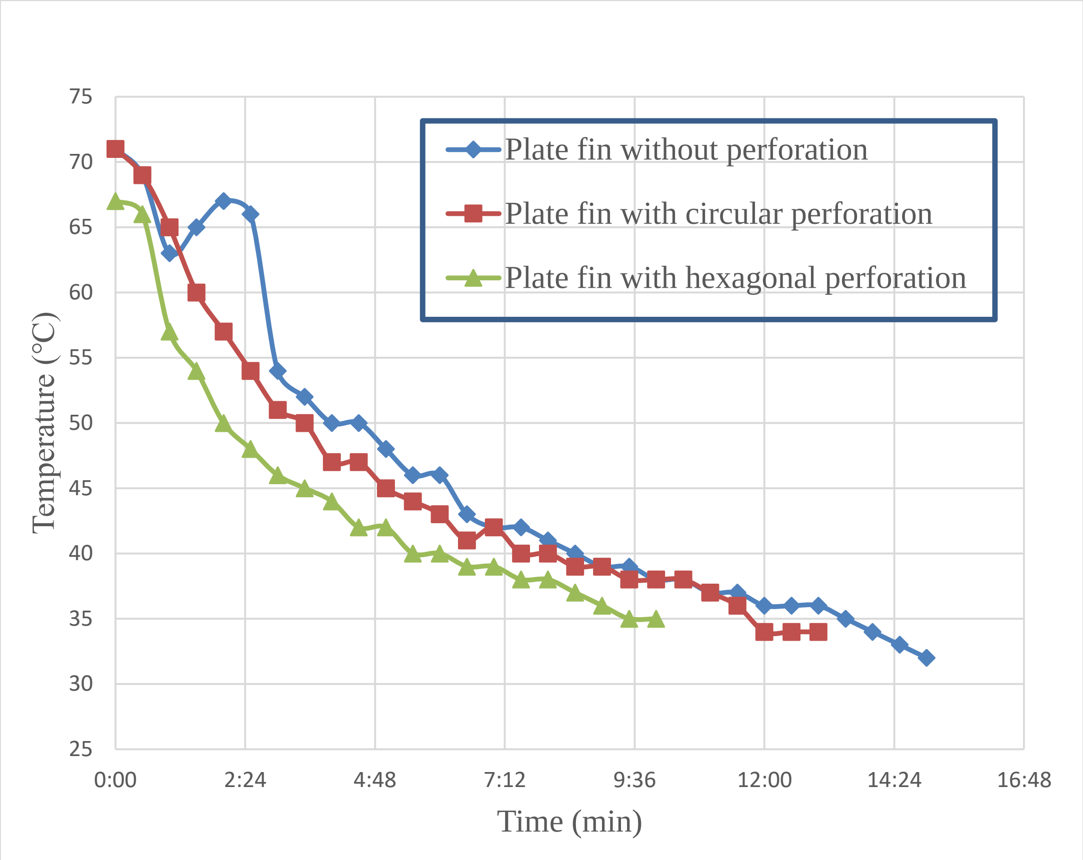


Figure 4.4: Variation of cooling time for different plate fins for 10m/s air velocity

At 10m/s, from the graph, we get the result that solid plate fin without any perforation takes almost 15 minutes for reaching at room temperature; plate fin with circular perforation needs almost 13 minutes, plate fin with hexagonal perforation needs 10 minutes. As circular perforation makes more surface area than no perforation, the heat is transferred at a higher rate and cooling occurs more quickly in it than solid plate fin. On the other hand, hexagonal perforation makes more surface area than circular perforation, so the heat is transferred at a higher rate and cooling occurs more quickly in it than plate fin with circular perforation. At 10m/s, all the respective fins take less time for cooling than at 4m/s, 6m/s and 8m/s. Because, more velocity of air causing more quick heat transfer.

4.1.5 Temperature Vs Time Graph for the Cooling of Plate Fins at 12 m/s

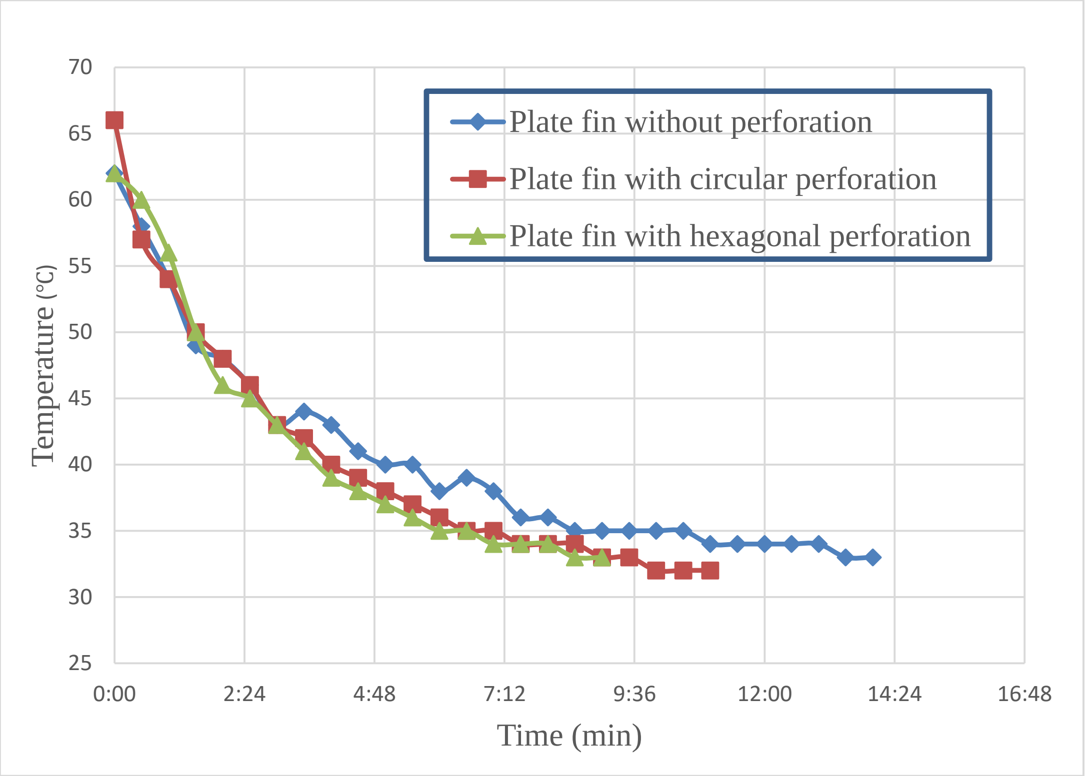


Figure 4.5: Variation of cooling time for different plate fins for 12m/s air velocity

At 12m/s, from the graph, we get the result that solid plate fin without any perforation takes almost 14 minutes for reaching at room temperature; plate fin with circular perforation needs almost 11 minutes, plate fin with hexagonal perforation needs 8 minutes. As circular perforation makes more surface area than no perforation, the heat is transferred at a higher rate and cooling occurs more quickly in it than solid plate fin. On the other hand, hexagonal perforation makes more surface area than circular perforation, so the heat is transferred at a higher rate and cooling occurs more quickly in it than plate fin with circular perforation. At 12m/s, all the respective fins take less time for cooling than at 4m/s, 6m/s, 8m/s and 10m/s. Because, more velocity of air causing more quick heat transfer.

4.2 Change of Air Temperature during Cooling of Base Plate by Different Plate Fins at Different Air Velocity

4.2.1 Change of Air Temperature during Cooling of Base Plate by Solid Plate Fins at Different Air Velocities

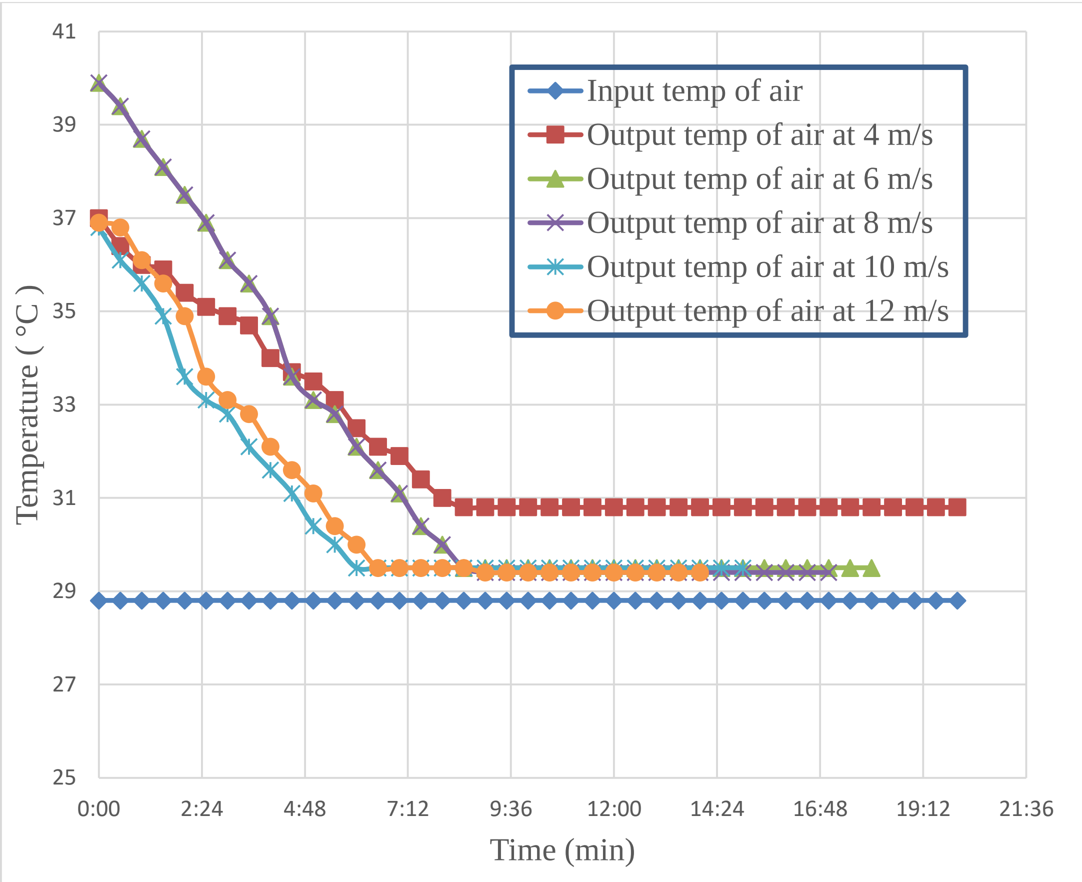


Figure 4.6: Air temperature Vs cooling time graph for solid plate fin

The graph shows that the time needed for the temperature of base plate is to come close to the ambient temperature is gradually decreased with the increase of air velocity for the solid plate fin. The input temperature remains nearly constant throughout the cooling time for all the air velocity. But the time required for the temperature of output to become close to the input ambient temperature is varied for different velocity of air. For 4m/s,6m/s,8m/s,10m/s,12m/s, it needs 20 minute,18 minute,17 minute,15 minute,14 minute respectively. More velocity of air assists the cooling of the base plate.

4.2.2 Change of Air Temperature During Cooling of Base Plate by Plate Fins with Circular Perforation at Different Air Velocities

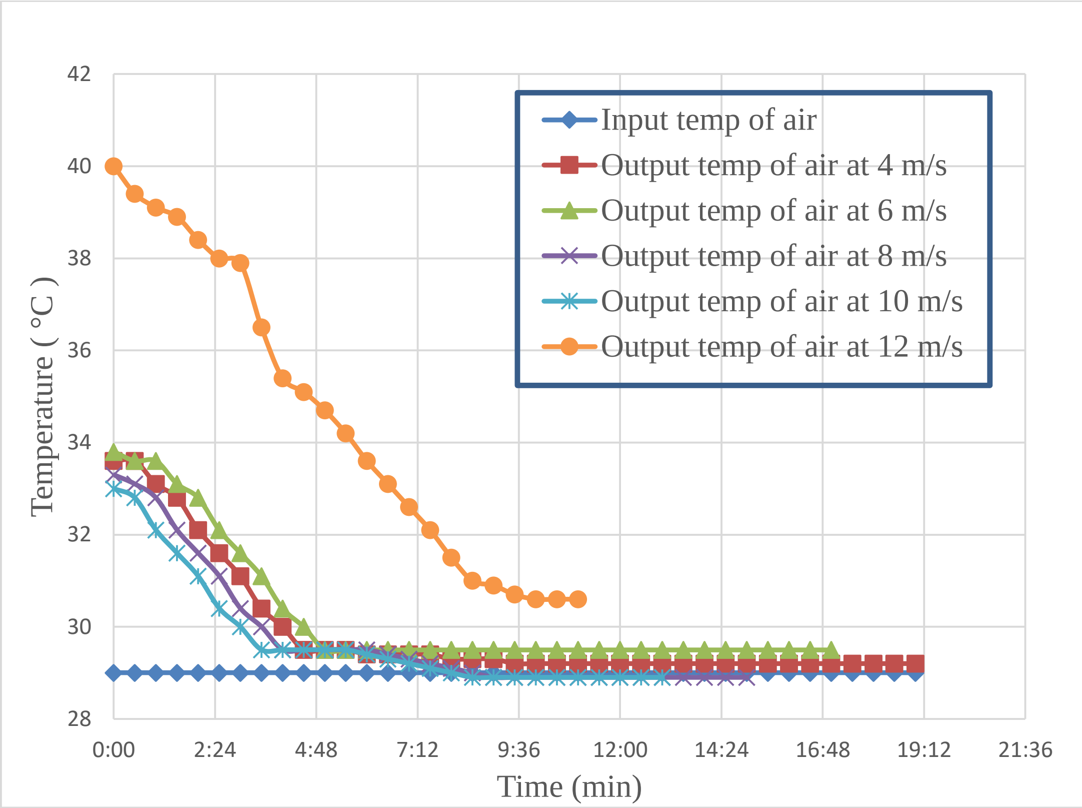


Figure 4.7: Air temperature Vs cooling time graph for plate fin with circular perforation.

The graph shows that the time needed for the temperature of base plate is to come close to the ambient temperature is gradually decreased with the increase of air velocity for the plate fin with circular perforation. The input temperature remains nearly constant throughout the cooling time for all the air velocity. But the time required for the temperature of output to become close to the input ambient temperature is varied for different velocity of air. For 4m/s,6m/s,8m/s,10m/s,12m/s, it needs 19 minute,16 minute,15 minute,13 minute,11 minute respectively. More velocity of air assists the cooling of the base plate. Here it is also noted that this required time are less for the corresponding velocity for solid plate fin as the circular perforation is creating more surface area to reject heat more and cooling more quickly.

4.2.3 Change of Air Temperature During Cooling of Base Plate by Plate Fins with Hexagonal Perforation at Different Air Velocities

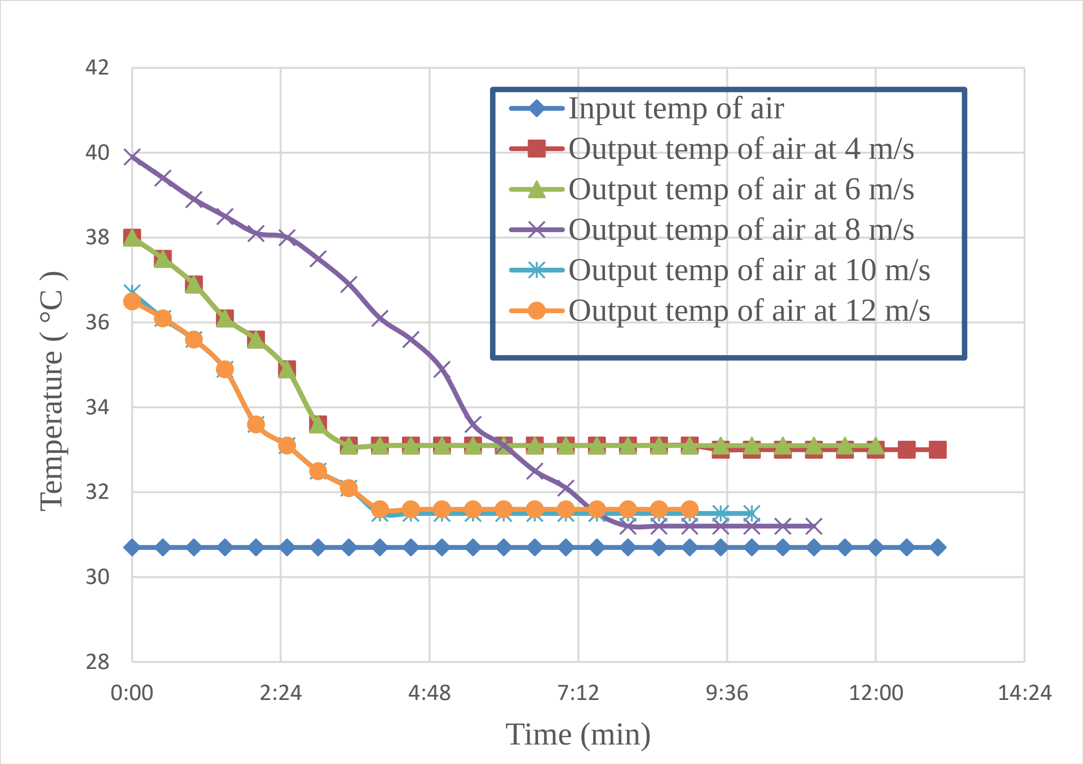


Figure 4.8: Air temperature Vs cooling time graph for plate fin with hexagonal perforation.

The graph shows that the time needed for the temperature of base plate is to come close to the ambient temperature is gradually decreased with the increase of air velocity for the plate fin with hexagonal perforation. The input temperature remains nearly constant throughout the cooling time for all the air velocity. But the time required for the temperature of output to become close to the input ambient temperature is varied for different velocity of air. For 4m/s,6m/s,8m/s,10m/s,12m/s, it needs 13 minute,12 minute,11 minute,10 minute,8 minute respectively. More velocity of air assists the cooling of the base plate. Here it is also noted that this required time are less for the corresponding velocity for solid plate fin and plate fin with circular perforation as the hexagonal perforation is creating more surface area than solid and circular perforated plate fin to reject heat more and cooling more quickly.

So, the time needed for cooling of base plate is least for plate fin with hexagonal perforation because of increased surface area.

4.3 Change of Base Plate Temperature During Heating in Different Plate Fins at Different Velocity

4.3.1 Change of Base Plate Temperature During Heating in Plate Fin without Perforation at Different Velocities

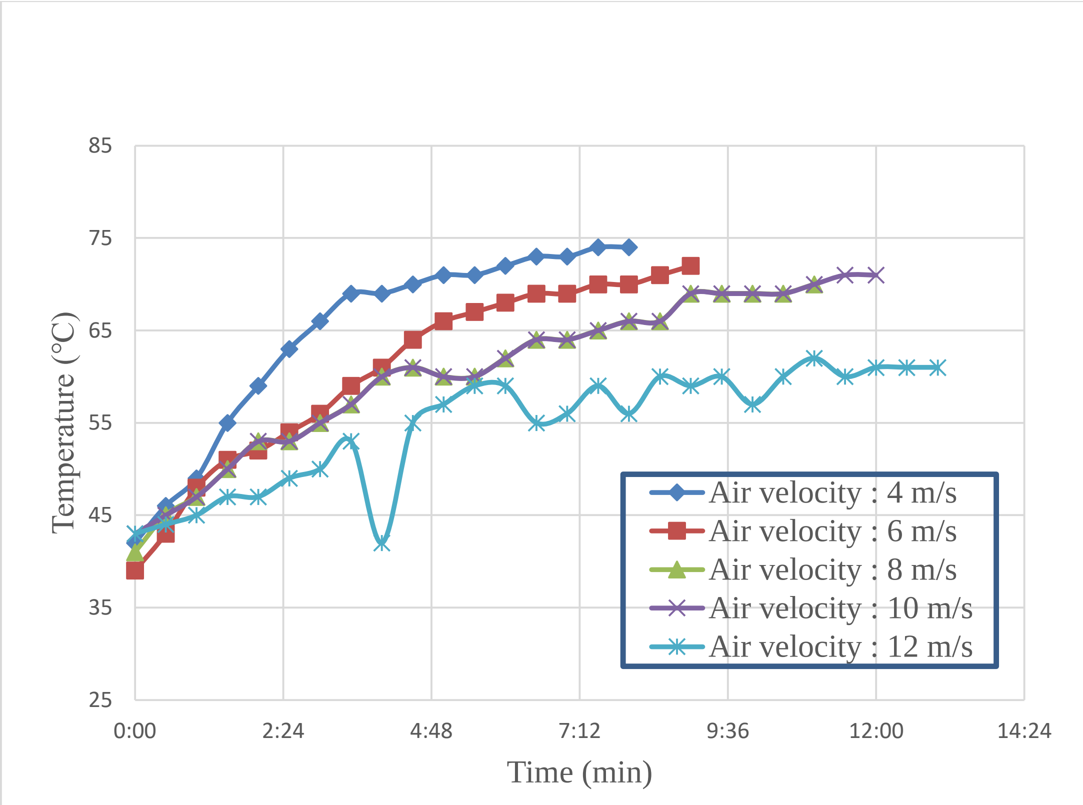


Figure 4.9: Base plate temperature Vs heating time graph for solid plate fin

The graph shows that with the increase of air velocity, the time needed for heating of solid plate fin is increasing. As increased air velocity hinders the heating of the base plate so the time required increased.

4.3.2 Change of Base Plate Temperature during Heating in Plate Fin with Circular Perforation at Different Velocities

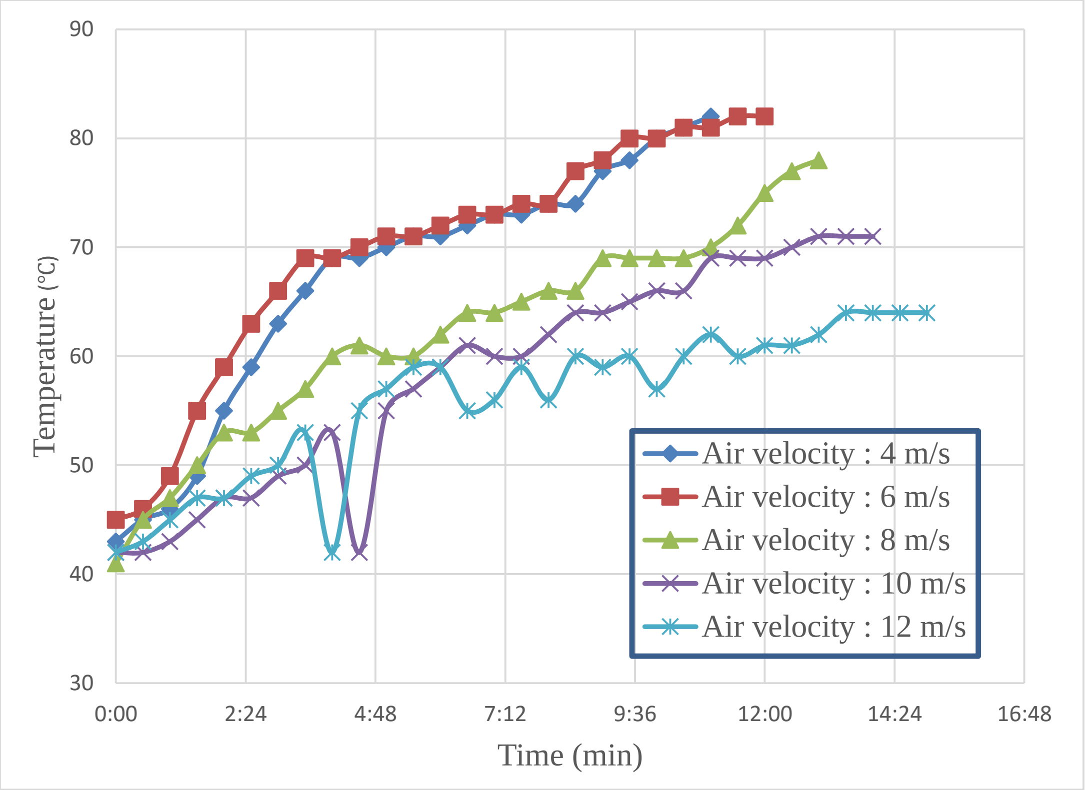


Figure 4.10: Base plate temperature Vs heating time graph for plate fin with circular perforation.

The graph shows that with the increase of air velocity, the time needed for heating of circular perforated plate fin is increasing. As increased air velocity hinders the heating of the base plate so the time required increased. The required time at air velocity 4m/s,6m/s,8m/s,10m/s,12m/s of plate fin with circular perforation are higher than that of solid plate fin respectively. As because of circular perforation, the heat is being lost at the perforated area which does not occur at solid plate fin. For overcoming that loss, plate fin with circular perforation needs more time for being heated.

4.3.3 Change of Base Plate Temperature During Heating in Plate Fin with Hexagonal Perforation at Different Velocities

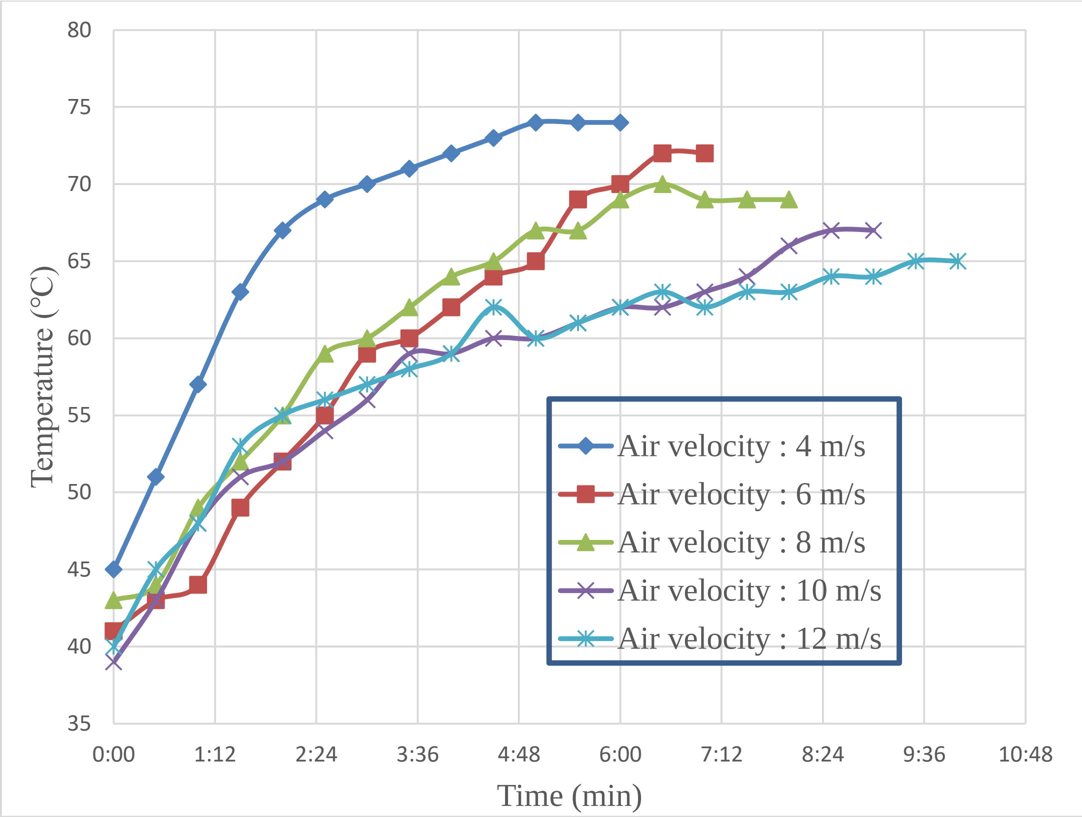


Figure 4.11: Base plate temperature Vs heating time graph for plate fin with hexagonal perforation.

The graph shows that with the increase of air velocity, the time needed for heating of hexagonally perforated plate fin is increasing. But in this case, because of excessive hindrance and heat loss, the plate cannot go to that much of higher temp at all. The required time at air velocity 4m/s,6m/s,8m/s,10m/s,12m/s of plate fin with hexagonal perforation are higher than that of solid plate fin and plate fin with circular perforation respectively if the temperature is taken to that much of higher. But here the increase of temperature become much slower so it slows down before so much higher temperature

4.4 Change of Base Plate Temperature During Cooling in Different Plate Fin at Different Velocities

4.4.1 Change of Base Plate Temperature during Cooling in Solid Plate Fin without Perforation at Different velocities

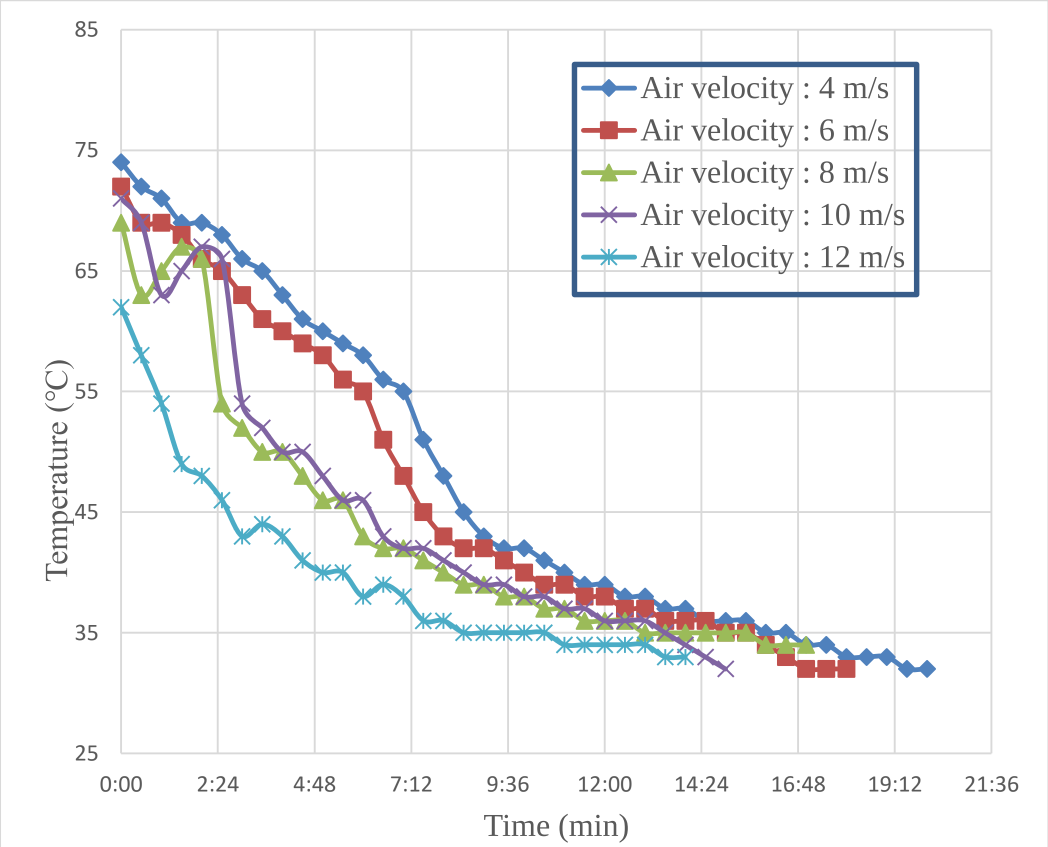


Figure 4.12: Base plate temperature Vs cooling time graph for solid plate fin

This graph shows that the time needed for cooling is more for 4m/s and less for 12 m/s. as increased air velocity helps for cooling in solid plate fin.

4.4.2 Change of Base Plate Temperature during Cooling in Plate Fin with Circular Perforation at Different Velocities

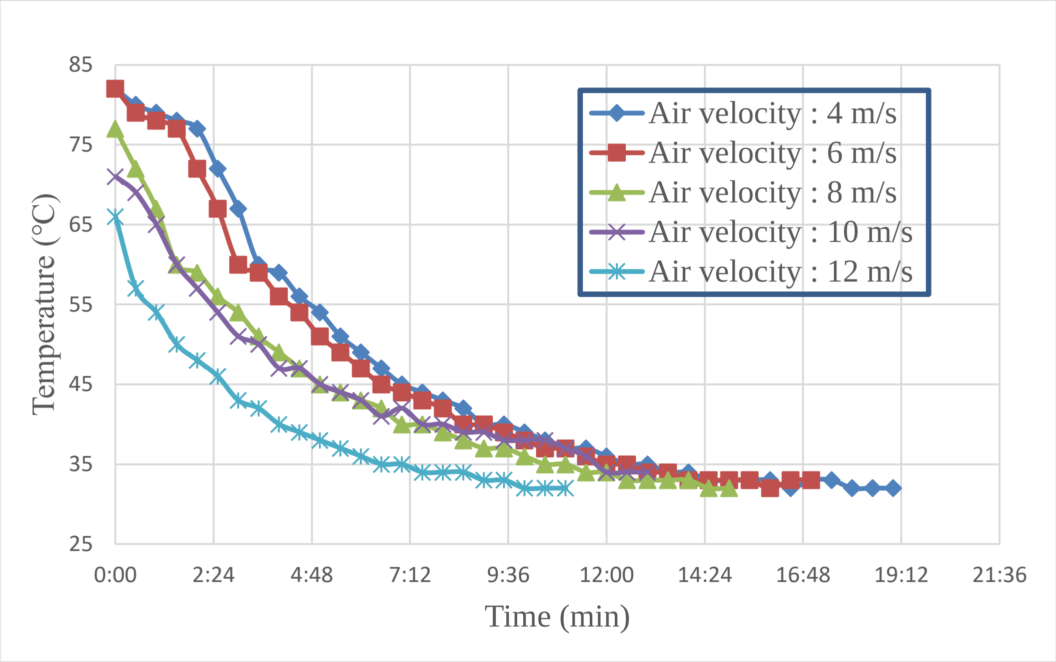


Figure 4.13: Base plate temperature Vs cooling time graph for plate fin with circular perforation.

This graph shows that the time needed for cooling is more for 4m/s and less for 12 m/s at plate fin with circular perforation as increased air velocity helps for cooling. Also the required time for cooling is less than that of solid plate fin. Increased area by circular perforation assist in cooling.

4.4.3 Change of Base Plate Temperature during Cooling in Plate Fin with Hexagonal Perforation at Different Velocities

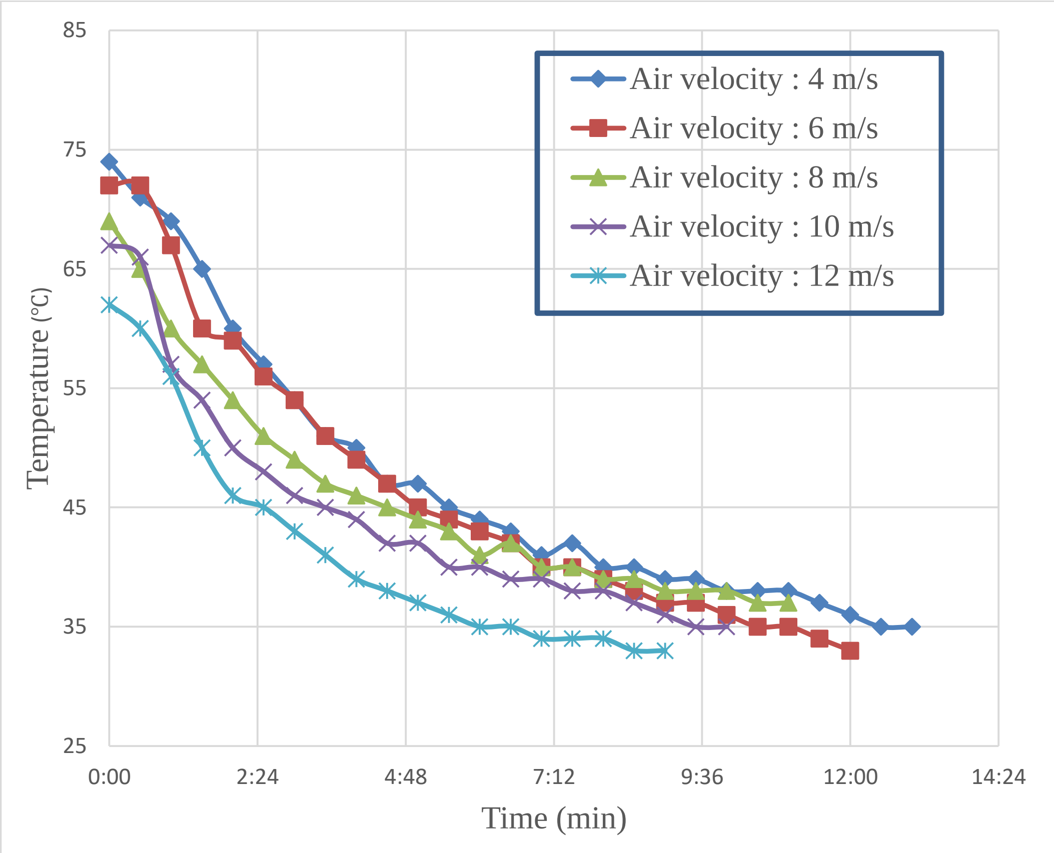


Figure 4.14: Base plate temperature Vs cooling time graph for plate fin with hexagonal perforation.

This graph shows that the time needed for cooling is more for 4m/s and less for 12 m/s at plate fin with hexagonal perforation as increased air velocity helps for cooling. Also the required time for cooling is less than that of solid plate fin and plate fin with circular perforation. Increased area by hexagonal perforation assist in cooling.

4.5 Variation of Temperature along the Different Plate Fin Length at Different Air Velocity

For all the plate fin, the temperature along the fin length is decreasing. Because, the heat of the heater is transferring to the fin through the base plate. So, with the increase of length the temperature is reduced.

4.5.1 Variation of Temperature along the Different Plate Fin Length at an Air Velocity of 4 m/s

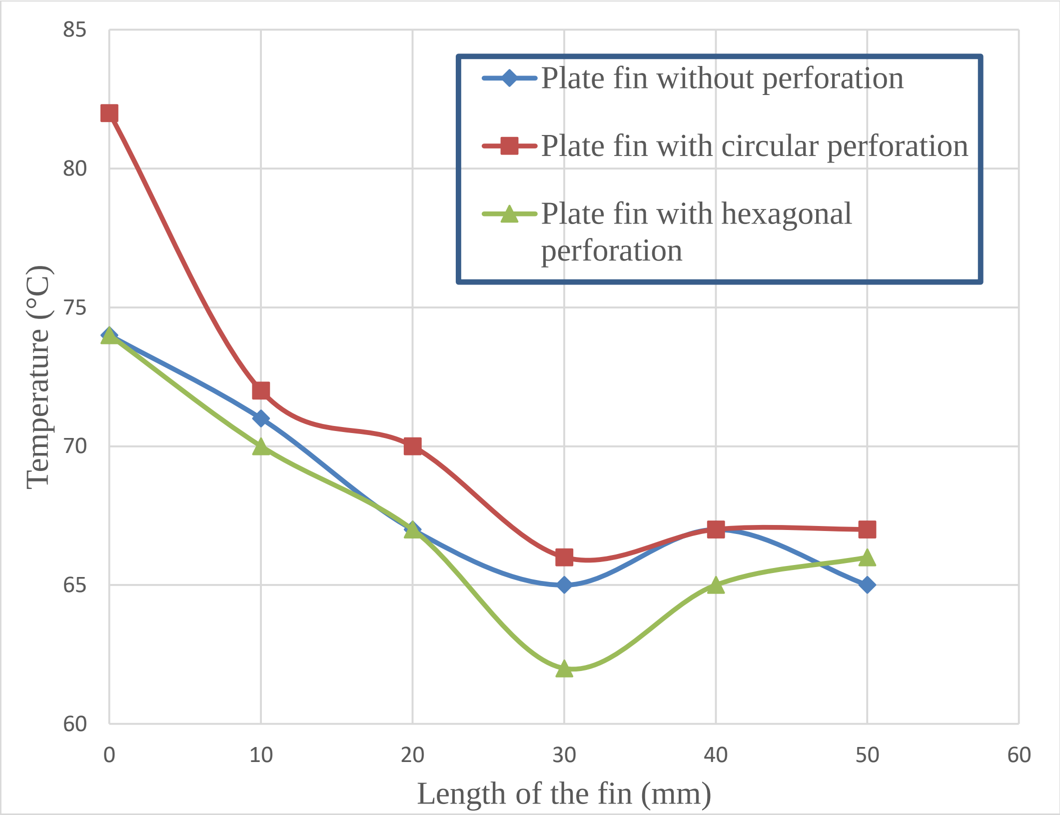


Figure 4.15: Temperature Vs length of the fin graph for different plate fin at 4m/s

At 4m/s, for all the plate fin, the temperature along the fin length is decreasing. Because, the heat of the heater is transferring to the fin through the base plate. So, with the increase of length the temperature is reduced.

4.5.2 Variation of Temperature along the Different Plate Fin Length at an Air Velocity of 6 m/s

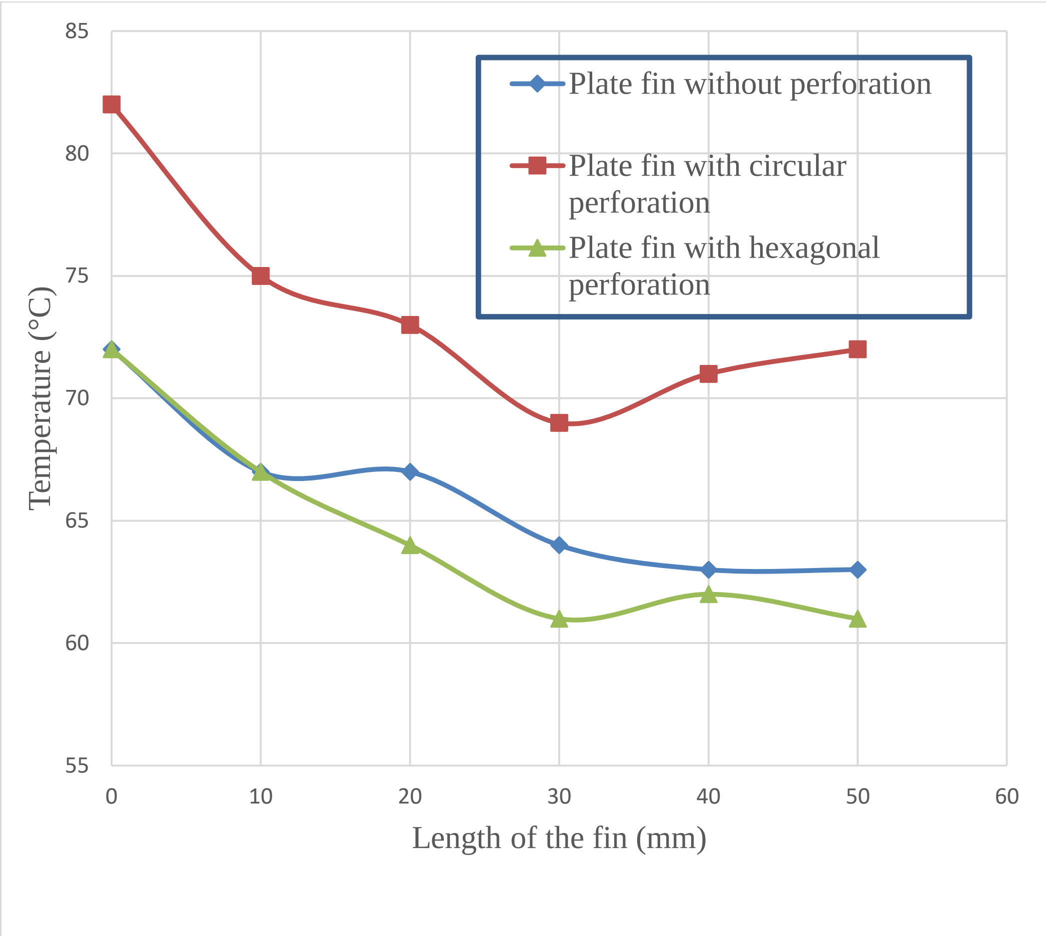


Figure 4.16: Temperature Vs length of the fin graph for different plate fin at 6m/s

At 8m/s, for all the plate fin, the temperature along the fin length is decreasing. Because, the heat of the heater is transferring to the fin through the base plate. So, with the increase of length the temperature is reduced.

4.5.3 Variation of Temperature along the Different Plate Fin Length at an Air Velocity of 8 m/s

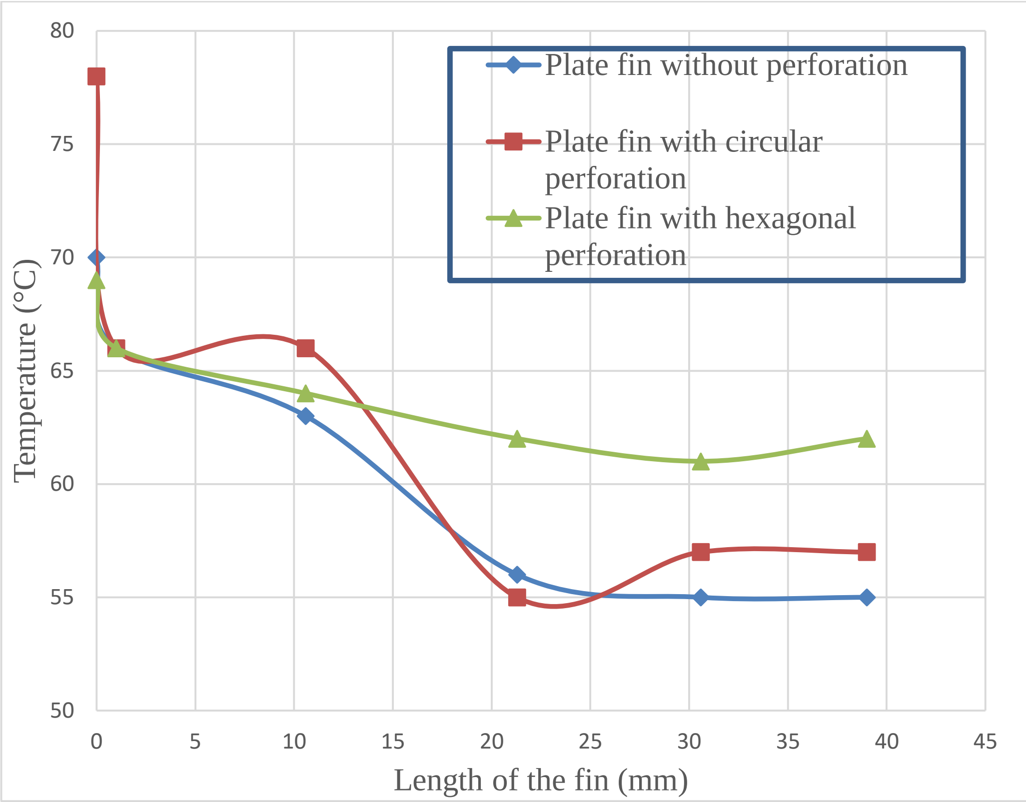


Figure 4.17: Temperature Vs length of the fin graph for different plate fin at 8m/s

At 8m/s, for all the plate fin, the temperature along the fin length is decreasing. Because, the heat of the heater is transferring to the fin through the base plate. So, with the increase of length the temperature is reduced.

4.5.4 Variation of Temperature along the Different Plate Fin Length at an Air Velocity of 10 m/s

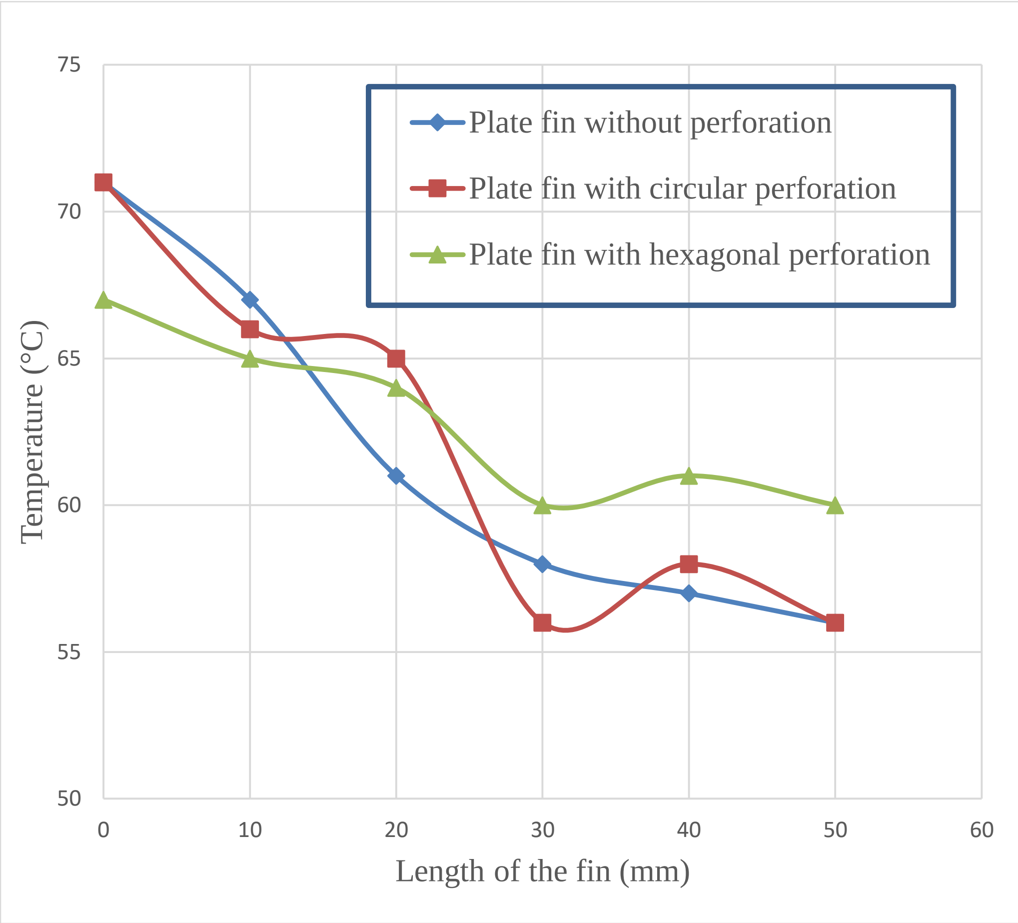


Figure 4.18: Temperature Vs length of the fin graph for different plate fin at 10m/s

At 10m/s, for all the plate fin, the temperature along the fin length is decreasing. Because, the heat of the heater is transferring to the fin through the base plate. So, with the increase of length the temperature is reduced.

4.5.5 Variation of Temperature along the Different Plate Fin Length at an Air Velocity of 12 m/s

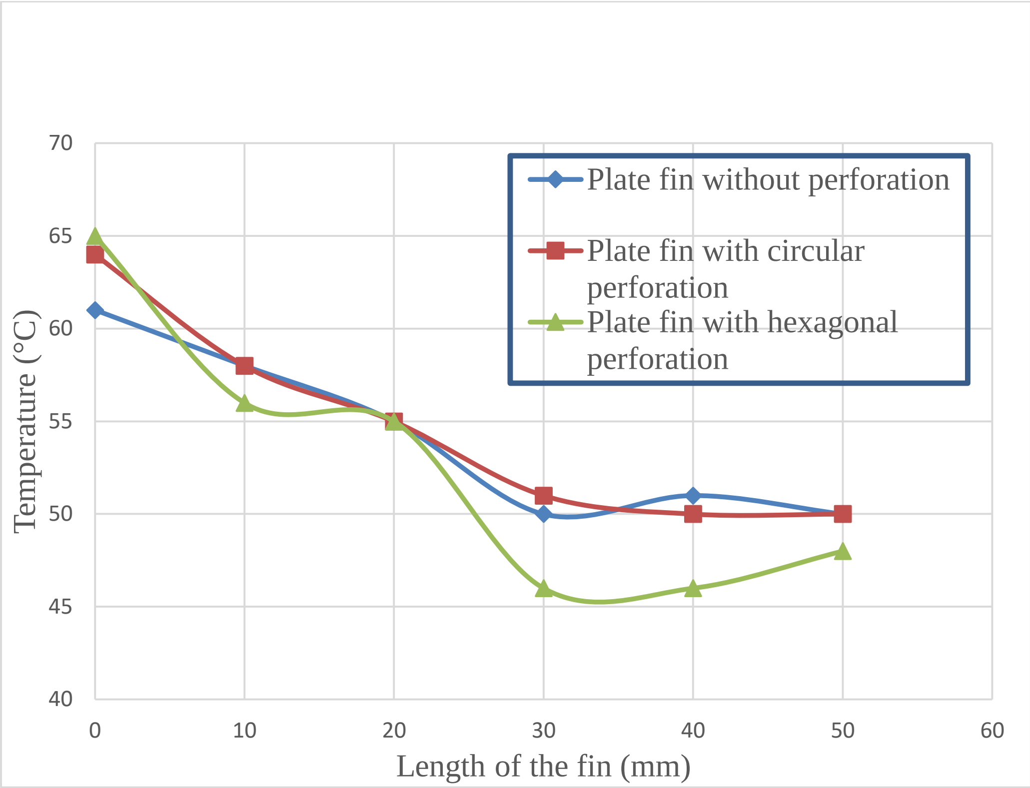


Figure 4.19: Temperature Vs length of the fin graph for different plate fin at 12m/s

At 12m/s, for all the plate fin, the temperature along the fin length is decreasing. Because, the heat of the heater is transferring to the fin through the base plate. So, with the increase of length the temperature is reduced.

4.6 Variation of Different Fin Characteristics with Reynolds Number for Different Plate Fins

4.6.1 Variation of Fin Effectiveness with Reynolds No for Different Plate fins

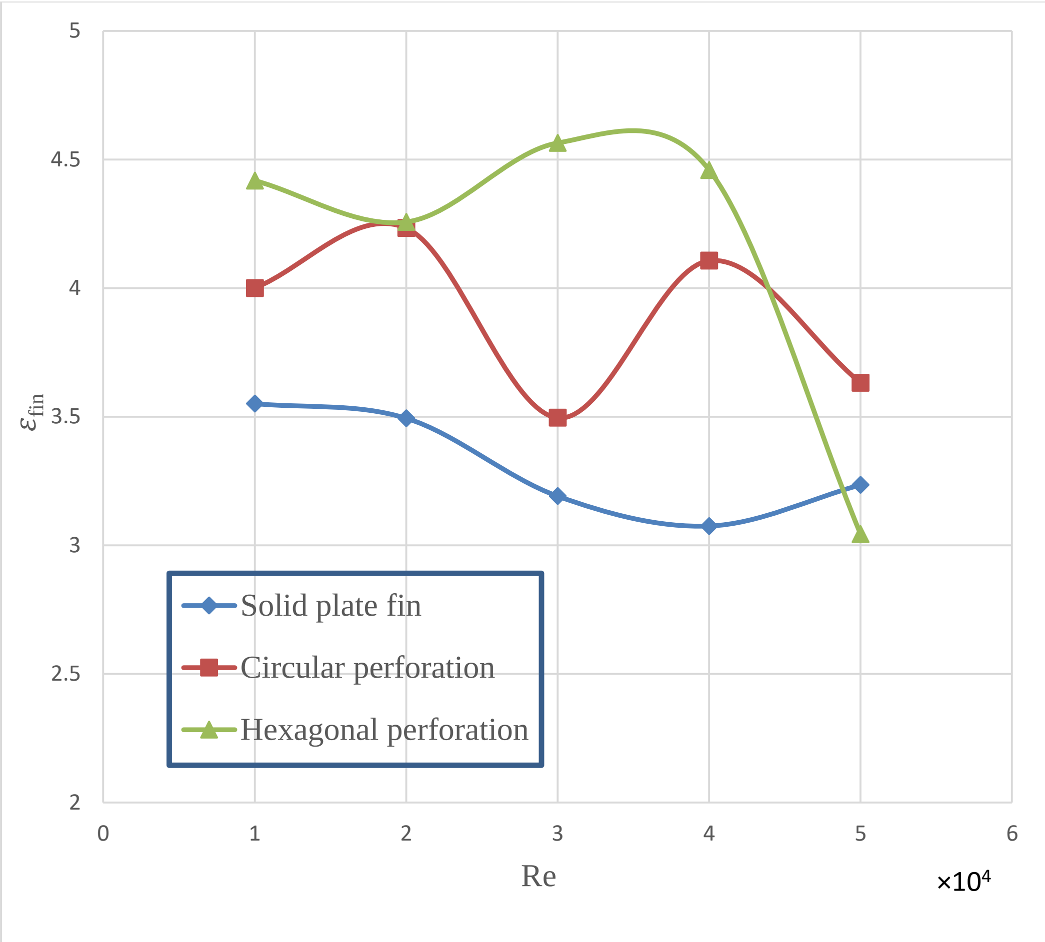


Figure 4.20: Variation of fin effectiveness with Reynolds no for different kind of plate fins

The effect of Reynolds number for different kind of plate fins on fin effectiveness is shown in figure. The result suggests that fin effectiveness for plate fin with hexagonal perforation is most effective fin than any other ones in this graph. As this is an experimental result, so there creates some error. If we consider best fitted graph, then we can say that the fin effectiveness is decreased with the increasing Reynolds number.

4.6.2 Variation of Fin Efficiency with Reynolds No for Different Plate fins

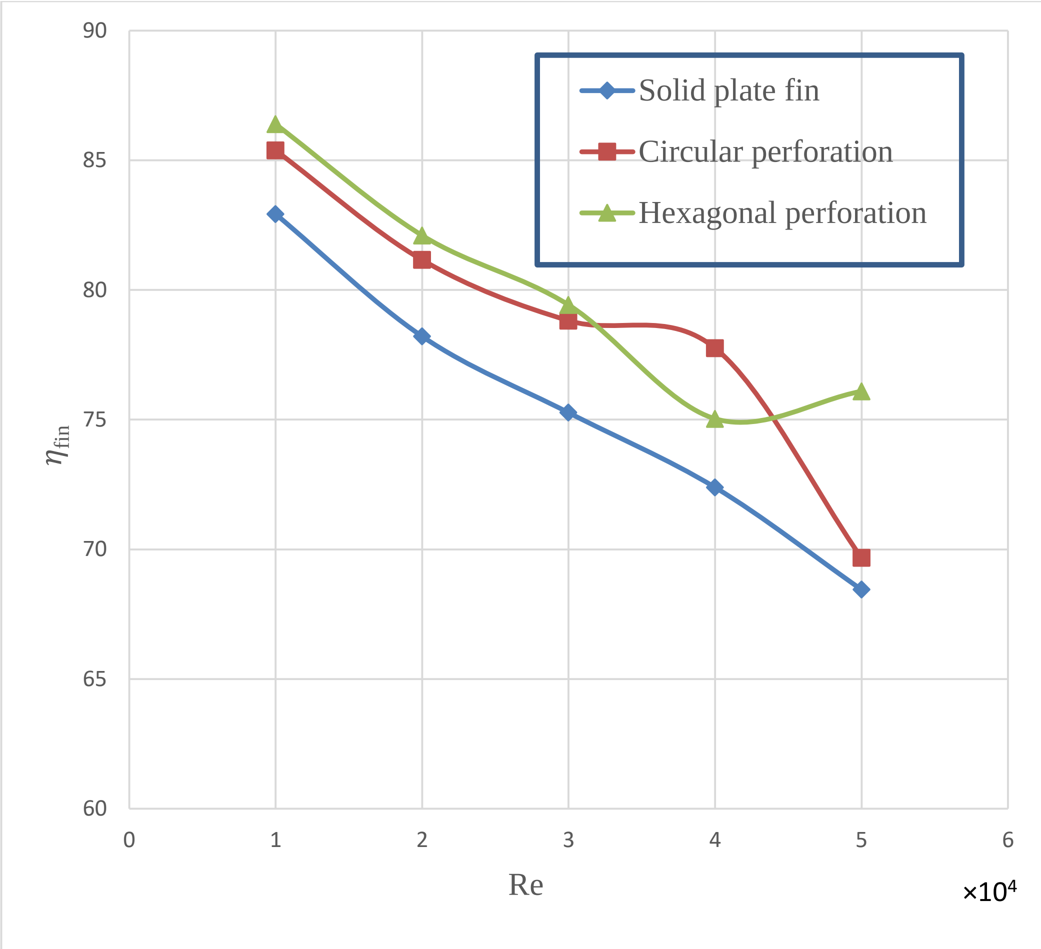


Figure 4.21: Variation of fin efficiency with Reynolds no for different kind of plate fins

The effect of Reynolds number for different kind of plate fins on fin efficiency is shown in figure. The result suggests that fin efficiency for plate fin with hexagonal perforation is comparatively higher than any other ones in this graph. As this is an experimental result, so there creates some error. If we consider best fitted graph, then we can say that the fin efficiency is decreased with the increasing Reynolds number.

4.6.3 Variation of Convective Heat Transfer Coefficient with Reynolds No for Different Plate fins

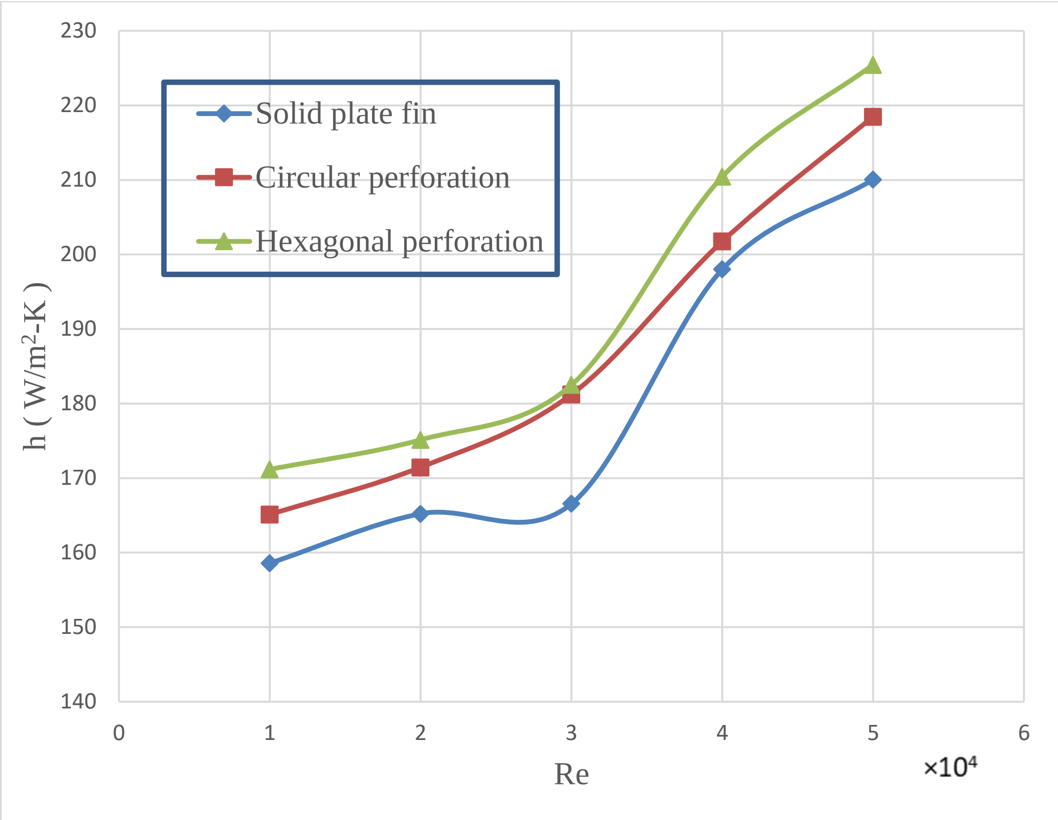


Figure 4.22: Variation of convective heat transfer coefficient with Reynolds no for different kind of plate fins

The effect of Reynolds number for different kind of plate fins on convective heat transfer coefficient is shown in figure. The result suggests that convective heat transfer coefficient for plate fin with hexagonal perforation is comparatively higher than any other ones in this graph. However, convective heat transfer coefficient is increased with the increasing Reynolds number.

4.6.4 Variation of Nusselt No with Reynolds No for Different Plate fins

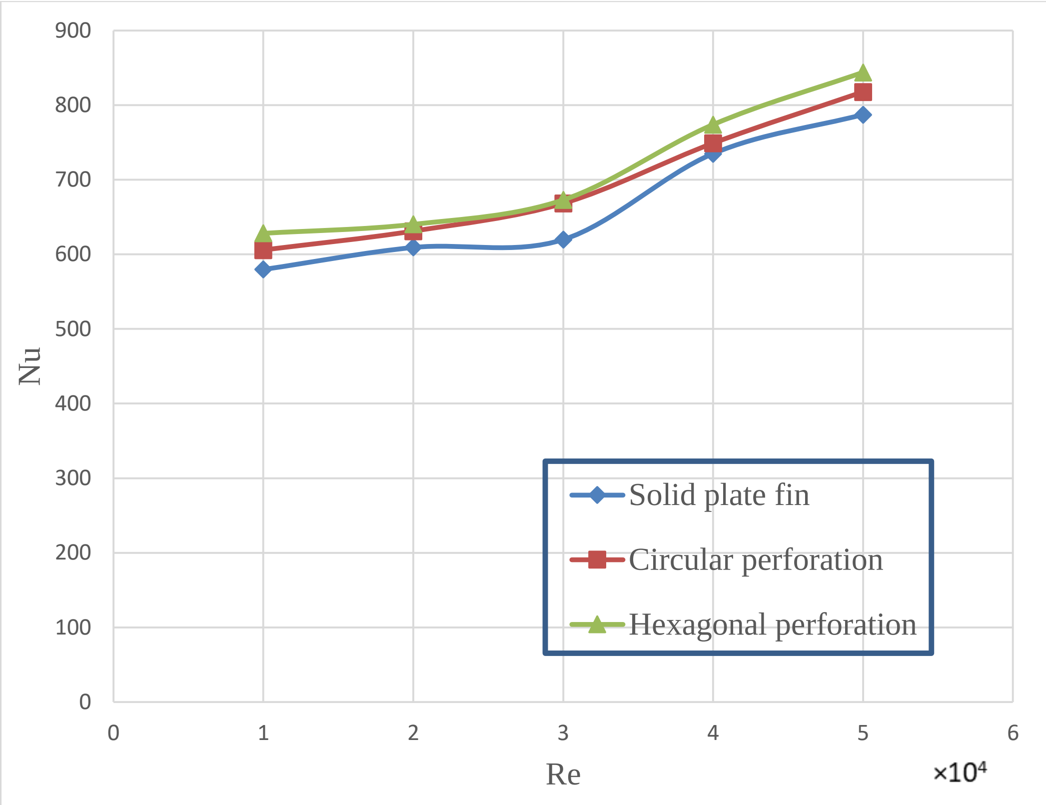


Figure 4.23: Variation of Nusselt number with Reynolds number for different kind of plate fins

The effect of Reynolds number for different kind of plate fins on Nusselt number is shown in figure. The result suggests that Nusselt number for plate fin with hexagonal perforation is comparatively higher than any other ones in this graph. However, Nusselt number is increased with the increasing Reynolds number.

4.6.5 Variation of Pressure Drop with Reynolds No for Different Plate fins

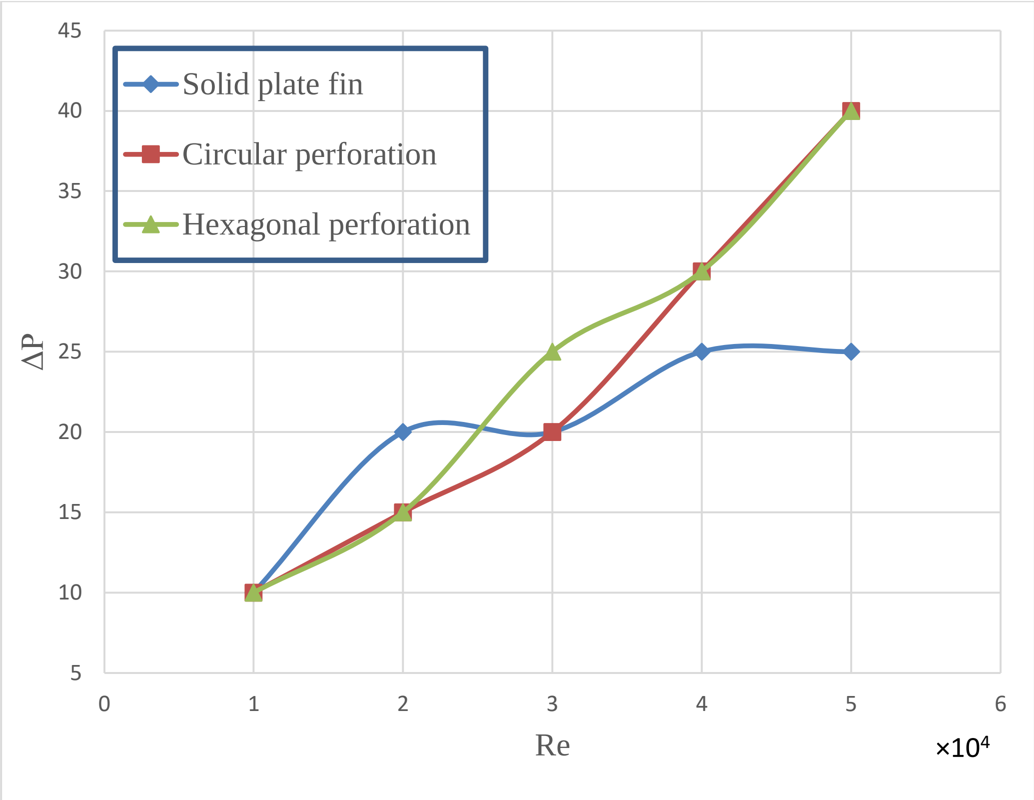


Figure 4.24: Variation of pressure drop with Reynolds no for different kind of plate fins

The effect of Reynolds number for different kind of plate fins on pressure drop is shown in figure. The result suggests that pressure drop for plate fin with hexagonal perforation is comparatively higher than any other ones in this graph. However, pressure drop is increased with the increasing Reynolds number and also with the perforation. As perforation creates more pressure difference between upstream and downstream pressure.

4.6.6 Variation of Thermal Resistance with Reynolds No for Different Plate fins

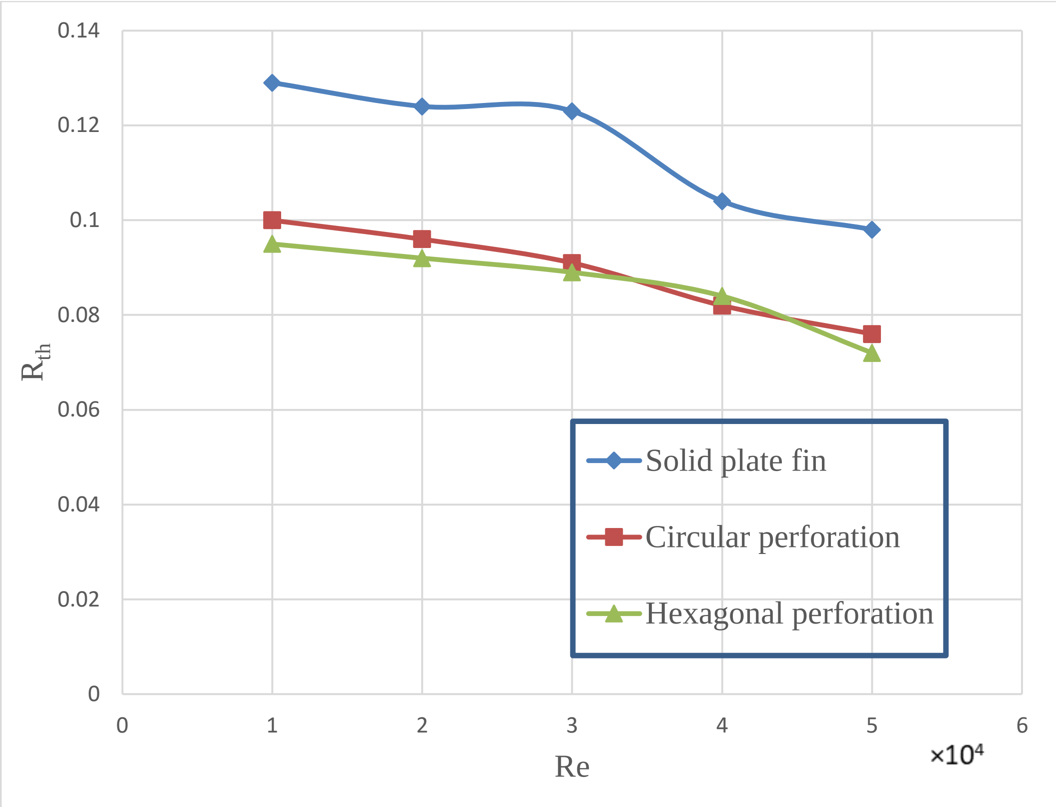


Figure 4.25: Variation of thermal resistance with Reynolds no for different kind of plate fins

The effect of Reynolds number for different kind of plate fins on thermal resistance is shown in figure. The result suggests that the thermal resistance for plate fin with hexagonal perforation is comparatively higher than any other ones in this graph. However, thermal resistance is increased with the increasing Reynolds number.

4.6.7 Variation of Dimensionless Pressure Drop with Reynolds No for Different Plate fin

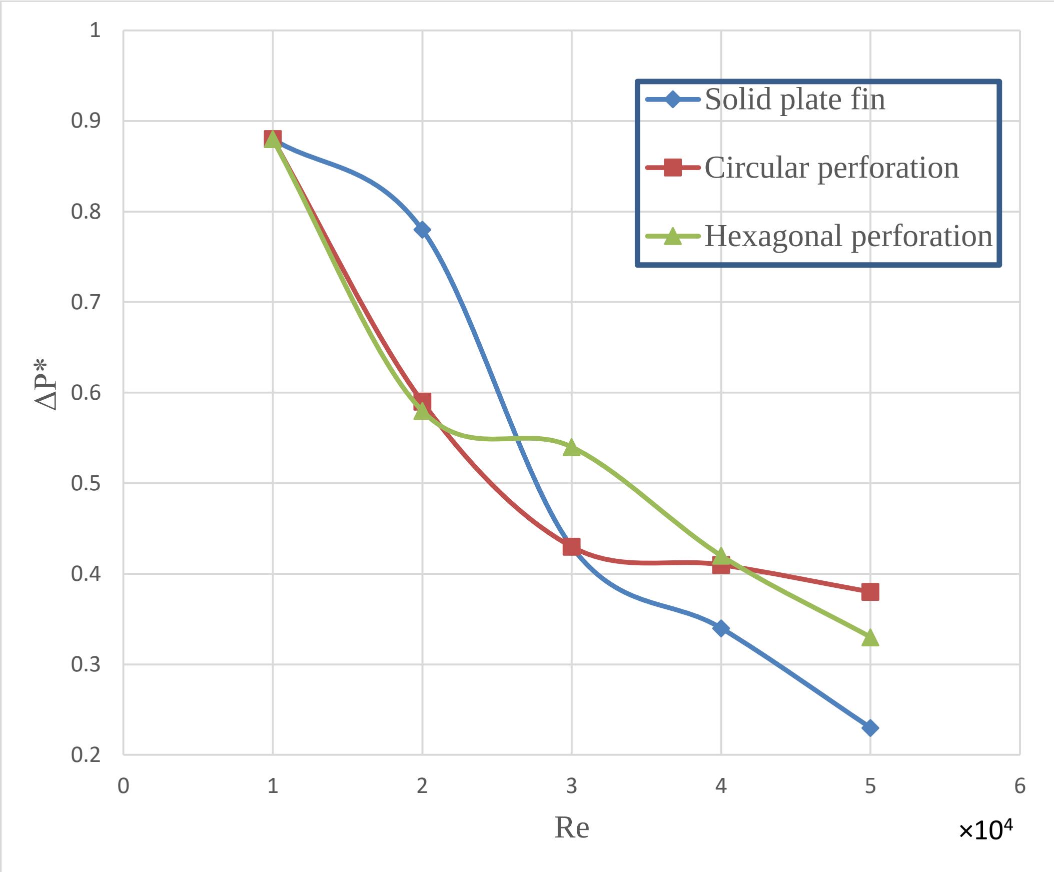


Figure 4.26: Variation of dimensionless pressure drop with Reynolds no for different kind of plate fins

The effect of Reynolds number for different kind of plate fins on dimensionless pressure drop is shown in figure. The result suggests that dimensionless pressure drop for plate fin with hexagonal perforation is comparatively lower than any other ones in this graph. However, Dimensionless pressure drop is decreased with the increasing Reynolds number and also with the perforation.

4.7 Variation of cooling time for different pin fins for different air velocity

With the increase of air velocity, time needed for cooling is decreasing. Because increasing air velocity is assisting the cooling process.

4.7.1 Temperature Vs Time Graph for Cooling of Solid Pin Fin at 4m/s

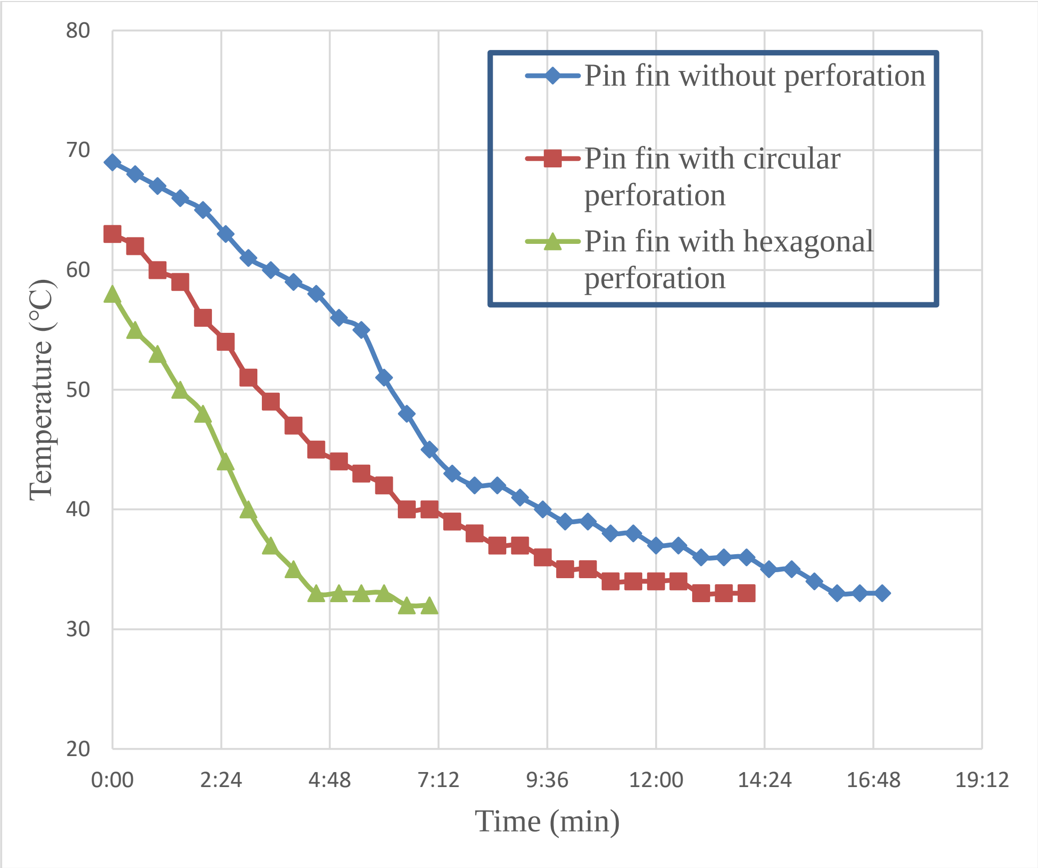


Figure 4.27: Variation of cooling time for different pin fins for 4m/s air velocity

At 4m/s, from the graph, we get the result that solid pin fin without any perforation takes almost 17 minutes for reaching at room temperature; pin fin with circular perforation needs almost 14 minutes, pin fin with hexagonal perforation needs 7 minutes. As circular perforation makes more surface area than no perforation, the heat is transferred at a higher rate and cooling occurs more quickly in it than solid pin fin. On the other hand, hexagonal perforation makes more surface area than circular perforation, so the heat is transferred at a higher rate and cooling occurs more quickly in it than pin fin with circular perforation.

4.7.2 Temperature vs Time Graph for the Cooling of Pin Fins at 6 m/s

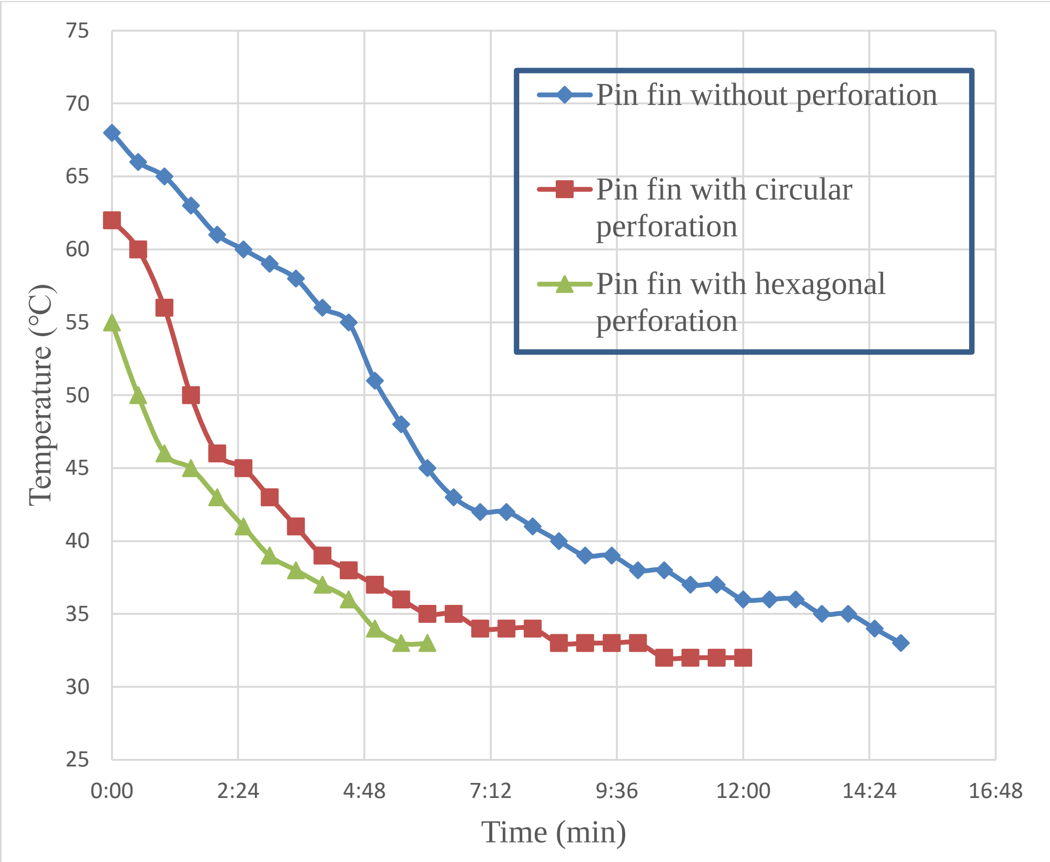


Figure 4.28: Variation of cooling time for different pin fins for 6m/s air velocity

At 6m/s, from the graph, we get the result that solid pin fin without any perforation takes almost 15 minutes for reaching at room temperature; pin fin with circular perforation needs almost 12 minutes, pin fin with hexagonal perforation needs 6 minutes. As circular perforation makes more surface area than no perforation, the heat is transferred at a higher rate and cooling occurs more quickly in it than solid pin fin. On the other hand, hexagonal perforation makes more surface area than circular perforation, so the heat is transferred at a higher rate and cooling occurs more quickly in it than pin fin with circular perforation. At 6m/s all the respective fins take less time for cooling than at 4m/s. Because, more velocity of air causing more quick heat transfer.

4.7.3 Temperature Vs Time Graph for the Cooling of Pin Fins at 8 m/s

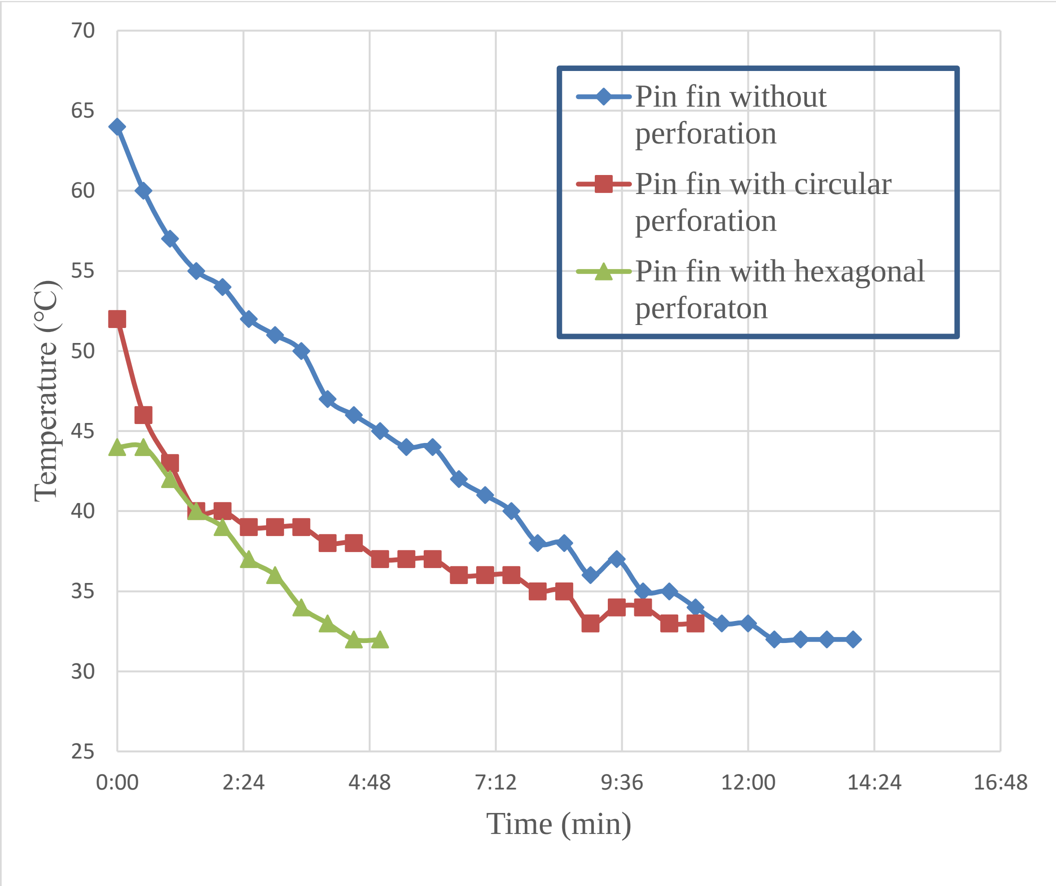


Figure 4.29: Variation of cooling time for different pin fins for 8m/s air velocity

At 8m/s, from the graph, we get the result that solid pin fin without any perforation takes almost 14 minutes for reaching at room temperature; pin fin with circular perforation needs almost 11 minutes, pin fin with hexagonal perforation needs 5 minutes. As circular perforation makes more surface area than no perforation, the heat is transferred at a higher rate and cooling occurs more quickly in it than solid pin fin. On the other hand, hexagonal perforation makes more surface area than circular perforation, so the heat is transferred at a higher rate and cooling occurs more quickly in it than pin fin with circular perforation. At 8m/s, all the respective fins take less time for cooling than at 4m/s and 6m/s. Because, more velocity of air causing more quick heat transfer.

4.7.4 Temperature Vs Time Graph for the Cooling of Pin Fins at 10 m/s

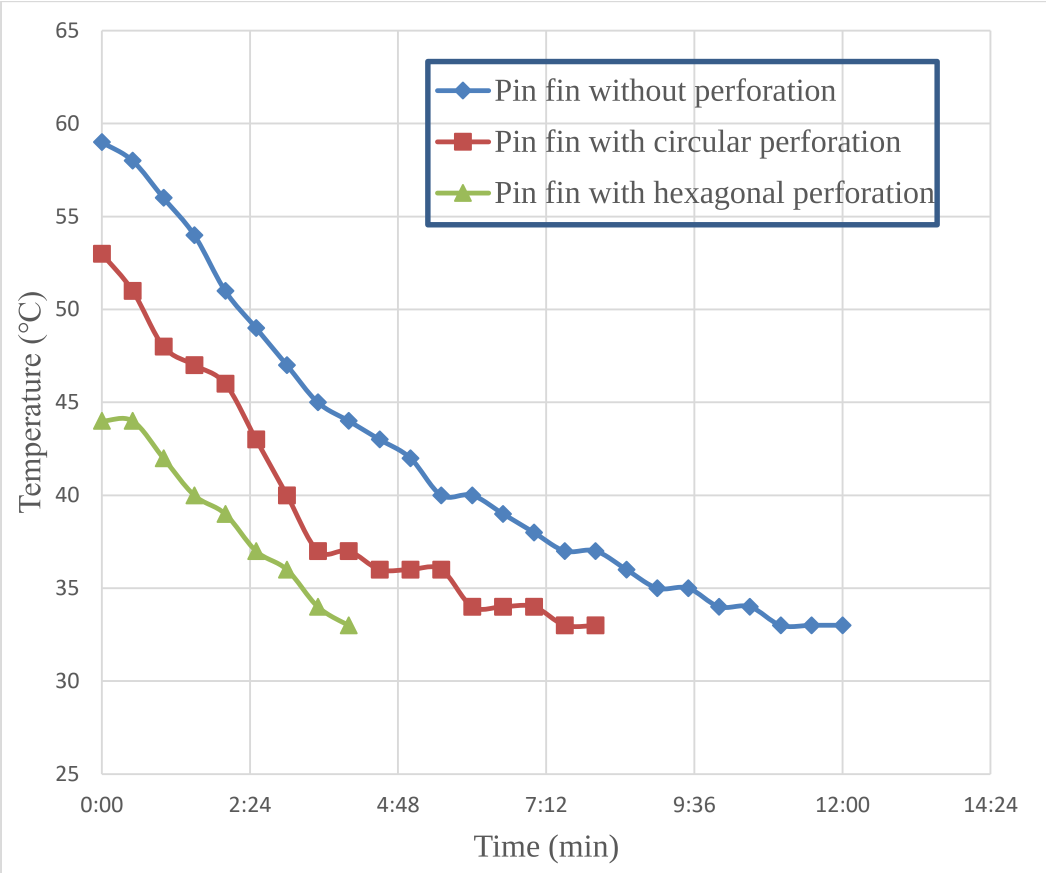


Figure 4.30: Variation of cooling time for different pin fins for 10m/s air velocity

At 10m/s, from the graph, we get the result that solid pin fin without any perforation takes almost 12 minutes for reaching at room temperature; pin fin with circular perforation needs almost 8minutes, pin fin with hexagonal perforation needs 3 minutes. As circular perforation makes more surface area than no perforation, the heat is transferred at a higher rate and cooling occurs more quickly in it than solid pin fin. On the other hand, hexagonal perforation makes more surface area than circular perforation, so the heat is transferred at a higher rate and cooling occurs more quickly in it than pin fin with circular perforation. At 10m/s, all the respective fins take less time for cooling than at 4m/s,6m/s and 8 m/s. Because, more velocity of air causing more quick heat transfer.

4.7.5 Temperature vs Time Graph for the Cooling of Pin Fins at 12 m/s

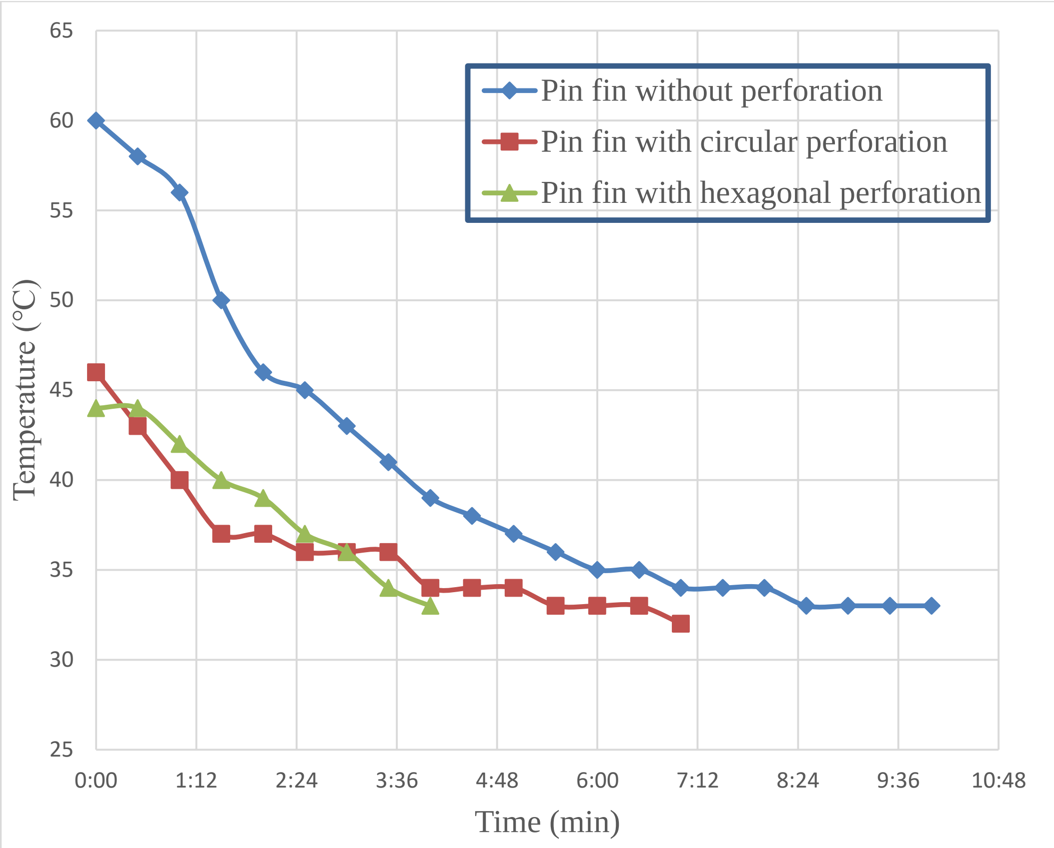


Figure 4.31: Variation of cooling time for different pin fins for 12m/s air velocity

At 12m/s, from the graph, we get the result that solid pin fin without any perforation takes almost 10 minutes for reaching at room temperature; pin fin with circular perforation needs almost 7 minutes, pin fin with hexagonal perforation needs 4 minutes. As circular perforation makes more surface area than no perforation, the heat is transferred at a higher rate and cooling occurs more quickly in it than solid pin fin. On the other hand, hexagonal perforation makes more surface area than circular perforation, so the heat is transferred at a higher rate and cooling occurs more quickly in it than pin fin with circular perforation. At 12m/s, all the respective fins take less time for cooling than at 4m/s,6m/s,8m/s and 10m/s. Because, more velocity of air causing more quick heat transfer.

4.8 Change of Air Temperature During Cooling of Base Plate by Different Pin Fins at Different Air Velocity

4.8.1 Change of Air Temperature during Cooling of Base Plate by Solid Pin Fins at Different Air Velocities

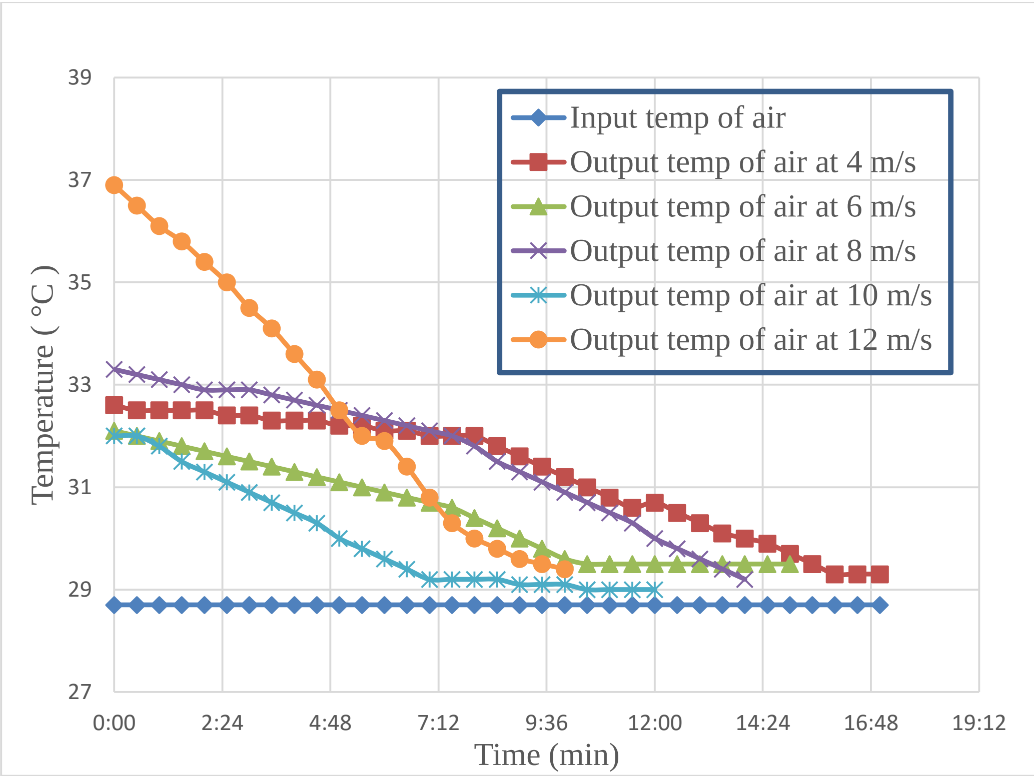


Figure 4.32: Air temperature Vs cooling time graph for solid pin fin

The graph shows that the time needed for the temperature of base plate is to come close to the ambient temperature is gradually decreased with the increase of air velocity for the solid pin fin. The input temperature remains nearly constant throughout the cooling time for all the air velocity. But the time required for the temperature of output to become close to the input ambient temperature is varied for different velocity of air. For 4m/s,6m/s,8m/s,10m/s,12m/s, it needs 17 minute,15 minute,14 minute,12 minute,10 minute respectively. More velocity of air assists the cooling of the base plate. Here it is also noted that this required time are less for the corresponding velocity for solid plate fin as the solid circular pin fin is creating more surface area to reject heat more and cooling more quickly.

4.8.2 Change of Air Temperature during Cooling of Base Plate by Pin Fins with Circular Perforation at Different Air Velocities

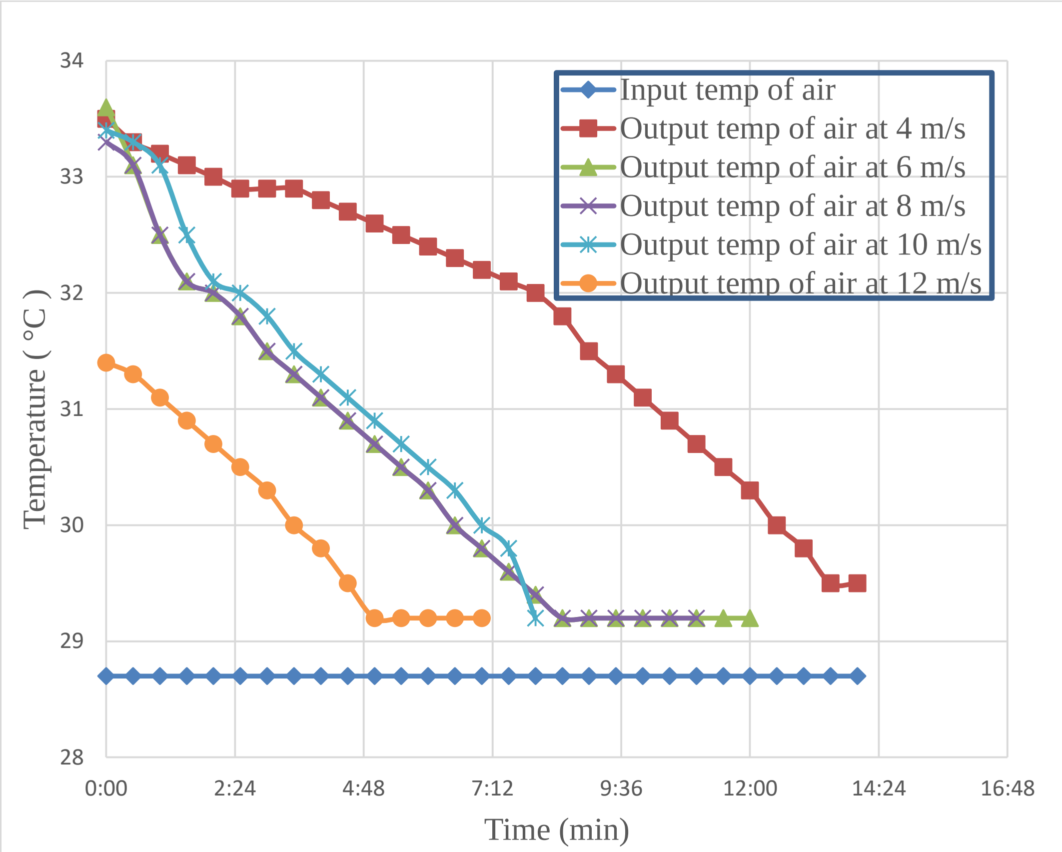


Figure 4.33: Air temperature Vs cooling time graph for pin fin with circular perforation.

The graph shows that the time needed for the temperature of base plate is to come close to the ambient temperature is gradually decreased with the increase of air velocity for the pin fin with circular perforation. The input temperature remains nearly constant throughout the cooling time for all the air velocity. But the time required for the temperature of output to become close to the input ambient temperature is varied for different velocity of air. For 4m/s,6m/s,8m/s,10m/s,12m/s, it needs 14 minute,12 minute,11 minute,8 minute,7 minute respectively. More velocity of air assists the cooling of the base plate. Here it is also noted that this required time are less for the corresponding velocity for solid pin fin as the circular perforation is creating more surface area to reject heat more and cooling more quickly. This time is also less than that of solid plate fin and plate fin with circular perforation as pin fin has more area than that of plate fin.

4.8.3 Change of Air Temperature during Cooling of Base Plate by Pin Fins with Hexagonal Perforation at Different Air Velocities

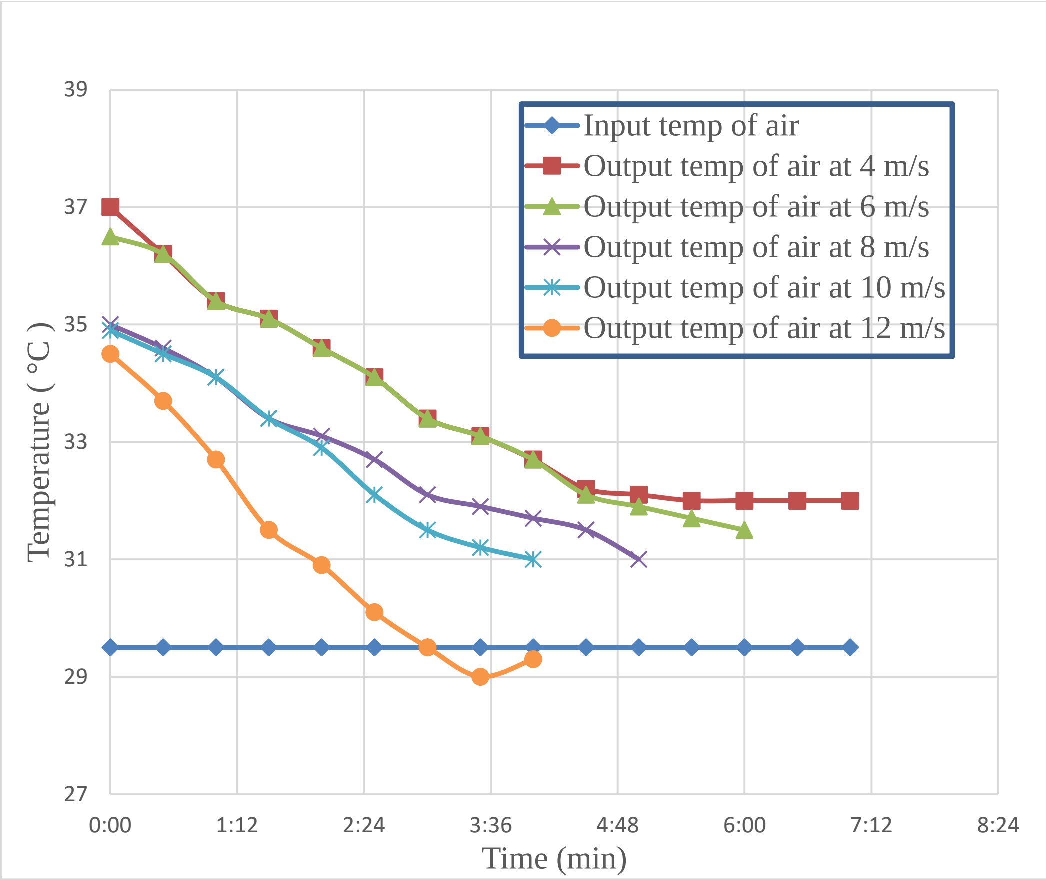


Figure 4.34: Air temperature Vs cooling time graph for pin fin with hexagonal perforation.

The graph shows that the time needed for the temperature of base plate is to come close to the ambient temperature is gradually decreased with the increase of air velocity for the pin fin with hexagonal perforation. The input temperature remains nearly constant throughout the cooling time for all the air velocity. But the time required for the temperature of output to become close to the input ambient temperature is varied for different velocity of air. For 4m/s,6m/s,8m/s,10m/s,12m/s, it needs 7 minute,6 minute,5 minute,4 minute,4 minute respectively. More velocity of air assists the cooling of the base plate. Here it is also noted that this required time are less for the corresponding velocity for solid pin fin and pin fin with circular perforation as the hexagonal perforation is creating more surface area to reject heat more and cooling more quickly.

This time is also less than that of solid plate fin and plate fin with circular perforation as pin fin has more area than that of plate fin.

4.9 Change of Base Plate Temperature during Heating in Different Pin Fins at Different Velocity

4.9.1 Change of Base Plate Temperature during Heating in Pin Fin Without Perforation at Different Velocities

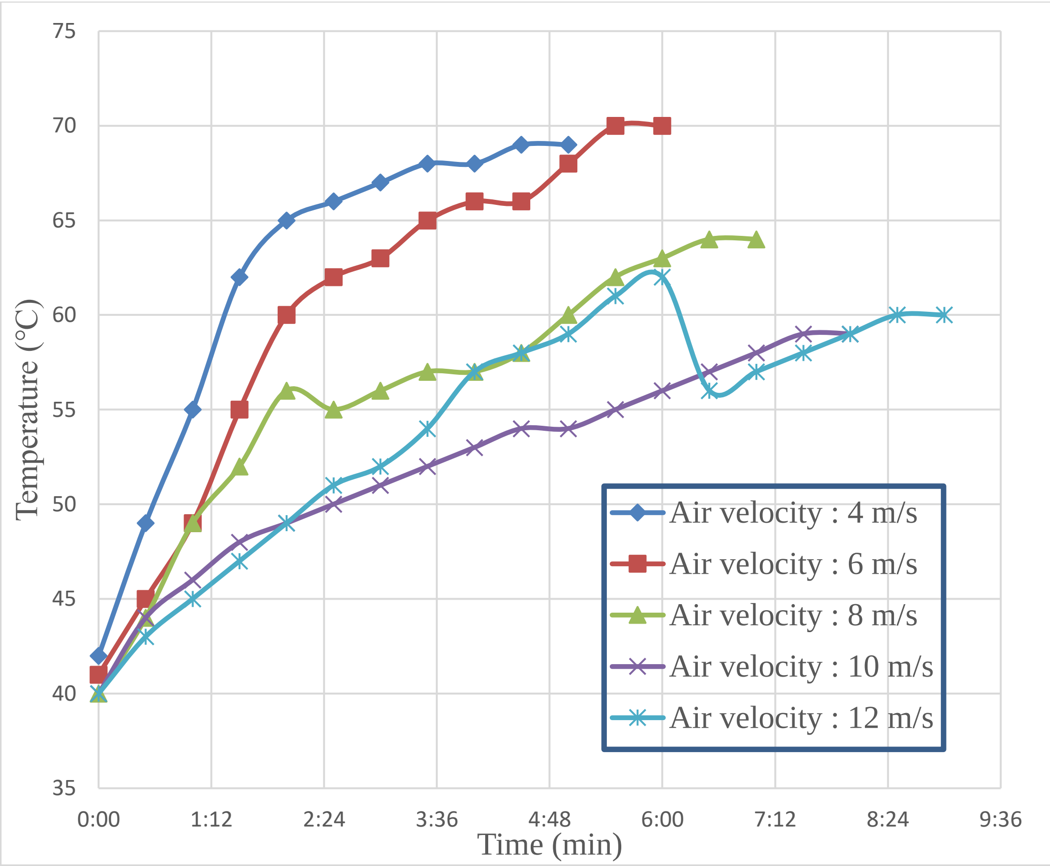


Figure 4.35: Base plate temperature vs heating time graph for solid pin fin

The graph shows that with the increase of air velocity, the time needed for heating of solid pin fin is increasing. As increased air velocity hinders the heating of the base plate so the time required increased.

4.9.2 Change of base Plate Temperature during Heating in Pin Fin with Circular Perforation at Different Velocities

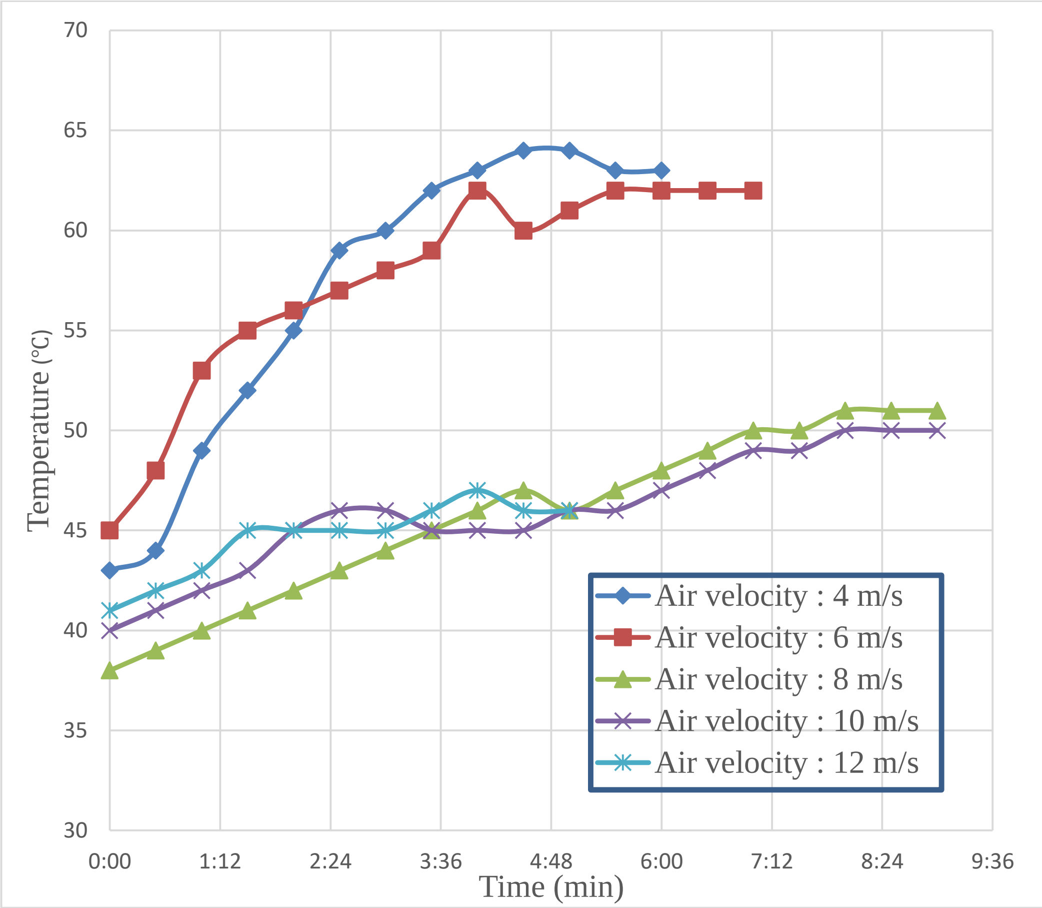


Figure 4.36: Base plate temperature vs heating time graph for pin fin with circular perforation

The graph shows that with the increase of air velocity, the time needed for heating of circular perforated pin fin is increasing. As increased air velocity hinders the heating of the base plate so the time required increased. The required time at air velocity 4m/s,6m/s,8m/s,10m/s,12m/s of pin fin with circular perforation are higher than that of solid pin fin respectively. As because of circular perforation, the heat is being lost at the perforated area which does not occur at solid pin fin. For overcoming that loss, pin fin with circular perforation needs more time for being heated.so heating become almost slowly steady at comparatively low temperature and don’t get so much higher temperature.

4.9.3 Change of Base Plate Temperature during Heating in Pin Fin with Hexagonal Perforation at Different Velocities

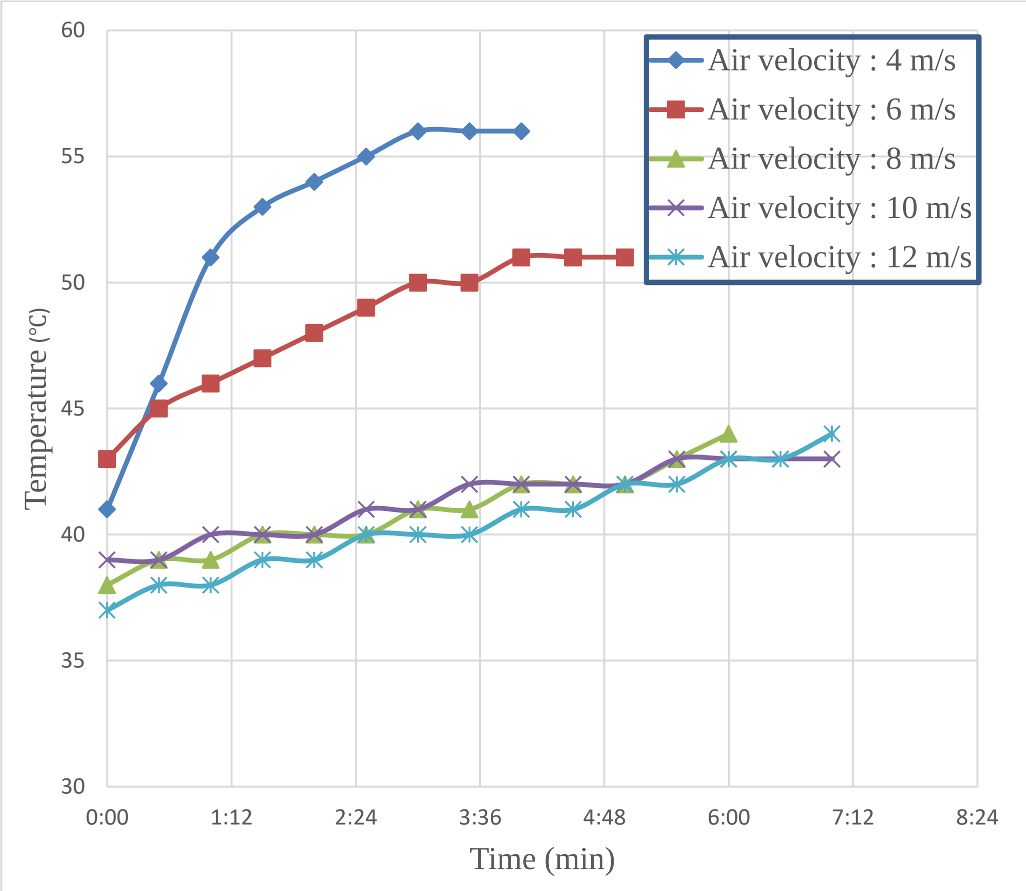


Figure 4.37: Base plate temperature Vs heating time graph for pin fin with hexagonal perforation

The graph shows that with the increase of air velocity, the time needed for heating of hexagonally perforated pin fin is increasing. But in this case, because of excessive hindrance and heat loss, the base plate cannot go to that much of higher temp at all. The required time at air velocity 4m/s,6m/s,8m/s,10m/s,12m/s of pin fin with hexagonal perforation are higher than that of solid pin fin and pin fin with circular perforation respectively if the temperature is taken to that much of higher. But here the increase of temperature become much slower so it slows down before so much higher temperature.

4.10 Change of Base Plate Temperature during Cooling in Different Pin Fin at Different Velocities

4.10.1 Change of Base Plate Temperature during Cooling in Solid Pin Fin without Perforation at Different velocities

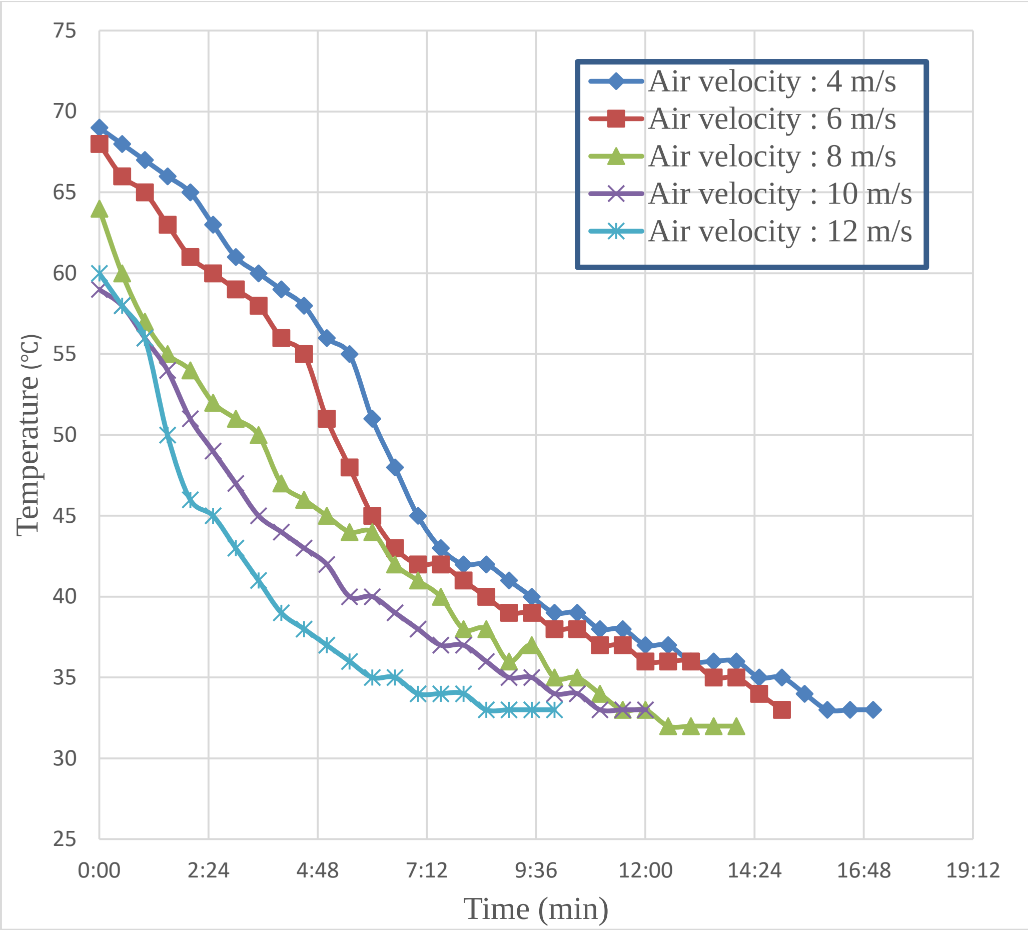


Figure 4.38: Base plate temperature Vs cooling time graph for solid pin fin

This graph shows that the time needed for cooling is more for 4m/s and less for 12 m/s. as increased air velocity helps for cooling in solid pin fin.

4.10.2 Change of Base Plate Temperature during Cooling in Pin Fin with Circular Perforation at Different Velocities

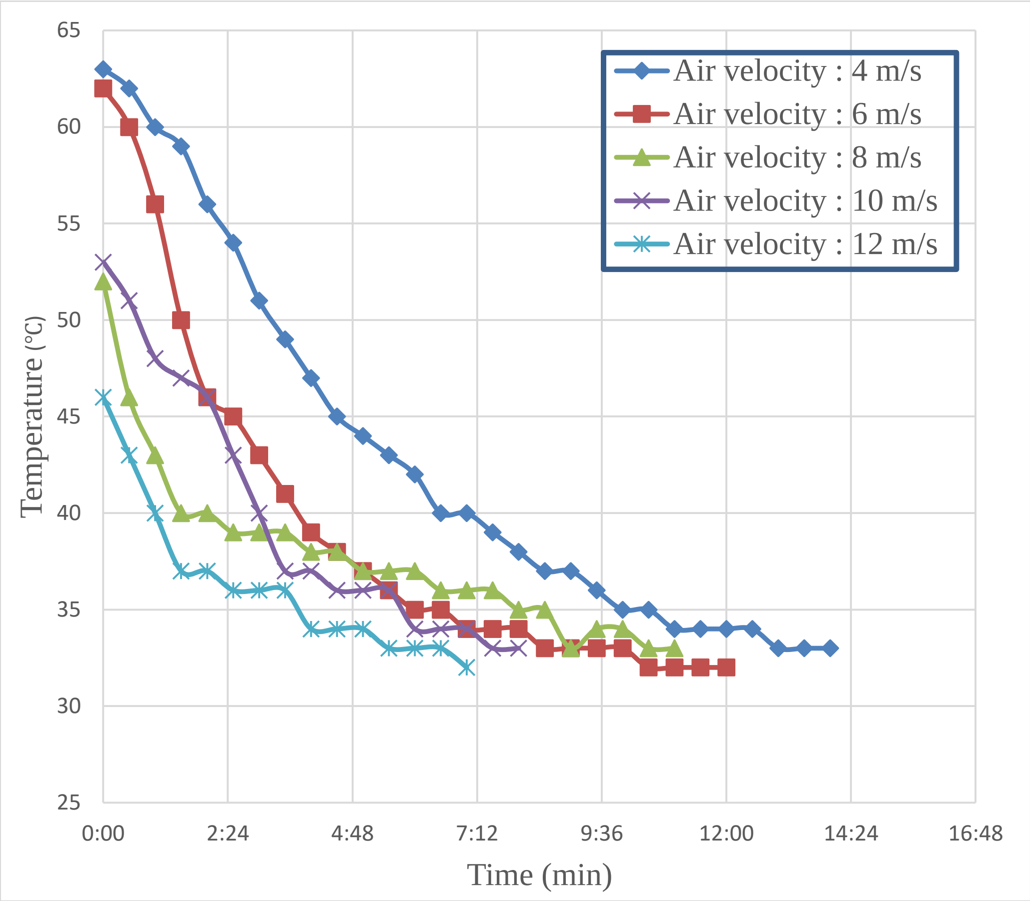


Figure 4.39: Base plate temperature Vs cooling time graph for pin fin with circular perforation

This graph shows that the time needed for cooling is more for 4m/s and less for 12 m/s at pin fin with circular perforation as increased air velocity helps for cooling. Also the required time for cooling is less than that of solid pin fin. Increased area by circular perforation assist in cooling

4.10.3 Change of Base Plate Temperature during Cooling in Pin Fin with Hexagonal Perforation at Different Velocities

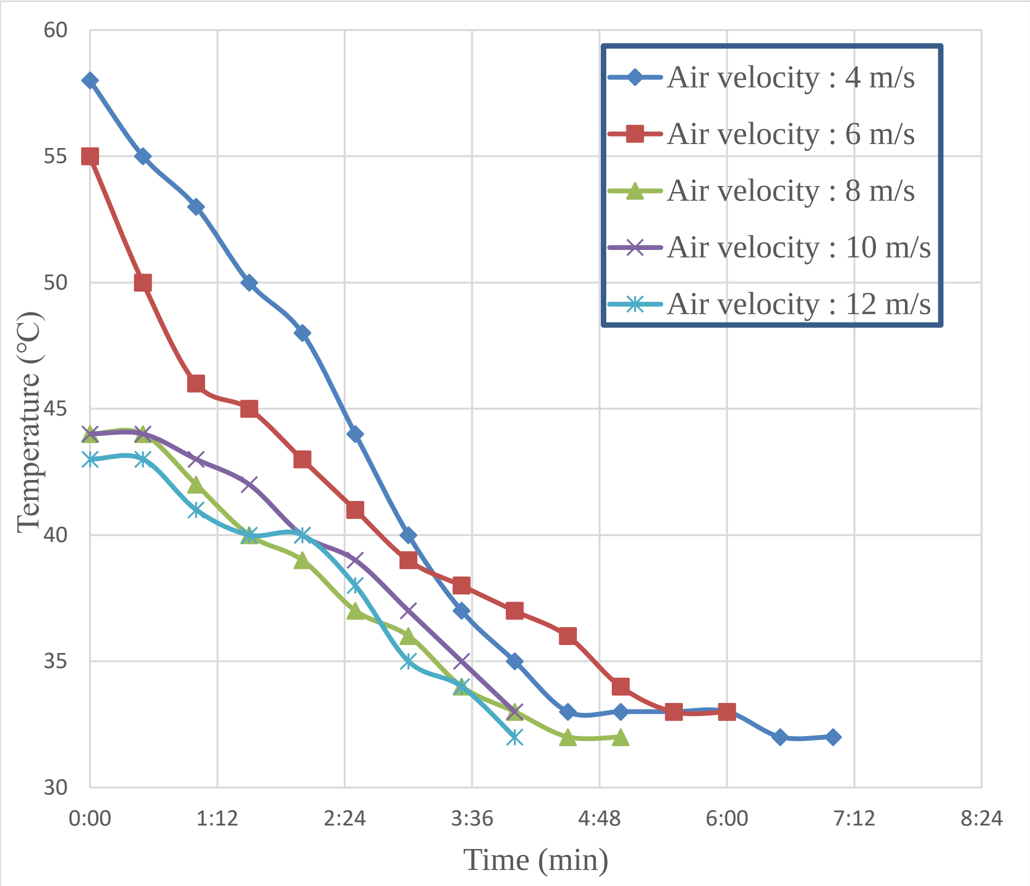


Figure 4.40: Base plate temperature Vs cooling time graph for pin fin with hexagonal perforation

This graph shows that the time needed for cooling is more for 4m/s and less for 12 m/s at pin fin with hexagonal perforation as increased air velocity helps for cooling. Also the required time for cooling is less than that of solid pin fin and pin fin with circular perforation. Increased area by hexagonal perforation assist in cooling.

4.11 Variation of Temperature along the Different Pin Fin Length at Different Air Velocity

The temperature along the length is reduced in pin fin with hexagonal perforation than pin fin with circular perforation and solid pin fin. The perforation helps to decrease the temperature along the length.

4.11.1 Variation of Temperature along the Different Pin Fin Length at an Air Velocity of 4 m/s

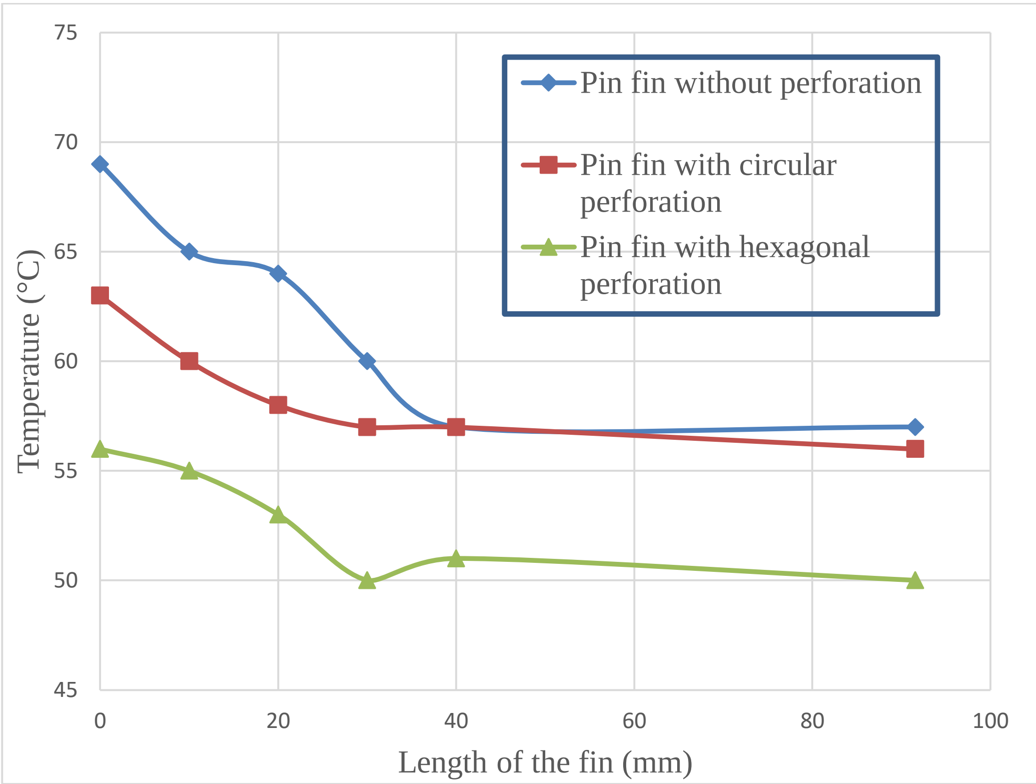


Figure 4.41: Temperature Vs length of the fin graph for different pin fin at 4m/s

At 4m/s, for all the pin fin, the temperature along the fin length is decreasing. Because, the heat of the heater is transferring to the fin through the base plate. So, with the increase of length the temperature is reduced.

4.11.2 Variation of Temperature along the Different Pin Fin Length at an Air Velocity of 6 m/s

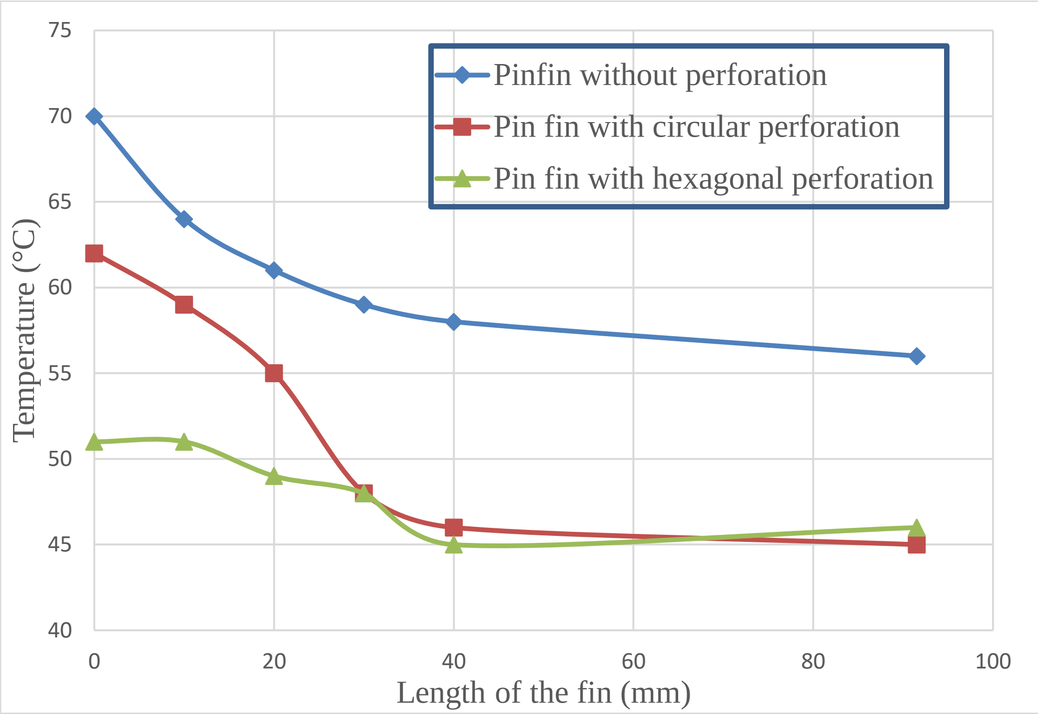


Figure 4.42: Temperature vs length of the fin graph for different pin fin at 6m/s

At 6m/s, for all the pin fin, the temperature along the fin length is decreasing. Because, the heat of the heater is transferring to the fin through the base plate. So, with the increase of length the temperature is reduced.

4.11.3 Variation of Temperature along the Different Pin Fin Length at an Air Velocity of 8 m/s

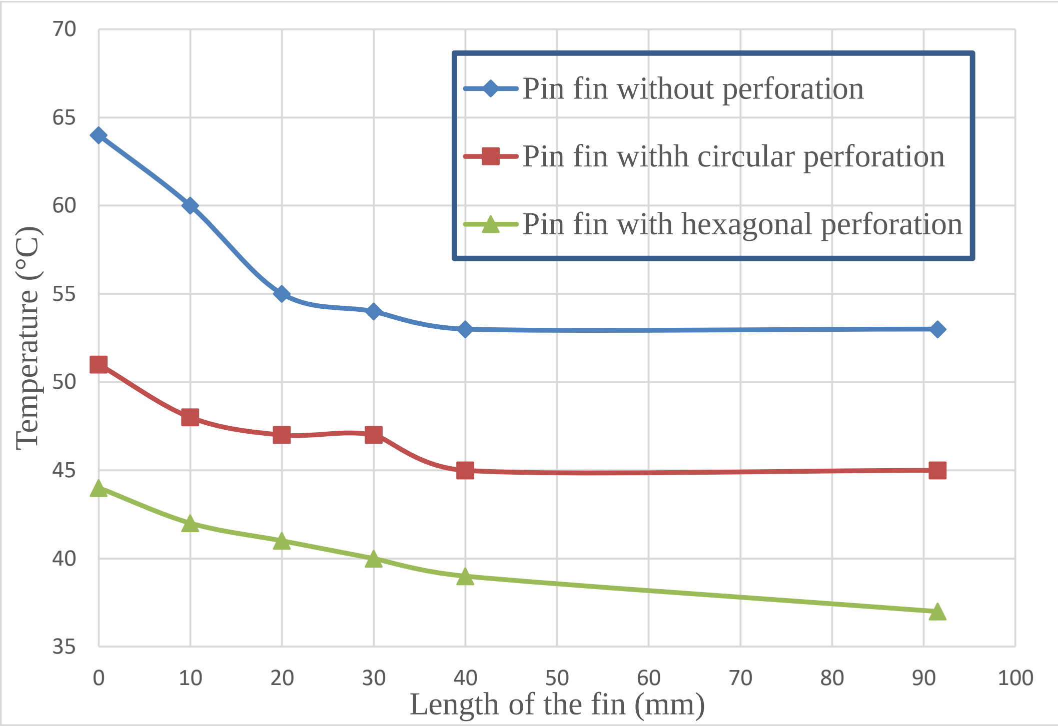


Figure 4.43: Temperature Vs length of the fin graph for different pin fin at 8m/s

At 8m/s, for all the plate fin, the temperature along the fin length is decreasing. Because, the heat of the heater is transferring to the fin through the base plate. So, with the increase of length the temperature is reduced.

4.11.4 Variation of Temperature along the Different Plate Fin Length at an Air Velocity of 10 m/s

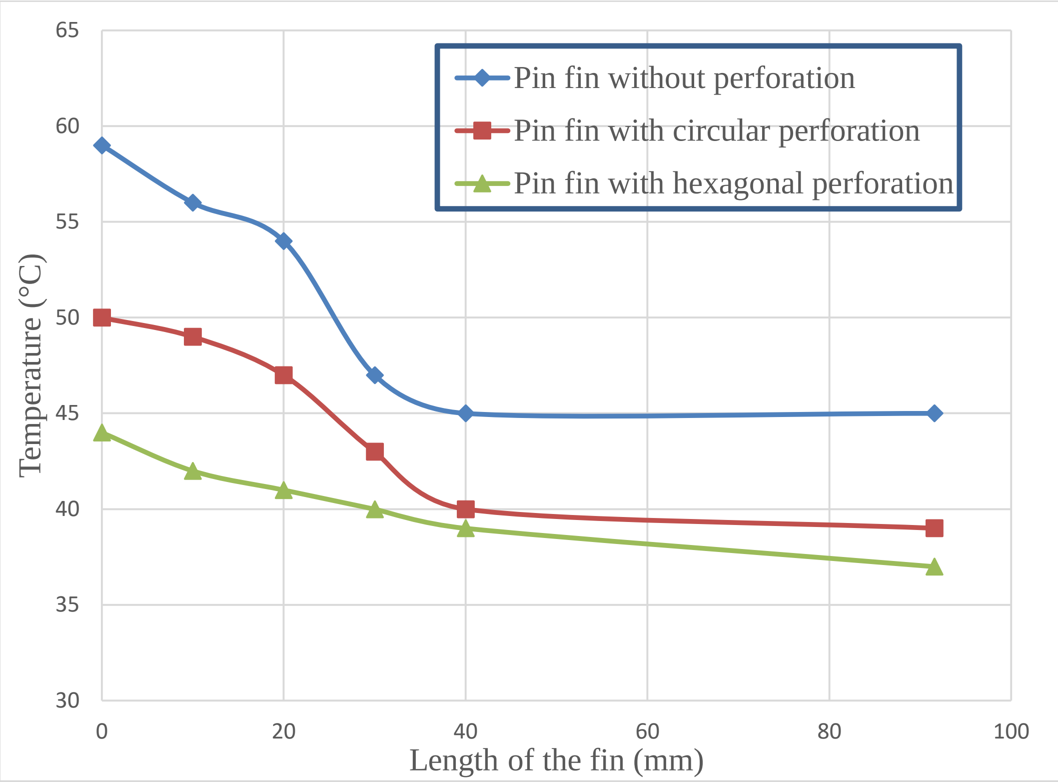


Figure 4.44: Temperature vs length of the fin graph for different pin fin at 10m/s

At 10m/s, for all the plate fin, the temperature along the fin length is decreasing. Because, the heat of the heater is transferring to the fin through the base plate. So, with the increase of length the temperature is reduced.

4.11.5 Variation of Temperature along the Different Pin Fin Length at an Air Velocity of 12 m/s

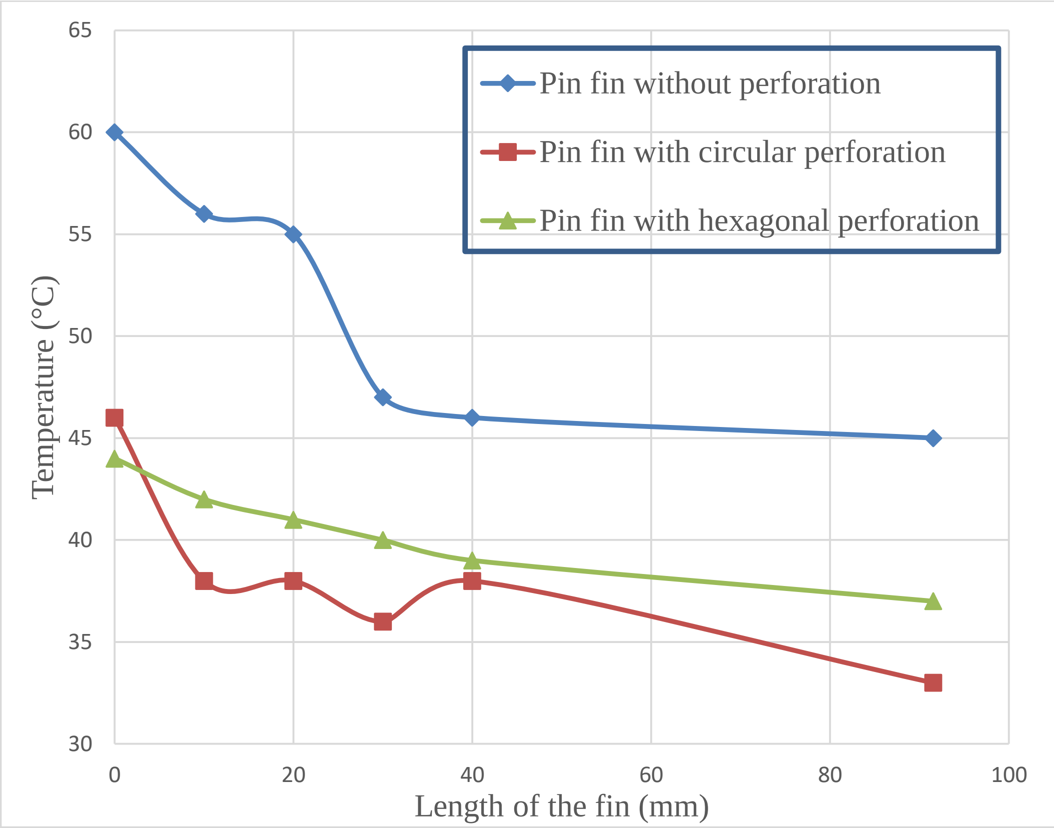


Figure 4.45: Temperature vs length of the fin graph for different pin fin at 12m/s

At 12m/s, for all the plate fin, the temperature along the fin length is decreasing. Because, the heat of the heater is transferring to the fin through the base plate. So, with the increase of length the temperature is reduced

4.12 Variation of Different Fin Characteristics with Reynolds Number for Different Pin Fins

4.12.1 Variation of Fin Effectiveness with Reynolds No for Different Pin fins

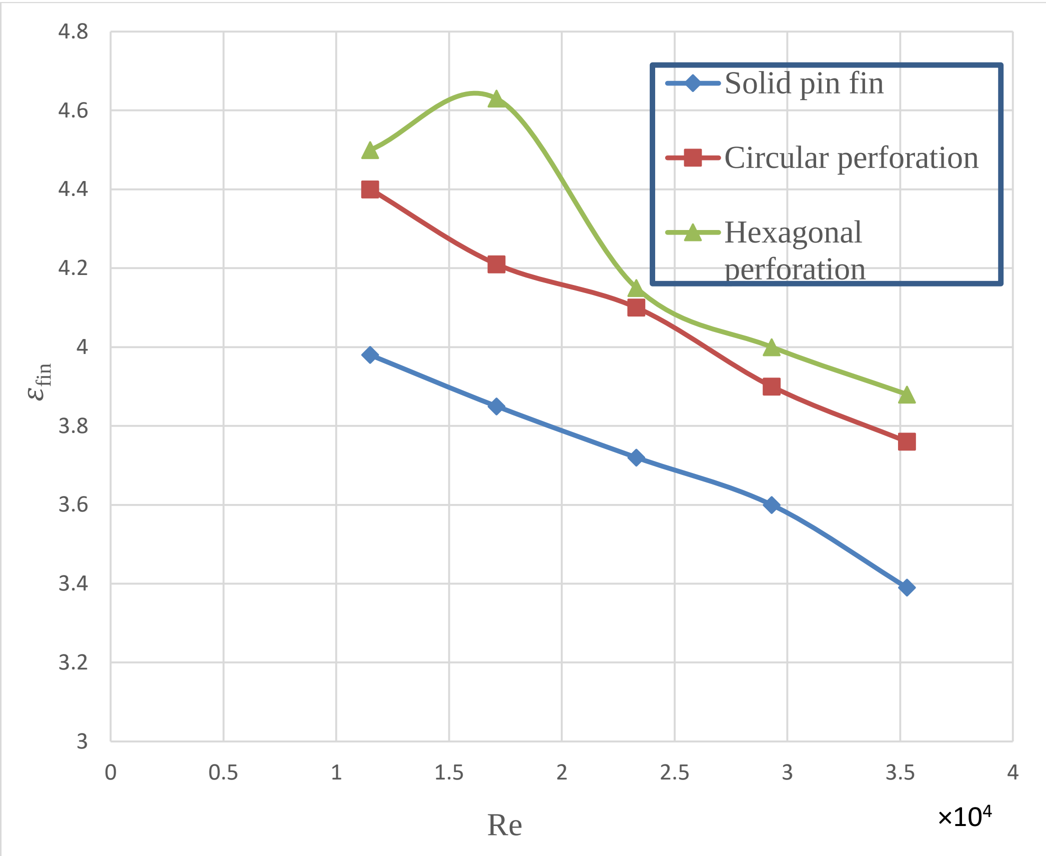


Figure 4.46: Variation of fin effectiveness with Reynolds no for different kind of pin fins

The effect of Reynolds number for different kind of pin fins on fin effectiveness is shown in figure. The result suggests that fin effectiveness for pin fin with hexagonal perforation is most effective fin than any other ones in this graph. As this is an experimental result, so there creates some error. If we consider best fitted graph, then we can say that the fin effectiveness is decreased with the increasing Reynolds number.

4.12.2 Variation of Fin Efficiency with Reynolds No for Different Pin fins

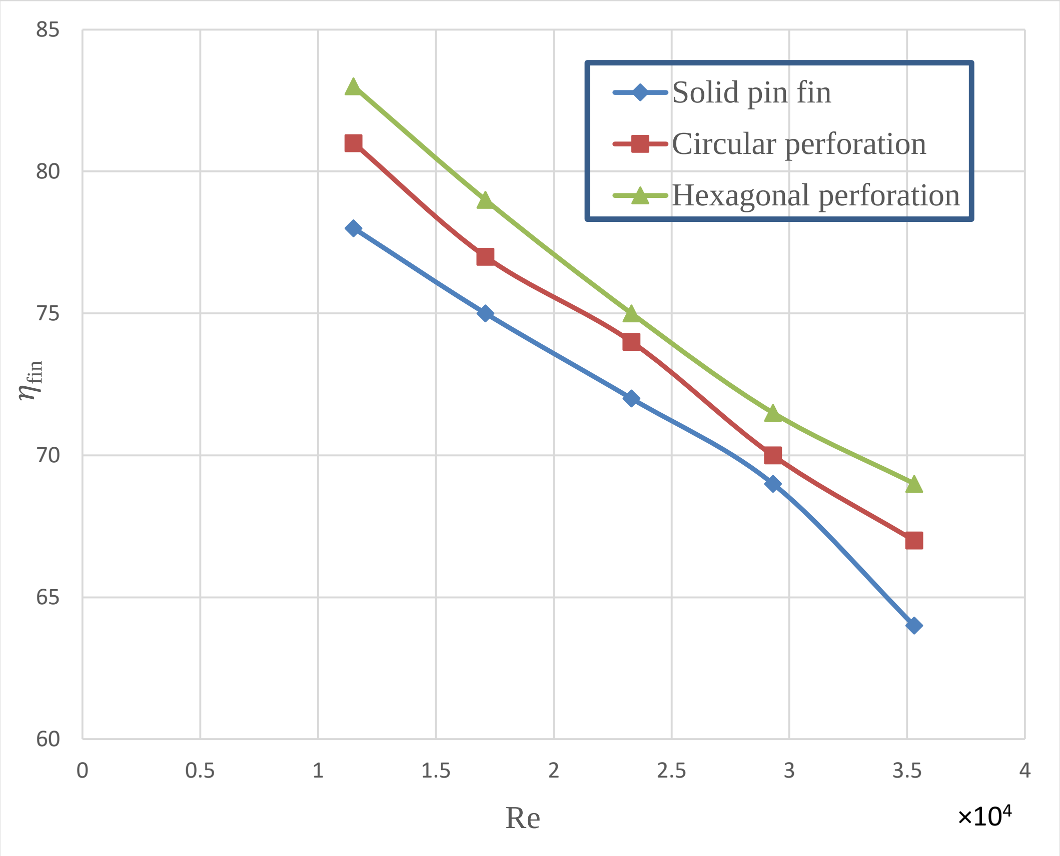


Figure 4.47: Variation of fin efficiency with Reynolds no for different kind of pin fins

The effect of Reynolds number for different kind of pin fins on fin efficiency is shown in figure. The result suggests that fin efficiency for pin fin with hexagonal perforation is comparatively higher than any other ones in this graph. As this is an experimental result, so there creates some error. If we consider best fitted graph, then we can say that the fin efficiency is decreased with the increasing Reynolds number.

4.12.3 Variation of Convective Heat Transfer Coefficient with Reynolds No for Different Pin fins

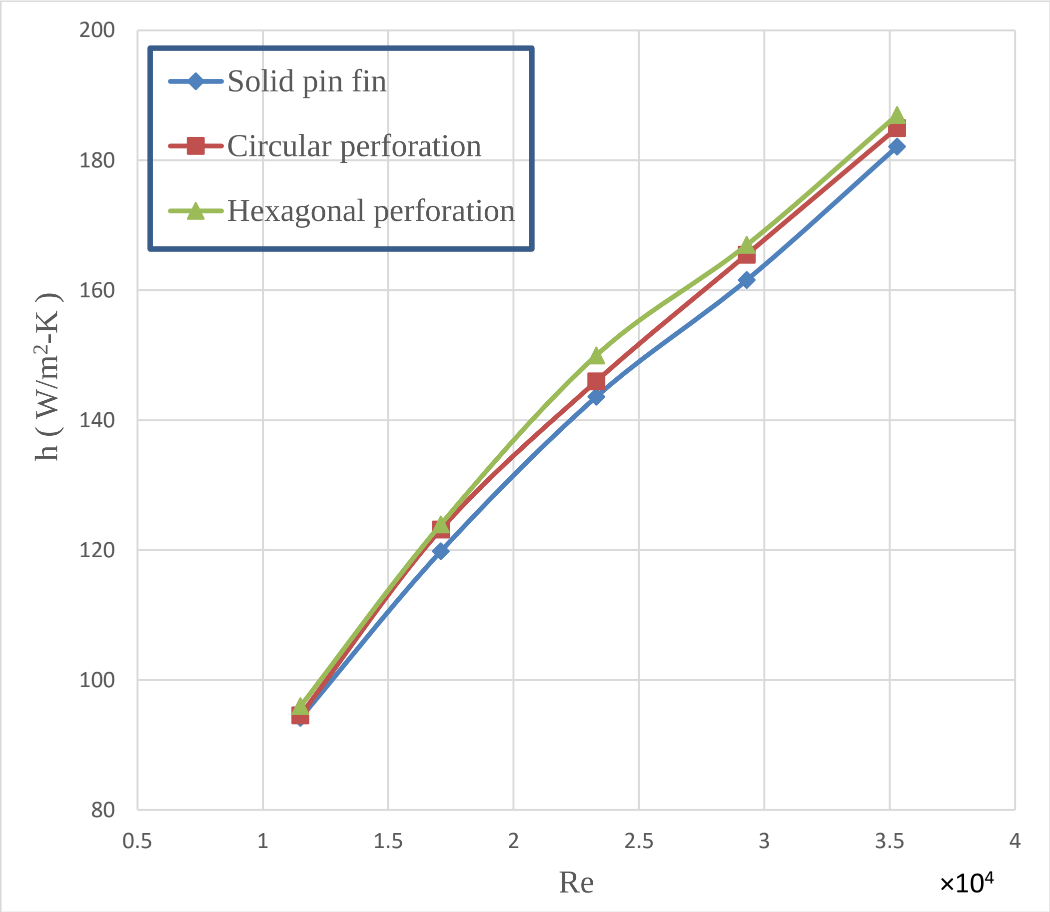


Figure 4.48: Variation of convective heat transfer coefficient with Reynolds no for different kind of pin fins

The effect of Reynolds number for different kind of pin fins on convective heat transfer coefficient is shown in figure. The result suggests that convective heat transfer coefficient for pin fin with hexagonal perforation is comparatively higher than any other ones in this graph. However, convective heat transfer coefficient is increased with the increasing Reynolds number.

4.12.4 Variation of Nusselt No with Reynolds No for Different Pin fins

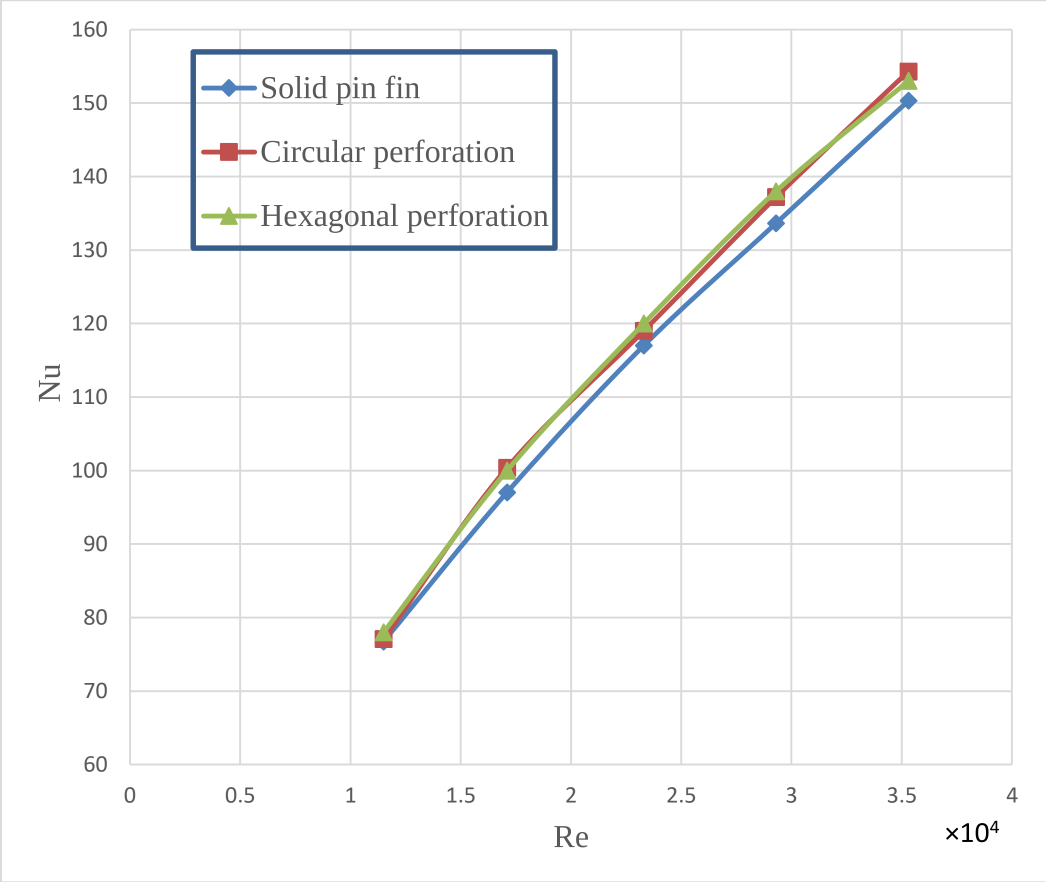


Figure 4.49: Variation of Nusselt number with Reynolds number for different kind of pin fins

The effect of Reynolds number for different kind of pin fins on Nusselt number is shown in figure. The result suggests that Nusselt number for pin fin with hexagonal perforation is comparatively higher than any other ones in this graph. However, Nusselt number is increased with the increasing Reynolds number.

4.12.5 Variation of Pressure Drop with Reynolds No for Different Pin fins

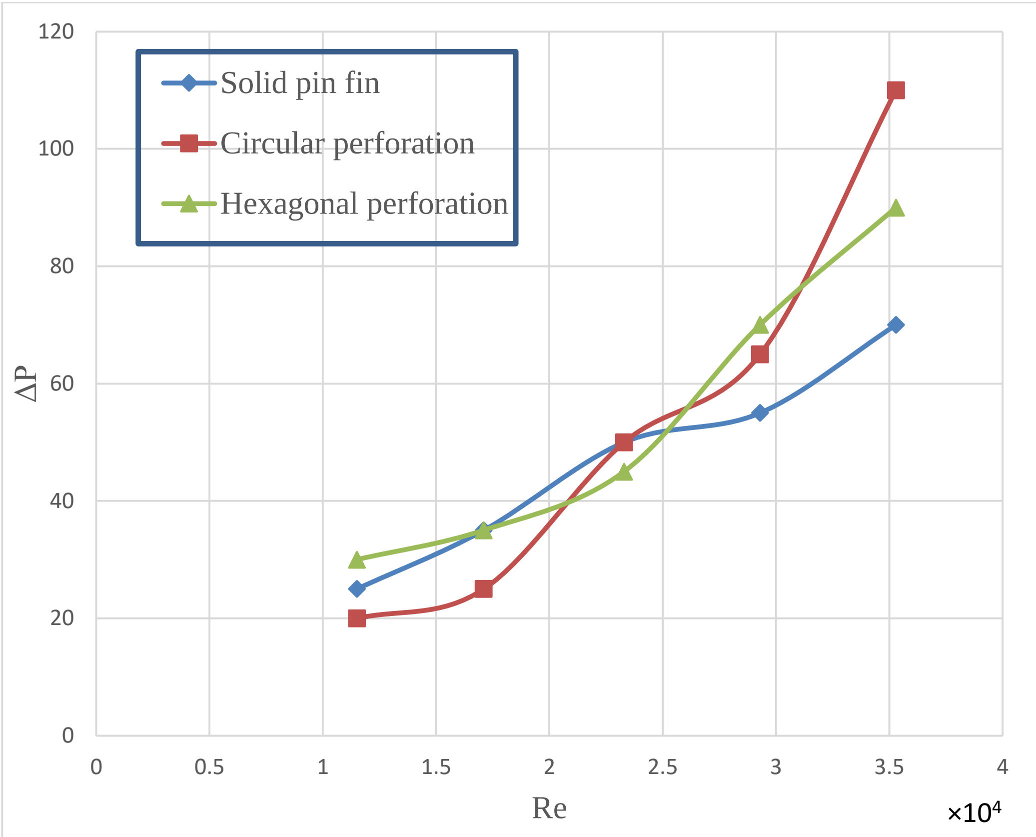


Figure 4.50: Variation of pressure drop with Reynolds no for different kind of pin fins

The effect of Reynolds number for different kind of pin fins on pressure drop is shown in figure. The result suggests that pressure drop for pin fin with hexagonal perforation is comparatively higher than any other ones in this graph. However, pressure drop is increased with the increasing Reynolds number and also with the perforation. As perforation creates more pressure difference between upstream and downstream pressure.

4.12.6 Variation of Thermal Resistance with Reynolds No for Different Pin fins

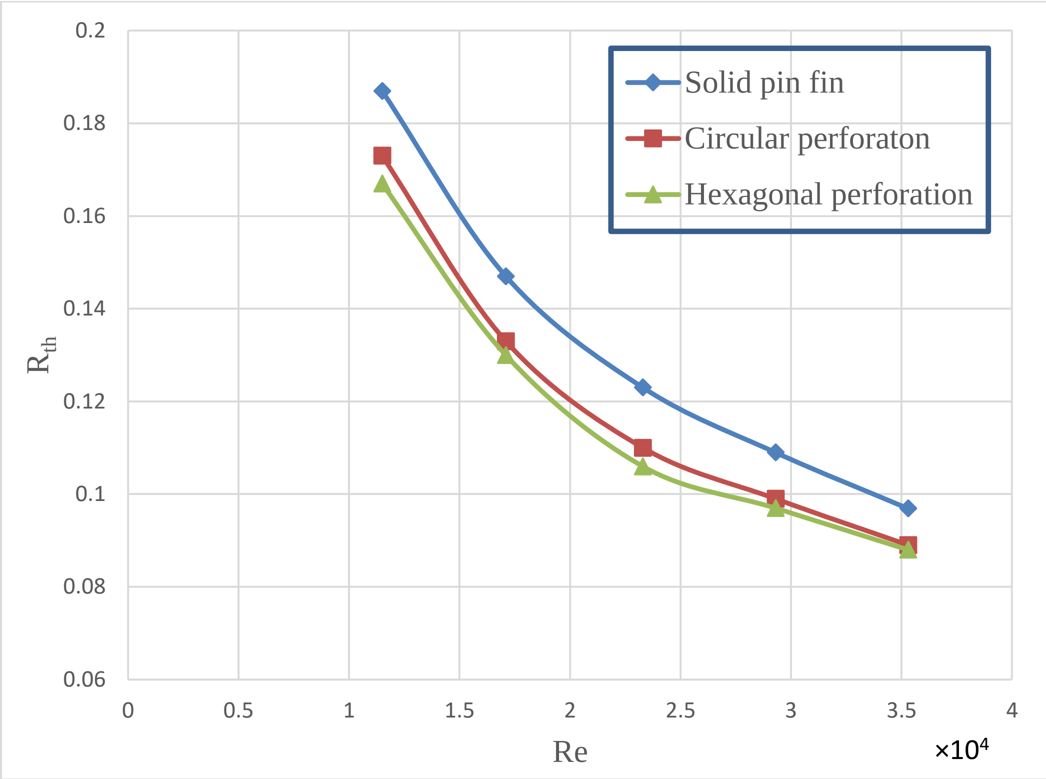


Figure 4.51: Variation of thermal resistance with Reynolds no for different kind of pin fins

The effect of Reynolds number for different kind of pin fins on thermal resistance is shown in figure. The result suggests that the thermal resistance for pin fin with hexagonal perforation is comparatively higher than any other ones in this graph. However, thermal resistance is decreased with the increasing Reynolds number.

4.12.7 Variation of Dimensionless Pressure Drop with Reynolds No for Different Pin fin

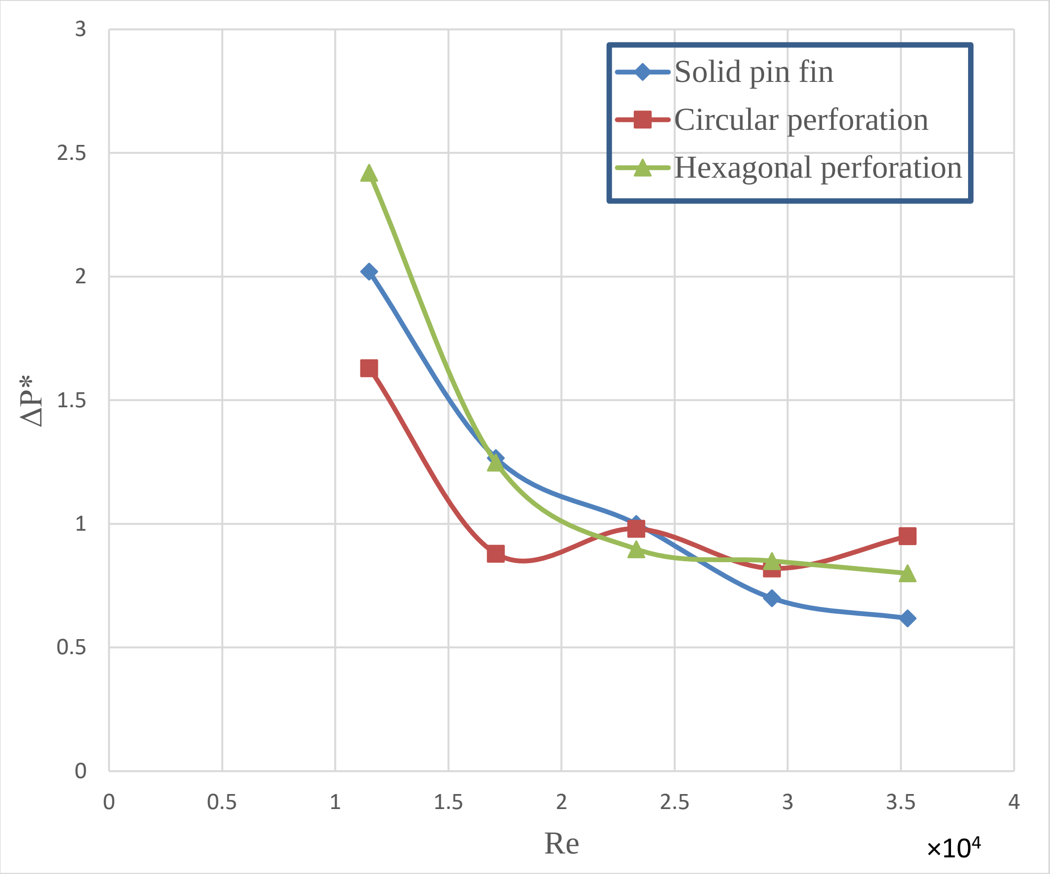


Figure 4.52: Variation of dimensionless pressure drop with Reynolds no for different kind of pin fins

The effect of Reynolds number for different kind of pin fins on dimensionless pressure drop is shown in figure. The result suggests that dimensionless pressure drop for pin fin with hexagonal perforation is comparatively lower than any other ones in this graph. However, Dimensionless pressure drop is decreased with the increasing Reynolds number and also with the perforation.

4.13 ANSYS Simulation

ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user designed size) called elements. The software implements that govern the behavior of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole.

In ANSYS methodology, the thermal analysis is selected in preferences. Next, the proper element i.e. Aluminium is selected and it’s in material properties like film coefficient (in $W/mm^2.°C$) is entered. In modelling stage, the fins are designed in SolidWorks and eventually imported to ANSYS for steady state thermal analysis.

Meshing is considered as discretization of the specimen into elements of finite number and each element is solved and added to obtain results. The element shape is polygonal. In meshing stage, a fine shape of 2.5 is selected and made the meshing and apply thermal loads in terms of temperature at base level of fin and convection heat transfer coefficient (h) value is provided on selected at outer surfaces or areas and Bulk temperature is provided as ambient temperature which it acts as medium for pin fin.

By selecting the steady state heat transfer analysis and solving the problem the results are obtained. In post processing, the plot results temperature distribution level is known through images.

By analyzing the specimen in ANSYS Software, the following images are obtained for selected material i.e. Aluminium.

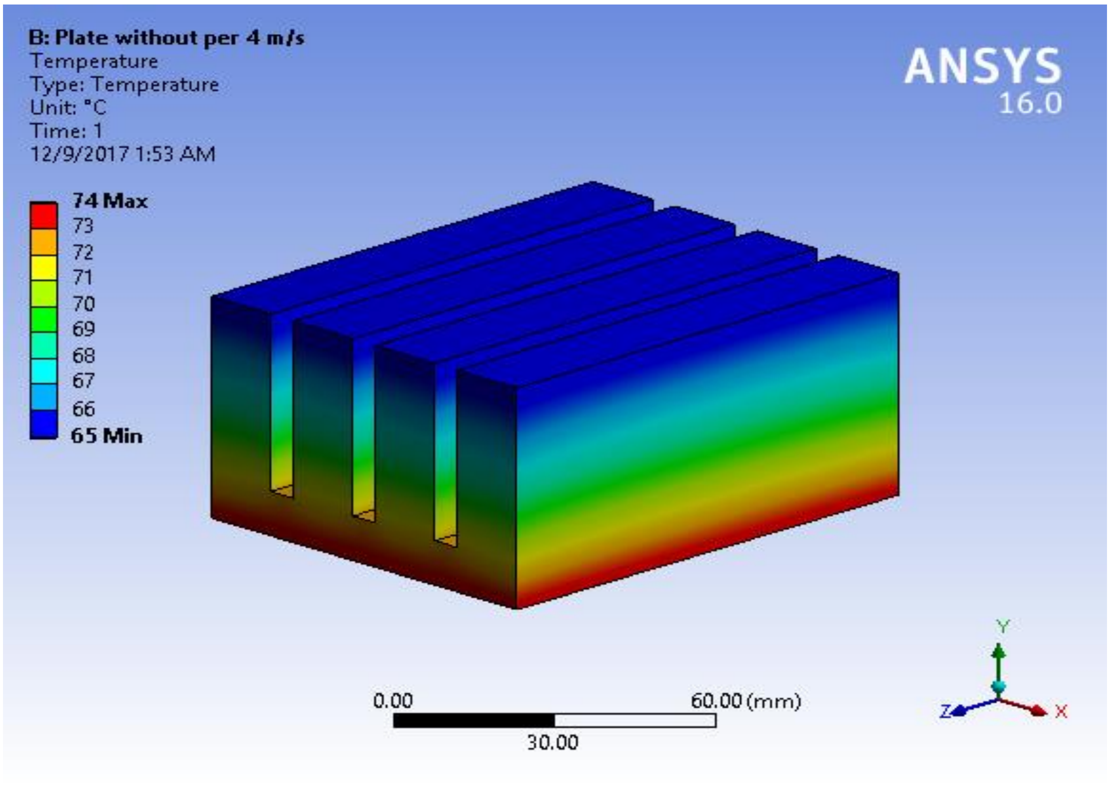


Figure 4.53: Stimulation of plate fin without perforation at 4m/s

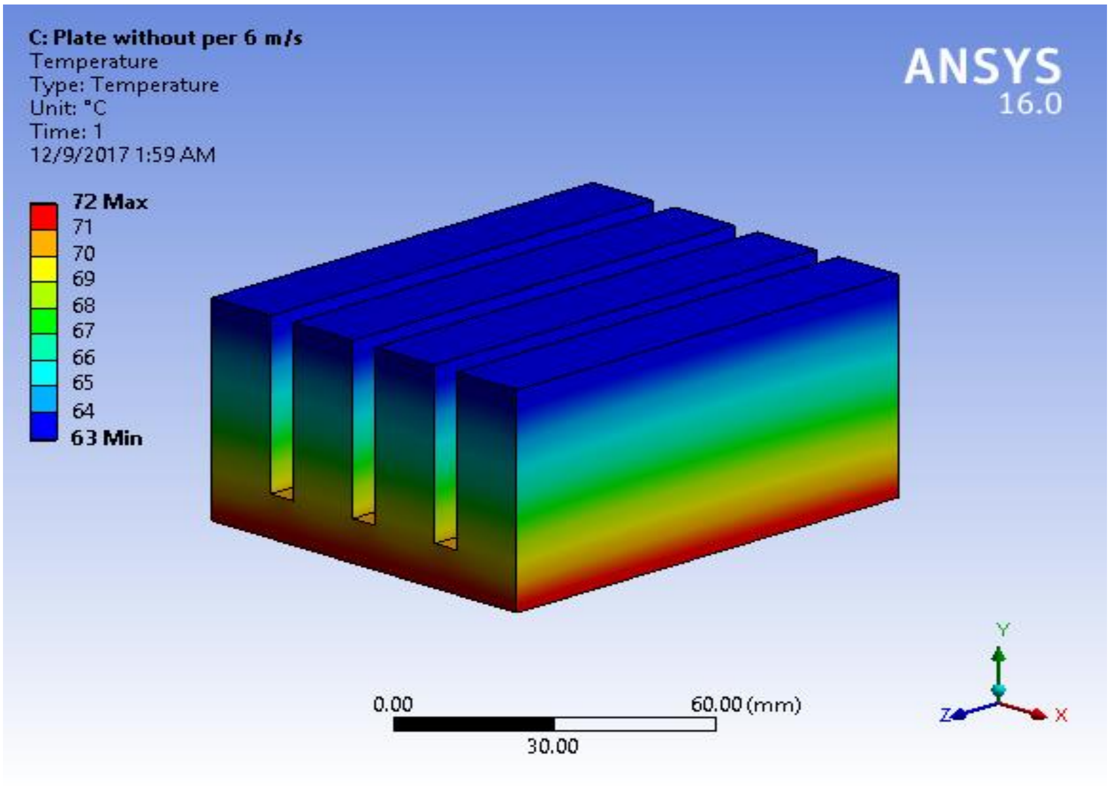


Figure 4.54: Stimulation of plate fin without perforation at 6m/s

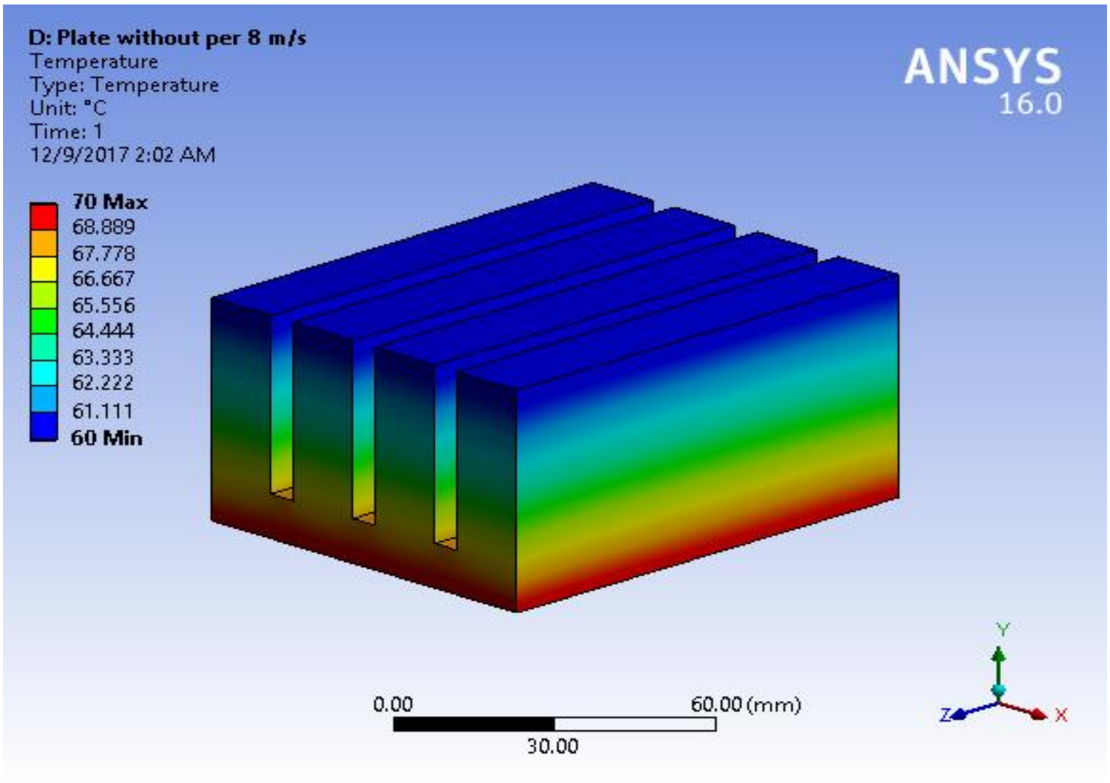


Figure 4.55: Stimulation of plate fin without perforation at 8m/s

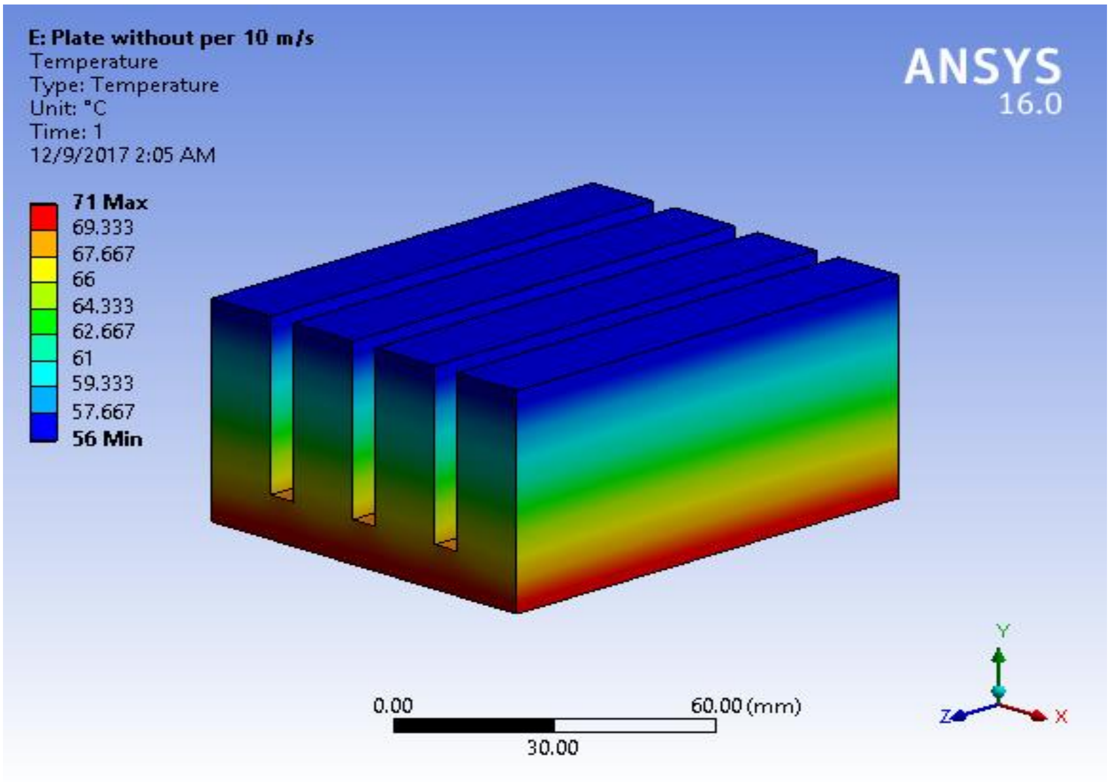


Figure 4.56: Stimulation of plate fin without perforation at 10m/s

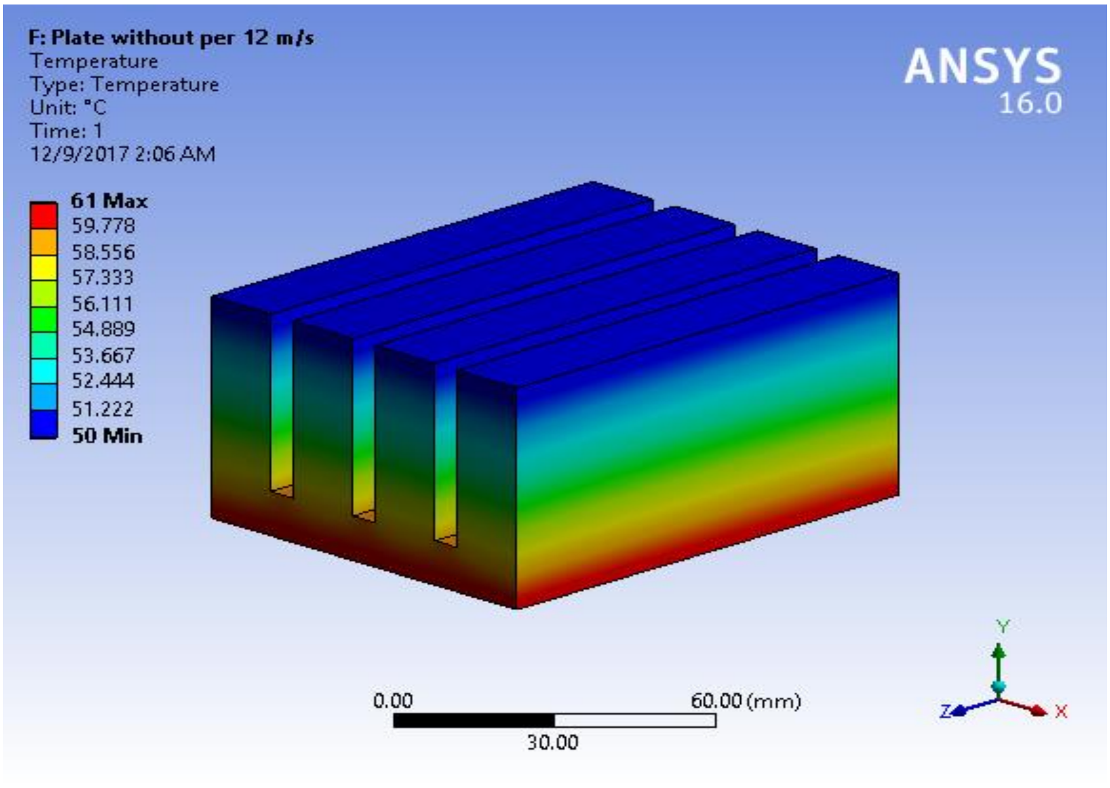


Figure 4.57: Stimulation of plate fin without perforation at 12m/s

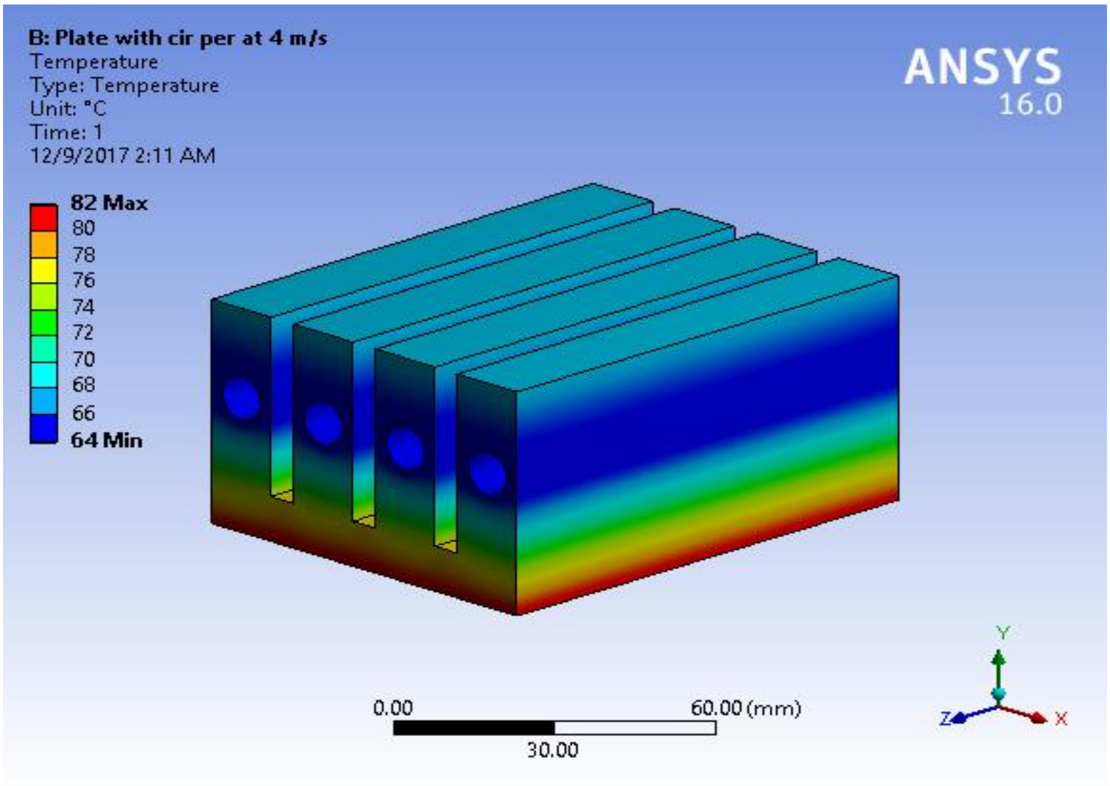


Figure 4.58: Stimulation of plate fin with circular perforation at 4m/s

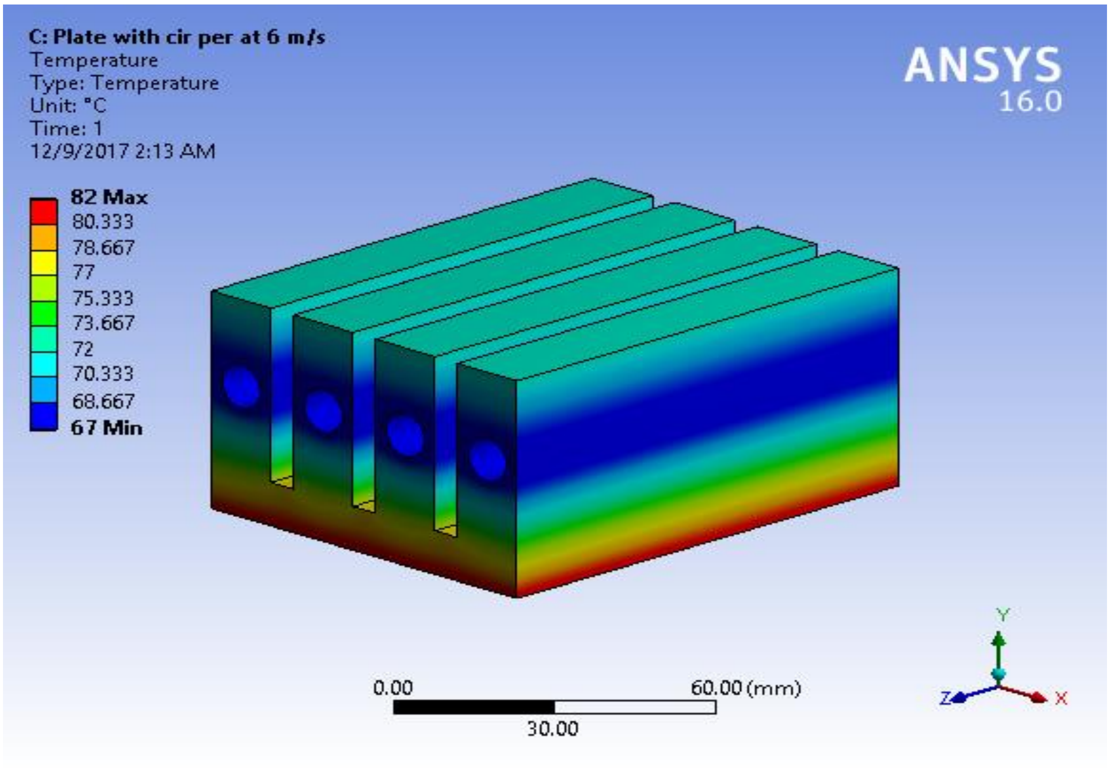


Figure 4.59: Stimulation of plate fin with circular perforation at 6m/s

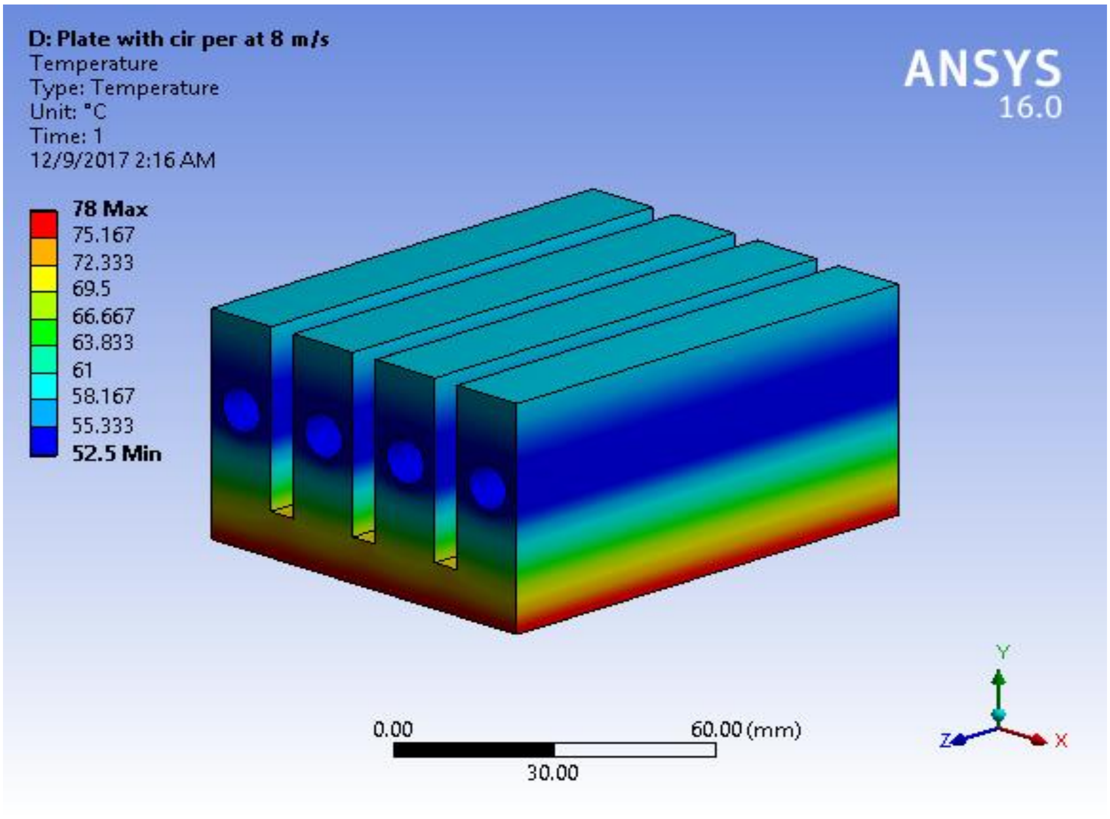


Figure 4.60: Stimulation of plate fin with circular perforation at 8m/s

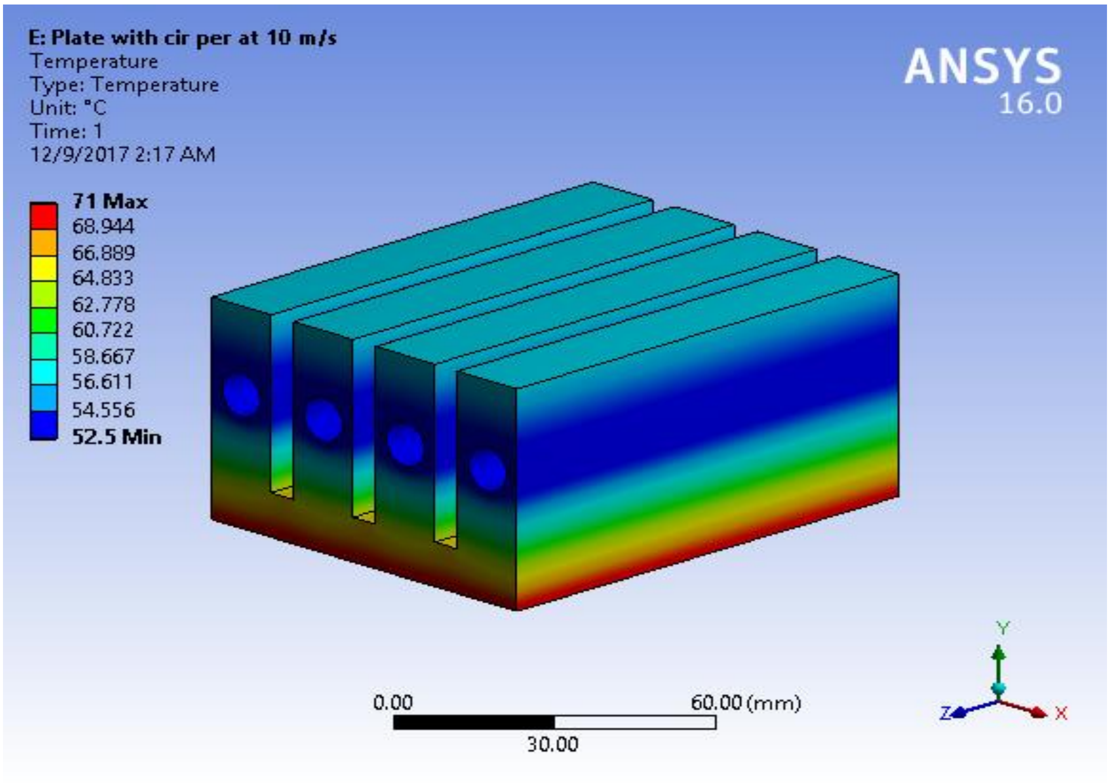


Figure 4.61: Stimulation of plate fin with circular perforation at 10m/s

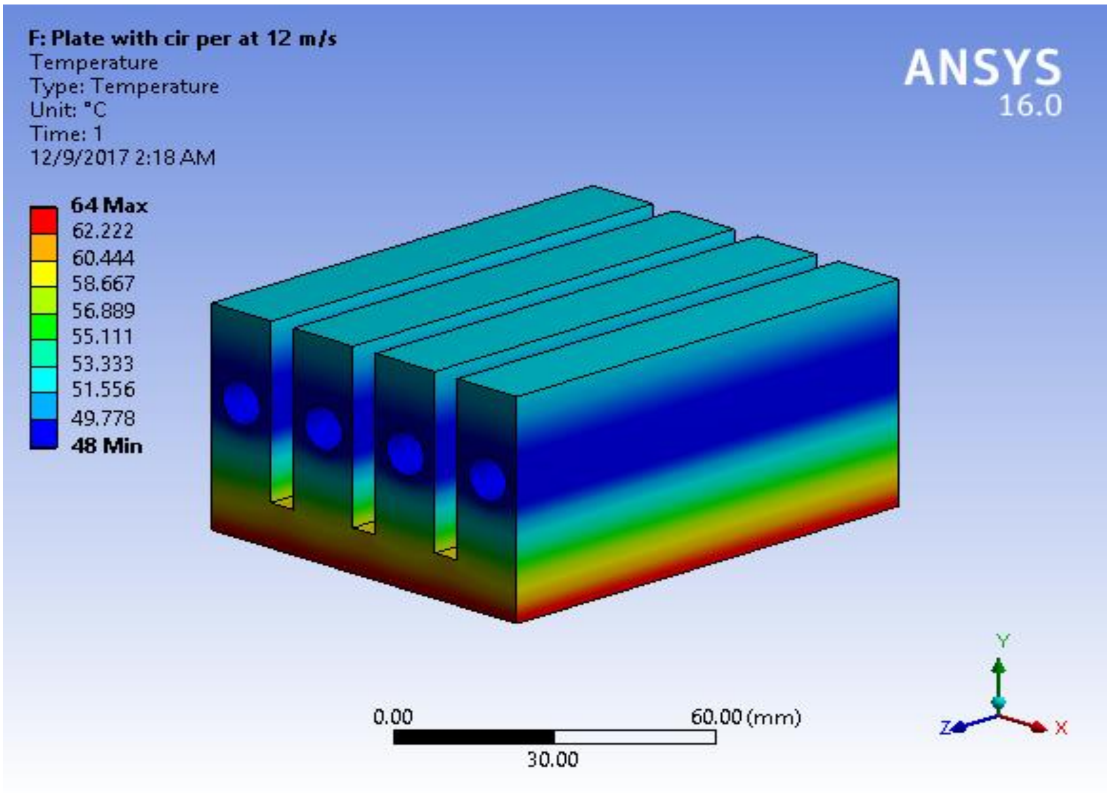


Figure 4.62: Stimulation of plate fin with circular perforation at 12m/s

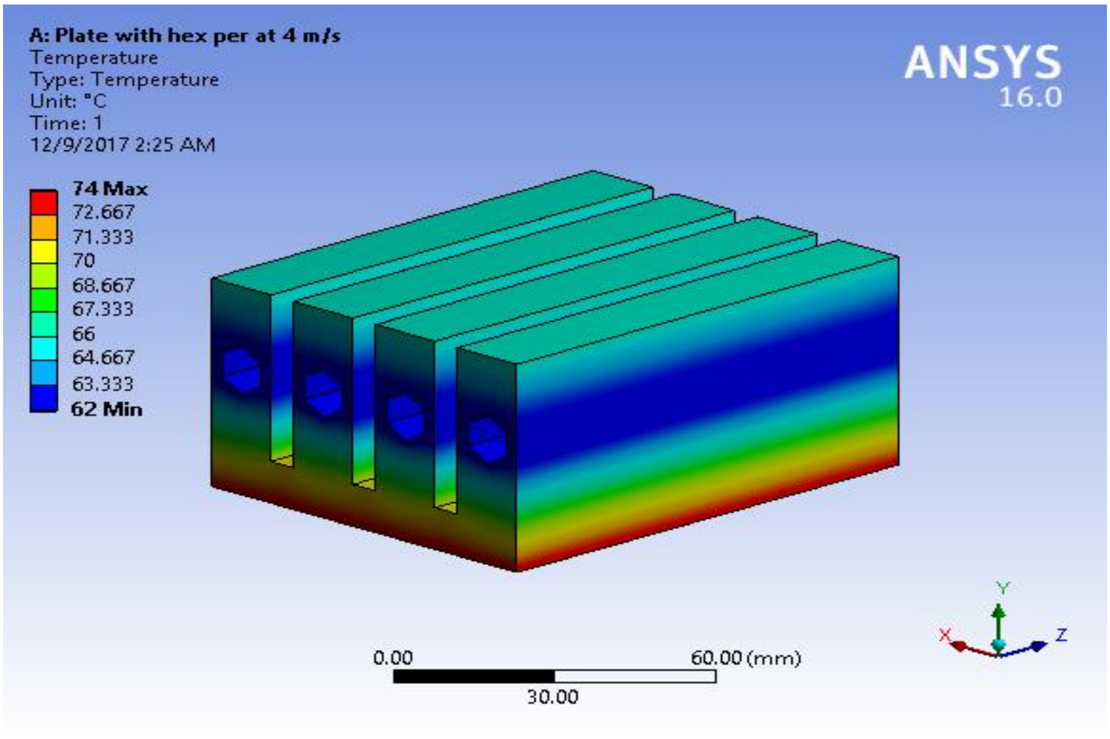


Figure 4.63: Stimulation of plate fin with hexagonal perforation at 4m/s

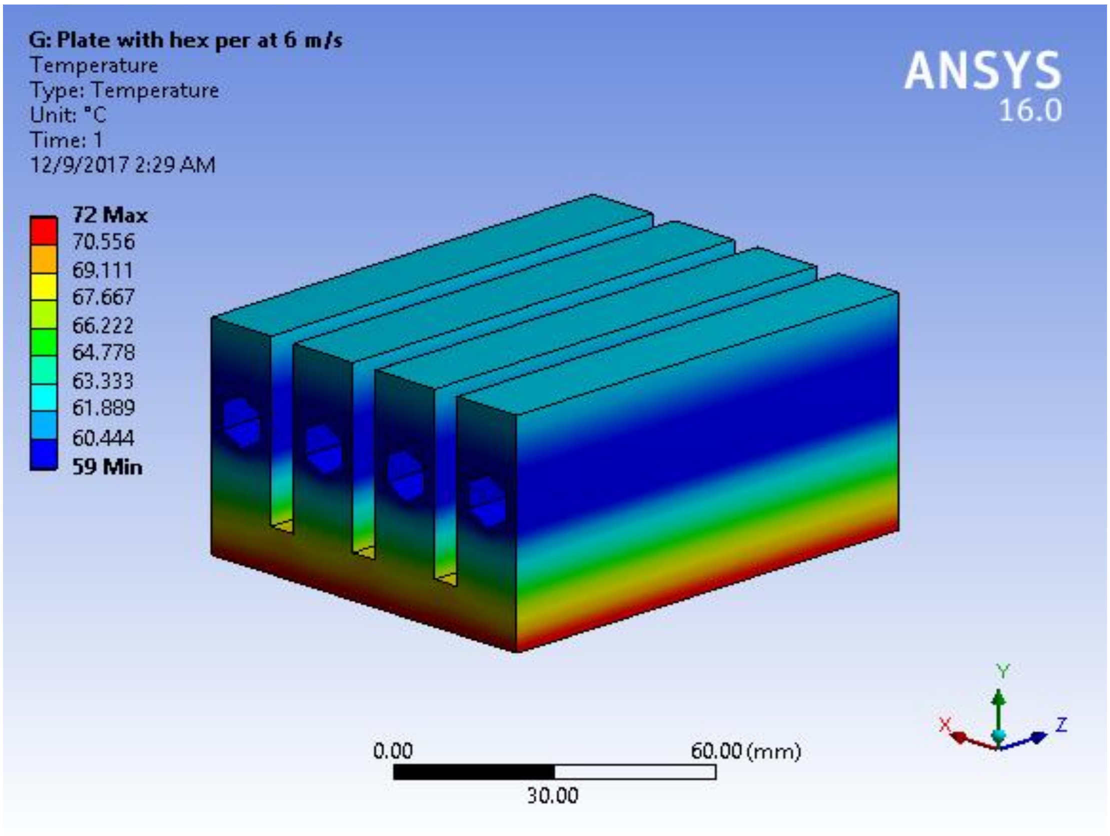


Figure 4.64: Stimulation of plate fin with hexagonal perforation at 6m/s

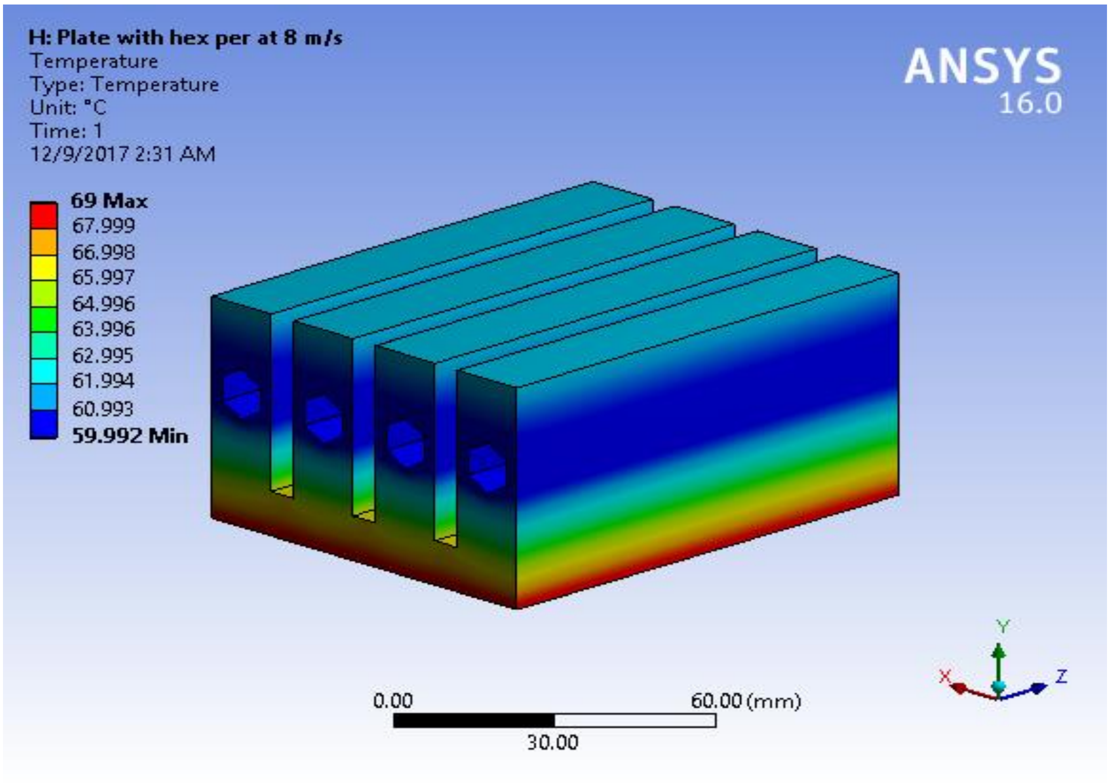


Figure 4.65: Stimulation of plate fin with hexagonal perforation at 8m/s

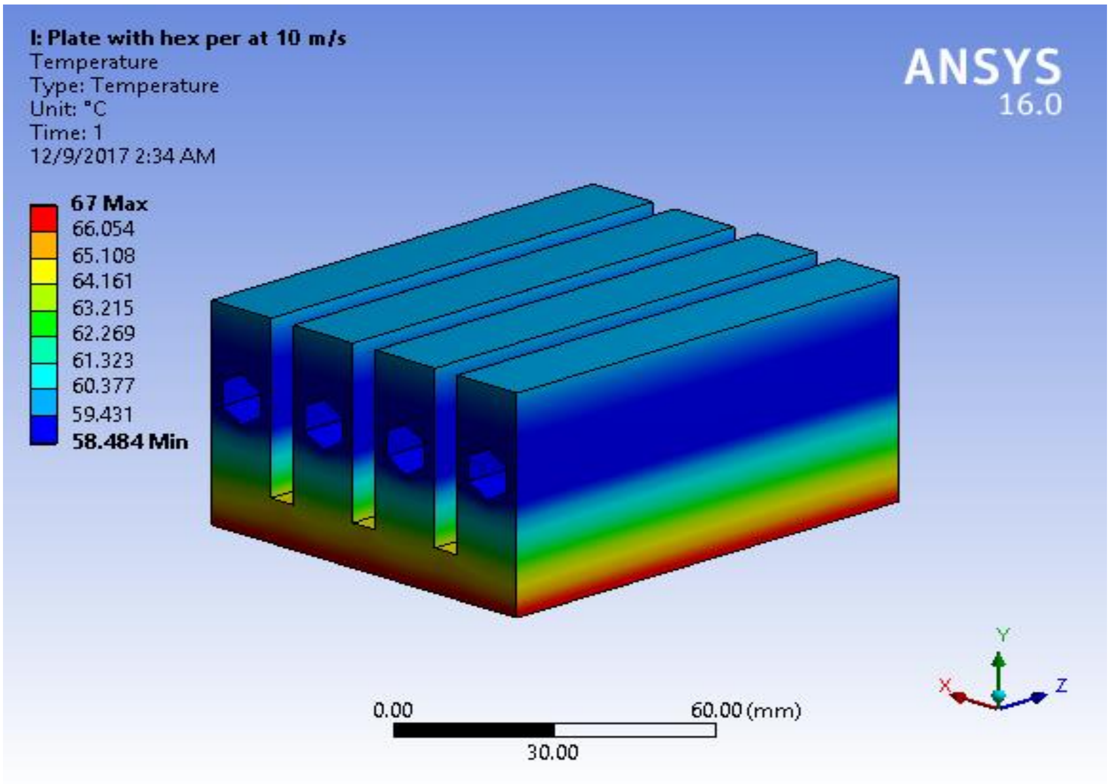


Figure 4.66: Stimulation of plate fin with hexagonal perforation at 10m/s

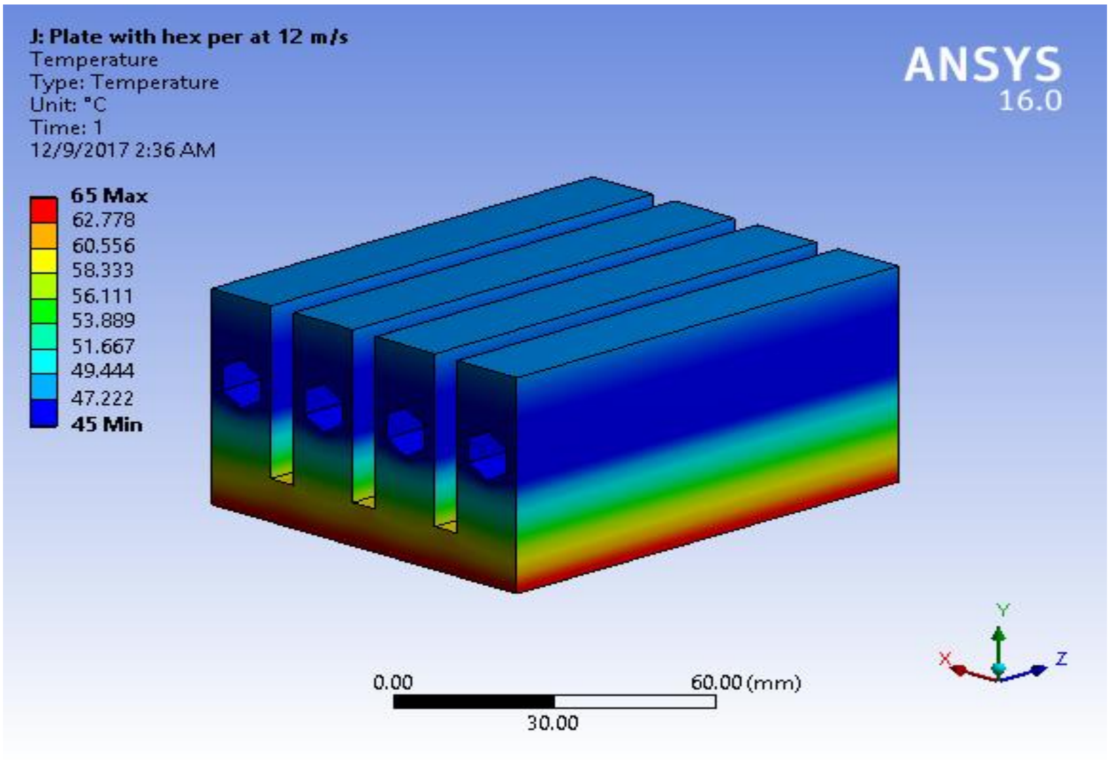


Figure 4.67: Stimulation of plate fin with hexagonal perforation at 12m/s

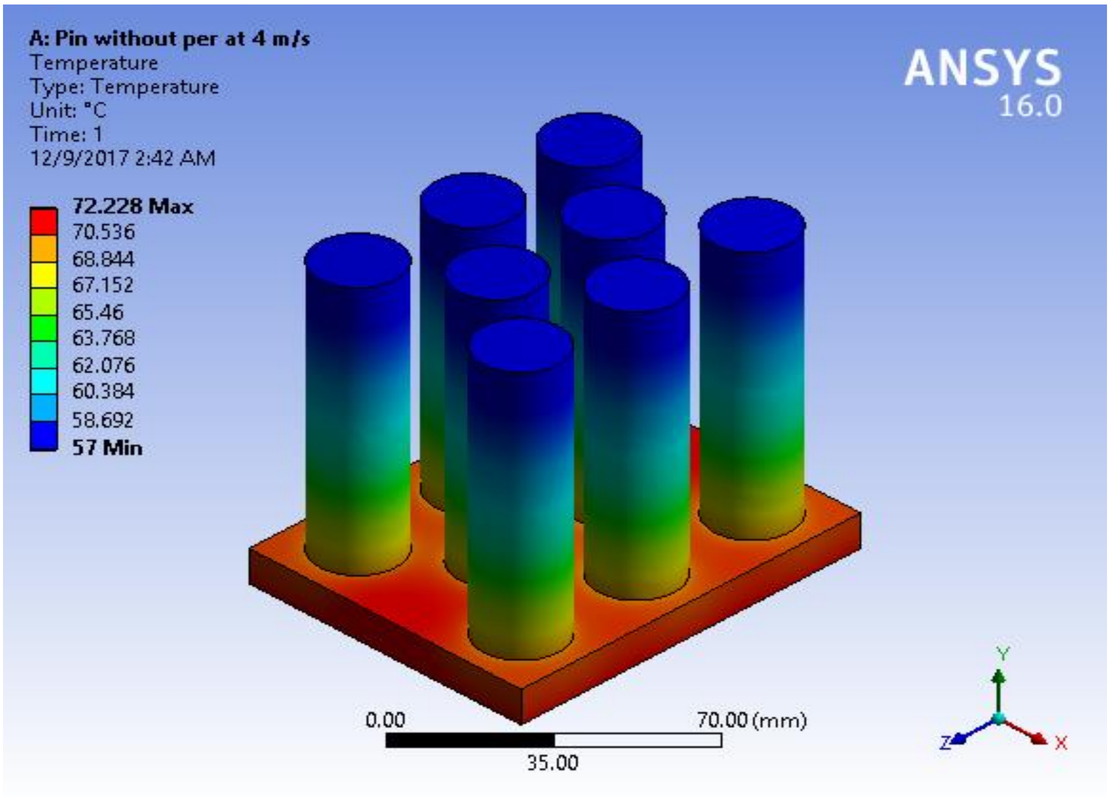


Figure 4.68: Stimulation of solid pin fin at 4m/s

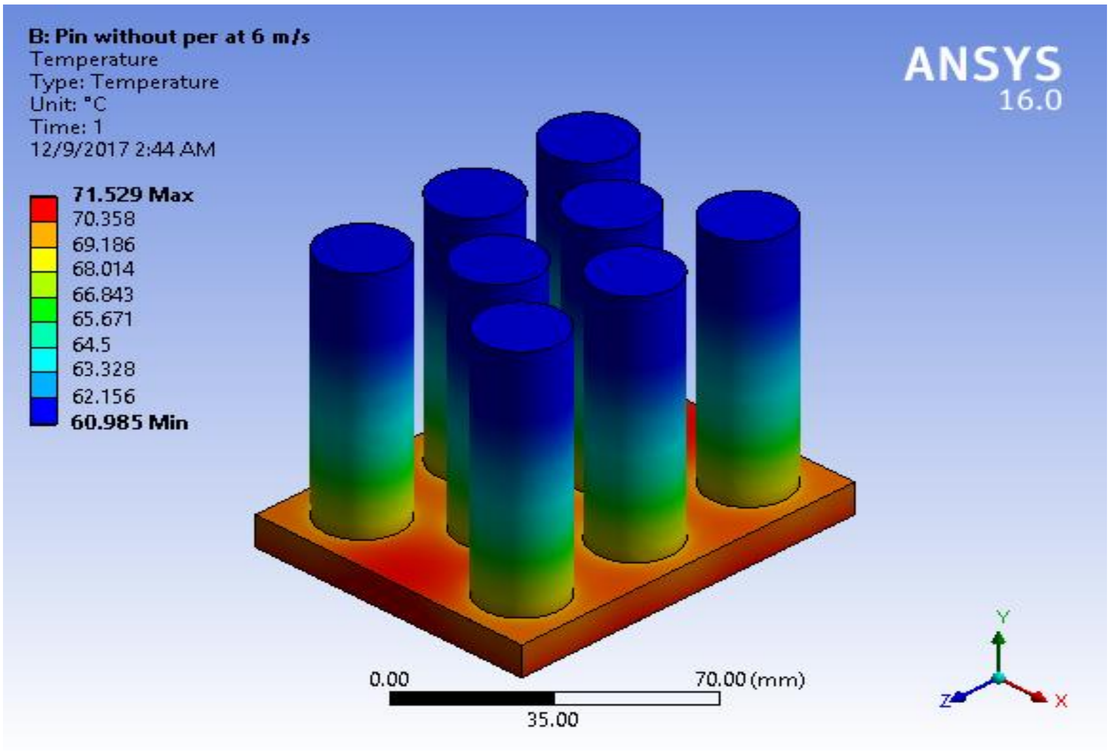


Figure 4.69: Stimulation of solid pin fin at 6m/s

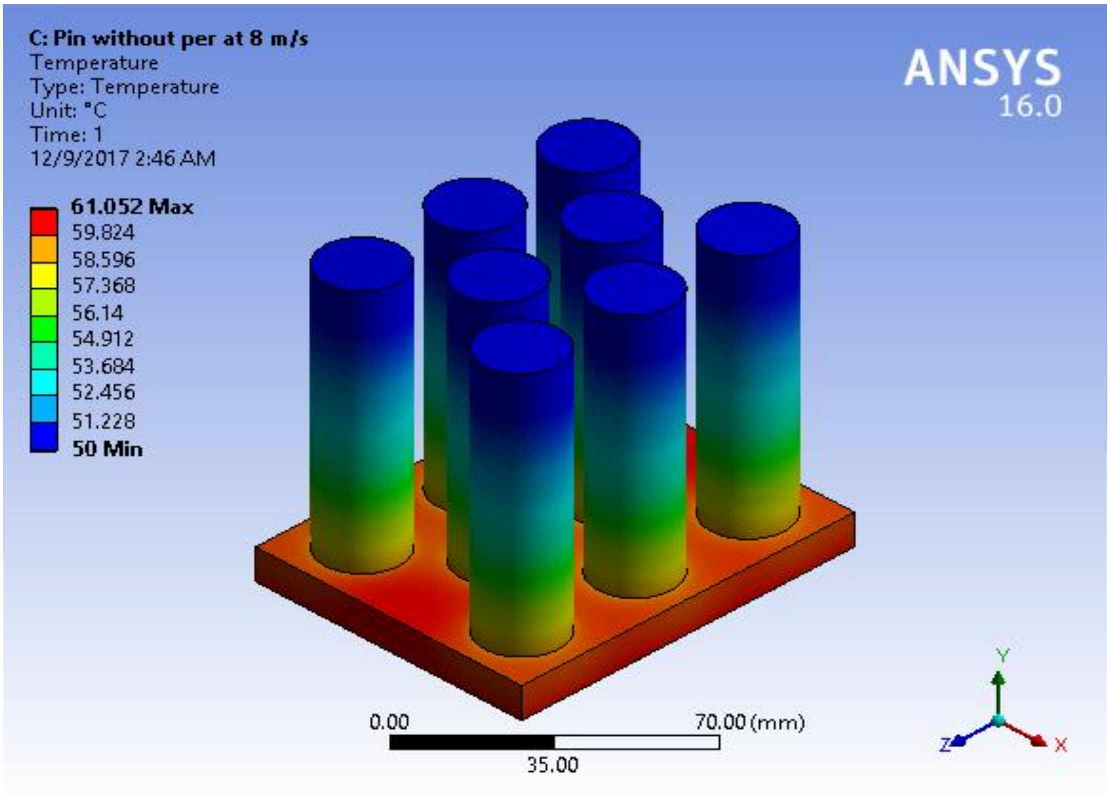


Figure 4.70: Stimulation of solid pin fin at 8m/s

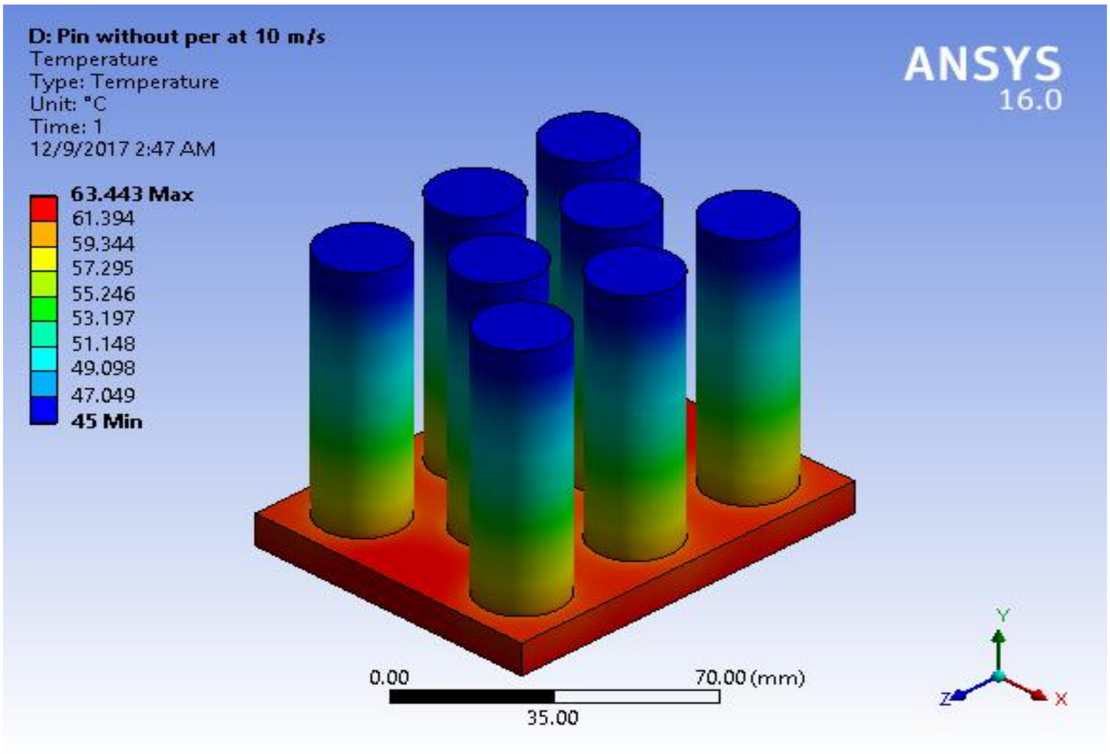


Figure 4.71: Stimulation of solid pin fin at 10m/s

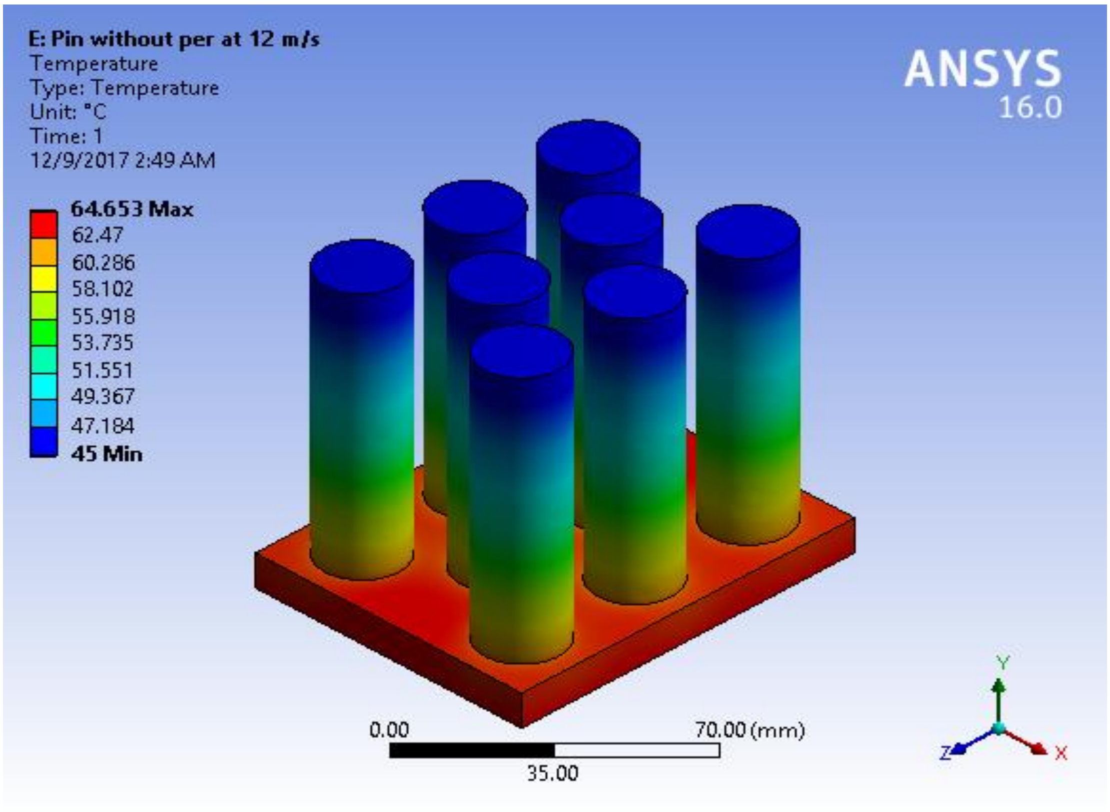


Figure 4.72: Stimulation of solid pin fin at 12m/s

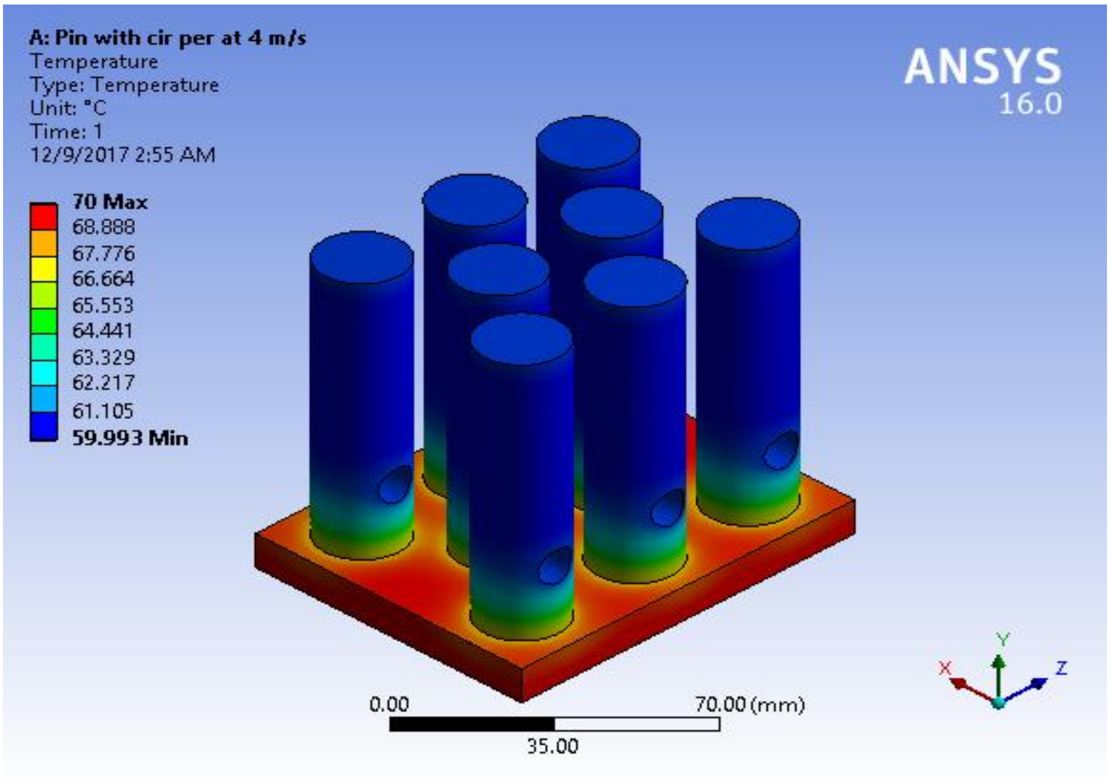


Figure 4.73: Stimulation of pin fin with circular perforation at 4m/s

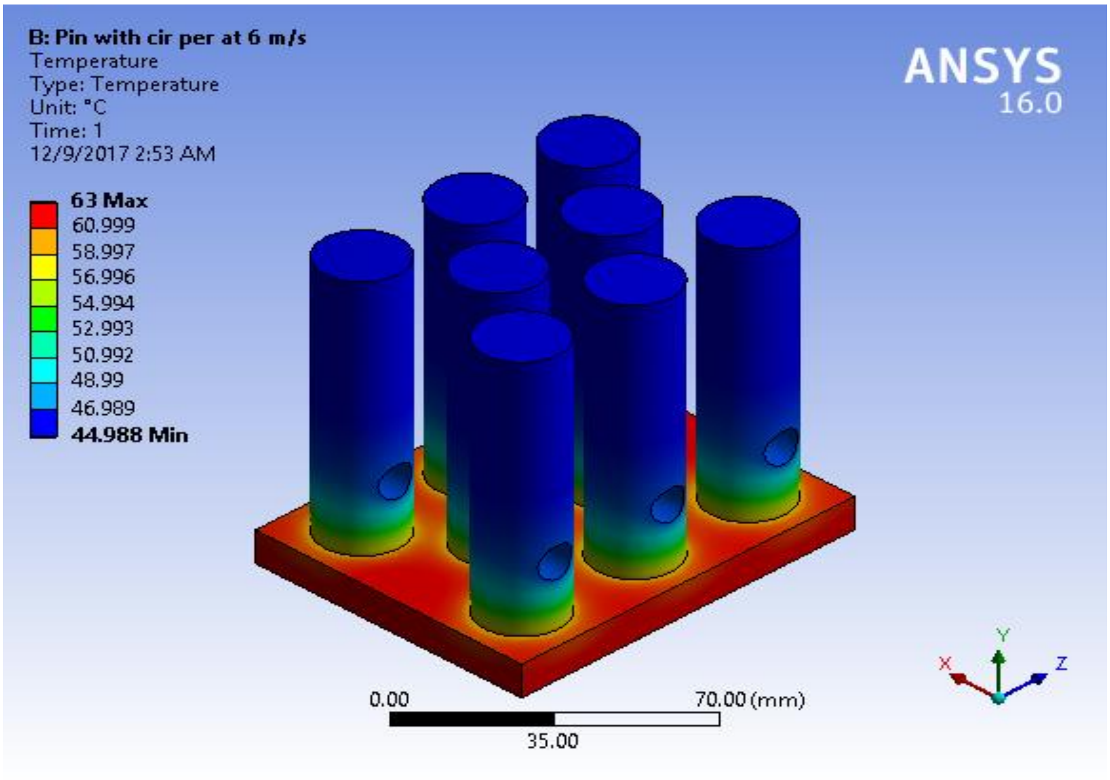


Figure 4.74: Stimulation of pin fin with circular perforation at 4m/s

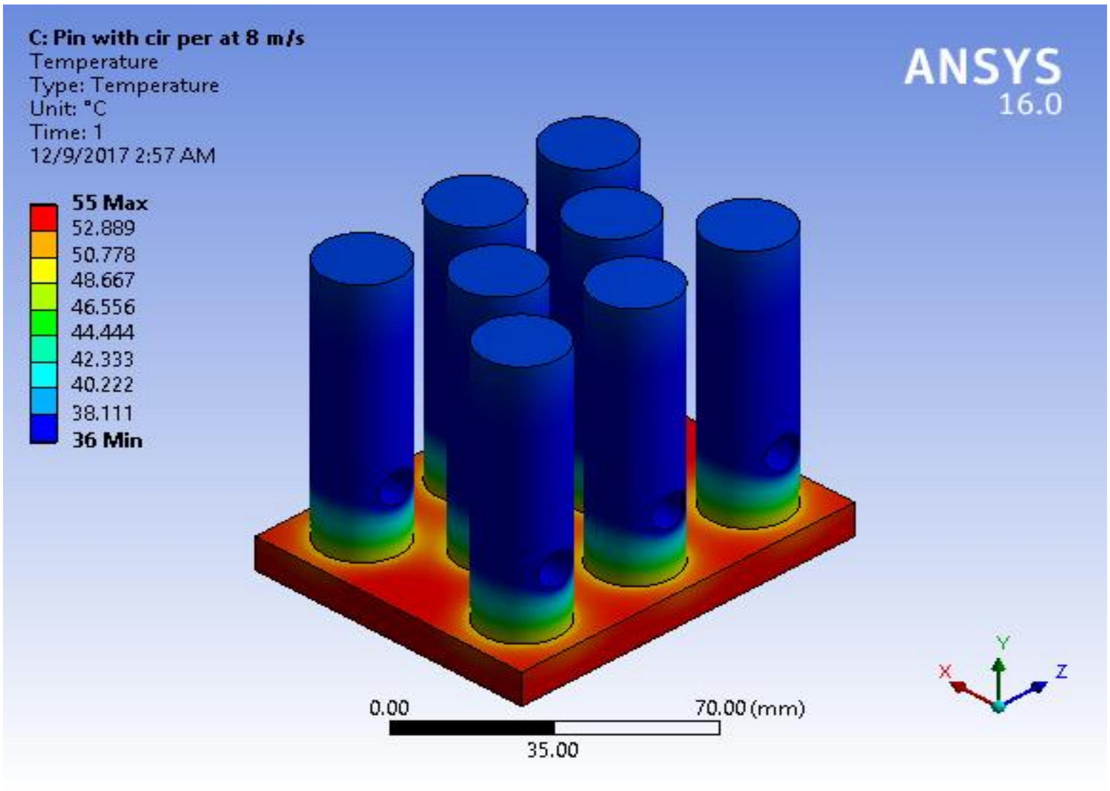


Figure 4.75: Stimulation of pin fin with circular perforation at 8m/s

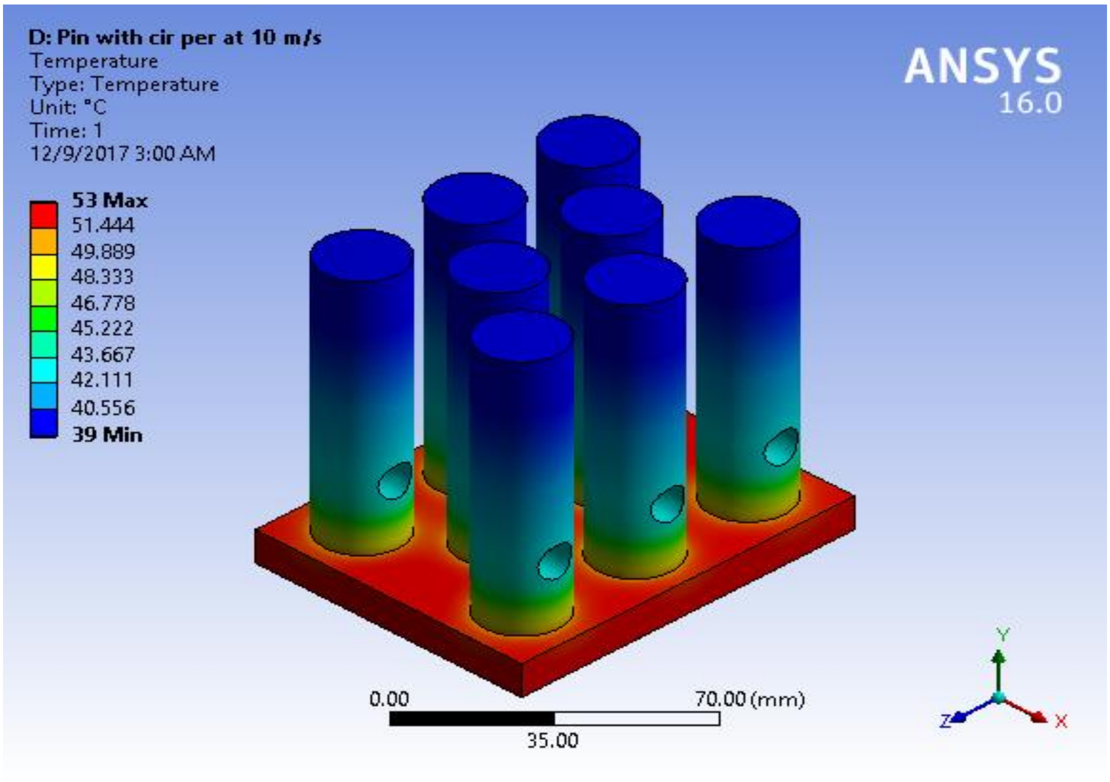


Figure 4.72: Stimulation of pin fin with circular perforation at 4m/s

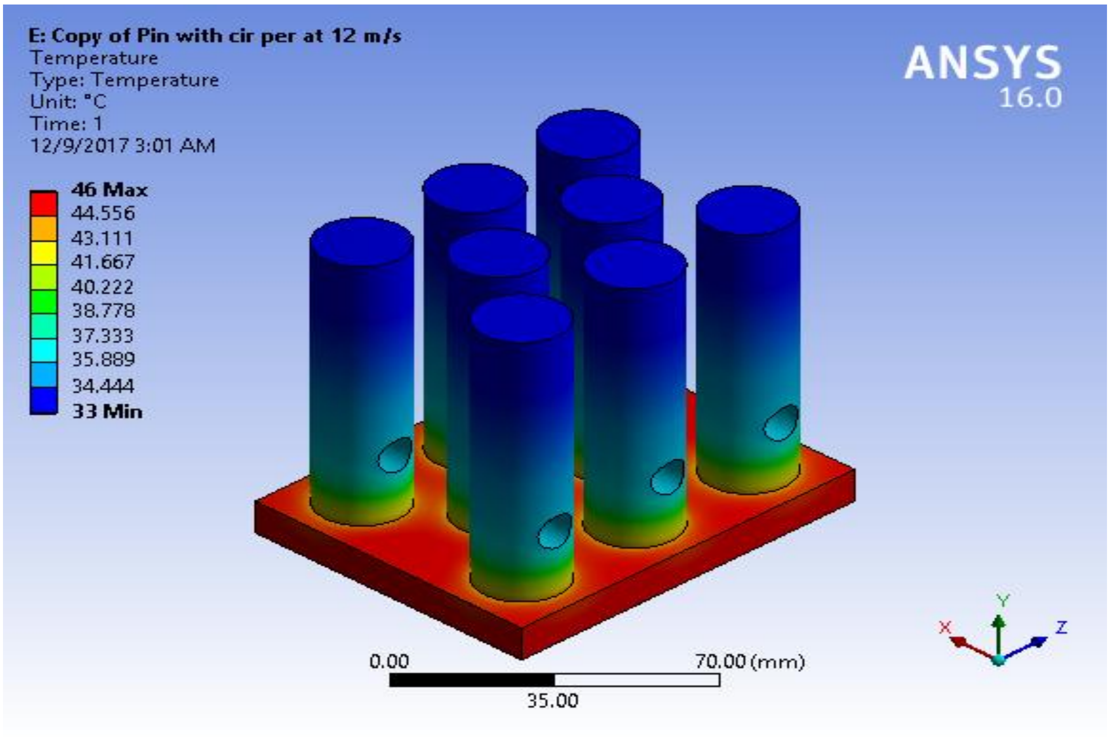


Figure 4.77: Stimulation of pin fin with circular perforation at 12m/s

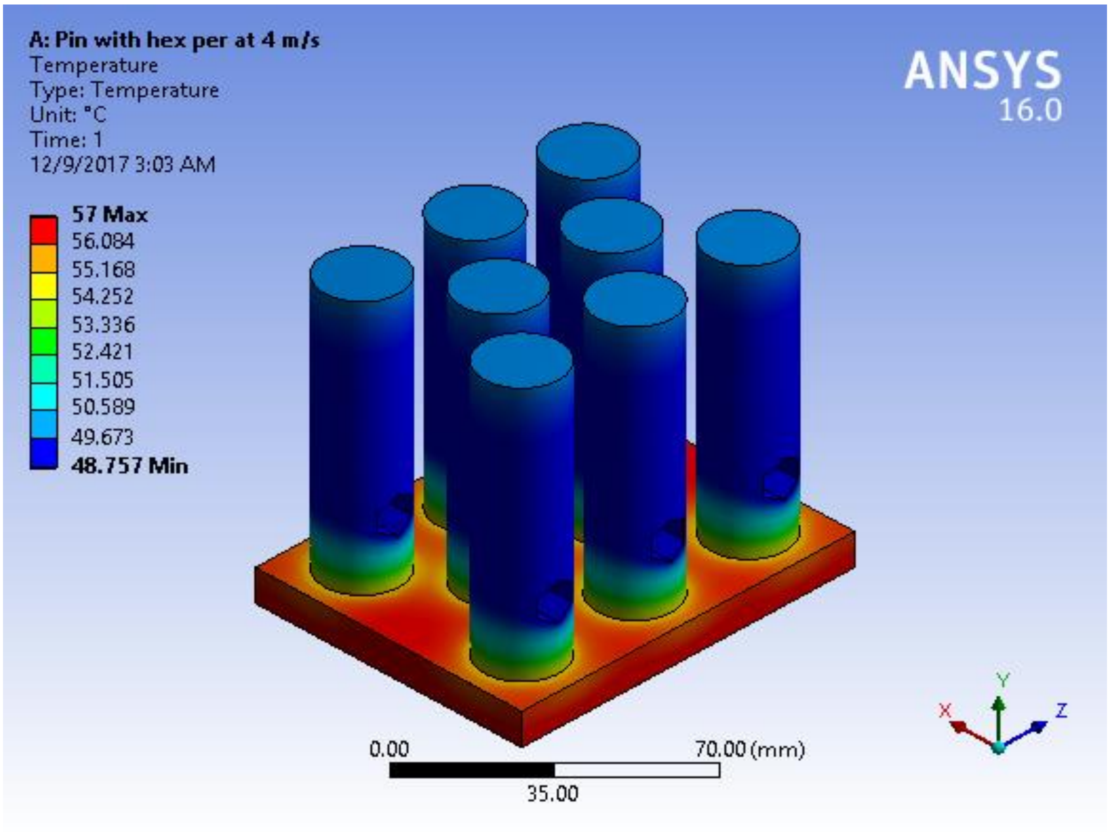


Figure 4.78: Stimulation of pin fin with hexagonal perforation at 4m/s

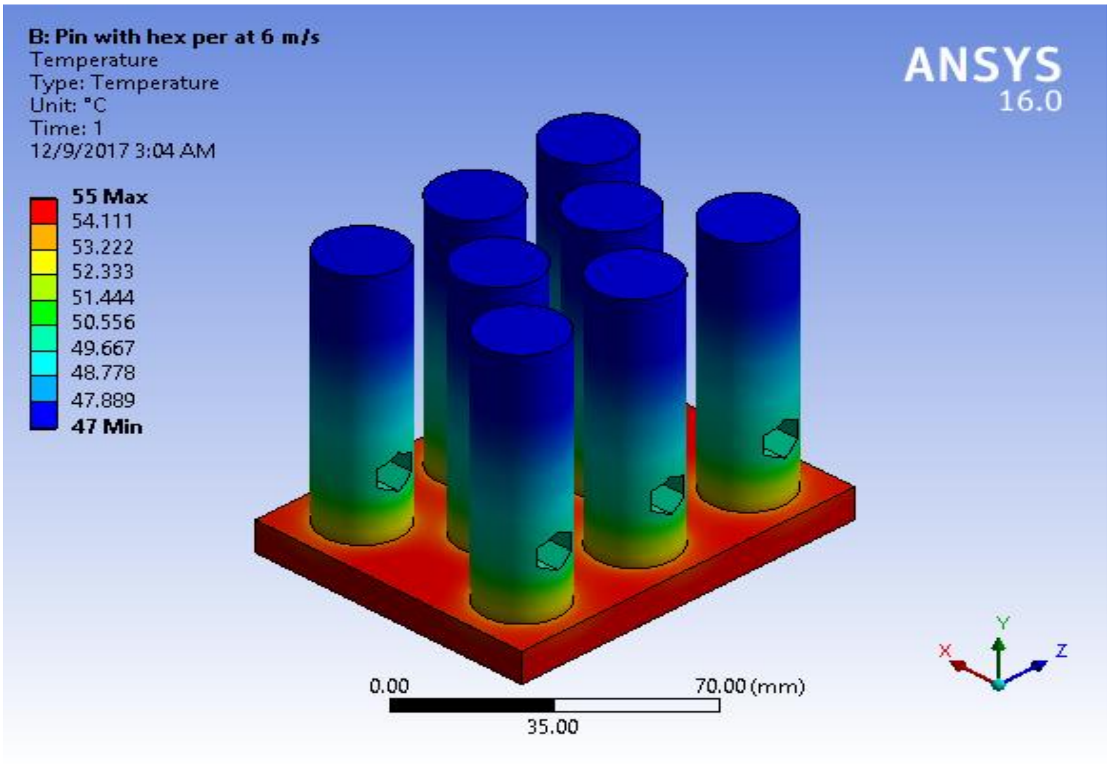


Figure 4.79: Stimulation of pin fin with hexagonal perforation at 6m/s

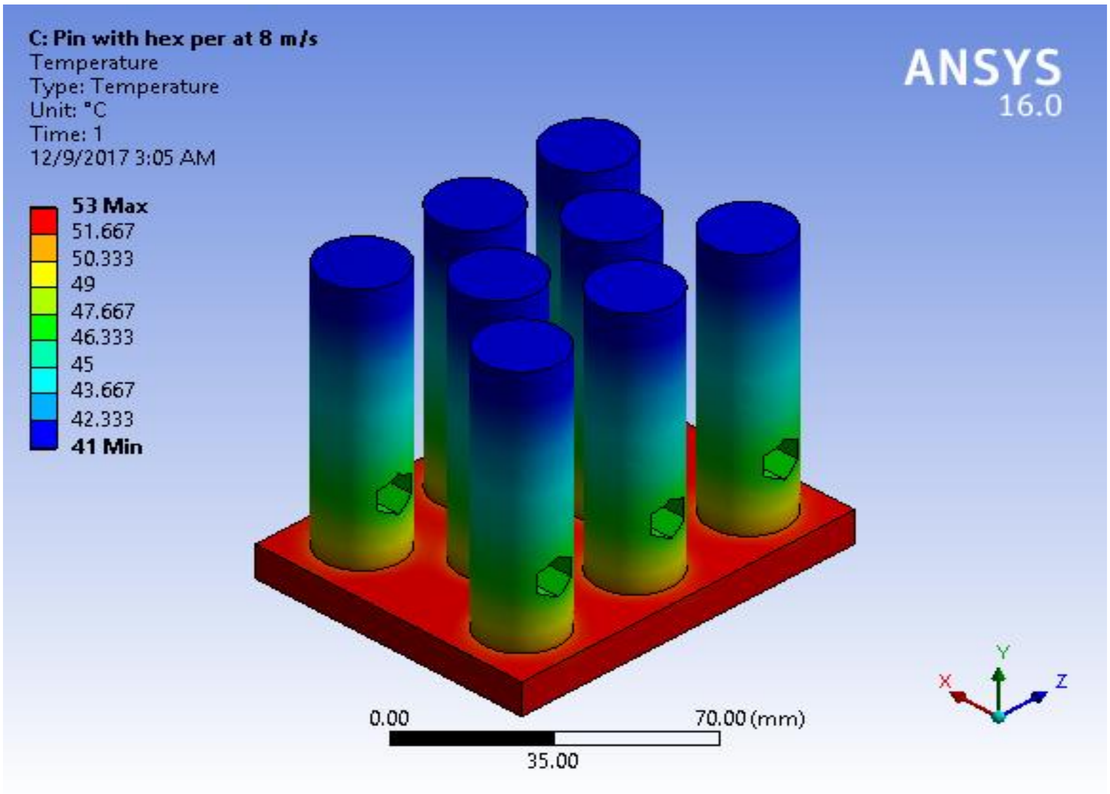


Figure 4.80: Stimulation of pin fin with hexagonal perforation at 8m/s

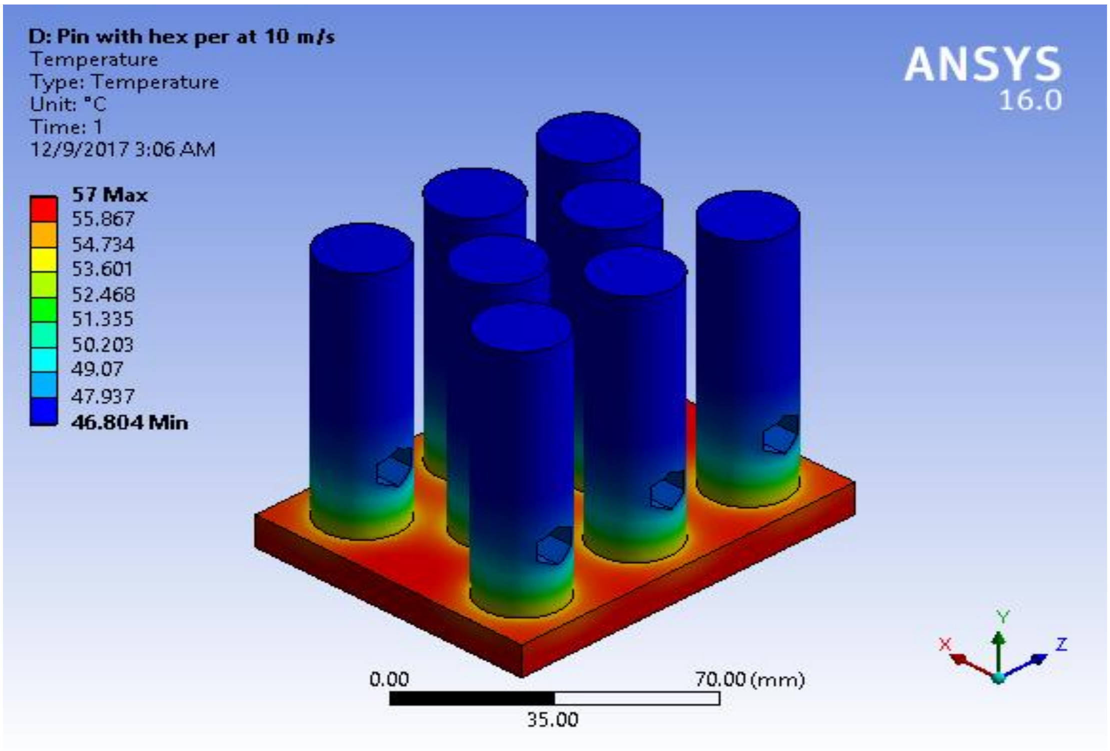


Figure 4.81: Stimulation of pin fin with hexagonal perforation at 10m/s

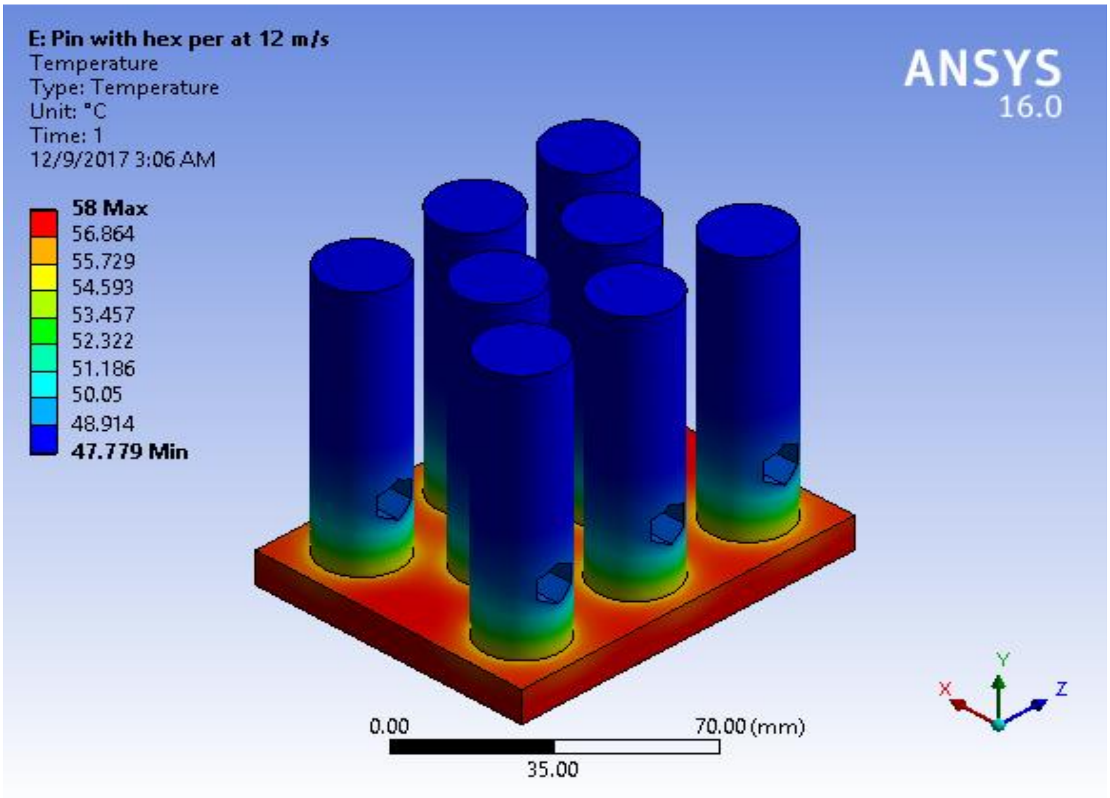


Figure 4.82: Stimulation of pin fin with hexagonal perforation at 12m/s

The temperature distribution at the tip of the plate fin is found out by providing the temperature at the base of the pin fin. The temperature variation along the length obtained from the ANSYS simulation is more or less close to the experimental values. From the images obtained for plate fin, it is observed that temperature at the base of the fin is maximum and it decreases along the length of the fin. And finally, temperature is minimum at the tip of the fin. This is because of its high thermal conductivity and thermal resistance of the constituent material. But in case of plate fin with circular and hexagonal perforation it's observed that, there is a sudden temperature drop in the perforation and area surrounding it. This phenomenon occurs due to the increased surface area provided by the perforation in the finned surface.

Similarly, the temperature distribution at the tip of the pin fin is also found out by providing the temperature at the base of the pin fin. Here the temperature variation obtained in the simulation is also close to the experimental values obtained earlier. For the pin fin it's observed that temperature is maximum at the base of the pins. But along the length this temperature eventually decreases. One notable feature observed here is that, pin fins cools the heated surface more rapidly and ununiformly. Whereas, plate fins (both perforated and non-perforated) cools the heated surface considerably slowly and more uniformly. In case of perforated pin fins, a temperature drop is observed but not as significant as the plate fins with circular and hexagonal perforations. Eventually the temperature drops along the length of the pins. And the minimum temperature is observed at the tip of the fin.

In the above results, the values change with respect to air velocity. The behavior of the temperature on the fins at various set of air velocities is shown in the figures. With the increase in velocity, the maximum temperature, minimum temperature and their in between range decreases.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The following conclusions can be drawn:

- In the experiment six different fin types are tested to observe different parameters like- convective heat transfer co-efficient, Nusselt Number, thermal resistance, efficiency and effectiveness with varied Reynolds Number.
- Nusselt number, convective heat transfer coefficient and pressure drop increase with increasing Reynolds number for all fins. Heat transfer is more at higher air velocities. So forced convection is much more desirable for efficient cooling.
- Perforated fins show higher values of Nu and h and lower values of pressure drop than solid fins. Between circular and hexagonal perforation, in hexagonal perforation the value of Nu and h is higher.
- The values of thermal resistance, efficiency, effectiveness and dimensionless pressure drop, in general, decrease with the increasing Reynolds number for all the fins.
- It is found that for hexagonal perforations than circular perforations, thermal resistance and dimensionless pressure drop decrease whereas efficiency and effectiveness increase.
- It takes time to increase temperature in case of hexagonal perforation both for plate fins and plate fins than circular perforation or without perforation because in hexagonal perforation the cooling tendency is more than the other type of fins.
- The temperature along the length of the fin seems to decrease. But there is a noticeable temperature drop at the perforation. Because the flowing air cools down the fin at that particular point of perforation while passing through the perforation.
- At hexagonal perforation the temperature drop is more than the circular perforation. Because there is more surface are of the perforation exposed to the flowing air than the circular ones.

- The cooling of the heated base plate is done most rapidly by pin fin with hexagonal perforations than any other fin models.

5.2 Recommendation

The present study is conducted by varying the fin geometry and cross sectional area as well as the Reynolds Number. The aim of study of fin should be directed towards to ensure the increase of fin performance to enhance heat transfer. By analyzing the observations of this study, some general recommendations are made for future research directions:

- The number of perforations can be varied. The increase of number of perforation seems to increase the heat transfer at a noticeable extent.
- The size of the perforations can be varied. With the increased size of the perforations heat transfer area will be increased which will result in increased heat transfer.
- By varying the number of fins on the base plate of same area of our experimental one, the performance of the fins can be tested.
- The height/width ratio of the plate fins can be changed to obtain better heat transfer.
- In case of pin fins, the height/diameter ratio of fin can be changed to observe the effect on heat transfer.
- In-line arrangement of pin fins can also be tested to check whether it gives an increase in convective heat transfer co-efficient.
- The experiment can be conducted at natural convection condition to compare the results with forced convection heat transfer.
- The transverse pitch and longitudinal pitch can be changed and its effect can be observed on heat transfer.

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APPENDIX

CALCULATION

Pin fin without perforation at an air velocity of 4ms^{-1}

Here,

S_T = Transverse pitch

S_D = Diagonal pitch

S_L = Longitudinal pitch

V = Approach velocity

V_{max} = Maximum velocity

D = Fin diameter

For staggered arrangement;

$V_{max} = \frac{S_T}{2(S_D - D)} V$

$= \frac{34}{2\,(29.41 - 22)} \times 4$

= 9.177 m/s

Reynold's number, Re = $\frac{V_{max} \times D}{\nu}$

Now; kinematic viscosity, ν = 1.756 × 10^{-5} m^2,   [At film temperature, T_f =45.63 °C]

Therefore, Re = $\frac{9.177 \times 0.022}{1.756 \times 10^{-5}}$

= 1.1497 × 10^4

For staggered arrangement and Reynold's number ranging from 1000 to 2×10^5;

Nusselt number, Nu = $F \times [0.35(\frac{S_T}{S_L})^{0.2} \times (Re)^{0.6} \times (Pr)^{0.36} \times (\frac{Pr}{Pr_s})^{0.25}]$

Here,

Pr = Prandtl number at film temperature

Pr_s = Prandtl number at average surface temperature of fin array

F = Correction factor

For, number of row, N_L = 3 and staggered arrangement, F = 0.84[5]

Therefore, $Nu = 0.84\times 0.35 \times (\frac{34}{24})^{0.2}\times (1.1497\times10^4)^{0.6}\times 0.7239^{0.36}\times (\frac{0.7239}{0.72005})^{0.25}$

$= 76.74$

Now,

$Nu = \frac{hD}{k}$;   [Where, k = thermal conductivity of air at film temperature i.e. 0.027 $W/m^2.k$]

$\Rightarrow h = \frac{Nu \times k}{D}$

$\Rightarrow h = \frac{76.74 \times 0.027}{0.022}$

$\therefore h = 94.18$

Thermal resistance, $R_{th} = \frac{1}{h \times A_S}$

$= \frac{1}{94.18 \times 56690.8}$

$= 0.187$

Here, A_s = Total surface area

Where, Fin surface area = $8 \times [\pi(11\}^2 + 2\pi\times11\times81.55]$

$= 48131.825\ mm^2$

Base surface area (upper) = $80\times100 - (8\pi\times11^2)$

$= 4958.94\ mm^2$

Side and front = $(80\times10\times2) + (100\times10\times2)$

$= 3600\ mm^2$

Therefore, A_s = Fin surface area + Base surface area + Side and front

= 48131.825 + 4958.94 + 3600

= 56690.8 mm^2

Fin efficiency, $\eta_{fin} = \frac{h\, A_S\, (\, T_S - T_\infty\,)}{h\, A_S\, (\, T_b - T_\infty\,)} \times 100\%$

Where, T_s = Average temperature of fin array = 60.6℃

T_b = Base temperature = 69℃

T_∞= Average temperature of bulk airflow = $\frac{T_{in} + T_{out}}{2}$

T_f = Film temperature = $\frac{T_S + T_\infty}{2}$

Therefore, $\eta_{fin} = \frac{60.6\, - 30.65}{69\, - 30.65} \times 100\%$

= 78%

Now,

$A_{un\text{-}fin}$ = (2×80×100) + (2×100×10) + (80×100 $-\pi$ ×11^2×8)

= 8558.93 mm^2

A_{fin} = 48131.83 mm^2

$A_{no\text{-}fin}$ = (80×100) + (2×80×10) + (2×100×10)

= 11600 mm^2

∴ Overall efficiency, $\varepsilon_{fin-overall} = \frac{h\,\left(A_{un-fin} + \eta_{fin} A_{fin}\right)(T_b - T_\infty)}{h\, A_{no-fin}\,(T_b - T_\infty)}$

$= \frac{8558.93 + (\, 0.78 \times 48131.83\,)}{11600}$

= 3.98

Plate fin without perforation at an air velocity of 4ms^{-1}

Here, from data table we get,

T_2 = 71 ℃

T_3 = 67 ℃

T_4 = 65 ℃

T_5 = 67 ℃

T_6 = 65 ℃

Now, average surface temperature of fin array,

$T_s = \frac{71 + 67 + 65 + 67 + 65}{5}$ ℃

= 67℃

Now,

T_i = Inlet temperature of air (℃) = 29 ℃

T_0 = Outlet temperature of air (℃) = 37 ℃

Average temperature of bulk air flow,

$T_\infty = \frac{29 + 37}{2}$

= 33^o c

Film temperature,

$T_f = \frac{67 + 33}{2}$

= 50^o c

<u>At T_f = 50^o c;</u>

From Table (A-15) [Yunus. A. Cengel]

k = 0.02735

υ = 1.798 × 10^{-5}

Pr = 0.7228

Now, Reynolds number;

Re = $\frac{V_{avg} - d_h}{\nu}$

$= \frac{4.55140 \times 0.07625}{1.798 \times 10^{-5}}$

= 19301.68242

≅ 2 × 10^4

$\dot{Q}_{Conv} = \dot{Q}_T - \dot{Q}_{Cond} - \dot{Q}_{Rad}$

Now,

$\dot{Q}_T = V \times L$

= 220 × 1.2 W

= 264 W

$\dot{Q}_{Cond} = \frac{T_x - T_y}{R_1 + R_2}$

Here,

R_1 = 21.0084 $\frac{℃}{W}$

R_2 = 1.233197 $\frac{℃}{W}$

T_x = 74 ℃

T_y = 33 ℃

$$\dot{Q}_{Cond} = \frac{74 - 33}{21.0084 + 1.233197}$$

= 1.84340 W

$\dot{Q}_{Rad} = \varepsilon A_s \sigma (T_s^4 - T_\infty^4)$

$= 0.025 \times 48560 \times 10^{-6} \times 5.67 \times 10^{-8} \times ((67 + 273)^4 - (33 + 273)^4)$

= 0.316336 W

Therefore, Q $_{Convection}$ = $264 - 1.84340 - 0.316336$

= 261.840264 W

Convective heat transfer co-efficient, h = $\frac{\dot{Q}_{Conv}}{A_S\,(T_S - T_\infty}$

$= \frac{261.840264}{48560 \times 10^{-8} \times (67-33)}$

$= 158.5911\ \frac{W}{m^2.℃}$

Fin efficiency,η_{fin} = $\frac{h\,A_S\,(T_S - T_\infty)}{h\,A_S\,(T_S - T_\infty)}$

$= \frac{158.5911 \times 48560 \times 10^{-6}\,(67-33)}{158.5911 \times 48560 \times 10^{-6}\,(74-33)}$

= 82.926 %

Fin effectiveness, ε_{fin} = $\frac{h\,(A_{unfin} + \eta_{fin} A_{fin})\,(T_b - T_\infty)}{h\,A_{nofin}\,(T_b - T_\infty)}$

$= \frac{158.5911\,(\,5400 \times 10^{-6} + 0.8226 \times 43160 \times 10^{-6})}{158.5911 \times (11600 \times 10^{-6})}$

= 3.55093

Thermal resistance; R_{th} = $\frac{1}{h \times A_S}$

$= \frac{1}{158.5911 \times 48650 \times 10^{-6}}$

= 0.129850

Nu = $\frac{h\,L}{K}$

$= \frac{158.5911 \times 0.200}{0.02735}$

= 579.8577

EXPERIMENTAL DATA COLLECTION

TEMPERATURE TABLES

Table A.1: Plate fin without perforation at 4ms^{-1}

Upstream Pressure fluctuates between 20-25

Downstream pressure fluctuates between 10-25

Time	Air velocity 4ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	29	42	40	39	36	38	37	30.9	29	74	71	67	65	67	65	37
0:30	29	46	45	44	40	43	42	31.4	29	72	69	66	63	65	64	36.4
1:00	29	49	47	46	43	44	43	31.9	29	71	69	65	61	64	62	36
1:30	29	55	52	50	49	50	49	32.7	29	69	68	63	60	62	60	35.9
2:00	29	59	56	53	53	53	52	33.2	29	69	66	61	59	60	60	35.4
2:30	29	63	60	57	55	56	54	33.8	29	68	65	60	58	60	58	35.1
3:00	29	66	62	60	57	58	58	34.5	29	66	63	59	56	58	57	34.9
3:30	29	69	65	63	59	60	59	35.2	29	65	61	58	55	57	55	34.7
4:00	29	69	66	66	59	63	59	35.9	29	63	60	56	51	55	54	34
4:30	29	70	68	67	61	64	61	36.5	29	61	59	55	48	54	51	33.7
5:00	29	71	68	67	62	65	62	37	29	60	58	51	45	51	45	33.5
5:30	29	71	69	67	63	65	62	37	29	59	56	48	43	45	44	33.1
6:00	29	72	69	68	63	66	63	37	29	58	55	45	42	44	43	32.5
6:30	29	73	70	68	64	66	65	37	29	56	51	43	42	43	41	32.1
7:00	29	73	70	68	65	67	66	37	29	55	48	42	41	41	41	31.9
7:30	29	74	70	67	65	67	66	37	29	51	45	42	41	41	40	31.4
8:00	29	74	71	67	65	67	65	37	29	48	43	41	40	40	39	31
8:30									29	45	42	41	39	39	40	30.8
9:00									29	43	42	40	38	37	40	30.8
9:30									29	42	39	39	37	36	39	30.8
10:00									29	42	38	38	36	35	36	30.8
10:30									29	41	36	38	35	36	36	30.8
11:00									29	40	36	37	34	35	34	30.8
11:30									29	39	36	36	33	35	35	30.8
12:00									29	39	35	36	33	34	35	30.8
12:30									29	38	34	35	32	33	34	30.8
13:00									29	38	34	34	32	33	34	30.8
13:30									29	37	33	34	31	32	33	30.8
14:00									29	37	32	34	31	32	33	30.8
14:30									29	36	32	33	30	31	31	30.8
15:00									29	36	32	32	29	32	31	30.8

Time	Air velocity $4ms^{-1}$															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
15:30									29	36	32	32	29	31	31	30.8
16:00									29	35	32	32	28	31	31	30.8
16:30									29	35	32	32	28	31	30	30.8
17:00									29	34	32	32	27	31	30	30.8
17:30									29	34	31	31	26	30	30	30.8
18:00									29	33	31	31	26	30	30	30.8
18:30									29	33	30	31	26	30	30	30.8
19:00									29	33	30	31	25	30	29	30.8
19:30									29	32	30	30	25	30	29	30.8
20:00									29	32	30	30	25	30	29	30.8

Table A.2: Plate fin without perforation at $6ms^{-1}$

Upstream Pressure fluctuates between 30-35

Downstream pressure fluctuates between 15-35

Time	Air velocity $6ms^{-1}$															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28.6	39	38	37	34	36	35	29.8	28.7	72	67	67	63	64	63	39.9
0:30	28.6	43	39	38	36	38	37	30.4	28.7	69	66	65	61	63	63	39.4
1:00	28.6	48	44	39	38	39	38	30.9	28.7	69	65	63	60	61	61	38.7
1:30	28.7	51	46	44	42	43	42	31.4	28.7	68	63	61	59	60	60	38.1
2:00	28.7	52	50	46	45	44	44	31.8	28.7	66	61	60	58	59	59	37.5
2:30	28.7	54	53	50	49	49	49	32.4	28.7	65	60	59	56	58	58	36.9
3:00	28.7	56	57	53	52	54	53	32.9	28.7	63	59	58	55	56	56	36.1
3:30	28.7	59	60	57	55	56	55	33.3	28.7	61	58	56	51	55	55	35.6
4:00	28.7	61	63	60	58	59	58	34	28.7	60	56	55	48	51	51	34.9
4:30	28.7	64	66	63	59	60	59	34.4	28.7	59	55	51	45	48	48	33.6
5:00	28.7	66	67	66	60	62	61	34.9	28.7	58	51	48	43	45	45	33.1
5:30	28.7	67	67	67	61	62	61	35.6	28.7	56	48	45	42	43	43	32.8
6:00	28.7	68	67	67	61	63	62	36.2	28.7	55	45	43	42	42	42	32.1
6:30	28.7	69	68	67	62	62	62	36.7	28.7	51	43	42	41	42	42	31.6
7:00	28.7	69	68	68	62	63	63	38.5	28.7	48	42	42	41	41	41	31.1
7:30	28.7	70	68	68	62	63	62	39.5	28.7	45	42	41	40	41	41	30.4
8:00	28.7	70	67	68	63	64	63	39.9	28.7	43	41	41	39	40	40	30
8:30	28.7	71	67	67	63	63	63	39.9	28.7	42	40	40	38	39	39	29.5
9:00	28.7	72	67	67	64	63	63	39.9	28.7	42	39	39	37	38	38	29.5
9:30									28.7	41	39	38	36	37	37	29.5
10:00									28.7	40	38	37	35	36	36	29.5

Time	Air velocity 6ms-1															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
10:30									28.7	39	38	36	34	35	35	29.5
11:00									28.7	39	37	35	33	34	34	29.5
11:30									28.7	38	37	34	34	33	33	29.5
12:00									28.7	38	36	33	33	34	34	29.5
12:30									28.7	37	36	34	33	33	33	29.5
13:00									28.7	37	36	33	32	33	33	29.5
13:30									28.7	36	35	33	32	32	32	29.5
14:00									28.7	36	35	32	32	32	32	29.5
14:30									28.7	36	34	32	31	32	32	29.5
15:00									28.7	35	33	32	31	31	31	29.5
15:30									28.7	35	32	31	31	31	31	29.5
16:00									28.7	34	32	31	30	31	31	29.5
16:30									28.7	33	32	31	30	30	30	29.5
17:00									28.7	32	31	30	30	30	30	29.5
17:30									28.7	32	31	30	29	30	30	29.5
18:00									28.7	32	31	30	29	30	30	29.5

Table A.3: Plate fin without perforation at 8ms^{-1}

Upstream Pressure remains constant at 50

Downstream pressure fluctuates between 20-50

Time	Air velocity 8ms-1															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28.6	41	40	37	35	36	36	29.8	28.5	69	65	62	55	57	56	39.9
0:30	28.6	45	43	40	36	39	37	29.8	28.5	63	62	60	52	53	54	39.4
1:00	28.6	47	45	42	38	40	38	30.4	28.5	65	61	58	51	52	51	38.7
1:30	28.6	50	48	44	43	43	42	30.9	28.5	67	57	55	48	48	49	38.1
2:00	28.6	53	50	47	44	44	44	31.4	28.5	66	56	52	48	48	46	37.5
2:30	28.6	53	50	48	43	43	45	31.8	28.5	54	53	51	46	47	46	36.9
3:00	28.6	55	52	50	45	45	44	32.4	28.5	52	50	50	41	43	45	36.1
3:30	28.6	57	55	52	48	47	48	32.9	28.5	50	48	47	41	42	45	35.6
4:00	28.6	60	59	54	51	52	51	33.3	28.5	50	47	46	40	43	45	34.9
4:30	28.6	61	57	54	49	50	50	34	28.5	48	44	45	38	41	43	33.6
5:00	28.6	60	58	55	48	49	49	34.4	28.5	46	43	43	37	39	42	33.1
5:30	28.6	60	59	56	51	52	51	34.9	28.5	46	42	43	35	38	41	32.8
6:00	28.6	62	59	57	50	51	51	35.6	28.5	43	41	40	35	37	40	32.1
6:30	28.6	64	59	57	51	51	52	36.2	28.5	42	39	39	33	36	39	31.6
7:00	28.6	64	61	59	53	52	52	36.7	28.5	42	38	38	32	35	38	31.1
7:30	28.6	65	61	59	52	53	54	38.5	28.5	41	36	38	32	36	36	30.4

Time	Air velocity 8ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
8:00	28.6	66	64	61	53	54	55	39.5	28.5	40	36	37	30	35	34	30
8:30	28.6	66	65	61	53	54	54	39.7	28.5	39	36	36	31	35	35	29.5
9:00	28.6	69	63	62	54	55	57	39.7	28.5	39	35	36	30	34	35	29.4
9:30	28.6	69	64	62	55	58	60	39.7	28.5	38	34	35	29	33	34	29.4
10:00	28.6	69	65	62	55	54	56	39.7	28.5	38	34	34	29	33	34	29.4
10:30	28.6	69	66	63	55	55	56	39.7	28.5	37	33	34	28	32	33	29.4
11:00	28.6	70	66	63	56	55	55	39.7	28.5	37	32	34	27	32	33	29.4
11:30									28.5	36	32	33	27	31	31	29.4
12:00									28.5	36	32	32	27	32	31	29.4
12:30									28.5	36	32	32	27	31	31	29.4
13:00									28.5	35	32	32	26	31	31	29.4
13:30									28.5	35	32	32	26	31	30	29.4
14:00									28.5	35	32	32	26	31	30	29.4
14:30									28.5	35	31	31	25	30	30	29.4
15:00									28.5	35	31	31	25	30	30	29.4
15:30									28.5	35	30	31	25	30	30	29.4
16:00									28.5	34	30	31	25	30	29	29.4
16:30									28.5	34	30	30	25	30	29	29.4
17:00									28.5	34	30	30	25	30	29	29.4

Table A.4: Plate fin without perforation at 10ms^{-1}

Upstream Pressure fluctuates between 80-90

Downstream pressure fluctuates between 40-80

Time	Air velocity 10ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28.7	43	40	37	35	36	36	30	28.9	71	67	61	57	60	61	36.8
0:30	28.7	45	43	40	36	39	37	30.4	28.9	69	65	62	55	57	56	36.1
1:00	28.7	47	45	42	38	40	38	30.9	28.9	63	62	60	52	53	54	35.6
1:30	28.8	50	48	44	43	43	42	31.4	28.9	65	61	58	51	52	51	34.9
2:00	28.8	53	50	47	44	44	44	31.8	28.9	67	57	55	48	48	49	33.6
2:30	28.8	53	50	48	43	43	45	32.4	28.9	66	56	52	48	48	46	33.1
3:00	28.8	55	52	50	45	45	44	32.9	28.9	54	53	51	46	47	46	32.8
3:30	28.8	57	55	52	48	47	48	33.3	28.9	52	50	50	41	43	45	32.1
4:00	28.9	60	59	54	51	52	51	34	28.9	50	48	47	41	42	45	31.6
4:30	28.9	61	57	54	49	50	50	34.4	28.9	50	47	46	40	43	45	31.1
5:00	28.9	60	58	55	48	49	49	34.9	28.9	48	44	45	38	41	43	30.4
5:30	28.9	60	59	56	51	52	51	35.6	28.9	46	43	43	37	39	42	30
6:00	28.9	62	59	57	50	51	51	36.2	28.9	46	42	43	35	38	41	29.5

Time	Air velocity $10ms^{-1}$															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
6:30	28.9	64	59	57	51	51	52	36.4	28.9	43	41	40	35	37	40	29.5
7:00	28.9	64	61	59	53	52	52	36.6	28.9	42	39	39	33	36	39	29.5
7:30	28.9	65	61	59	52	53	54	36.8	28.9	42	38	38	32	35	38	29.5
8:00	28.9	66	64	61	53	54	55	36.8	28.9	41	36	38	32	36	36	29.5
8:30	28.9	66	65	61	53	54	54	36.8	28.9	40	36	37	30	35	34	29.5
9:00	28.9	69	63	62	54	55	57	36.8	28.9	39	36	36	31	35	35	29.5
9:30	28.9	69	64	62	55	58	60	36.8	28.9	39	35	36	30	34	35	29.5
10:00	28.9	69	65	62	55	54	56	36.8	28.9	38	34	35	29	33	34	29.5
10:30	28.9	69	66	63	55	55	56	36.8	28.9	38	34	34	29	33	34	29.5
11:00	28.9	70	66	65	56	58	56	36.8	28.9	37	33	34	28	32	33	29.5
11:30	28.9	71	67	61	58	57	56	36.8	28.9	37	32	34	27	32	33	29.5
12:00	28.9	71	67	61	58	57	56	36.8	28.9	36	32	33	27	31	31	29.5
12:30									28.9	36	32	32	27	32	31	29.5
13:00									28.9	36	32	32	27	31	31	29.5
13:30									28.9	35	32	32	27	31	31	29.5
14:00									28.9	34	32	31	27	30	30	29.5
14:30									28.9	33	31	31	27	30	30	29.5
15:00									28.9	32	31	30	27	29	29	29.5

Table A.5: Plate fin without perforation at $12ms^{-1}$

Upstream Pressure fluctuates between 110

Downstream pressure fluctuates between 50-100

Time	Air velocity $12ms^{-1}$															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28.9	43	42	38	34	38	36	30.1	28.9	62	57	54	51	53	49	36.9
0:30	28.9	44	42	38	35	39	38	30.5	28.9	58	56	53	47	49	48	36.8
1:00	28.9	45	45	40	36	39	39	31.1	28.9	54	53	50	43	47	43	36.1
1:30	28.9	47	44	41	36	38	38	31.4	28.9	49	47	47	39	46	40	35.6
2:00	28.9	47	44	42	37	39	39	31.8	28.9	48	45	45	39	44	41	34.9
2:30	28.9	49	47	44	39	42	41	32.4	28.9	46	42	42	37	43	39	33.6
3:00	28.9	50	49	45	40	42	41	32.9	28.9	43	41	40	35	41	37	33.1
3:30	28.9	53	51	47	43	43	44	33.3	28.9	44	40	40	35	40	38	32.8
4:00	28.9	42	51	47	42	45	43	34	28.9	43	39	38	35	39	38	32.1
4:30	28.9	55	52	48	45	46	44	34.4	28.9	41	38	37	32	38	36	31.6
5:00	28.9	57	52	49	45	46	45	34.9	28.9	40	37	36	32	34	35	31.1
5:30	28.9	59	55	40	50	47	49	35.6	28.9	40	36	36	32	34	35	30.4
6:00	28.9	59	54	50	48	47	48	36.2	28.9	38	35	35	29	32	33	30
6:30	28.9	55	52	50	45	48	44	36.4	28.9	39	34	34	29	32	32	29.5

7:00	28.9	56	55	51	45	48	45	36.6	28.9	38	34	33	29	32	33	29.5
7:30	28.9	59	55	51	48	49	49	36.8	28.9	36	33	33	28	32	32	29.5
8:00	28.9	56	52	50	44	48	43	36.8	28.9	36	32	32	27	31	31	29.5
8:30	28.9	60	57	53	51	48	51	36.8	28.9	35	32	32	26	31	31	29.5
9:00	28.9	59	56	52	48	49	47	36.8	28.9	35	32	32	26	31	31	29.4
9:30	28.9	60	56	53	47	49	46	36.8	28.9	35	31	31	26	31	31	29.4
10:00	28.9	57	53	51	47	48	47	36.8	28.9	35	31	31	26	31	30	29.4
10:30	28.9	60	55	52	49	48	46	36.8	28.9	35	31	31	26	31	30	29.4
11:00	28.9	62	58	54	51	49	51	36.8	28.9	34	30	31	26	29	30	29.4
11:30	28.9	60	56	54	49	49	48	36.8	28.9	34	30	30	25	28	30	29.4
12:00	28.9	61	58	54	52	51	52	36.8	28.9	34	30	30	25	26	29	29.4
12:30	28.9	61	58	55	51	51	50	36.8	28.9	34	30	29	25	25	29	29.4
13:00	28.9	61	58	55	50	51	50	36.8	28.9	34	29	29	25	25	29	29.4
13:30									28.9	33	29	29	25	25	29	29.4
14:00									28.9	33	29	29	25	25	29	29.4

Table A.6: Plate fin circular perforation at $4ms^{-1}$
Upstream Pressure fluctuates between 40-50
Downstream pressure fluctuates between 10-40

Time	Air velocity $4ms^{-1}$															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	29	43	40	39	37	38	39	31	28.9	82	73	70	69	71	72	33.6
0:30	29	45	42	40	37	38	39	31.1	28.9	80	72	69	68	68	67	33.6
1:00	29	46	45	44	40	43	42	31.1	28.9	79	71	69	65	67	66	33.1
1:30	29	49	47	46	43	44	43	31.3	28.9	78	70	66	62	65	64	32.8
2:00	29	55	52	50	49	50	49	31.4	28.9	77	66	59	58	57	58	32.1
2:30	29	59	56	53	53	53	52	31.8	28.9	72	63	57	52	54	53	31.6
3:00	29	63	60	57	55	56	54	32.4	28.9	67	60	55	49	52	52	31.1
3:30	29	66	62	60	57	58	58	32.9	28.9	60	57	52	46	50	49	30.4
4:00	29	69	65	63	59	60	59	33.3	28.9	59	55	51	45	48	49	30.0
4:30	29	69	66	66	5	6	5	33.	28.	5	5	4	4	4	4	29.

Time	Air velocity 4ms^{-1}															
	heating								**cooling**							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
					9	3	9	4	9	6	2	9	2	6	5	5
5:00	29	70	68	67	61	64	61	33.5	28.9	54	50	48	41	45	44	29.5
5:30	29	71	68	67	62	65	62	33.6	28.9	51	47	46	39	44	43	29.5
6:00	29	71	69	67	63	65	62	33.6	28.9	49	43	44	38	42	41	29.4
6:30	29	72	69	68	63	66	63	33.6	28.9	47	42	42	36	40	39	29.4
7:00	29	73	70	68	64	66	65	33.6	28.9	45	41	42	35	40	39	29.4
7:30	29	73	70	68	65	67	66	33.6	28.9	44	40	40	35	39	38	29.4
8:00	29	74	70	67	65	67	66	33.6	28.9	43	39	39	34	38	38	29.3
8:30	29	74	71	67	65	67	65	33.6	28.9	42	39	39	33	37	37	29.3
9:00	29	77	71	67	65	68	66	33.6	28.9	40	38	38	32	36	38	29.3
9:30	29	78	71	68	66	68	68	33.6	28.9	40	38	37	31	36	37	29.2
10:00	29	80	72	70	66	67	68	33.6	28.9	39	38	36	30	35	36	29.2
10:30	29	81	72	70	67	67	68	33.6	28.9	38	38	35	30	35	36	29.2
11:00	29	82	72	70	66	67	67	33.6	28.9	37	37	35	29	34	36	29.2
11:30									28.9	37	35	35	28	34	35	29.2
12:00									28.9	36	35	35	29	33	35	29.2
12:30									28.9	35	35	34	28	33	35	29.2
13:00									28.9	35	34	34	28	33	34	29.2
13:30									28.9	34	34	34	27	33	34	29.2
14:00									28.9	34	32	34	27	33	34	29.2

Time	Air velocity 4ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
14:30									28.9	33	32	33	26	33	33	29.2
15:00									28.9	33	32	33	26	33	33	29.2
15:30									28.9	33	32	33	26	33	32	29.2
16:00									28.9	33	32	33	26	33	32	29.2
16:30									28.9	32	32	32	26	33	32	29.2
17:00									28.9	33	32	32	26	31	32	29.2
17:30									28.9	33	32	31	26	30	31	29.2
18:00									28.9	32	31	30	26	29	30	29.2
18:30									28.9	32	31	30	26	29	30	29.2
19:00									28.9	32	31	30	26	29	30	29.2

Table A.7: Plate fin circular perforation at 6ms^{-1}
Upstream Pressure fluctuates between 40-50
Downstream pressure fluctuates between 10-40

Time	Air velocity 6ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28.9	45	42	40	37	38	39	30.8	28.9	82	75	73	69	71	72	33.8
0:30	28.9	46	45	44	40	43	42	31	28.9	79	73	69	65	67	66	33.6
1:00	28.9	49	47	46	43	44	43	31.1	28.9	78	70	66	62	65	64	33.6
1:30	28.9	55	52	50	49	50	49	31.1	28.9	77	66	59	58	57	58	33.1
2:00	28.9	59	56	53	53	53	52	31.3	28.9	72	63	57	52	54	53	32.8
2:30	28.9	63	60	57	55	56	54	31.4	28.9	67	60	55	49	52	52	32.1
3:00	28.9	66	62	60	57	58	58	31.8	28.9	60	57	52	46	50	49	31.6

3:30	28.9	69	65	63	59	60	59	32.4	28.9	59	55	51	45	48	49	31.1
4:00	28.9	69	66	66	59	63	59	32.9	28.9	56	52	49	42	46	45	30.4
4:30	28.9	70	68	67	61	64	61	33.3	28.9	54	50	48	41	45	44	30.0
5:00	28.9	71	68	67	62	65	62	33.4	28.9	51	47	46	39	44	43	29.5
5:30	28.9	71	69	67	63	65	62	33.5	28.9	49	43	44	38	42	41	29.5
6:00	28.9	72	69	68	63	66	63	33.6	28.9	47	42	42	36	40	39	29.5
6:30	28.9	73	70	68	64	66	65	33.6	28.9	45	41	42	35	40	39	29.5
7:00	28.9	73	70	68	65	67	66	33.6	28.9	44	40	40	35	39	38	29.5
7:30	28.9	74	70	67	65	67	66	33.6	28.9	43	39	39	34	38	38	29.5
8:00	28.9	74	71	67	65	67	65	33.6	28.9	42	39	39	33	37	37	29.5
8:30	28.9	77	71	67	65	68	66	33.7	28.9	40	38	38	32	36	38	29.5
9:00	28.9	78	71	68	66	68	68	33.7	28.9	40	38	37	31	36	37	29.5
9:30	28.9	80	72	70	66	67	68	33.8	28.9	39	38	36	30	35	36	29.5
10:00	28.9	80	72	71	67	67	69	33.8	28.9	38	38	35	30	35	36	29.5
10:30	28.9	81	73	72	67	67	69	33.8	28.9	37	37	35	29	34	36	29.5
11:00	28.9	81	74	73	67	68	70	33.8	28.9	37	35	35	28	34	35	29.5
11:30	28.9	82	75	73	68	70	71	33.8	28.9	36	35	35	29	33	35	29.5
12:00	28.9	82	75	73	69	71	72	33.8	28.9	35	35	34	28	33	35	29.5
12:30									28.9	35	34	34	28	33	34	29.5
13:00									28.9	34	34	34	27	33	34	29.5
13:30									28.9	34	32	34	27	33	34	29.5
14:00									28.9	33	32	33	26	33	33	29.5
14:30									28.9	33	32	33	26	33	33	29.5
15:00									28.9	33	32	33	26	33	32	29.5
15:30									28.9	33	32	33	26	33	32	29.5
16:00									28.9	32	32	32	26	33	32	29.5
16:30									28.9	33	32	32	26	31	32	29.5
17:00									28.9	33	32	31	26	30	31	29.5

Table A.8: Plate fin circular perforation at 8ms^{-1}
Upstream Pressure fluctuates between 40-50
Downstream pressure fluctuates between 10-40

Time	**Air velocity 8ms^{-1}**															
	heating								**cooling**							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28.8	41	40	37	35	35	36	30.6	28.8	77	66	59	54	57	56	33.3
0:30	28.8	45	43	40	36	39	37	30.8	28.8	72	63	57	52	54	53	33.1
1:00	28.8	47	45	42	38	40	38	31,0	28.8	67	60	55	49	52	52	32.8

1:30	28.8	50	48	44	43	43	42	31.1	28.8	60	57	52	46	50	49	32.1
2:00	28.8	53	50	47	44	44	44	31.1	28.8	59	55	51	45	48	49	31.6
2:30	28.8	53	50	48	43	43	45	31.3	28.8	56	52	49	42	46	45	31.1
3:00	28.8	55	52	50	45	45	44	31.4	28.8	54	50	48	41	45	44	30.4
3:30	28.8	57	55	52	48	47	48	31.8	28.8	51	47	46	39	44	43	30.0
4:00	28.8	60	59	54	51	52	51	32.4	28.8	49	43	44	38	42	41	29.5
4:30	28.8	61	57	54	49	50	50	32.9	28.8	47	42	42	36	40	39	29.5
5:00	28.8	60	58	55	48	49	49	33.3	28.8	45	41	42	35	40	39	29.5
5:30	28.8	60	59	56	51	52	51	33.3	28.8	44	40	40	35	39	38	29.5
6:00	28.8	62	59	57	50	51	51	33.3	28.8	43	39	39	34	38	38	29.5
6:30	28.8	64	59	57	51	51	52	33.3	28.8	42	39	39	33	37	37	29.4
7:00	28.8	64	61	59	53	52	52	33.3	28.8	40	38	38	32	36	38	29.3
7:30	28.8	65	61	59	52	53	54	33.3	28.8	40	38	37	31	36	37	29.2
8:00	28.8	66	64	61	53	54	55	33.3	28.8	39	38	36	30	35	36	29.1
8:30	28.8	66	65	61	53	54	54	33.3	28.8	38	38	35	30	35	36	29.0
9:00	28.8	69	63	62	54	55	54	33.3	28.8	37	37	35	29	34	36	28.9
9:30	28.8	69	64	62	55	58	55	33.3	28.8	37	35	35	28	34	35	28.9
10:00	28.8	69	65	62	55	54	56	33.3	28.8	36	35	35	29	33	35	28.9
10:30	28.8	69	66	63	55	55	56	33.3	28.8	35	35	34	28	33	35	28.9
11:00	28.8	70	66	65	56	58	56	33.3	28.8	35	34	34	28	33	34	28.9
11:30	28.8	72	66	66	55	58	55	33.3	28.8	34	34	34	27	33	34	28.9
12:00	28.8	75	66	66	55	58	56	33.3	28.8	34	32	34	27	33	34	28.9
12:30	28.8	77	66	66	55	58	57	33.3	28.8	33	32	33	26	33	33	28.9
13:00	28.8	78	66	66	55	57	57	33.3	28.8	33	32	33	26	33	33	28.9
13:30									28.8	33	32	33	26	33	32	28.9
14:00									28.8	33	32	33	26	33	32	28.9
14:30									28.8	32	32	32	26	33	32	28.9
15:00									28.8	32	32	32	26	31	32	28.9

Table A.9: Plate fin circular perforation at $10ms^{-1}$
Upstream Pressure fluctuates between 40-50
Downstream pressure fluctuates between 10-40

Time	Air velocity $10ms^{-1}$															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28	42	40	37	34	35	36	30	28	71	66	65	56	58	56	33.0
0:30	28	42	41	38	34	38	36	30.6	28	69	63	60	53	54	53	32.8
1:00	28	43	42	38	35	39	38	30.8	28	65	59	57	52	53	53	32.1

1:30	28	45	45	40	36	39	39	31	28	60	57	55	48	50	49	31.6
2:00	28	47	44	41	36	38	38	31.1	28	57	56	53	45	49	47	31.1
2:30	28	47	44	42	37	39	39	31.1	28	54	53	49	43	46	45	30.4
3:00	28	49	47	44	39	42	41	31.3	28	51	51	48	42	44	43	30.0
3:30	28	50	49	45	40	42	41	31.4	28	50	49	47	39	43	41	29.5
4:00	28	53	51	47	43	43	44	31.8	28	47	47	45	38	41	40	29.5
4:30	28	42	51	47	42	45	43	32.4	28	47	46	44	36	40	40	29.5
5:00	28	55	52	48	45	46	44	32.9	28	45	43	43	35	39	38	29.5
5:30	28	57	52	49	45	46	45	33	28	44	42	42	34	38	38	29.5
6:00	28	59	55	50	46	47	49	33	28	43	41	38	33	38	37	29.4
6:30	28	61	57	54	49	50	50	33	28	41	39	36	32	36	35	29.3
7:00	28	60	58	55	48	49	49	33	28	42	39	36	32	36	36	29.2
7:30	28	60	59	56	51	52	51	33	28	40	37	35	31	35	35	29.1
8:00	28	62	59	57	50	51	51	33	28	40	36	35	30	35	34	29.0
8:30	28	64	59	57	51	51	52	33	28	39	36	35	29	34	34	28.9
9:00	28	64	61	59	53	52	52	33	28	39	35	34	29	34	33	28.9
9:30	28	65	61	59	52	53	54	33	28	38	35	34	29	34	33	28.9
10:00	28	66	64	61	53	54	55	33	28	38	34	32	28	33	33	28.9
10:30	28	66	65	61	53	54	54	33	28	38	34	32	28	33	32	28.9
11:00	28	69	63	62	54	55	54	33	28	37	33	32	27	33	32	28.9
11:30	28	69	64	62	55	58	55	33	28	36	33	32	27	33	32	28.9
12:00	28	69	65	62	55	54	56	33	28	34	33	32	27	32	32	28.9
12:30	28	70	65	63	55	54	56	33	28	34	32	32	27	33	32	28.9
13:00	28	71	65	64	55	56	56	33	28	34	33	32	27	33	32	28.9
13:30	28	71	66	65	56	57	56	33								
14:00	28	71	66	65	56	58	56	33								

Table A.10: Plate fin circular perforation at 12ms^{-1}
Upstream Pressure fluctuates between 100-110
Downstream pressure fluctuates between 60-120

Time	**Air velocity 12ms^{-1}**															
	heating								**cooling**							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	30.4	42	41	38	34	38	36	31.5	30.4	66	60	49	44	47	48	40.0
0:30	30.4	43	42	38	35	39	38	31.5	30.4	57	56	48	42	45	46	39.4
1:00	30.4	45	45	40	36	39	39	31.9	30.4	54	53	45	39	45	43	39.1
1:30	30.4	47	44	41	36	38	38	32.7	30.4	50	50	43	37	43	41	38.9
2:00	30.4	47	44	42	37	39	39	33.2	30.4	48	49	42	37	42	41	38.4

2:30	30.4	49	47	44	39	42	41	33.8	30.4	46	46	40	34	40	38	38.0
3:00	30.4	50	49	45	40	42	41	34.5	30.4	43	45	38	34	39	38	37.9
3:30	30.4	53	51	47	43	43	44	35.2	30.4	42	44	38	32	38	37	36.5
4:00	30.4	42	51	47	42	45	43	35.9	30.4	40	42	37	31	39	36	35.4
4:30	30.4	55	52	48	45	46	44	36.5	30.4	39	42	36	31	38	35	35.1
5:00	30.4	57	52	49	45	46	45	37.0	30.4	38	40	35	29	36	34	34.7
5:30	30.4	59	55	50	46	47	49	37.0	30.4	37	40	35	29	35	34	34.2
6:00	30.4	59	54	50	48	47	48	37.0	30.4	36	39	34	29	34	34	33.6
6:30	30.4	55	52	50	45	48	44	37.0	30.4	35	39	34	28	34	33	33.1
7:00	30.4	56	55	51	45	48	45	37.0	30.4	35	38	34	28	34	33	32.6
7:30	30.4	59	55	51	48	49	49	37.0	30.4	34	38	34	27	33	33	32.1
8:00	30.4	56	52	50	44	48	43	37.0	30.4	34	37	33	27	33	32	31.5
8:30	30.4	60	57	53	51	48	51	37.5	30.4	34	37	33	27	33	32	31.0
9:00	30.4	59	56	52	48	49	47	37.9	30.4	33	37	33	26	32	32	30.9
9:30	30.4	60	56	53	47	49	46	38.1	30.4	33	36	32	26	32	32	30.7
10:00	30.4	57	53	51	47	48	47	38.5	30.4	32	36	32	26	32	32	30.6
10:30	30.4	60	55	52	49	48	46	38.7	30.4	32	36	32	26	32	32	30.6
11:00	30.4	62	58	54	51	49	51	38.7	30.4	32	35	32	26	32	32	30.6
11:30	30.4	60	56	54	49	49	48	38.7								
12:00	30.4	61	58	54	52	50	52	38.7								
12:30	30.4	61	58	55	50	50	50	38.7								
13:00	30.4	62	58	54	52	49	49	38.7								
13:30	30.4	64	58	53	52	48	49	38.7								
14:00	30.4	64	58	54	52	48	50	38.7								
14:30	30.4	64	58	54	51	48	50	38.7								
15:00	30.4	64	58	55	51	50	50	38.7								

Table A.11: Plate fin hexagonal perforation at 4ms^{-1}

Upstream Pressure fluctuates between 50-60

Downstream pressure fluctuates between 10-60

Time	Air velocity 4ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	31	45	41	39	35	36	37	35	31	74	70	67	62	65	66	38
0:30	31	51	45	41	39	39	40	35.4	31	71	66	65	56	58	56	37.5
1:00	31	57	49	45	41	41	42	36.1	31	69	63	60	53	54	53	36.9
1:30	31	63	55	49	45	45	46	36.9	31	65	59	57	52	53	53	36.1
2:00	31	67	60	55	49	49	50	37.4	31	60	57	55	48	50	49	35.6
2:30	31	69	62	60	55	55	56	37.9	31	57	56	53	45	49	47	34.9

3:00	31	70	63	62	60	60	61	38	31	54	53	49	43	46	45	33.6
3:30	31	71	65	63	61	62	63	38	31	51	51	48	42	44	43	33.1
4:00	31	72	66	65	61	62	63	38	31	50	49	47	39	43	41	33.1
4:30	31	73	66	66	62	63	64	38	31	47	47	45	38	41	40	33.1
5:00	31	74	68	66	62	64	65	38	31	47	46	44	36	40	40	33.1
5:30	31	74	70	67	62	65	66	38	31	45	43	43	35	39	38	33.1
6:00	31	74	70	67	62	65	66	38	31	44	42	42	34	38	38	33.1
6:30									31	43	41	38	33	38	37	33.1
7:00									31	41	39	36	32	36	35	33.1
7:30									31	42	39	36	32	36	36	33.1
8:00									31	40	37	35	31	35	35	33.1
8:30									31	40	36	35	30	35	34	33.1
9:00									31	39	36	35	29	34	34	33.1
9:30									31	39	35	34	29	34	33	33
10:00									31	38	35	34	29	34	33	33
10:30									31	38	34	32	28	33	33	33
11:00									31	38	34	32	28	33	32	33
11:30									31	37	33	32	27	33	32	33
12:00									31	36	33	32	27	33	32	33
12:30									31	35	32	31	27	32	31	33
13:00									31	35	32	31	27	32	31	33

Table A.12: Plate fin hexagonal perforation at 6ms^{-1}

Upstream Pressure fluctuates between 50-60

Downstream pressure fluctuates between 10-60

Time	Air velocity 6ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	30.9	41	39	38	36	37	38	34.6	30.9	72	67	64	61	62	61	38
0:30	30.9	43	42	40	37	39	40	34.9	30.9	72	63	57	52	54	53	37.5
1:00	30.9	44	43	41	38	40	41	35	30.9	67	60	55	49	52	52	36.9
1:30	30.9	49	47	45	40	43	44	35.4	30.9	60	57	52	46	50	49	36.1
2:00	30.9	52	50	47	43	45	46	35.9	30.9	59	55	51	45	48	49	35.6
2:30	30.9	55	53	50	46	46	47	36.4	30.9	56	52	49	42	46	45	34.9
3:00	30.9	59	57	53	49	52	53	36.7	30.9	54	50	48	41	45	44	33.6
3:30	30.9	60	59	57	52	55	56	37	30.9	51	47	46	39	44	43	33.1
4:00	30.9	62	60	59	57	59	60	37.4	30.9	49	43	44	38	42	41	33.1
4:30	30.9	64	61	60	58	59	60	38	30.9	47	42	42	36	40	39	33.1
5:00	30.9	65	62	61	58	60	61	38	30.9	45	41	42	35	40	39	33.1
5:30	30.9	69	64	62	59	61	61	38	30.9	44	40	40	35	39	38	33.1
6:00	30.9	70	66	64	60	61	61	38	30.9	43	39	39	34	38	38	33.1
6:30	30.9	72	67	64	61	62	61	38	30.9	42	39	39	33	37	37	33.1
7:00	30.9	72	67	64	61	62	61	38	30.9	40	38	38	32	36	38	33.1

7:30									30.9	40	38	37	31	36	37	33.1
8:00									30.9	39	38	36	30	35	36	33.1
8:30									30.9	38	38	35	30	35	36	33.1
9:00									30.9	37	37	35	29	34	36	33.1
9:30									30.9	37	35	35	28	34	35	33.1
10:00									30.9	36	35	35	29	33	35	33.1
10:30									30.9	35	35	34	28	33	35	33.1
11:00									30.9	35	34	34	28	33	34	33.1
11:30									30.9	34	33	33	28	32	33	33.1
12:00									30.9	33	33	32	28	31	32	33.1

Table A.13: Plate fin hexagonal perforation at 8ms^{-1}

Upstream Pressure fluctuates between 50-60

Downstream pressure fluctuates between 10-60

Time	Air velocity 8ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	30.5	43	42	40	37	39	40	33.6	30.5	69	63	60	53	54	53	39.9
0:30	30.5	44	43	41	38	40	41	34	30.5	65	59	57	52	53	50	39.4
1:00	30.5	49	47	45	40	43	44	34.6	30.5	60	57	55	48	50	48	38.9
1:30	30.5	52	50	47	43	45	46	34.9	30.5	57	56	53	45	49	47	38.5
2:00	30.5	55	53	50	46	46	47	35	30.5	54	53	49	43	46	45	38.1
2:30	30.5	59	57	53	49	52	53	35.4	30.5	51	51	48	42	44	43	38
3:00	30.5	60	59	57	52	55	56	35.9	30.5	49	48	47	39	43	41	37.5
3:30	30.5	62	60	59	57	59	60	36.4	30.5	47	47	45	38	41	40	36.9
4:00	30.5	64	61	60	58	59	60	36.7	30.5	46	45	44	36	40	40	36.1
4:30	30.5	65	62	61	58	60	61	37	30.5	45	43	43	35	39	38	35.6
5:00	30.5	67	65	62	59	60	61	37.4	30.5	44	42	42	34	38	38	34.9
5:30	30.5	67	65	63	60	60	61	38.1	30.5	43	41	38	33	38	37	33.6
6:00	30.5	69	66	64	61	61	62	38.4	30.5	41	39	36	32	36	35	33.1
6:30	30.5	70	66	64	61	61	62	38.9	30.5	42	38	36	32	36	36	32.5
7:00	30.5	69	66	64	62	61	62	39.4	30.5	40	37	35	31	35	35	32.1
7:30	30.5	69	66	64	62	61	62	39.6	30.5	40	36	35	30	35	34	31.5
8:00	30.5	69	66	64	62	61	62	39.9	30.5	39	36	35	29	34	34	31.2
8:30									30.5	39	35	34	29	33	33	31.2
9:00									30.5	38	35	34	29	33	33	31.2
9:30									30.5	38	34	32	28	33	33	31.2
10:00									30.5	38	34	32	28	33	32	31.2
10:30									30.5	37	33	32	27	33	32	31.2
11:00									30.5	37	33	32	27	33	32	31.2

Table A.14: Plate fin hexagonal perforation at 10ms^{-1}

Upstream Pressure fluctuates between 50-60

Downstream pressure fluctuates between 10-60

Time	Air velocity 10ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	30.5	39	38	37	34	36	35	34.5	30.5	67	65	64	60	61	60	36.7
0:30	30.5	43	39	38	36	38	37	34.7	30.5	66	60	54	50	52	50	36.1
1:00	30.5	48	44	39	38	39	38	34.9	30.5	57	56	48	42	45	46	35.6
1:30	30.5	51	46	44	42	43	42	35.1	30.5	54	53	45	39	45	43	34.9
2:00	30.5	52	50	46	45	44	44	35.2	30.5	50	50	43	37	43	41	33.6
2:30	30.5	54	53	50	49	49	49	35.3	30.5	48	49	42	37	42	41	33.1
3:00	30.5	56	57	53	52	54	53	35.4	30.5	46	46	40	34	40	38	32.5
3:30	30.5	59	60	57	55	56	55	35.4	30.5	45	43	38	34	39	38	32.1
4:00	30.5	59	60	57	57	56	56	35.4	30.5	44	42	38	32	38	37	31.5
4:30	30.5	60	61	60	57	57	56	35.9	30.5	42	40	37	31	39	36	31.5
5:00	30.5	60	61	60	60	57	57	36.4	30.5	42	39	36	31	38	35	31.5
5:30	30.5	61	62	61	60	58	57	36.7	30.5	40	38	35	29	36	34	31.5
6:00	30.5	62	62	61	61	59	58	36.7	30.5	40	37	35	29	35	34	31.5
6:30	30.5	62	62	62	61	59	59	36.7	30.5	39	36	34	29	34	34	31.5
7:00	30.5	63	63	62	62	59	59	36.7	30.5	39	35	34	28	34	33	31.5
7:30	30.5	64	64	62	61	60	59	36.7	30.5	38	35	34	28	34	33	31.5
8:00	30.5	66	65	63	61	60	60	36.7	30.5	38	34	34	27	33	33	31.5
8:30	30.5	67	65	64	60	61	60	36.7	30.5	37	34	33	27	33	32	31.5
9:00	30.5	67	65	64	60	61	60	36.7	30.5	36	33	33	27	32	32	31.5
9:30									30.5	35	33	32	27	32	31	31.5
10:00									30.5	35	33	32	27	32	31	31.5

Table A.15: Plate fin hexagonal perforation at 12ms^{-1}

Upstream Pressure fluctuates between 100

Downstream pressure fluctuates between 60-100

Time	Air velocity 12ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	30.4	40	38	37	36	37	38	34.3	30.4	62	58	55	44	47	46	36.5
0:30	30.4	45	40	38	36	37	38	34.5	30.4	60	56	50	47	48	47	36.1
1:00	30.4	48	43	39	37	37	39	34.7	30.4	56	52	44	45	46	45	35.6
1:30	30.4	53	45	40	38	38	39	34.9	30.4	50	47	43	42	44	43	34.9
2:00	30.4	55	49	45	41	40	41	35.1	30.4	46	42	43	38	40	39	33.6
2:30	30.4	56	49	47	43	42	41	35.2	30.4	45	40	41	38	40	39	33.1

3:00	30.4	57	51	49	43	42	42	35.3	30.4	43	40	40	38	39	38	32.5
3:30	30.4	58	51	50	44	44	43	35.4	30.4	41	38	40	36	37	36	32.1
4:00	30.4	59	53	51	45	45	44	35.4	30.4	39	37	39	35	36	35	31.6
4:30	30.4	62	52	51	45	46	46	35.4	30.4	38	37	36	35	36	35	31.6
5:00	30.4	60	54	52	45	45	46	35.9	30.4	37	36	35	34	35	34	31.6
5:30	30.4	61	54	52	45	45	46	36.1	30.4	36	36	34	34	34	34	31.6
6:00	30.4	62	53	52	45	45	46	36.2	30.4	35	34	34	33	34	33	31.6
6:30	30.4	63	55	53	46	46	47	36.3	30.4	35	33	34	33	34	33	31.6
7:00	30.4	62	55	53	44	45	47	36.4	30.4	34	33	33	32	33	32	31.6
7:30	30.4	63	55	53	44	45	47	36.5	30.4	34	33	33	31	33	32	31.6
8:00	30.4	63	55	54	45	45	47	36.5	30.4	34	32	33	30	33	31	31.6
8:30	30.4	64	54	54	45	46	48	36.5	30.4	33	32	32	29	31	31	31.6
9:00	30.4	64	54	54	45	46	48	36.5	30.4	33	32	32	29	31	30	31.6
9:30	30.4	65	55	55	46	46	48	36.5								
10:00	30.4	65	56	55	46	46	48	36.5								

Table A.16: Pin fin without perforation at 4ms^{-1}

Upstream Pressure fluctuates between 80- 90

Downstream pressure fluctuates between 20-50

Time	**Air velocity 4ms^{-1}**															
	heating								**cooling**							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28.7	42	40	39	37	36	35	31	28.7	69	65	64	60	57	57	32.6
0:30	28.7	49	45	40	38	37	36	31.2	28.7	68	64	63	60	57	56	32.5
1:00	28.7	55	49	45	39	38	37	31.4	28.7	67	63	61	60	56	55	32.5
1:30	28.7	62	53	49	40	39	38	31.6	28.7	66	61	60	59	55	54	32.5
2:00	28.7	65	55	53	45	40	39	31.7	28.7	65	60	59	58	55	53	32.5
2:30	28.7	66	56	55	49	45	44	31.8	28.7	63	59	58	56	55	52	32.4
3:00	28.7	67	58	56	53	49	47	32	28.7	61	58	56	56	55	51	32.4
3:30	28.7	68	60	58	55	53	51	32.2	28.7	60	56	55	52	51	48	32.3
4:00	28.7	68	62	60	56	55	53	32.4	28.6	59	55	51	49	48	45	32.3
4:30	28.7	69	64	62	58	56	54	32.5	28.6	58	51	48	46	45	43	32.3
5:00	28.7	69	65	64	60	57	57	32.6	28.6	56	48	45	44	43	42	32.2
5:30									28.6	55	45	43	42	42	42	32.2
6:00									28.6	51	43	42	41	41	41	32.1
6:30									28.6	48	42	42	41	41	41	32.1
7:00									28.5	45	42	41	41	41	40	32
7:30									28.5	43	41	41	40	40	39	32
8:00									28.5	42	40	40	39	39	38	32
8:30									28.5	42	39	39	38	38	37	31.8
9:00									28.5	41	39	38	37	37	36	31.6
9:30									28.5	40	38	37	36	36	35	31.4
10:00									28.5	39	38	36	35	35	34	31.2

10:30									28.5	39	37	35	34	34	33	31
11:00									28.5	38	37	34	33	33	34	30.8
11:30									28.5	38	36	33	34	34	33	30.6
12:00									28.5	37	36	34	33	33	33	30.7
12:30									28.5	37	36	33	33	33	32	30.5
13:00									28.5	36	35	33	32	32	32	30.3
13:30									28.5	36	35	32	32	32	32	30.1
14:00									28.5	36	34	32	32	32	31	30
14:30									28.5	35	33	32	31	31	31	29.9
15:00									28.5	35	32	31	31	31	31	29.7
15:30									28.5	34	32	31	30	30	30	29.5
16:00									28.5	33	32	31	30	30	30	29.3
16:30									28.5	33	32	31	29	28	28	29.3
17:00									28.5	33	32	31	29	28	27	29.3

Table A.17: Pin fin without perforation at 6ms^{-1}

Upstream Pressure fluctuates between 80- 90

Downstream pressure fluctuates between 20-50

Time	**Air velocity 6ms^{-1}**															
	heating								**cooling**							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28.9	41	39	37	36	35	34	30.9	28.9	68	63	61	59	58	56	32.1
0:30	28.9	45	41	40	39	39	38	30.8	28.9	66	61	60	59	59	56	32
1:00	28.9	49	45	42	41	41	40	30.7	28.9	65	60	59	58	58	56	31.9
1:30	28.9	55	49	46	45	45	44	30.9	28.9	63	59	58	56	56	55	31.8
2:00	28.9	60	55	50	49	49	48	31	28.9	61	58	56	56	55	51	31.7
2:30	28.9	62	60	52	50	49	48	31.2	28.9	60	56	55	52	51	48	31.6
3:00	28.9	63	61	54	52	50	49	31.4	28.9	59	55	51	49	48	45	31.5
3:30	28.9	65	62	55	54	52	49	31.6	28.9	58	51	48	46	45	43	31.4
4:00	28.9	66	62	56	55	54	50	31.7	28.9	56	48	45	44	43	42	31.3
4:30	28.9	66	63	57	56	55	52	31.8	28.8	55	45	43	42	42	42	31.2
5:00	28.9	68	63	59	57	56	54	31.9	28.8	51	43	42	41	41	41	31.1
5:30	28.9	70	64	61	59	58	55	32	28.8	48	42	42	41	41	41	31
6:00	28.9	70	64	61	59	58	56	32.1	28.8	45	42	41	41	41	40	30.9
6:30									28.8	43	41	41	40	40	39	30.8
7:00									28.8	42	40	40	39	39	38	30.7
7:30									28.8	42	39	39	38	38	37	30.6
8:00									28.8	41	39	38	37	37	36	30.4
8:30									28.8	40	38	37	36	36	35	30.2
9:00									28.8	39	38	36	35	35	34	30
9:30									28.8	39	37	35	34	34	33	29.8
10:00									28.8	38	37	34	33	33	34	29.6
10:30									28.8	38	36	33	34	34	33	29.5

11:00									28.7	37	36	34	33	33	33	29.5
11:30									28.7	37	36	33	33	33	32	29.5
12:00									28.7	36	35	33	32	32	32	29.5
12:30									28.7	36	35	32	32	32	32	29.5
13:00									28.7	36	34	32	32	32	31	29.5
13:30									28.7	35	33	32	31	31	31	29.5
14:00									28.7	35	32	31	31	31	31	29.5
14:30									28.7	34	32	31	31	31	30	29.5
15:00									28.7	33	32	31	30	30	29	29.5

Table A.18: Pin fin without perforation at 8ms^{-1}

Upstream Pressure fluctuates between 80- 90

Downstream pressure fluctuates between 20-50

Time	Air velocity 8ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28.7	40	39	37	36	35	35	30.6	28.8	64	60	55	54	53	53	33.3
0:30	28.7	44	42	37	36	37	36	30.9	28.8	60	56	51	50	49	49	33.2
1:00	28.7	49	44	37	37	37	36	31.3	28.8	57	55	51	50	49	48	33.1
1:30	28.7	52	47	39	38	38	37	31.7	28.8	55	52	51	49	48	47	33
2:00	28.7	56	50	39	37	39	38	31.9	28.8	54	51	51	48	47	45	32.9
2:30	28.7	55	52	40	38	39	39	32	28.8	52	51	50	47	46	44	32.9
3:00	28.7	56	53	40	39	40	39	32.3	28.8	51	50	48	45	46	43	32.9
3:30	28.7	57	54	43	42	42	42	32.5	28.7	50	49	48	44	44	42	32.8
4:00	28.7	57	55	46	45	43	43	32.7	28.7	47	46	46	42	41	39	32.7
4:30	28.7	58	55	48	47	45	45	33	28.7	46	45	47	41	40	40	32.6
5:00	28.7	60	56	50	48	48	46	33.1	28.7	45	44	46	40	39	39	32.5
5:30	28.7	62	57	51	49	49	48	33.2	28.7	44	43	45	39	38	39	32.4
6:00	28.7	63	58	52	50	49	49	33.3	28.7	44	42	43	36	37	38	32.3
6:30	28.7	64	59	53	53	51	51	33.3	28.7	42	41	42	37	36	37	32.2
7:00	28.7	64	60	55	54	53	53	33.3	28.7	41	40	41	36	35	37	32.1
7:30									28.7	40	38	40	36	34	36	32
8:00									28.6	38	38	40	35	34	36	31.8
8:30									28.6	38	35	39	35	34	34	31.5
9:00									28.6	36	36	37	34	34	34	31.3
9:30									28.6	37	37	36	34	33	33	31.1
10:00									28.6	35	35	35	33	32	33	30.9
10:30									28.6	35	34	34	34	32	33	30.7
11:00									28.6	34	33	33	33	32	32	30.5
11:30									28.6	33	33	32	33	32	32	30.3
12:00									28.6	33	33	33	32	31	31	30
12:30									28.6	32	33	32	32	31	31	29.8
13:00									28.6	32	33	31	31	31	30	29.6

13:30									28.6	32	32	31	31	30	30	29.4
14:00									28.6	32	32	31	31	30	30	29.2

Table A.19: Pin fin without perforation at 10ms^{-1}

Upstream Pressure fluctuates between 80- 90

Downstream pressure fluctuates between 20-50

Time	**Air velocity 10ms^{-1}**															
	heating								**cooling**							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28.6	40	39	38	38	37	36	30.5	28.8	59	56	54	47	45	45	32
0:30	28.6	44	40	38	38	37	36	31	28.8	58	55	51	47	44	45	32
1:00	28.6	46	43	39	39	37	37	31.4	28.8	56	52	49	46	45	42	31.8
1:30	28.6	48	45	40	39	38	38	31.7	28.8	54	50	48	45	44	41	31.5
2:00	28.6	49	49	45	41	41	40	32	28.8	51	47	46	44	43	39	31.3
2:30	28.6	50	49	47	41	43	42	32.5	28.7	49	43	44	42	41	38	31.1
3:00	28.6	51	51	49	42	43	42	32.9	28.7	47	42	42	40	39	36	30.9
3:30	28.6	52	51	50	43	44	44	33.3	28.7	45	41	42	40	39	35	30.7
4:00	28.6	53	53	51	44	45	45	33.7	28.7	44	40	40	39	38	35	30.5
4:30	28.6	54	52	51	46	46	45	34	28.7	43	39	39	38	38	34	30.3
5:00	28.6	54	54	52	46	45	45	34.2	28.7	42	39	39	37	37	33	30
5:30	28.6	55	54	52	46	45	45	34.5	28.7	40	38	38	36	38	32	29.8
6:00	28.6	56	53	52	46	45	45	34.7	28.7	40	38	37	36	37	31	29.6
6:30	28.6	57	55	53	47	46	46	34.8	28.7	39	38	36	36	36	30	29.4
7:00	28.6	58	55	53	47	45	44	34.8	28.6	38	38	35	36	36	30	29.2
7:30	28.6	59	55	53	47	45	44	34.9	28.6	37	37	35	35	35	29	29.2
8:00	28.6	59	56	54	47	45	45	35	28.6	37	35	35	34	35	28	29.2
8:30									28.5	36	35	35	33	33	29	29.2
9:00									28.5	35	35	34	33	33	28	29.1
9:30									28.5	35	34	34	33	32	28	29.1
10:00									28.5	34	34	33	32	32	27	29.1
10:30									28.5	34	33	32	32	31	27	29
11:00									28.5	33	32	32	31	31	26	29
11:30									28.5	33	32	31	31	30	26	29
12:00									28.5	33	32	31	31	30	26	29

Table A.20: Pin fin without perforation at 12ms^{-1}

Upstream Pressure fluctuates between 120-140

Downstream pressure fluctuates between 40-80

Time	Air velocity 12ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28.9	40	38	37	36	36	35	30.1	28.9	60	56	55	47	44	45	36.9
0:30	28.9	43	38	38	39	37	36	30.5	28.9	58	50	50	48	47	46	36.5
1:00	28.9	45	39	39	39	37	37	30.9	28.9	56	46	44	46	45	43	36.1
1:30	28.9	47	45	40	40	38	38	31.4	28.9	50	45	43	44	42	39	35.8
2:00	28.9	49	49	43	43	40	41	31.7	28.9	46	43	43	40	38	36	35.4
2:30	28.9	51	49	42	44	42	43	32.1	28.9	45	41	41	40	38	35	35
3:00	28.9	52	51	43	44	42	43	32.6	28.9	43	39	40	39	38	34	34.5
3:30	28.9	54	51	45	44	44	44	33	28.9	41	38	40	37	36	33	34.1
4:00	28.9	57	53	47	46	45	45	33.6	28.9	39	36	39	36	35	31	33.6
4:30	28.9	58	52	48	45	46	45	33.9	28.9	38	35	36	36	35	31	33.1
5:00	28.9	59	54	48	46	45	45	34.2	28.9	37	35	35	35	34	30	32.5
5:30	28.9	61	54	51	46	45	45	34.7	28.9	36	34	34	34	34	29	32
6:00	28.9	62	53	52	46	45	45	35.1	28.9	35	34	34	34	33	29	31.9
6:30	28.9	56	55	54	46	46	46	35.7	28.9	35	33	34	34	33	28	31.4
7:00	28.9	57	53	55	46	45	44	36.1	28.9	34	33	33	33	32	28	30.8
7:30	28.9	58	55	55	46	45	44	36.4	28.9	34	32	33	33	32	28	30.3
8:00	28.9	59	55	55	46	45	45	36.5	28.9	34	32	33	33	32	27	30
8:30	28.9	60	56	55	47	46	45	36.7	28.9	33	32	32	32	32	27	29.8
9:00	28.9	60	56	55	47	46	45	36.8	28.9	33	32	32	32	30	26	29.6
9:30									28.9	33	32	31	31	29	26	29.5
10:00									28.9	33	32	31	30	29	26	29.4

Table A.21: Pin fin circular perforation at 4ms^{-1}

Upstream Pressure fluctuates between 80

Downstream pressure fluctuates between 3-40

Time	Air velocity 4ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28.9	43	42	40	37	39	37	30.8	28.8	63	60	58	57	57	56	33.5
0:30	28.9	44	43	41	38	40	38	31.4	28.8	62	60	58	50	52	51	33.3
1:00	28.9	49	47	45	40	41	40	31.9	28.8	60	57	52	46	50	49	33.2
1:30	28.9	52	50	47	43	42	43	32.3	28.8	59	55	51	45	48	49	33.1
2:00	28.9	55	53	52	46	46	46	32.7	28.8	56	52	49	42	46	45	33
2:30	28.9	59	54	53	49	50	49	32.9	28.8	54	50	48	41	45	44	32.9
3:00	28.9	60	56	55	52	53	52	33.1	28.8	51	47	46	39	44	43	32.9
3:30	28.9	62	57	56	54	55	54	33.3	28.7	49	43	44	38	42	41	32.9
4:00	28.9	63	58	57	55	56	55	33.4	28.7	47	42	42	36	40	39	32.8
4:30	28.9	64	59	59	56	57	56	33.5	28.7	45	41	42	35	40	39	32.7
5:00	28.9	64	59	58	56	57	56	33.5	28.7	44	40	40	35	39	38	32.6

5:30	28.9	63	60	58	57	57	56	33.5	28.7	43	39	39	34	38	38	32.5
6:00	28.9	63	60	58	57	57	56	33.5	28.7	42	39	39	33	37	37	32.4
6:30									28.7	40	38	38	32	36	38	32.3
7:00									28.7	40	38	37	31	36	35	32.2
7:30									28.7	39	38	36	30	36	34	32.1
8:00									28.7	38	38	35	30	35	35	32
8:30									28.7	37	37	35	29	34	35	31.8
9:00									28.7	37	35	35	28	34	35	31.5
9:30									28.7	36	35	35	29	33	35	31.3
10:00									28.7	35	35	34	28	33	35	31.1
10:30									28.7	35	34	34	28	33	34	30.9
11:00									28.7	34	34	34	27	32	33	30.7
11:30									28.7	34	33	34	27	31	32	30.5
12:00									28.7	34	33	33	26	31	32	30.3
12:30									28.7	34	32	33	26	30	30	30
13:00									28.7	33	32	32	26	29	29	29.8
13:30									28.7	33	32	32	26	29	28	29.5
14:00									28.7	33	32	31	26	28	27	29.5

Table A.22: Pin fin circular perforation at 6ms^{-1}

Upstream Pressure fluctuates between 80

Downstream pressure fluctuates between 3-40

Time	Air velocity 6ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28.9	45	40	38	38	37	36	30.7	28.8	62	56	55	47	44	45	33.6
0:30	28.9	48	43	39	39	37	37	30.9	28.8	60	50	50	48	47	46	33.1
1:00	28.9	53	45	40	39	38	38	31.3	28.8	56	46	44	46	45	43	32.5
1:30	28.9	55	49	45	41	41	40	31.7	28.8	50	45	43	44	42	39	32.1
2:00	28.9	56	49	47	41	43	42	31.9	28.8	46	43	43	40	38	36	32
2:30	28.9	57	51	49	42	43	42	32	28.8	45	41	41	40	38	35	31.8
3:00	28.8	58	51	50	43	44	44	32.3	28.8	43	39	40	39	38	34	31.5
3:30	28.8	59	53	51	44	45	45	32.5	28.8	41	38	40	37	36	33	31.3
4:00	28.8	62	52	51	46	46	45	32.7	28.8	39	36	39	36	35	31	31.1
4:30	28.8	60	54	52	46	45	45	33	28.8	38	35	36	36	35	31	30.9
5:00	28.8	61	54	52	46	45	45	33.1	28.7	37	35	35	35	34	30	30.7
5:30	28.8	62	53	52	46	45	45	33.2	28.7	36	34	34	34	34	29	30.5
6:00	28.8	62	55	53	47	46	46	33.3	28.7	35	34	34	34	33	29	30.3
6:30	28.8	62	57	54	47	45	44	33.5	28.7	35	33	34	34	33	28	30
7:00	28.8	62	59	55	48	46	45	33.6	28.7	34	33	33	33	32	28	29.8
7:30									28.6	34	32	33	33	32	28	29.6
8:00									28.6	34	32	33	33	32	27	29.4
8:30									28.6	33	32	32	32	32	27	29.2

9:00									28.6	33	32	32	32	30	26	29.2
9:30									28.6	33	32	31	31	29	26	29.2
10:00									28.6	33	32	31	30	29	26	29.2
10:30									28.6	32	31	30	29	28	26	29.2
11:00									28.6	32	31	30	29	28	26	29.2
11:30									28.6	32	31	30	29	28	25	29.2
12:00									28.6	32	31	30	29	28	25	29.2

Table A.23: Pin fin circular perforation at 8ms^{-1}

Upstream Pressure fluctuates between 80

Downstream pressure fluctuates between 3-40

Time	Air velocity 8ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28.8	38	37	36	35	35	32	30.6	28.8	52	47	44	46	43	39	33.3
0:30	28.8	39	38	37	36	36	32	30.7	28.8	46	46	43	43	42	38	33.1
1:00	28.8	40	39	38	37	37	33	30.9	28.8	43	46	42	40	40	37	32.5
1:30	28.8	41	40	39	38	38	33	31.3	28.8	40	43	37	36	36	35	32.1
2:00	28.8	42	41	39	39	38	34	31.7	28.8	40	40	36	35	35	34	32
2:30	28.8	43	42	40	39	39	34	31.9	28.8	39	40	36	33	35	34	31.8
3:00	28.8	44	43	41	39	38	35	32	28.8	39	39	36	33	34	33	31.5
3:30	28.8	45	44	41	40	40	36	32.3	28.8	39	39	36	32	33	32	31.3
4:00	28.8	46	45	40	41	39	38	32.5	28.8	38	38	35	32	33	32	31.1
4:30	28.8	47	46	42	40	39	37	32.7	28.8	38	37	35	32	33	32	30.9
5:00	28.8	46	46	45	41	39	38	33	28.8	37	37	35	31	32	31	30.7
5:30	28.8	47	47	46	42	41	39	33.1	28.8	37	37	34	31	32	31	30.5
6:00	28.8	48	48	47	43	42	40	33.2	28.8	37	37	33	31	32	31	30.3
6:30	28.8	49	48	46	45	44	42	33.3	28.8	36	34	34	30	31	30	30
7:00	28.8	50	48	46	47	45	43	33.3	28.8	36	34	33	30	31	30	29.8
7:30	28.8	50	48	47	47	45	44	33.3	28.8	36	33	33	30	31	30	29.6
8:00	28.8	51	48	47	47	45	44	33.3	28.8	35	33	33	29	30	29	29.4
8:30	28.8	51	48	47	47	45	45	33.3	28.8	35	33	32	29	30	29	29.2
9:00	28.8	51	48	47	47	45	45	33.3	28.8	33	33	32	29	30	29	29.2
9:30									28.8	34	33	32	29	29	28	29.2
10:00									28.8	34	33	32	28	29	28	29.2
10:30									28.8	33	32	31	28	29	28	29.2
11:00									28.8	33	32	31	28	29	28	29.2

Table A.24: Pin fin circular perforation at 10ms^{-1}

Upstream Pressure fluctuates between 80

Downstream Pressure fluctuates between 3-40

Time	Air velocity 10ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28.8	40	39	38	36	37	36	29.9	28.8	53	49	48	46	46	45	33.4
0:30	28.8	41	39	39	37	38	37	30.1	28.8	51	48	47	43	45	42	33.3
1:00	28.8	42	39	39	38	39	38	30.5	28.8	48	47	45	39	42	38	33.1
1:30	28.8	43	39	39	38	39	38	30.6	28.8	47	45	42	36	39	35	32.5
2:00	28.8	45	40	39	39	39	38	30.7	28.8	46	43	39	34	38	33	32.1
2:30	28.8	46	41	40	39	39	37	30.9	28.8	43	40	39	34	38	33	32
3:00	28.8	46	42	40	39	40	37	31.3	28.8	40	39	38	33	36	33	31.8
3:30	28.8	45	42	41	39	40	38	31.7	28.8	37	36	37	32	35	32	31.5
4:00	28.8	45	44	42	40	41	38	31.9	28.8	37	35	35	32	34	32	31.3
4:30	28.8	45	45	43	42	42	39	32	28.8	36	35	34	31	33	32	31.1
5:00	28.8	46	45	43	42	43	39	32.3	28.8	36	34	34	30	33	31	30.9
5:30	28.8	46	46	44	43	43	42	32.5	28.8	36	32	33	30	33	31	30.7
6:00	28.8	47	46	44	44	44	42	32.7	28.8	34	33	33	30	32	30	30.5
6:30	28.8	48	46	45	44	44	43	33	28.8	34	32	32	29	32	30	30.3
7:00	28.8	49	47	45	44	45	44	33.1	28.8	34	32	32	29	32	30	30
7:30	28.8	49	48	47	45	45	44	33.2	28.8	33	32	31	29	31	29	29.8
8:00	28.8	50	48	48	46	47	46	33.3	28.8	33	32	31	29	30	29	29.2
8:30	28.8	50	48	48	46	46	45	33.4								
9:00	28.8	50	49	47	43	40	39	33.5								

Table A.25: Pin fin circular perforation at 12ms^{-1}

Upstream Pressure fluctuates between 180-160

Downstream pressure fluctuates between 20-80

Time	Air velocity 12ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28.7	41	37	35	30	34	30	29.9	28.7	46	43	39	34	38	33	31.4
0:30	28.7	42	37	36	31	35	31	30	28.7	43	40	39	34	38	33	31.3
1:00	28.7	43	37	36	31	35	32	30.2	28.7	40	39	38	33	36	33	31.1
1:30	28.7	45	38	36	32	36	32	30.6	28.7	37	36	38	32	35	32	30.9
2:00	28.7	45	38	36	33	36	32	30.9	28.7	37	35	37	32	34	32	30.7
2:30	28.7	45	38	37	32	36	32	31.1	28.7	36	35	37	31	33	32	30.5
3:00	28.7	45	39	37	33	37	33	31.2	28.7	36	35	35	30	33	31	30.3
3:30	28.7	46	39	37	33	37	33	31.3	28.7	36	35	35	30	33	31	30

4:00	28.7	47	39	38	35	38	33	31.4	28.7	34	34	35	30	32	30	29.8
4:30	28.7	46	38	38	36	38	33	31.4	28.7	34	32	34	29	32	30	29.5
5:00	28.7	46	38	38	36	38	33	31.4	28.7	34	32	34	29	32	30	29.2
5:30									28.7	33	31	33	29	31	29	29.2
6:00									28.7	33	31	32	29	31	29	29.2
6:30									28.7	33	31	30	29	30	29	29.2
7:00									28.7	32	31	30	29	30	29	29.2

Table A.26: Pin fin hexagonal perforation at 4ms^{-1}

Upstream Pressure fluctuates between 70-80

Downstream pressure fluctuates between 10-40

Time	Air velocity 4ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	30.5	41	39	37	34	35	34	34	30.5	58	56	53	50	51	50	37
0:30	30.5	46	40	39	36	37	36	34.6	30.5	55	53	50	48	49	45	36.2
1:00	30.5	51	41	40	37	38	37	35.1	30.5	53	50	49	47	44	41	35.4
1:30	30.5	53	46	41	39	38	37	35.7	30.5	50	48	47	45	46	39	35.1
2:00	30.5	54	51	46	40	41	40	36.2	30.5	48	45	45	43	44	37	34.6
2:30	30.5	55	53	51	41	42	41	36.5	30.5	44	41	43	42	43	34	34.1
3:00	30.5	56	54	53	46	47	45	36.6	30.5	40	38	42	40	41	33	33.4
3:30	30.5	56	55	53	48	49	47	36.8	30.5	37	35	40	38	39	32	33.1
4:00	30.5	56	55	53	50	51	50	37	30.5	35	34	38	35	36	31	32.7
4:30									30.5	33	33	35	33	35	31	32.2
5:00									30.4	33	33	32	32	34	31	32.1
5:30									30.4	33	32	31	31	32	30	32
6:00									30.4	33	32	31	31	31	30	32
6:30									30.4	32	32	31	31	30	29	32
7:00									30.4	32	32	31	30	30	29	32

Table A.27: Pin fin hexagonal perforation at 6ms^{-1}

Upstream Pressure fluctuates between 70-80

Downstream pressure fluctuates between 10-40

Time	Air velocity 6ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	30.4	43	41	40	38	39	38	32.7	30.4	55	50	48	43	47	46	36.5
0:30	30.4	45	44	42	39	39	37	33.1	30.4	50	45	43	43	42	39	36.2

1:00	30.4	46	46	45	41	39	38	33.6	30.4	46	43	43	40	38	36	35.4
1:30	30.4	47	47	46	42	41	39	33.9	30.4	45	41	41	40	38	35	35.1
2:00	30.4	48	48	47	43	42	40	34.5	30.4	43	39	40	39	38	34	34.6
2:30	30.4	49	49	48	45	44	42	34.9	30.4	41	38	40	37	36	33	34.1
3:00	30.4	50	50	48	47	46	43	35.2	30.4	39	36	39	36	35	31	33.4
3:30	30.4	50	51	49	48	47	44	35.8	30.4	38	35	36	36	35	31	33.1
4:00	30.4	51	51	49	48	45	45	36.1	30.4	37	35	35	35	34	30	32.7
4:30	30.4	51	50	49	48	45	46	36.2	30.3	36	34	34	34	34	29	32.1
5:00	30.4	51	51	49	48	45	46	36.5	30.3	34	34	33	33	32	29	31.9
5:30									30.3	33	33	32	32	31	28	31.7
6:00									30.3	33	32	31	31	30	28	31.5

Table A.28: Pin fin hexagonal perforation at 8ms^{-1}

Upstream Pressure fluctuates between 70-80

Downstream pressure fluctuates between 10-40

Time	Air velocity 8ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	29.8	38	36	35	35	34	33	33	29.9	44	42	41	40	39	37	35
0:30	29.8	39	37	36	36	35	34	33.3	29.9	44	42	40	39	37	36	34.6
1:00	29.8	39	38	36	36	35	34	33.9	29.9	42	40	39	37	36	34	34.1
1:30	29.8	40	39	37	36	35	34	34.1	29.9	40	39	37	36	34	33	33.4
2:00	29.8	40	39	38	37	36	35	34.7	29.9	39	37	36	34	33	32	33.1
2:30	29.9	40	40	39	38	36	35	34.8	29.9	37	36	34	33	32	32	32.7
3:00	29.9	41	40	39	39	37	36	34.9	29.9	36	34	33	32	32	32	32.1
s3:30	29.9	41	40	40	39	38	36	34.9	29.8	34	33	32	32	32	31	31.9
4:00	29.9	42	41	40	40	39	37	35	29.8	33	32	32	32	31	32	31.7
4:30	29.9	42	41	40	40	39	37	35	29.8	32	32	32	31	32	31	31.5
5:00	29.9	42	42	41	40	40	37	35	29.8	32	32	31	31	31	30	31
5:30	29.9	43	42	41	40	39	37	35								
6:00	29.9	44	42	41	40	39	37	35								

Table A.29: Pin fin hexagonal perforation at 10ms^{-1}

Upstream Pressure fluctuates between 70-80

Downstream pressure fluctuates between 10-40

Time	Air velocity 10ms^{-1}															
	heating								cooling							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28	38	36	35	35	34	33	29	28	44	42	41	40	39	37	34.9

0:30	28	39	37	36	36	35	34	29.4	28	44	42	40	39	37	36	34.5
1:00	28	39	38	36	36	35	34	30.1	28	42	40	39	37	36	34	34.1
1:30	28	40	39	37	36	35	34	30.8	28	40	39	37	36	34	33	33.4
2:00	28	40	39	38	37	36	35	31.2	28	39	37	36	34	33	32	32.9
2:30	28	40	40	39	38	36	35	31.7	28	37	36	34	33	32	32	32.1
3:00	28	41	40	39	39	37	36	32.4	28	36	34	33	32	32	32	31.5
3:30	28	41	40	40	39	38	36	32.9	28	34	33	32	32	32	31	31.2
4:00	28	42	41	40	40	39	37	33.4	28	33	32	32	32	31	32	31
4:30	28	42	41	40	40	39	37	34.1								
5:00	28	42	42	41	40	40	37	34.2								
5:30	28	43	42	41	40	39	37	34.3								
6:00	28	44	42	41	40	39	37	34.5								
6:30	28	44	42	41	40	39	37	34.9								
7:00	28	44	42	41	40	39	37	35								

Table A.30: Pin fin hexagonal perforation at 12ms^{-1}

Upstream Pressure fluctuate between 70-80

Downstream pressure fluctuates between 10-40

Time	**Air velocity 12ms^{-1}**															
	heating								**cooling**							
	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o	T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_o
0:00	28	38	36	35	35	34	33	29	28	44	42	41	40	39	37	34.5
0:30	28	39	37	36	36	35	34	29.2	28	44	42	40	39	37	36	33.7
1:00	28	39	38	36	36	35	34	29.4	28	42	40	39	37	36	34	32.7
1:30	28	40	39	37	36	35	34	30.1	28	40	39	37	36	34	33	31.5
2:00	28	40	39	38	37	36	35	30.8	28	39	37	36	34	33	32	30.9
2:30	28	40	40	39	38	36	35	31.2	28	37	36	34	33	32	32	30.1
3:00	28	41	40	39	39	37	36	31.7	28	36	34	33	32	32	32	29.5
3:30	28	41	40	40	39	38	36	32.4	28	34	33	32	32	32	31	29
4:00	28	42	41	40	40	39	37	32.9	28	33	32	32	32	31	32	29.3
4:30	28	42	41	40	40	39	37	33.4								
5:00	28	42	42	41	40	40	37	34.1								
5:30	28	43	42	41	40	39	37	34.2								
6:00	28	44	42	41	40	39	37	34.3								
6:30	28	44	42	41	40	39	37	34.5								
7:00	28	44	42	41	40	39	37	34.5								