ANALYSIS OF HEAT TRANSFER IN PORTABLE POWER SUPPLY

AHMAD NAZRIN BIN ALI @ YUSOF

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

SUPERVISOR DECLARATION

"I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive)"

Signature: ……………………………………….

Supervisor: Dr. MOHD AZMAN BIN ABDULLAH

Date: 30 JUNE 2015

ANALYSIS OF HEAT TRANSFER IN PORTABLE POWER SUPPLY

AHMAD NAZRIN BIN ALI @ YUSOF

This thesis is submitted in partial fulfillment of the requirements for the Bachelor of Mechanical Engineering (Automotive)

Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka

JUNE 2015

DECLARATION

"I hereby declare that the work in this thesis is my own except for summaries and quotations which have been duly acknowledged."

Signature: ....

Author: AHMAD NAZRIN BIN ALI @ YUSOF

Date: 30 JUNE 2015

DEDICATION

I dedicated this thesis to my beloved family especially to my father and my mother, to my supervisor, Dr. Mohd Azman Abdullah and my friends

ACKNOWLEDGEMENT

First of all, thank to God for giving me health, strength and opportunity to successfully completed Final Year Project. Eventhough there are few problems that I counter during conducting this project, but with God guidance and blessing, I finished my project.

I would like to thank to my beloved family especially my father and my mother, who's always give motivation and never stop pray for my success. They are my light and the root for my strength.

I also would like to express my gratitude to my supervisor, Dr. Mohd Azman Abdullah, who greatly support and encourage me while conduct this project. He has generously spending his time and never stops giving guidance to me. Without him, I would never successfully complete this project.

I would like to use this opportunity to express my gratitude to all parties at UTeM for their great kindness and cooperation. Last but not least, I would like to thanks to all my friends that gives support and helping me for finishing this project.

ABSTRACT

Solar, wind, and fuel cell are some example of power source that are environmentally friendly. Hence, portable power supply product that uses solar energy as energy source was introduced. This product can supply electric energy to home furniture such as fan, lamp and drill. As the portable power supply product continue to grow, thermal issues are becoming extremely important for the product reliability. Portable power supply is a hand–held electronic equipment that is placed in a completely sealed enclosures due to safety factors. Since the cooling system of this product relies primarily on natural convection, the effective thermal management was quite low. Any electronic component will produce heat while operate and each electronic component have their own maximum temperature allowed during the operation. For this project, battery, adapter and inverter of the portable become the main heat source. Therefore, CFD model was develop by using ANSYS FLUENT software to study heat flow inside portable power supply. CFD model results were analysis and study to optimize thermal removal system of the portable power supply. Plus, experiments also will conduct for this project in order to study heat flow inside Portable power supply thoroughly. CFD model analysis show that by placed main heat source such as battery at the middle position compare to rear position will have better heat removal system. Besides that, by hollowed, added fan blower to the portable power supply, the temperatures inside the portable power supply will decrease and the efficiency of heat removal system will increase.

ABSTRAK

Tenaga solar, angin dan sel bahan api merupakan contoh sumber tenaga yang mesra alam. Oleh itu, produk pembekal tenaga mudah alih yang menggunakan solar sebagai sumber tenaga telah diperkenalkan. Produk ini boleh membekalkan tenaga eletrik pada perkakas rumah seperti kipas, lampu dan alat pengerudi. Apabila produk pembekal tenaga mudah alih semakin berkembang, isu sistem penyingkiran haba menjadi amat penting untuk ketahanan produk. Pembekal tenaga mudah alih adalah alat eletronik yang mempunyai struktur yang ditutup sepenuhnya disebabkan faktor keselamatan. Oleh kerana sistem penyejukan produk ini bergantung kepada perolakan semulajadi, keberkesanan pengurusan haba adalah amat rendah. Setiap komponen elektronik menghasilkan haba apabila digunakan dan setiap komponen elektronik mempunyai nilai suhu maksimum tersendiri untuk berfungsi. Bagi projek ini, bateri, adapter dan inverter di dalam produk pembekal tenaga mudah alih merupakan pembekal haba yang utama. Model CFD dibina dengan menggunakan perisian ANSYS FLUENT untuk mengkaji aliran haba di dalam produk. Hasil kajian model CFD akan dianalisis dan dikaji bagi mengoptimumkan sistem penyingkiran haba dari produk pembekal tenaga mudah alih. Tambahan, eksperimen juga akan dijalankan bagi projek ini untuk mengkaji aliran haba di dalam pembekal mudah alih dengan lebih teliti. Analisis model CFD menunjukkan bahawa dengan meletakkan sumber haba utama seperti bateri di posisi tengah berbanding posisi belakang akan mempunyai sistem penyingkiran haba yang lebih baik. Selain itu, dengan menebuk lubang dan menambah kipas pada produk pembekal mudah alih, suhu di dalam produk akan menurun dan kecekapan sistem penyingkiran haba akan meningkat.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A	=	surface area
v	=	velocity
P	=	pressure
T	=	temperature
p	=	density
c_p	=	specific heat
k	=	thermal conductivity
μ	=	viscosity
v	=	voltage
^oC	=	celcius
cm	=	centimeter

LIST OF ABBREVIATIONS

FYP	Final Year Project
PSM	Projek Sarjana Muda
CFD	Computational Fluid Dynamic
Exp	Experiment
CFM	Cubic Feet Meter
CAD	Computer-aided Design
DC	Direct current
AC	Alternative Current
PPS	Portable Power Supply
IC, OC	Inlet closed, outlet closed
IO, OC	Inlet open, outlet closed
IC, OO	Inlet closed, outlet open
IF, OO	Inlet fan, outlet open
IO, OF	Inlet open, outlet closed
IF, OF	Inlet fan, outlet fan

LIST OF APPENDIX

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Nowadays, there are a lot of researches and developments have been done in many fields in order to accommodate to the arising of technologies. Not forgotten, the environmental issues also become main topic as the technologies shine and arise. In order to develop and create product that meet both customer demand and green technology are very challenging. A portable power supply is a product that uses 12 V battery (Nicd) that recharges by solar energy and convert it into electrical energy. This product can produce 240 V and can supply electrical energy to home furniture such as fan, lamp, iron, electric drill and others. This product produces electrical energy without using any fuel and does not produce any pollutants like any type of generator that use fuel. Thus, this product develops in order to meet both customer demand and green technology.

1.2 PROBLEM STATEMENT

Portable power supply is machine that can be very useful to human. Consumers can get electrical power supply anywhere and anytime they want. This product focuses on green technology which uses battery that can recharge by the solar energy. But, the problem is the battery inside the product become hotter while being used or being charger. There is temperature limit for each component inside portable power supply to function properly. The increment of the temperature inside the machine could cause the machine to failure or damage and make it not safe to be used. CFD model are develop to study the heat flow in portable power supply. There are few elements that being used as manipulate variable such as battery position, window position and the present of blowing fan in order to optimize thermal performance and improve the reliability of the product. Besides that, experiment also will be conducted during this project in order to study heat flow in PPS thoroughly.

1.3 OBJECTIVE

The purpose of this project is to develop CFD model and study heat flow in PPS. CFD modeling is a faster and more efficient tool than experimental cut-and-try methods for improving and optimizing the thermal management for high density power converter. However, experiment still be conducted to determine temperature inside PPS in order to get more data for heat transfer study. Generally, every electronic component produce heat while operate and each electronic component has their own maximum allowable operating temperature. It is important to optimize thermal management to avoid machine failure and increase reliability of the machine.

1.4 SCOPE

There are four scopes need to be done for this project. The first one is develop CFD model by using ANSYS software. Second, use few elements as manipulated variable such as battery position and fan blower present while setup the parameter. Another scope is conducted the experiment that use inlet, outlet hole and fan present as manipulated variable. The last scope for this project is study and analysis heat flow of portable power supply.

1.5 THESIS OUTLINE

The project background, problem statement, objectives and scope of this research have been discussed in this chapter. The research of this project generally divides to two which are develop CFD model and conduct experiment in order to study heat flow inside the model. First of all, this project will focus on CFD simulation of the model by using ANSYS FLUENT software. CFD modeling is a faster and more efficient tool than experimental methods for study heat flow. Plus, CFD modeling is more simple and cheap rather than experimental method. Three models are develop for this project. Model 1 and model 2 will use battery position as manipulative variable. Model 3 is developing to compare temperature of CFD result with experiment result. Besides that, there are three stage of the experiment that conduct for this project which are stage 1 (before hollowing), stage 2 (after hollowing) and stage 3 (with fan). Second chapter will discuss about study research that help and support while investigate this project.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, the research resources and literature review in the related field will be discussed thoroughly as it is an important step in every or whatever project to be done. It is an important method in order to get more understanding of this project and to gain ideas and improvements of the project. The literature review will be discussed in three subtopics to give clear view and understanding of the project, which are develop CFD model using ANSY software, changing the parameter of the setup and study the heat transfer. Analysis of heat transfer in portable power supply is a project that study heat transfer of the model that been researched and development which is still not completely efficient for use due to thermal removal problem. As the densities of the portable power supply continue to grow, environmental and thermal issues are becoming extremely important to the product quality.

2.2 CFD ANALYSES OF A NOTEBOOK COMPUTER THERMAL MANAGEMENT SYSTEM

According to Tari and Yalzin (2010), the increasing energy costs and consumer awareness on environmental issues together with the advances in related electronic components shifted the demand in the personal computer industry towards notebook computers which have low energy consumption and less noise compare to desktops. But, due to the compact chassis, thermal management of a notebook is more difficult than a desktop. Heat dissipation to ambient air from a typical desktop computer can be easily achieved using forced convection due to greater air volume inside the chassis for circulation and large chassis surface area for placing the vents and fans. This is different for notebook computer which should be small as possible in term of size and weight. Therefore, there is not much space left inside chassis among the components that are placed very tightly. Every electronic component produce heat while operate and each electronic components has their own maximum allowable operating temperature. For notebook computer, CPU is the main heat source and produce most of heat among others component. But, even the smallest heat dissipation should be considered, because the components are packed together inside the chassis very tightly and component temperatures depend on all heat sources that produced. It is important to optimize thermal management to avoid machine failure and increase the reliability of the machine.

The first part involves a CFD analysis of a notebook computer. Electronic component boxes and computer systems of various sizes have been numerically modeled and CFD simulation results have showed very good agreement with experimental test result. In addition, CFD simulation is fastest and efficient tool to study thermal flow of the model. In the study, the cooling system of notebook computer that was Sony Vaio PCG-GRX316MP is numerically investigated to access the heat loads on the active and passive paths. For the chassis as shown in Figure 1; CPU, CPU heat sink, heat pipes, heat exchanger, fans, aluminum heat dissipation plates, RAM, DVD, battery, PCMCIA card, hard disk drive (HDD), speakers, ventilation holes, PCB and miscellaneous cards attached to PCB are modeled according to measured dimensions. The components with little effect on the fluid flow and heat transfer are not modeled. Plus, there are two fans in the system, the first one is Fan 1 used to provide airflow to the fin-tube type remote heat exchanger (RHE) and the second one is Fan 2 that attached to an aluminum heat dissipation plate on the graphics chip and south bridge. The RHE is attached to the condenser ends of two heat pipes which transfer heat from the heat sink attached to the CPU. The heat pipes are represented as the solid rods having the same physical dimensions with the actual heat pipes and a high thermal conductivity in the axial direction taken as 40000 W/m.K.

For setup solution in CFD simulation, no slip boundary condition is applied for the chassis and the component walls in the domain. The heat transfer mechanism outside the notebook chassis was assumed to be natural convection and the convective effects of the flow coming through the fan exits and the ventilation holes are neglected in CFD modeled. The ambient temperature was 25 °C. Inside the chassis, radiative transfer and compressibility effects are neglected. With a conservative approach, radiative transfer from outer surfaces of the chassis to the surroundings was also neglected in this experiment. The simulations using the model of the notebook were performed for five different cases shown as **Table 2.1**. Case I corresponds to the standard use of the notebook. Case II is for the standard use while charging the battery of the notebook. Case III corresponds to the optical drive use. Case IV is for 100% CPU load. Case V is the extreme case that stresses the thermal management system of the notebook.

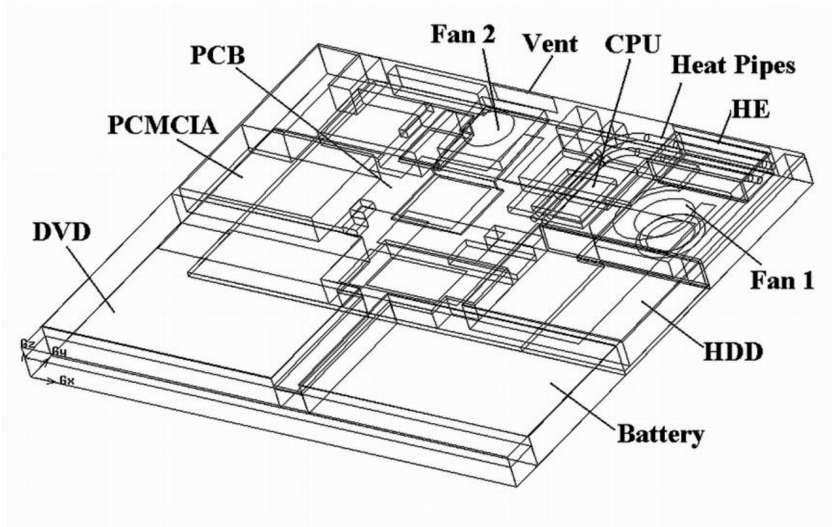


Figure 2.1: Computational domain (Tari and Yalzin ,2010)

Table 2.1: Heat dissipation values, average and hot spot temperatures of the components (Tari and Yalzin, 2010)

Component	CASE Heat Dissipation (W)					T_{max} (°C)	CASE CFD Avg. T (°C)					CASE CFD Hot spot T (°C)				
	I	II	III	IV	V		I	II	III	IV	V	I	II	III	IV	V
CPU	21	21	21	30	30	100	53.5	53.9	54.6	65.6	67.1	57.8	58.2	58.9	71.8	73.2
RAM	0.5	0.5	0.5	0.5	0.5	70	43.2	44.3	47.2	50.0	54.9	45.7	46.6	48.2	54.3	57.7
HDD	5	5	5	9	9	60	47.9	49.5	49.9	61.2	64.3	49.1	50.7	50.9	63.6	66.6
Graphics card	2	2	2	2	2	85	44.8	45.3	47.7	49.9	53.4	45.2	45.7	48.3	50.4	53.9
South bridge	0.5	0.5	0.5	0.5	0.5	85	43.8	44.5	46.9	49.9	53.6	44.2	44.9	47.2	50.8	54.5
PCMCIA	1	1	1	1	1	70	40.8	41.5	45.6	45.2	50.4	41.4	42.1	46.1	46.2	51.4
DVD	0	0	5	0	5	60	35.3	36.4	47.2	38.6	51.2	41.3	42.9	48.5	48.0	54.4
Battery	0	2	0	0	2	55	34.9	42.0	37.4	39.4	48.5	45.0	47.3	47.3	55.6	59.9
PCB	0	0	0	0	0	70	43.2	44.1	46.8	50.0	54.4	57.1	57.6	58.2	69.8	72.3
TOTAL	30	32	35	43	50											

2.3 EXPLORING ANSYS SOFTWARE

ANSYS FLUENT software is a state of the art computer program for modeling fluid flow, heat transfer, and chemical reactions in any type of geometries that exists. ANSYS FLUENT software contains the broad physical modeling capabilities for models flow, turbulence, heat transfer, and reaction for industrial application ranging from air flow over an aircraft wing to combustion in a furnace, from bubble column to oil platforms, from blood flow to semiconductor industry. Nowadays, thousands of companies around the world benefits from the use of ANSYS FLUENT software as a medium to design and optimization phases of their product development. Advanced solver technology provides fast, accurate CFD result, flexible moving and deforming meshes, and superior parallel scalability. User-defined functions allow the implementation of new user models and the extensive customization of existing ones. The interactive solver setup solution and post-processing capabilities of ANSYS FLLUENT make it easy to pauses a calculation, examine results with integrated post-processing, change any setting or parameter, and then continue the calculation within a single application. The integration of ANSYS FLUENT to ANSYS Workbench provides users with superior bi-directional connections to all major CAD system, powerful geometry modification and creation with ANSYS DesignModeler technology, and advanced meshing technologies in ANSYS Meshing. This platform allows any data and result to be shared between applications using an easy drag and drop transfer method.

ANSYS FLUENT is programmed in the C computer language and makes full use of the flexibility and power offered by the language. Consequently, true dynamic memory allocation, efficient data structures, and flexible solver control are all possible. In addition, ANSYS FLUENT uses a client or server architecture, which enables it to run as separate simultaneous processes on users desktop workstations and powerful computer servers. This architecture allows for efficient execution, interactive control, and complete flexibility between any types of operating systems. The ANSYS FLUENT serial solver manages file input and output, data storages, and flow field calculations using a single solver process on a single computer. ANSYS

FLUENT also uses a utility called cortex that manages ANSYS FLUENT's user interface and basic graphical functions. ANSYS FLUENT's parallel solver enables user to compute a solution using multiple processes that may be executing on the same computer, or on different computers in a same network. Plus, parallel processing in ANSYS FLUENT involves an interaction between ANSYS FLUENT, a host process, and a set of compute-node processes. ANSYS FLUENT interacts with the host process and the collection of compute nodes using the cortex user interface utility

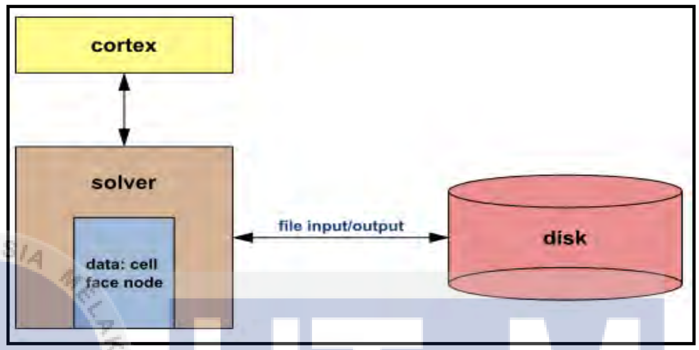


Figure 2.2: Series ANSYS FLUENT Architecture (Bauer, 2011)

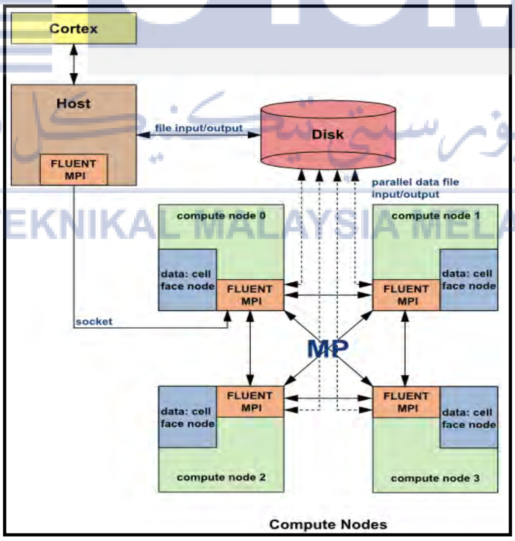


Figure 2.3: Parallel ANSYS FLUENT Architecture (Bauer, 2011)

2.4 PIPE ELBOW TURORIAL

2.4.1 PROBLEM DESCRIPTION

The problem to be considered is shown in **Figure 2.4**. A cold fluid at 293.15 K flow into the pipe through a large inlet, and mixes with a warmer fluid at 313.15 K that enter through smaller inlet located at the elbow. There are three flow materials with different properties as shown in **Table 2.2** that used for this problem including water, kerosene and air.

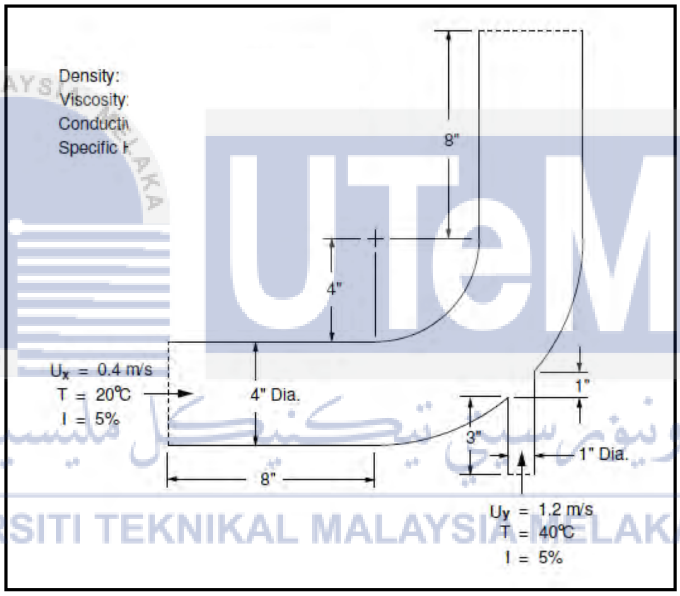


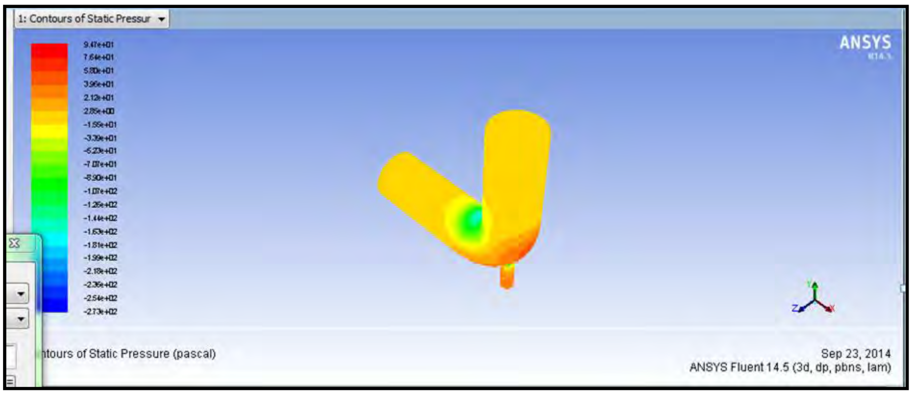
Figure 2.4: Pipe elbow specification (Stephane Guillet, 2009)

Table 2.2: Flow material properties

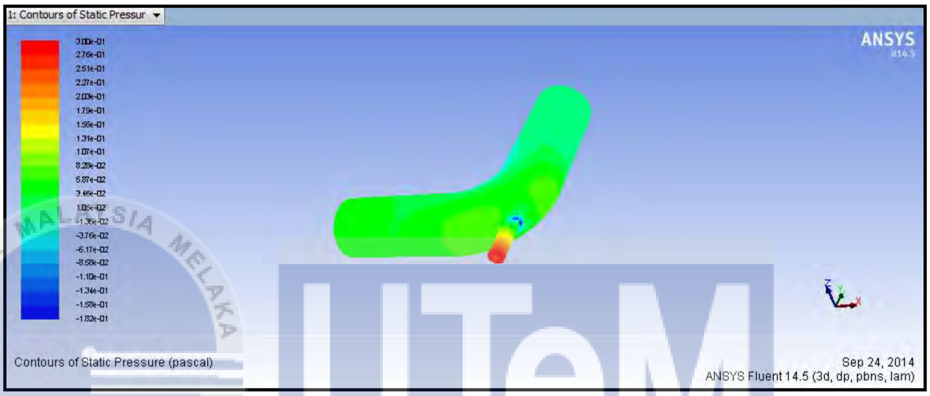
Flow material / Properties	Water	Air	Kerosene
Density, kg/m^3	1000	1.225	823
Specific heat, J/kg.K	4216	1006.43	2000
Conductivity, W/m.k	0.677	0.0242	0.15
Viscosity, Kg/m.s	8×10^{-4}	1.789×10^{-5}	$^{15.6}\ \times 10^{-4}$

2.4.2 ANSYS FLUENT WORKBENCH FOR PIPE ELBOW

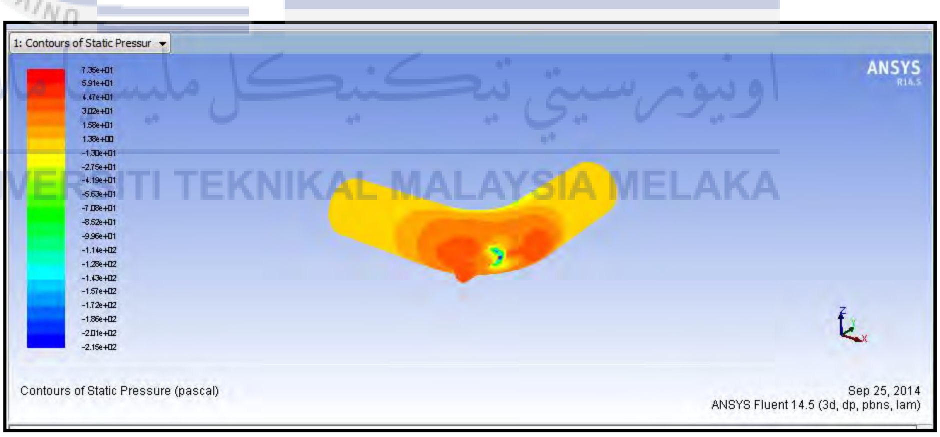
In this study, ANSYS FLUENT Workbench was used to set up and solve a three-dimensional turbulent fluid flow and heat transfer problem in a mixing elbow using fluid flow system. Within this study, pipe elbow geometry was created, the corresponding computational mesh using the geometry and meshing tools within ANSYS Workbench. Then, use ANSYS FLUENT to set up and solve the CFD problem. Next, visualize the result in this software and study heat flow inside the model. At the end of this study, compare and analysis the result for each flowing material. Procedures that involve while investigate for this study will show in **Appendix A. Figure 2.5** and **2.6** shows the result of this tutorial.



(a)

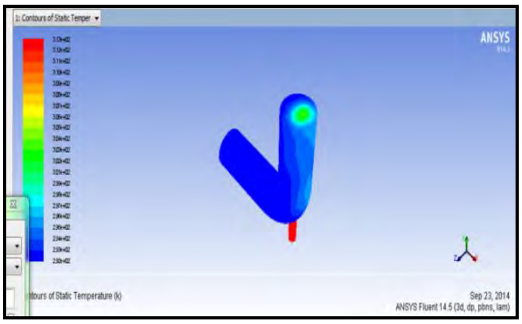


(b)

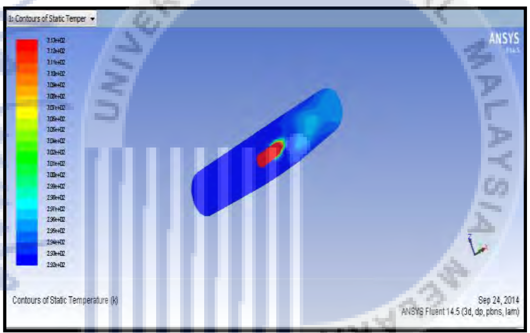


(c)

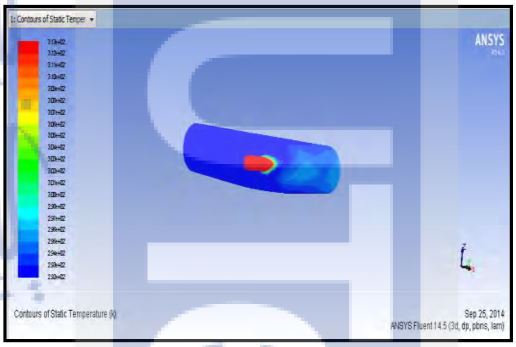
Figure 2.5: Contours of pressure for (a) water, (b) air and (c) kerosene



(a)



(b)



(c)

Figure 2.6: Contours of temperature for (a) water, (b) air and (c) kerosene

Each material that flow inside pipe elbow have difference flow heat rate. Based on **Figure 2.5** and **2.6**, water that flow inside model cause higher pressure compare to kerosene and air. There are no much different of temperature inside model between water and air but water transfer heat greater compare to air and kerosene.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter discussed about methodology used to develop the project from initial stage to the final stage. There are several stages need to be done in order to complete this project including literature study, research and development of the portable power supply, exploring ANSYS software and analysis of heat transfer of the model.

3.2 PROJECT FLOW CHART

In this project, a lot of study and research from literary resources are needed as reference to perform the project. The study will focus on the thermal system of the portable power supply using ANSYS software.

Figure 3.1 show the flow chart for this final year project. Firstly, for Final year project 1, the title of the project has been giving by supervisor. The process continues with discussion with supervisor about title and task that need to be done. Then, project will progress step by step from developing CFD model, changing parameter to the study of heat transfer of the model. There are also Seminar 1 that need to be attend during FYP 1. In addition, at week 15 presentation will be done and report need to be submitted at the week 15. If all of this process succeed and approved by the supervisor, this project will proceed to FYP 2. Experiments have been done to get the data and proceed to the next stage. Then, CFD model is develop and compare the result with experiment. A seminar been held to presenting the finding of the project and submit the report.

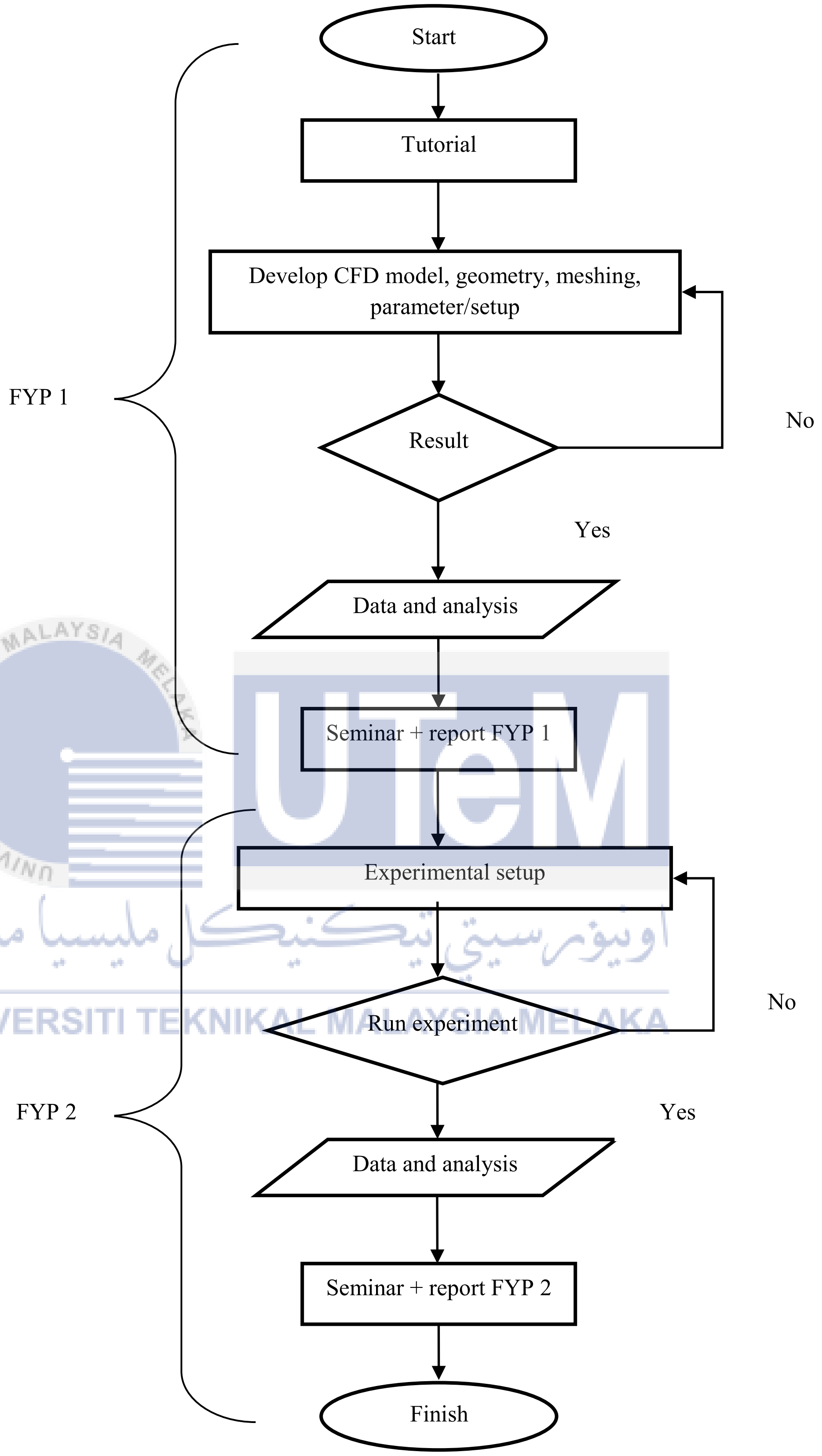


Figure 3.1: Flow chart

3.3 PORTABLE POWER SUPPLY

Portable power supply as shown in **Figure 3.2** is a products that convert solar energy into electrical energy. This product use Nicd battery that recharge by solar energy and the energy is convert from direct current (dc) into alternate current (ac). This product use 12 V battery and can produce 240 V power. The development of portable power supply that uses solar energy as energy source has been studied for many years to get improvement in order to replace power generator that use fuel as energy source. Power generator becomes quite famous back then. But, today the disadvantages of power generator become main issue as the technology in portable power supply rise. Power generator used fuel as energy source emit pollutant such as carbon monoxide, carbon dioxide and requires maintenance which is expensive. Therefore, portable power supply using solar energy has been developed from time to time in order to meet consumer demand and cater the environmental issue.

Figure 3.2: Portable power supply

This product is a hand held electronic device housed in a completely sealed enclosure. The cooling system primarily relies on natural convection and the effective of heat removal is quite low. Any electronic component will produce heat while operating. Plus, there are temperature limit for each component to function properly to avoid failure or damage. In order to improve the efficiency of heat removal management, a few modification of model design were made before developing CFD model for simulation. Fan blower as shown in **Figure 3.3** was used in this project as one of modification that was made. The fan will be placed on the front and at the back of the model. Airflow velocity of the fan is measured by using anemometer and this shown in **Appendix B**.

Figure 3.3: Laptop cooler pad

Table 3.1: Specifications of Fan model

Specification	Value
Size	50 mm x 50 mm
Operating voltage	5 V
Airflow	1.7- 2.2 m/s
Static pressure	1.29 mm/ H20
Sound level	23 dBA

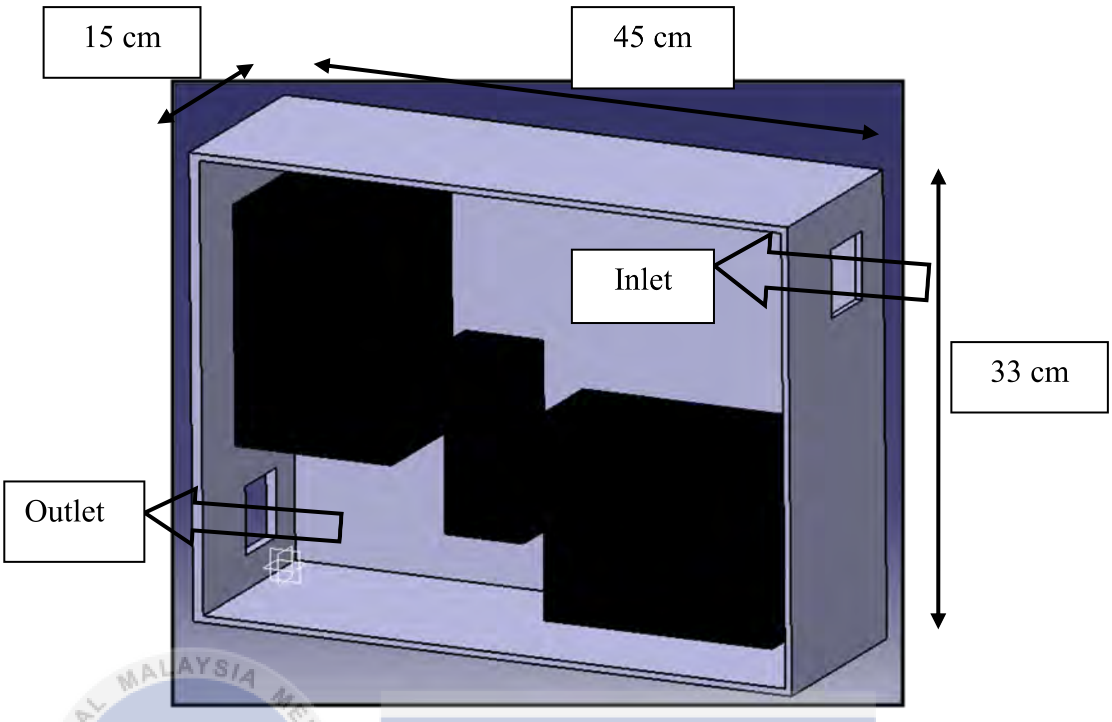


Figure 3.4: Sketch of the model 3

3.4 ANSYS FLUENT WORKBENCH

ANSYS FLUENT software is fully integrated into the ANSYS Workbench environments, the framework for the full engineering simulation suite of solutions from ANSYS. Its adaptive architecture enables users to easily set up any problem from standard fluid flow analyses to complex interacting systems with simple drag-and-drop operations. Plus, users can easily assess performance at multiple design points or compare several alternative designs. Within ANSYS Workbench, applications from multiple simulation disciplines can access tools such as CAD connection, geometry and meshing tools. Generally, there are four main stages in ANSYS FLUENT Workbench:

1. Geometry
2. Mesh
3. Setup solution
4. Result

For this project, there are three models that develop which are model 1, model2, and model 3. All of these models have same casing dimension but different interior design which show in **Figure 3.6**, **3.7**, and **3.8**. Plus, model 1 and model 2 have same boundary condition as shown in **Table 3.4**. But, for model 3 the boundary condition is base on the experiment and shown as **Table 3.5**. Model 1 and model 2 are developed to determine which model is better heat removal design. Model 3 is made to compare with experiment result in order to study the heat flow in PPS.

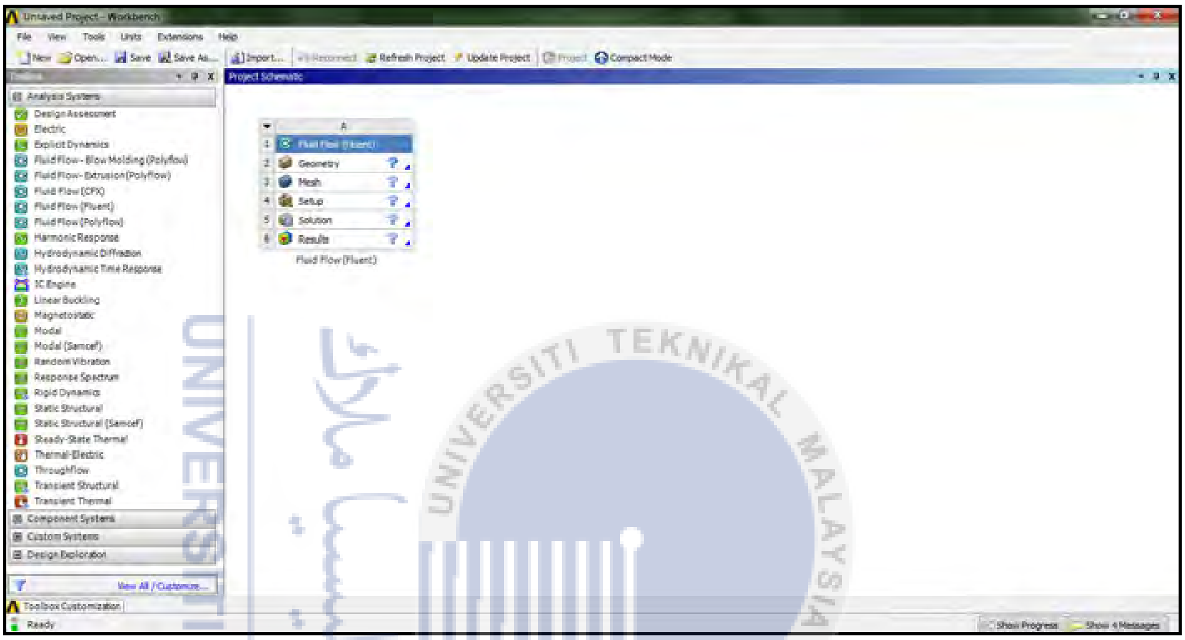


Figure 3.5: ANSYS FLUENT Workbench interface

3.4.1 GEOMETRY

The first stage in ANSYS FLUENT Workbench is design modeler which can be called as geometry. Geometry was utilized to draw the model which is portable power supply showing in **Figure 3.6**, **3.7** and **3.8**. This task of drawing can also be done using other commercial computer aided drawing software that compatible with ANSYS FLUENT software like AutoCAD, Solidwork, Unigraphic and many others. In order to speed up the solution, the model must be made small and simple, but must also meet the required shape of the model. This is due to the smaller the model, the lesser the meshing node and element required for calculation. The mesh grid quantity will directly impact to the duration of the solution.

Table 3.2: Model 1 and model 2 battery position

Model	Window position	Battery position
1	Upper	Rear
2	Upper	Middle

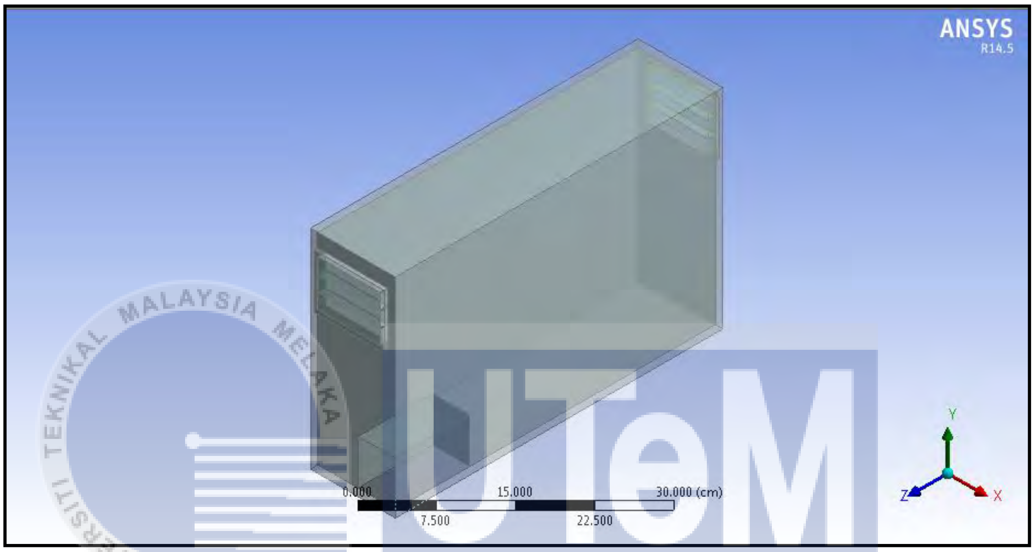


Figure 3.6: Model 1

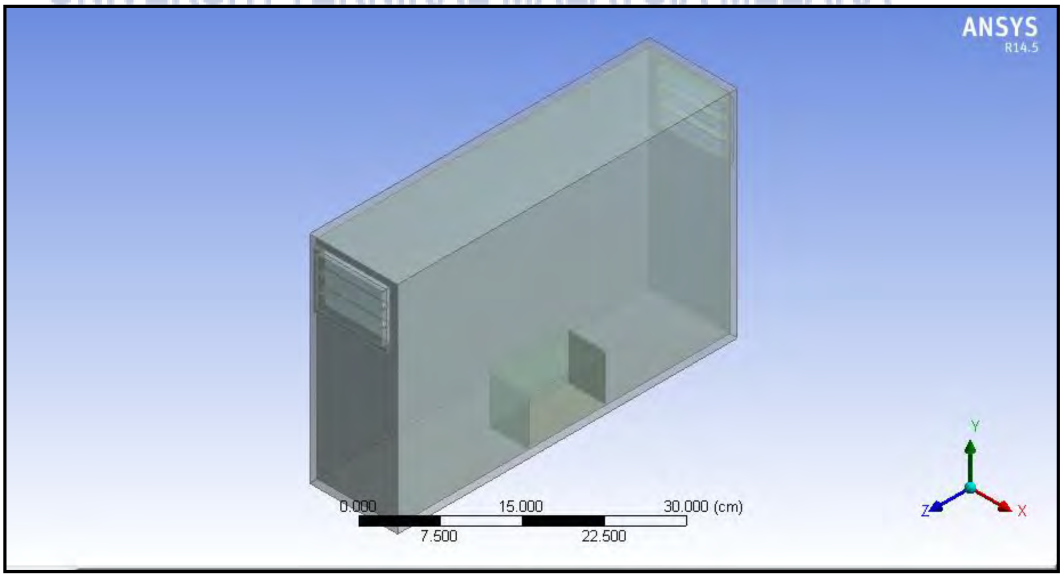


Figure 3.7: Model 2

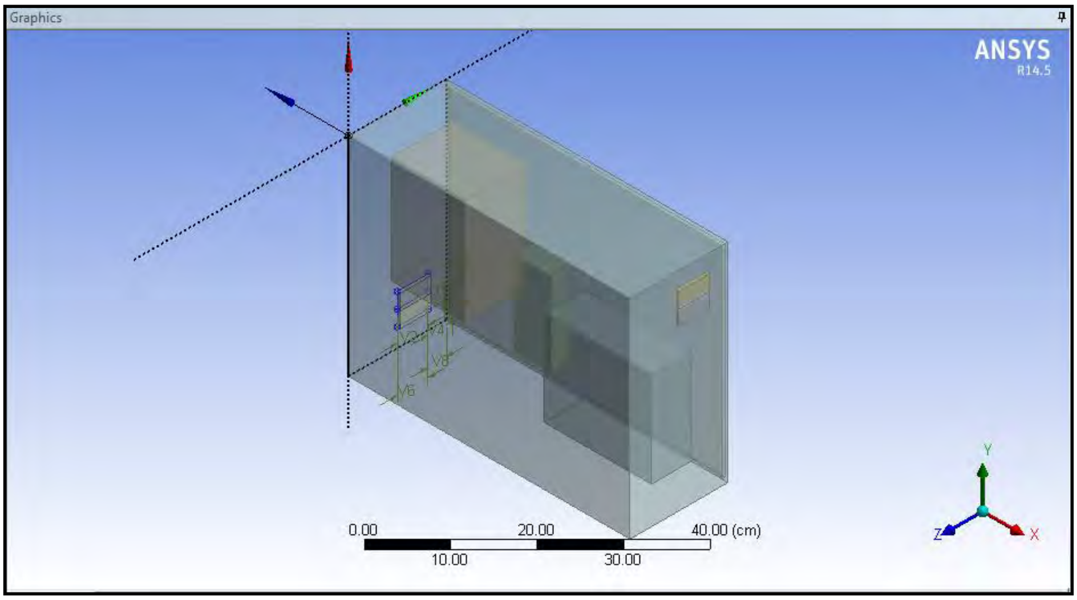
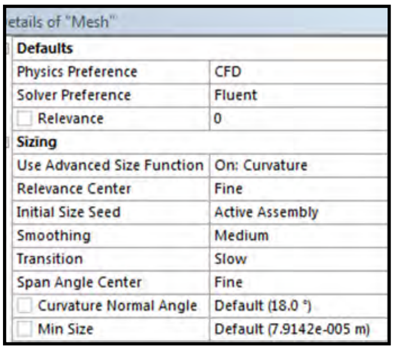


Figure 3.8: Model 3

3.4.2 MESH

Second stage of the CFD process is model meshing. The quality of meshing will be determined by the technique used for meshing. Meshing will create grid or cells of elements which all the desired fluid flow equations to be solved. The size of the grid will give significant impact to the computational time or Central Processing Unit (CPU) time which directly involves cost of the simulations. The grid also will give significant effect on the convergence speed and the solution accuracy. Inflation is very important for the new wall area or boundary layer mesh. In this project, meshing steps are same for all models that develop. Basically, there are four important parts in meshing stage for this project which shown as **Figure 3.9**, **3.10**, **3.11** and **3.12**.

1. Meshing sizing parameter setting



etails of "Mesh"	
Defaults	
Physics Preference	CFD
Solver Preference	Fluent
Relevance	0
Sizing	
Use Advanced Size Function	On: Curvature
Relevance Center	Fine
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Slow
Span Angle Center	Fine
Curvature Normal Angle	Default (18.0 °)
Min Size	Default (7.9142e-005 m)

Figure 3.9: Detail of Mesh

2. Generate meshing

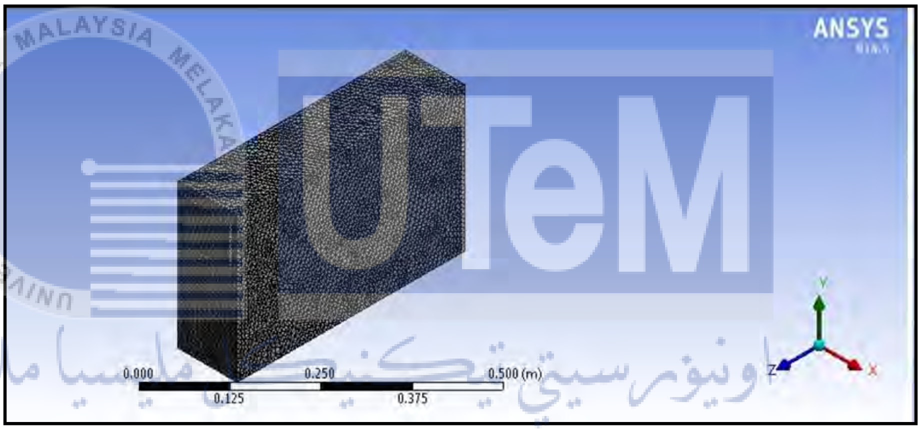


Figure 3.10: Generate meshing for model

3. Select and naming inlet and outlet

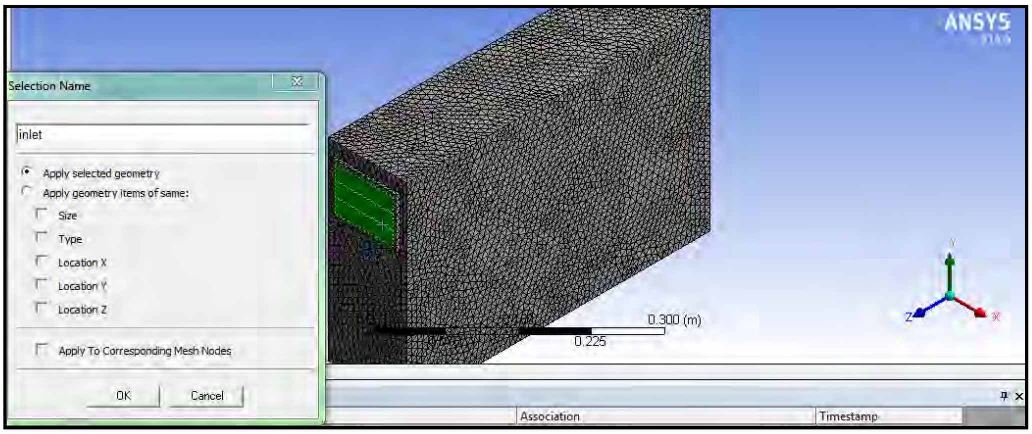


Figure 3.11: Select and naming inlet for model

4. Naming component of the model

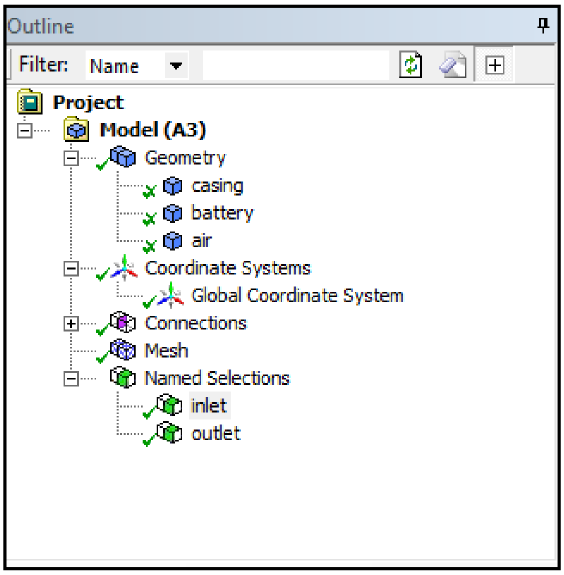


Figure 3.12: Naming each inlet/outlet and each components geometry

3.4.3 SETUP SOLUTION

Setup solution is important stage in ANSYS FLUENT. Setup solution is where the user applies operating condition, boundary condition, material properties and many others. Setup solution must be handles properly so that the result is appropriate and accurate. Setup solution for this project is showing in **Figure 3.13**, **3.14** and **3.15**. The setting for models is important since these parameters setting is related to the simulations condition including energy, radiation, turbulent viscous and species. These parameters are required to make the CFD simulation close to the real model in real environment. The model may be solved using either single or double precision. If double precision used, the solution will be slower but more precise. There were few parts in setting up the solution for this project. The setup solutions are same for all models used in this project.

1. MODEL SETTING

I. Energy equation must be turn on

- The energy equation must be turned on since the flowing material inside model is compressible which is air. Plus, the temperature of air is not constant and changing while flowing inside the domain

II. Enable radiation

- Any electronic component will produce heat while operate. The main heat source of the portable power supply is battery, adapter and inverter. The temperature of the battery can reach up to 60 °C. Heat will dispersed inside the model by convection and small amount of radiation.

III. Enable k-epsilon turbulence

- K-epsilon (k-*e*) turbulence model is commonly used in CFD to stimulate mean flow characteristics for turbulent flow condition. K-epsilon model has been shown to be useful for free-shear layer flows with relatively small pressure gradients. Besides that, k-epsilon was also used for wall-bounded and internal flows model. These characteristic are very compatible to portable power supply model used in this project.

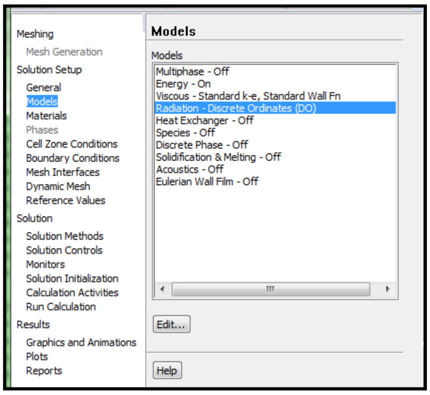


Figure 3.13: Model settings

2. EDIT/ CREATE MATERIAL

Type of material used in the model is an important criterion because each material have different density, specific heat, thermal conductivity, and viscosity. Heats transfers for each material are different and appropriate material need to be chosen to be that identical to the real model. So, the CFD result will be precise and accurate. **Table 3.3** show the material used in this project.

Table 3.3: Properties of materials for each component

Material	**Component**	**Density, kg/m^3**	**Specific heat, J/kg.K**	**Thermal conductivity, W/m,K**	**Viscosity, kg/m.s**
Abs plastic	Casing	721	1423.5	0.18	0
Steel	Battery, adapter and inverter	8030	502.48	16.27	0
Air	Flow material	1.255	1006.43	0.0242	1.789×10^{-5}

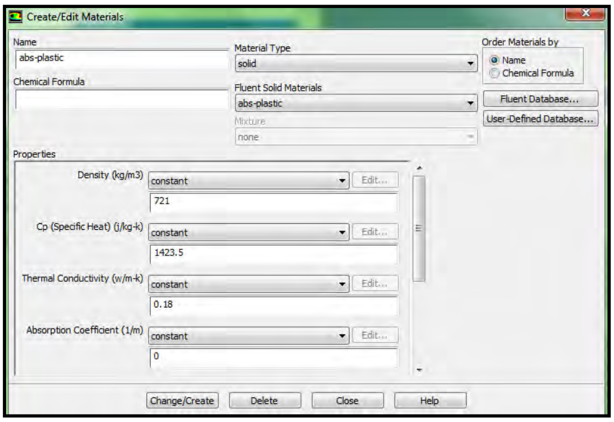


Figure 3.14: Create abs-plastic material

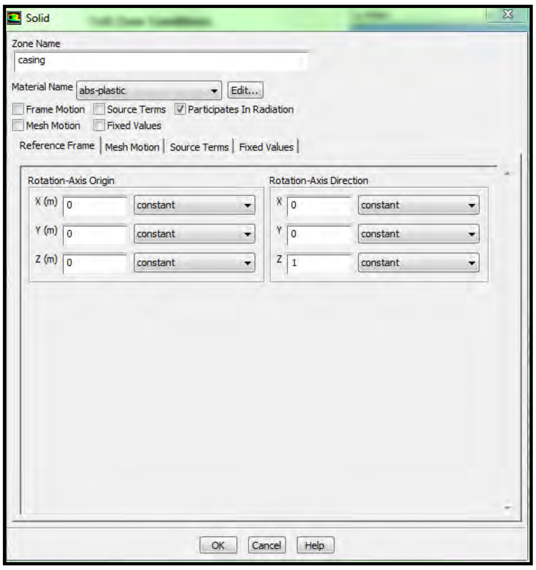


Figure 3.15: Select abs-plastic material for casing

3. BOUNDARY CONDITION

Boundary condition is the critical part of the model setup where parameter of inlet and outlet were changed. Any mistake occurs in this part will affect the results. Model 1 and model 2 have same boundary condition and this shown as **Table 3.4.** For model 3, boundary condition was made base on the experiment and this is shown as **Table 3.5**.

Table 3.4: Boundary condition for model 1 and model 2

BOUNDARY CONDITION	VALUE
Battery temperature	60 °C / 333 K
Inlet velocity	1.6 m/s
Outlet velocity	1.6 m/s

Table 3.5: Boundary condition for model 3

BOUNDARY CONDITION	VALUE
Battery temperature	40 °C / 313 K
Inverter temperature	40 °C / 313 K
Adapter temperature	43 °C/ 316 K
Inlet velocity	1.7 m/s
Outlet velocity	2.2 m/s

4. SOLUTION

After all setup solution was edited and changed, the model was run for calculation. For this part, the number of iteration plays an important role. Iteration is a repetition of computational procedure applied to the model. The greater the number of the iteration, the closer approximate of result that obtain. The greater the number of iterations, the longer time take to obtain the result. But, the result will be more precise and accurate depending on the residual setup. For this project, the number of iteration is set to 100.

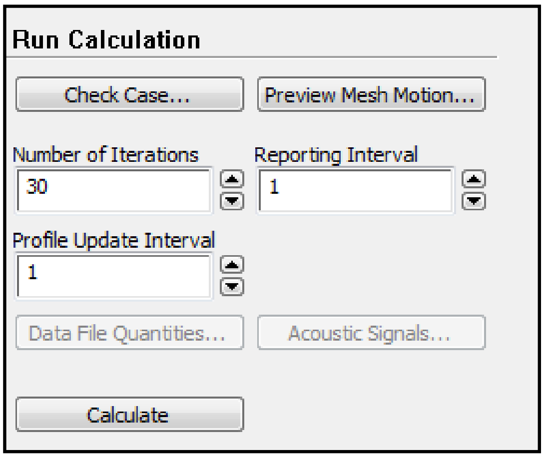


Figure 3.16: Run calculation

3.5 EXPERIMENTAL SETUP AND PROCEDURE

To achieve the objectives of this project, an experimental study must be carried out to study heat transfer inside the Portable power supply.

3.5.1 THERMOCOUPLE POSITION

Thermocouple is chosen as the sensor used to determine to temperature inside PPS for this experiment. 8 thermocouples are placed inside PPS at different point in order to study heat transfer in this product and this is shown by **Figure 3.17**.

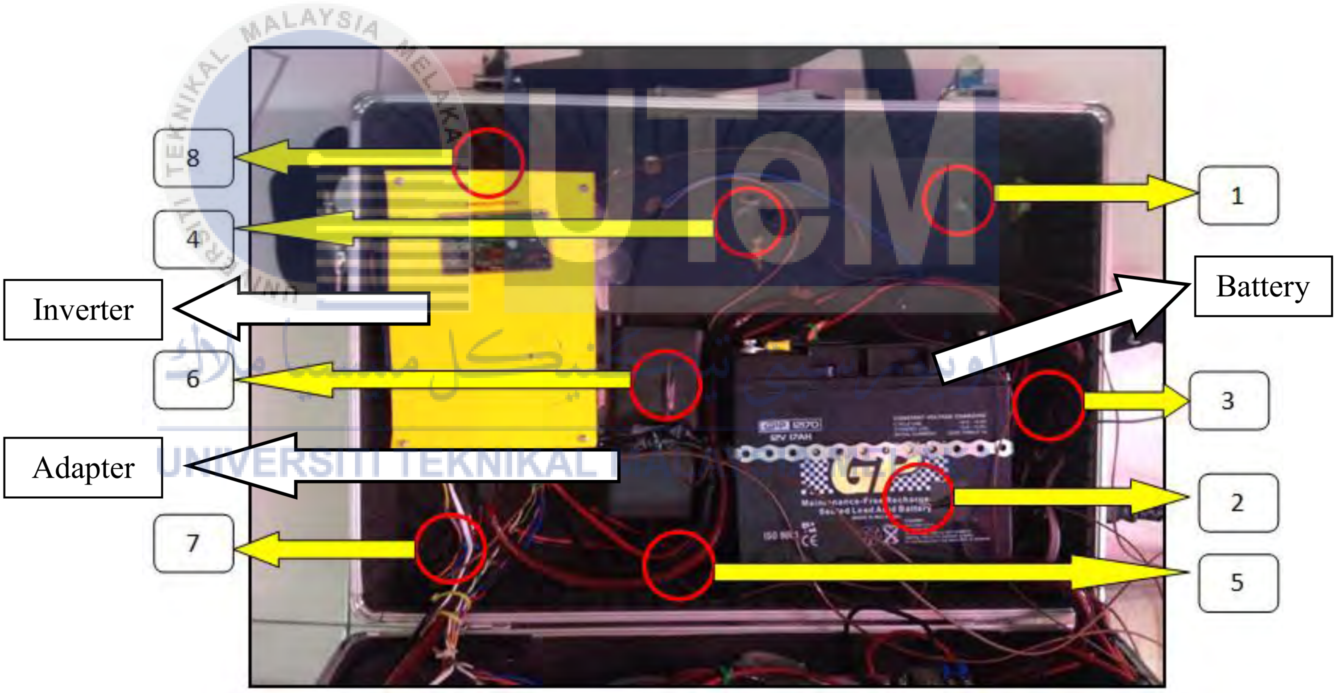


Figure 3.17: 8 points of thermocouples inside PPS

3.5.2 PICOLOG RECORDER SOFTWARE SETUP

Thermocouple will be connected to the PicoLog device and then the device will be connected to the laptop by using USB cable. Before experiment start, the setting of the software must be set first. This software function is to record the temperatures using thermocouples. **Figure 3.18**, **3.19** and **3.20** will show the steps of software settings.

1. The channel must be set to 8 channels for 8 thermocouples.

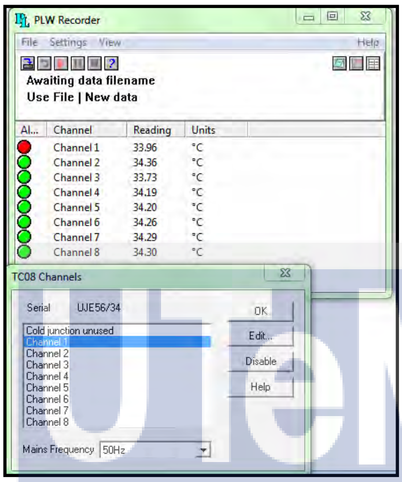


Figure 3.18: Insert channel

2. The software was set to record the temperature for each 5 minutes for 3 hours.

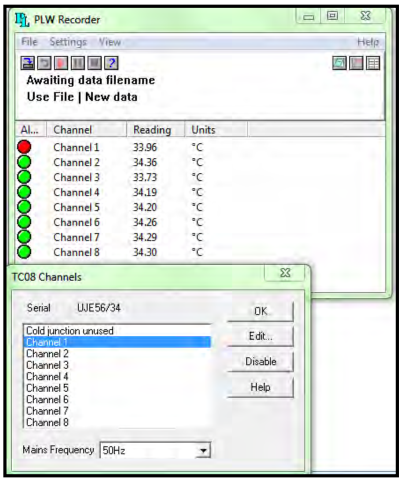


Figure 3.19: Sampling

3. The experiment was run
4. The data collected after the experiment finished.

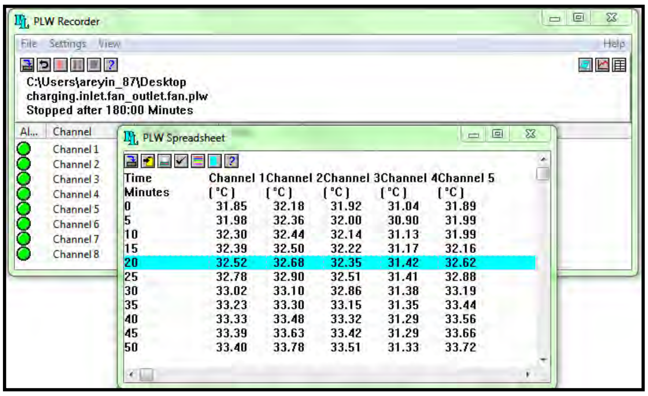


Figure 3.20: Data collected

3.6.3 EXPERIMENTAL SETUP

Figure 3.21 show the experiment setup that has been developed to conduct experiment for this project. The experiment need to use a laptop to run the software called PicoLog Recorder. First, 8 thermocouples will be placed inside PPS at 8 different points. Then, thermocouple will be connect to PicoLog device and the PicoLog device will be connected to the laptop by an USB cable wire to establish connection between software and thermocouples. Then, the experiment will be run for 3 hours inside normal room condition. The temperatures inside the product are determined under two conditions; charging and discharge. **Figure 3.22, 3.23, 3.24, 3.25, 3.26** and **3.27** shown the experiments conducted for this project:

1. Stage 1 (Before hollowing)
2. Stage 2 (After hollowing)
   - Inlet open, outlet closed
   - Outlet open, inlet closed
3. Stage 3 (With fan)
   - Inlet fan, outlet open
   - Inlet open, outlet fan
   - Inlet fan, outlet fan

Figure 3.21: Experiment setup

1. EXPERIMENT STAGE 1 (BEFORE HOLLOWING)

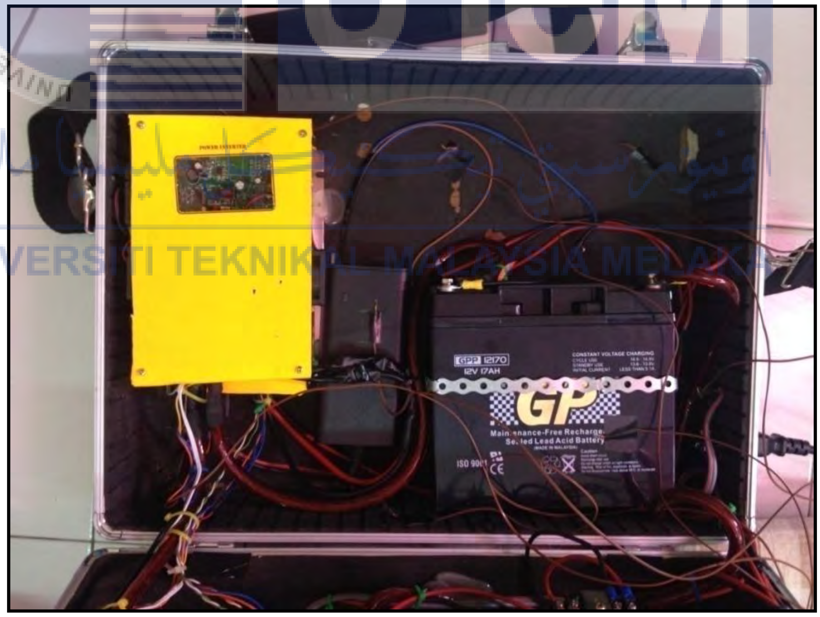


Figure 3.22: Experiment inlet closed, outlet open

2. EXPERIMENT STAGE 2 (AFTER HOLLOWING)

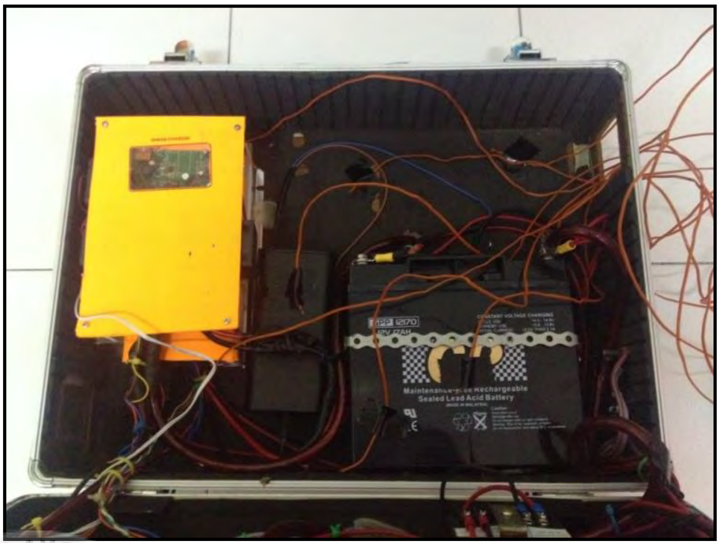


Figure 3.23: Experiment inlet open, outlet closed

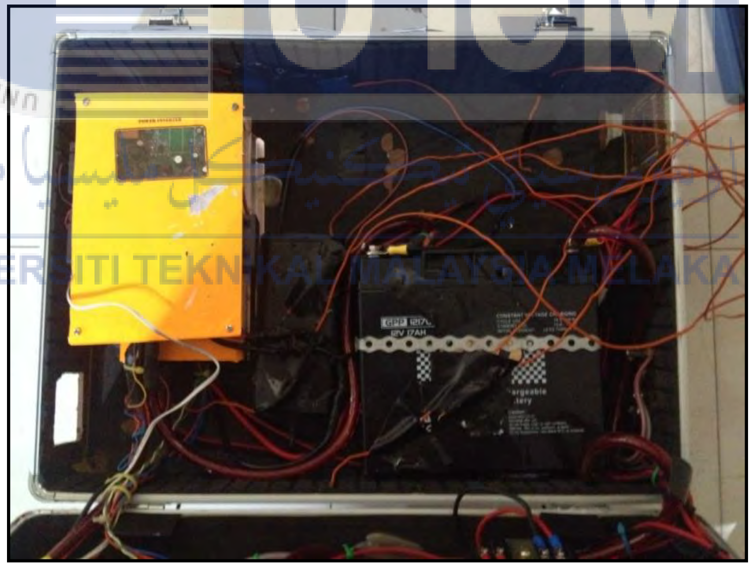


Figure 3.24: Experiment inlet closed, outlet open

3. EXPERIMENT STAGE 3 (WITH FAN)

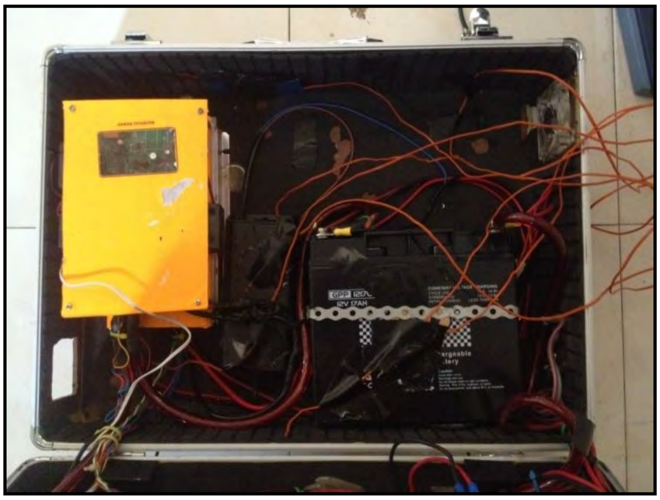


Figure 3.25: Experiment inlet fan, outlet open

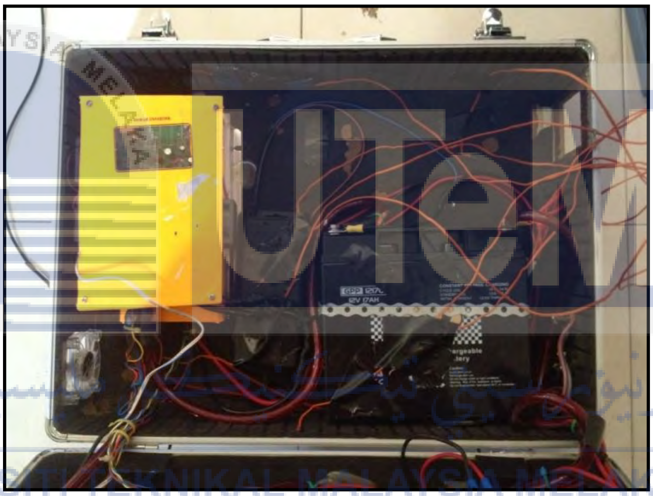


Figure 3.26: Experiment inlet open, outlet fan

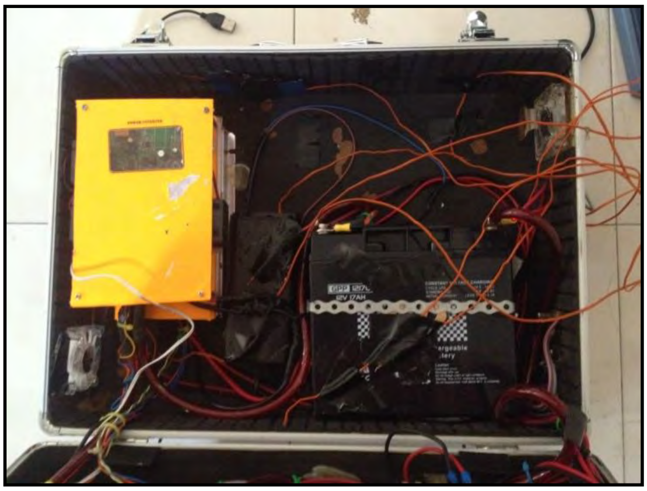


Figure 3.27: Experiment inlet fan, outlet fan

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

For this chapter, the analysis of the result will be shown and discussed thoroughly. This chapter will cover the result from CFD and all the experimental study performed.

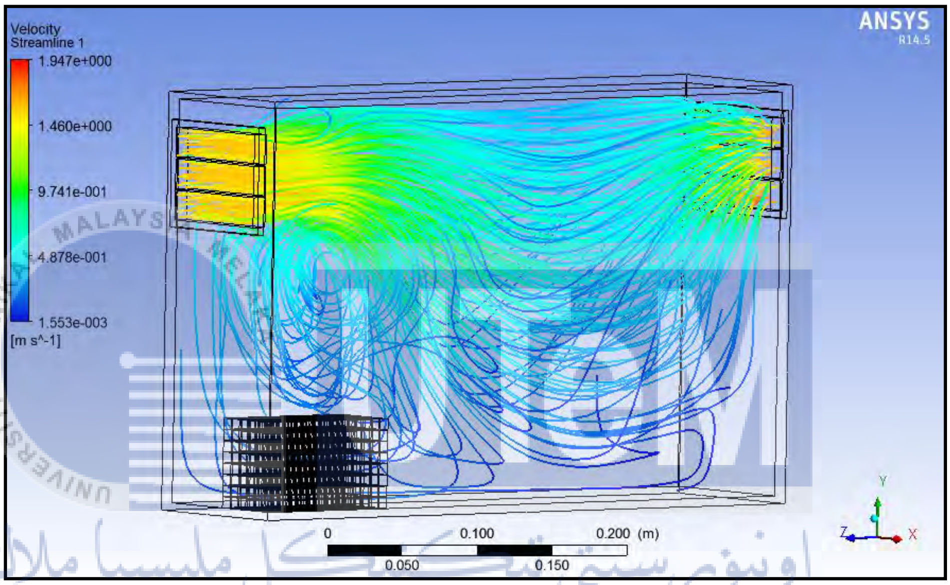
4.2 PROBLEM ANALYSIS

ANSYS software is the advanced software used in engineering industry. Developing CFD model of PPS is very challenging. The hardest part of this software is to setup the solution. Setup solution must be handles properly so that the result is appropriate and accurate. The setting for models is important since these parameters setting is related to the simulation of CFD close to the real model in real environment.

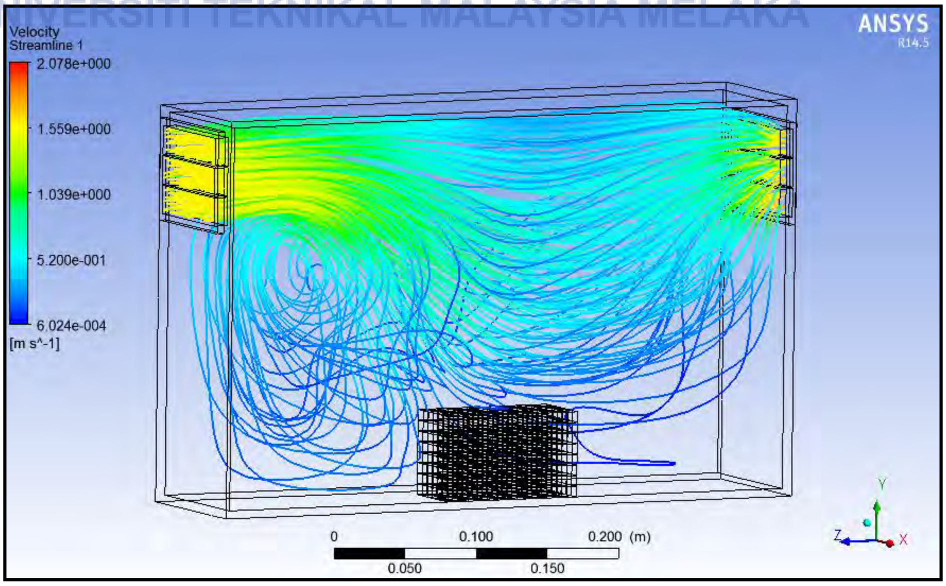
When performing experiment for this project, there were a few problems that occurred. The experiment must be conducted inside a normal room condition and there are few things that need to be controlled such as fan existence and closed room. But, there are few things than human cannot control such as weather. Rain will change the air humidity and this will affect the data collected. In addition, there are also a day that is hotter than normal day Thus, to reduce error for the data that collected, the experiment only perform on fine days.

4.3 ANSYS WORKBENCH RESULT

There are three models develop for these projects which are model 1, model 2 and model 3. Model 1 and model 2 use battery position as manipulative variable to determine which model have better heat removal system and this shown as **Figure 4.1** and **Figure 4.2**. Result of model 3 as shown in **Figure 4.3** will compare to the experiment in order to analysis heat flow inside PPS. The comparison between model 3 CFD result and experiment was shown as **Figure 4.10.**

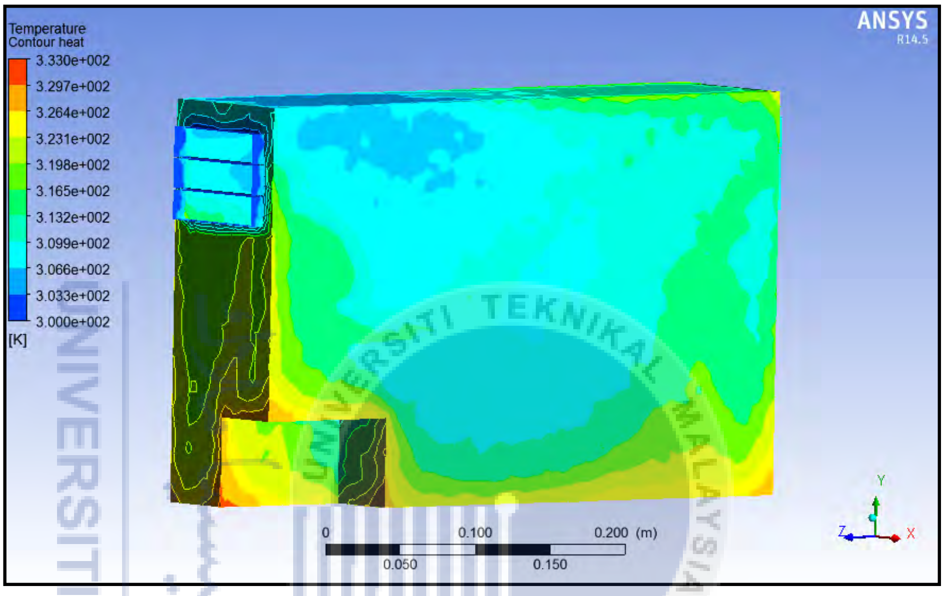


(a)

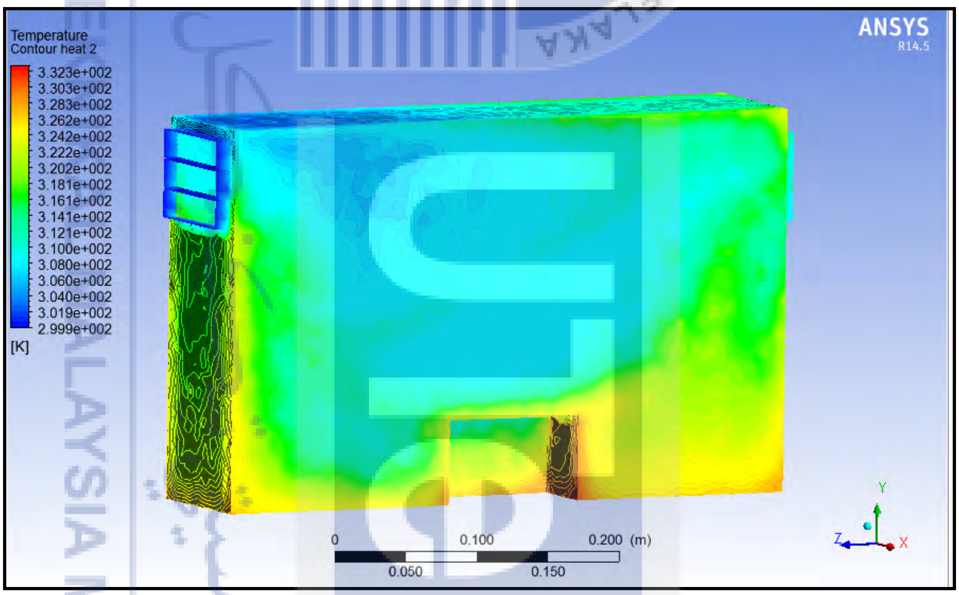


(b)

Figure 4.1: Pathlines of vector for (a) model 1, (b) model 2



(a)



(b)

Figure 4.2: Contours of heat for (a) model 1 and (b) model 2

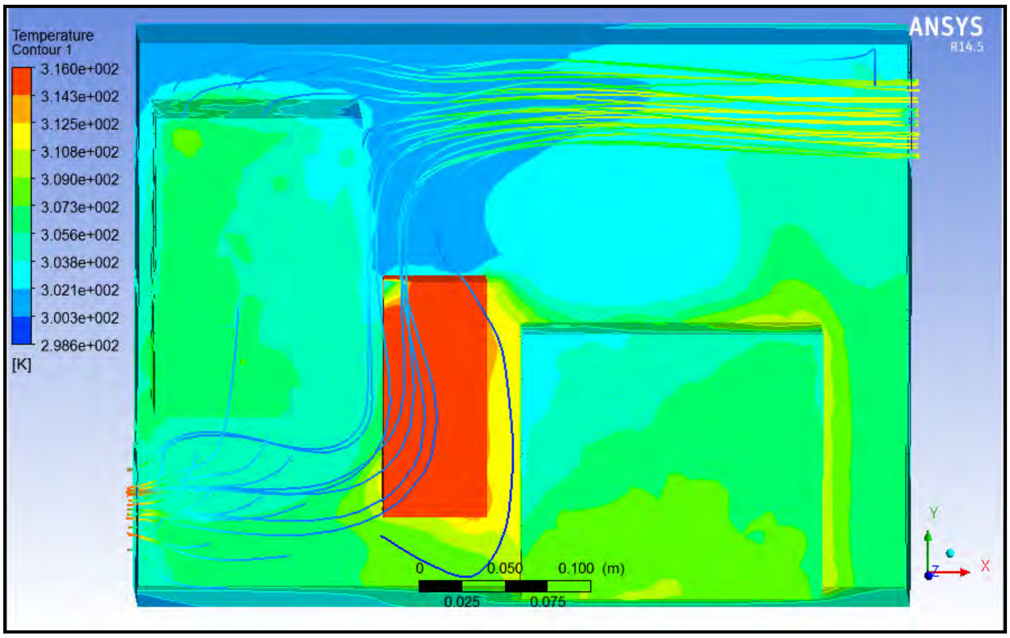


Figure 4.3: Contour of heat for model 3

4.3.1 CFD MODEL ANALYSIS

Portable power supply model was modeled and CFD simulated by using ANSYS FLUENT software. Based on **Figure 4.1** which show pathlines of vector, both model have same behavior but there was slightly different in airflow velocity. Model 2 has faster air flow velocity compare to model 1. Battery position at the middle make the air movement smooth compare to rear battery position which is model 1. Based on the **Figure 4.2** which shows contours of heat, both model have different heat flow. For model 1, there is more heat accumulated inside the model 1 than model 2. Due to rear battery position, air tends to flow backward inside the model. The highest temperature recorded for model 1 is 60 ºC and for model 2 is 59 ºC . Based on the result obtained, model 2 has better thermal removal design than model 1.

4.4 EXPERIMENTAL DATA

As for the data acquisition, the data collected from the experiment has been recorded and presented in **Table 4.1** and **Figure 4.2**. **Appendix B** also shows the data collected for this project from the experiment.

Table 4.1: Temperature inside PPS at 180 minutes during discharge

Experiment	**Temperature, °C**							
	Point 1	**Point 2**	**Point 3**	**Point 4**	**Point 5**	**Point 6**	**Point 7**	**Point 8**
Inlet closed, outlet closed	33.22	37.12	33.48	36.87	38.9	39.7	39.14	40.39
Inlet open, outlet closed	36.23	35.67	34.54	29.7	36.49	37.03	36.33	37.26
Inlet closed, outlet open	38.17	37.48	36.67	38.16	38.24	39.2	37.1	39.28
Inlet fan, outlet open	35.8	35.35	34.72	35.69	35.6	36.07	35.21	36.56
Inlet open, outlet fan	35.32	34.65	34.38	31.42	34.73	35.29	33.18	35.41
Inlet fan, outlet fan	32.55	33.99	33.16	30.92	34.28	34.79	35.15	29.15

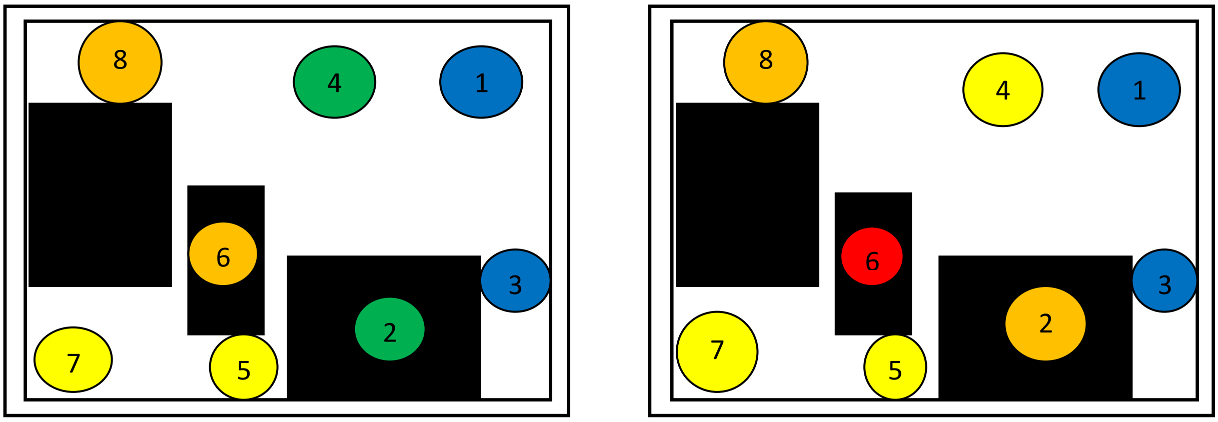
Table 4.2: Temperature inside PPS at 180 minutes during charge

Experiment	**Temperature, °C**							
	Point 1	**Point 2**	**Point 3**	**Point 4**	**Point 5**	**Point 6**	**Point 7**	**Point 8**
Inlet closed, outlet closed	32.77	39.96	32.74	39.41	38.9	43.06	37.9	40.53
Inlet open, outlet closed	38.09	37.19	35.77	30.2	36.64	38.78	35.09	37.69
Inlet closed, outlet open	37.49	36.15	36.84	37.65	35.63	38.94	33.95	38.01
Inlet fan, outlet open	33.73	35.24	33.13	32.67	32.59	34.09	32.4	33.96
Inlet open, outlet fan	33.31	33.65	32.93	30.88	32.19	34.56	31.97	34.7
Inlet fan, outlet fan	32.56	35.24	33.64	31.32	33.72	37.53	35.39	27.67

4.4.1 HEAT DISTRIBUTION AT 180 MINUTES OF EXPERIMENT (Top view)

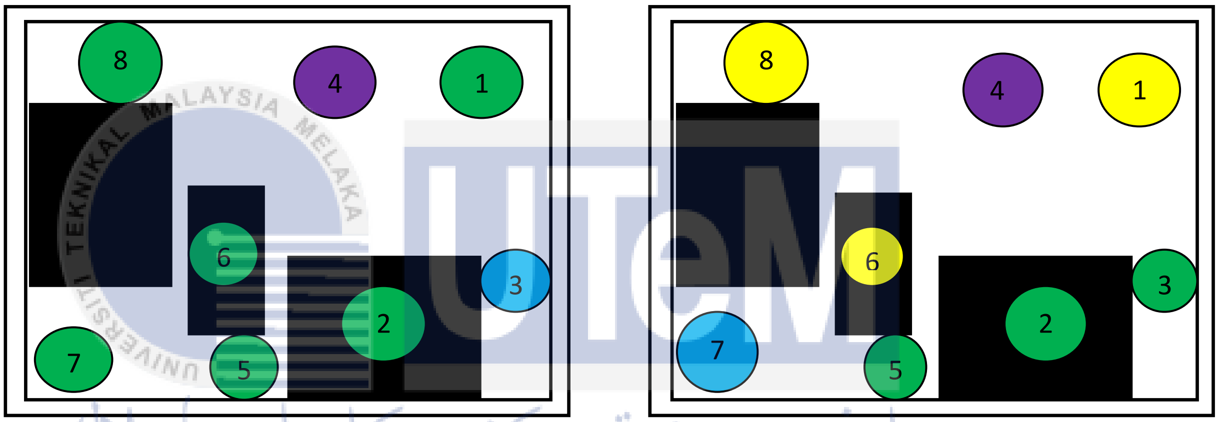
Table 7: Type of colour and temperatures

Colour		Temperature,ºC
Gray		26-27
Pink		28-29
Purple		30-31
Indigo		32-33
Blue		34-35
Green		36-37
Yellow		38-39
Orange		40-41
Red		42-43



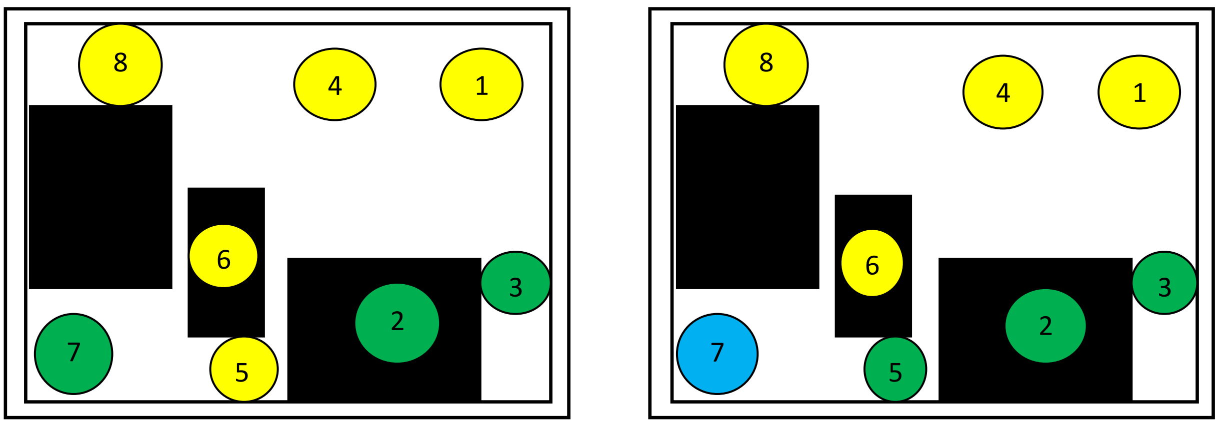
(a) (b)

Figure 4.4: Experiment inlet closed, outlet close (IC, OC) for (a) Discharge, (b) Charge



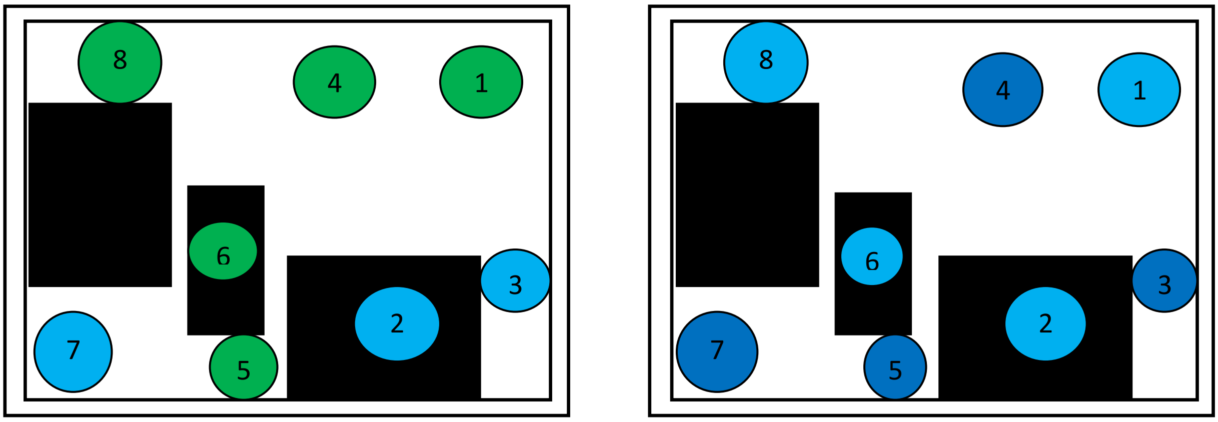
(a) (b)

Figure 4.5: Experiment inlet open, outlet closed (IO, OC) for (a Discharge, (b) Charge



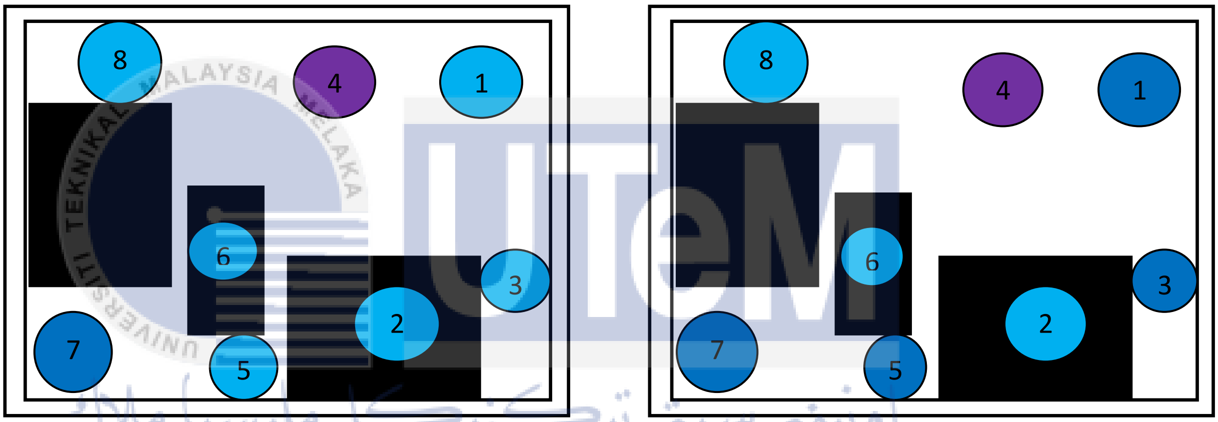
(a) (b)

Figure 4.6: Experiment inlet closed, outlet open (IC, OO) for (a) Discharge, (b) Charge



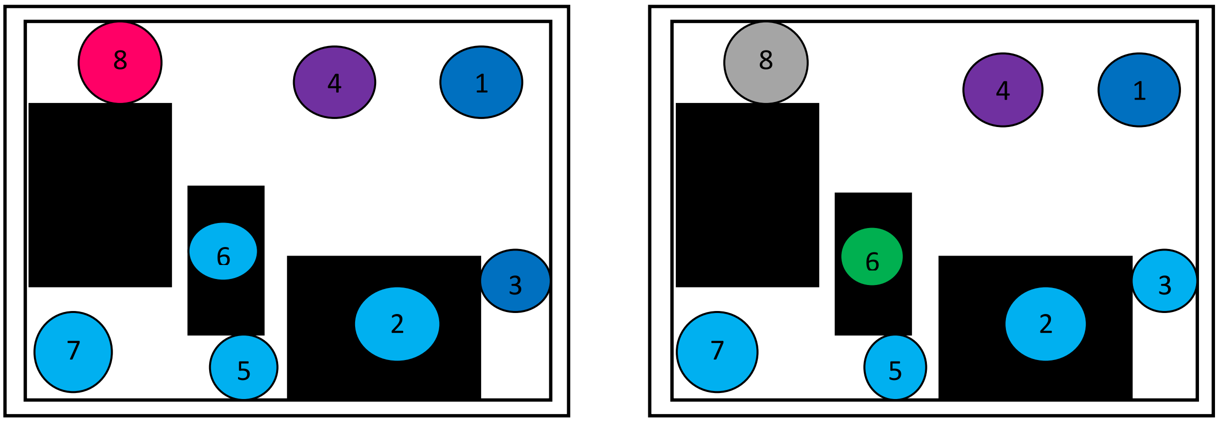
(a) (b)

Figure 4.7: Experiment inlet fan, outlet open (IF, OO) for (a) Discharge, (b) Charge



(a) (b)

Figure 4.8: Experiment inlet open, outlet fan (IO, OF) for (a) Discharge, (b) Charge



(a) (b)

Figure 4.9: Experiment inlet fan, outlet fan (IF, OF) for (a) Discharge, (b) Charge

Figure 4.4, 4.5, 4.6, 4.7, 4.8 and **4.9** show the temperature at each point inside PPS at 180 minutes after the start time of the experiment for both discharge and charging condition. The highest temperature recorded was at IC, OC experiment at point 6 for charging which is 43.06 ^{o}C. The lowest temperature recorded was at IF, OF experiment at point 8 for charging which is 27.67 ^{o}C. The figures show the decrement of the temperature inside PPS from the IC, OC experiment to IF, OF experiment.

Figure 4.4 show that IC, OC experiment does not have any efficient heat removal system. There are few points that reached orange colour and one point with red colour. This means that the temperature inside PPS is very high. This setup depends on natural convection to reduce heat temperature inside the PPS. Plus, the hot air does not flow freely but only move around appointed area. The average temperature inside PPS at 180 minutes is 37.35 ^{o}C for discharge and for charging is 38.16 ^{o}C. This is the highest average temperature recorded.

Figure 4.5 show that IO, OC experiment has poor heat removal system. There are few point that reach yellow colour and green colour. This means that the temperature inside PPS is quite high. Opened inlet on the casing of the PPS indicated a small improvement of the heat removal system compare to IC, OC. Although there are only the slight different between these two experiments but even 1 ^{o}C different is very important for electronic component. In addition, there are a certain point that show increment of the temperature which is at point 1. This shows that hot air flow to the outside of the PPS through point 1. The average temperature for IO, OC experiment is 35.53 ^{o}C for discharge and for charging is 36.18 ^{o}C.

Figure 4.6 show that IC, OO experiment has poor heat removal performance. This experiment show the result that are quite similar to the IO, OC experiment but with lesser efficient heat removal performance. Most of the point reached yellow colour and this show temperature inside PPS is high. There is outlet hole that opened at the bottom right of the casing is closed to the main electronic component such as battery, adapter and inverter. These main components produced most of the heat inside the product. Theoretically by mading a hole near to these components, the heat is allowed to move outside easily compared to IO, OC. But, there is no wind or fan that can push hot air to flow outside. This will cause the hot air to flow back inside PPS and only small amount of the hot air flow outside. The average of the temperature for IC, OP experiment is 36.84 °C for discharge and for charging is 36.83 °C.

Figure 4.7 show that IF,OO experiment has good heat removal system compare to IC, OC, IO, OC and IC, OP experiment. Most of the point reach green and blue colour that indicated the decrement of temperature. Add one fan that blow in at the inlet hole and opened the outlet hole make huge improvement on the heat removal system of the PPS. The fan at the inlet will blow in cool air to enter the PPS while hot air will flow exit the PPS. Means, by improving air flow enter and exit the PPS, the heat removal efficiency will increase too. The average temperature for 1F, OO for discharge is 35.63 °C and for charging is 33.48 °C.

Figure 4.8 show that IO, OF experiment has better heat removal system compared to 1F, OO. Most of the point reach blue and indigo colour which state temperature range from 32 °C. to 35 °C. Fan blow out hot air at outlet with inlet open is more efficient compare to fan blow in cool air with outlet open. Main component that produce heat is close to outlet hole. This will make the hot air to flow out easily. The average temperature for IO, OF experiment for discharge is 34.3 °C and for charging is 33.02 °C.

Figure 4.9 show that IF, OF experiment has very good heat removal system compare to others. All of the point reach temperature of 35 °C. and below. Fan blow in cool air and fan blow out hot air create most efficient air flow inside PPS. The average temperature for discharge is 32.92 °C and for charging is 33.38 °C. This is the lowest average temperature recorded.

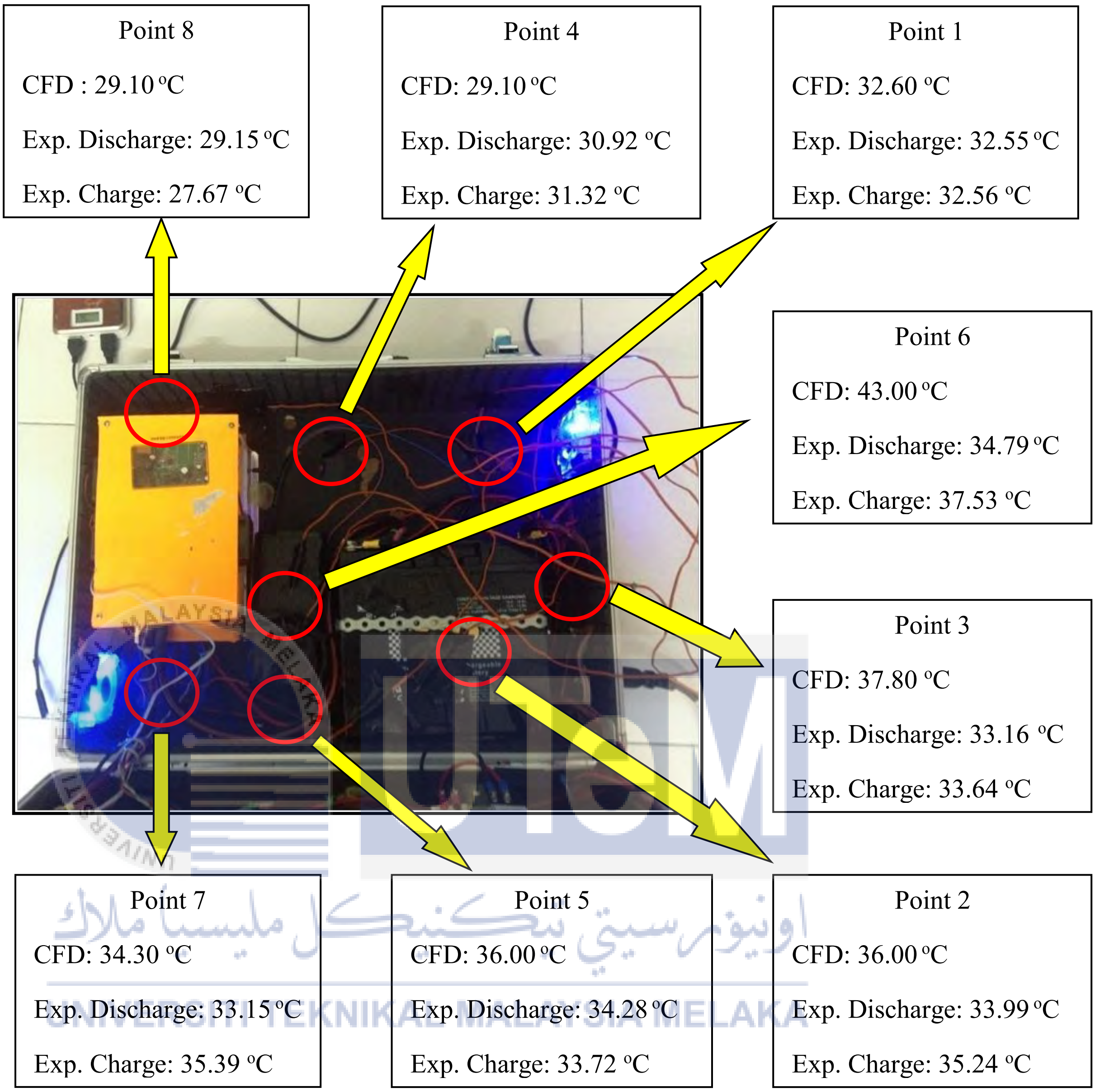


Figure 4.10: Comparison of temperature between CFD model 3 and experiment inlet fan, outlet fan (IF, OF)

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

Portable power supply was modeled using ANSYS FLUENT software. Based on **Figure 4.1** and **Figure 4.2**, both models have slightly different behavior. Middle battery position makes air flow movement smoother thus air flow velocity is faster. This will make lesser heat accumulated inside the model. Thus, model 2 is better thermal removal design compare to model 1. Based on the experiments performed, the most efficient heat removal system is inlet fan, outlet fan and the most poor heat removal system is inlet closed, outlet closed. This experiment show that existent of inlet and outlet hole will decrease the temperature inside the PPS or in others words, its improved the flow of air enter and exit the PPS. In addition, the existence of fan play huge role in remove hot air exit and blow in cool air in order to make sure the electronic component always operate at the maximum allowable operating temperature. This is important to ensure the reliability of the product. Based on **Figure 4.10**, the temperature between CFD model 3 and experiment inlet fan, outlet fan is small. These show that both CFD and the experiment are successful. The project of heat transfer analysis successfully achieve it objectives and goals.

5.2 RECOMMENDATION

This project is successfully completed its objectives and goals but it show some lacking aspect in develop CFD and experimental of the system, thus a few recommendation is make for further research in this project. For CFD, the software must be handle properly and use suitable setup solution to have more accurate result. Thus, the researcher should learn properly from the guide document to use this software in order to get an accurate data. Plus, number of the model should be increase to get more data and use various materials of the model for further research. For the experimental, there should be more situation or condition to run the experiment in the future such as room condition, room condition with air conditioner and outside room. Plus, the further research also could also include different type of fan speed as a part of manipulative variable. In addition, weather can be also become part of variable for further research for this project. This can determine how much weather can affect the heat transfer inside PPS. These recommendations will allow the improvement of the project in all aspects for further research.

REFERENCES

Yunus A.Cengel, Afshin J.Ghajar. (2011). Heat and Mass Transfer .(4th ed).New York. McGraw Hill Higher Education.

Y.Nakasone, S.Yoshimoto. (2006). Engineering Analysis with ANSYS Software.(1st ed). Tokyo. Butterworth-Heinemann

E. Ozturk and I. Tari. (2008). "Forced air cooling of CPUs with heat sinks: a numerical study," *IEEE Trans. Compon. Packag. Technol*,, vol. 31, no.3, pp. 650-660

Jianxiang, L., Qiangsheng, Z., & Huimin, C. (2007). A portable solar power supply device with high efficiency inverter. Pp 1473-1477

B. Yazicioğlu and H. Yüncü. (2007). "Optimum fin spacing of rectangular fins on a vertical base in free convection heat transfer," *Heat Mass Transfer*, vol. 44, no. 1, pp. 11-21

Ilker Tari and Fidan Seza Yalcin. (2010). "CFD analysis of a notebook computer thermal management system and proposed passive cooling alternative", *IEEE Trans. Compon. Packag. Technol,* vol 33,, No 2, pp. 443-452

Brian Mitchell (2014). “Ansys Fluent”. Websites address: http://www.ansys.com/Products/Simulation+Technology/Fluid+Dynamics/Fluid+Dynamics+Products/ANSYS+Fluent/Features. Last accessed: 11/07/2014

Stephane Guillet (2009). “Ansys Tutorial”. Website address: http://chamilo2.grenet.fr/inp/courses/ENSE3A24EMMABK0/document/Docs_logiciels/Fluent/Tutorials/Introductory/tutorial1/tut01.pdf. Last accessed: 16/04/2014

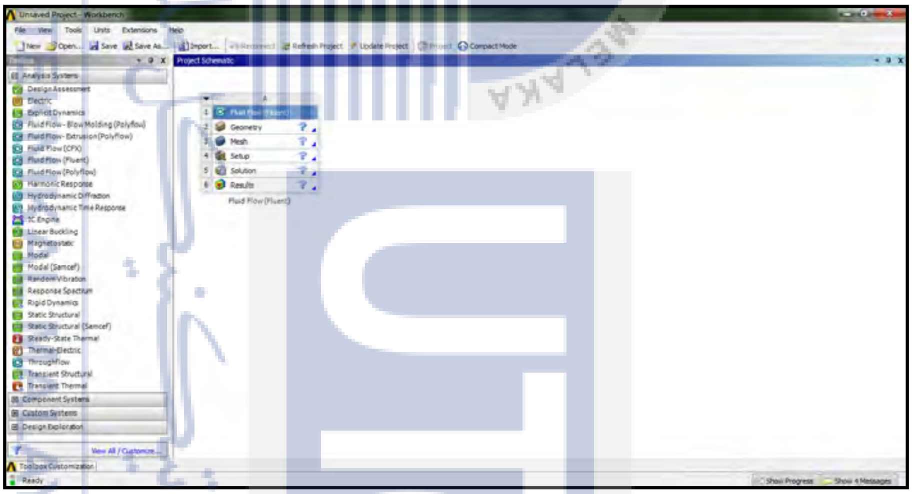
Portgas.D.Ace (2008). “Fluid Dynamics”. Website address: http://www.cadfemireland.com/ansys-for/fluid-dynamics/ansys-fluent/. Last accessed: 13/05/2015

Mike Bauer (2011).”ANSYS Architecture”. Website address: https://www.sharcnet.ca/Software/Fluent14/help/flu_gs/flu_gs_chp_intro_fluent_product.html. Last accessed: 13/05/2014

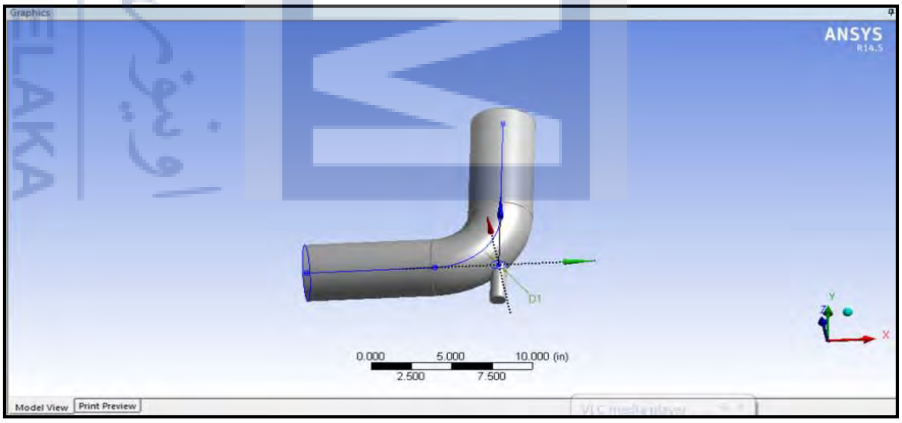
APPENDIX

APPENDIX A: PIPE ELBOW PROCEDURE

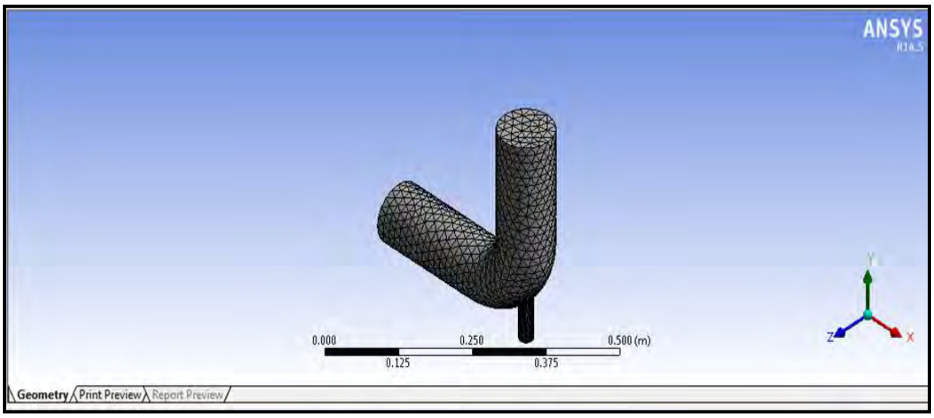
1. ANSYS Workbench was launched and created an ANSYS FLUENT fluid flow analysis system in ANSYS Workbench.

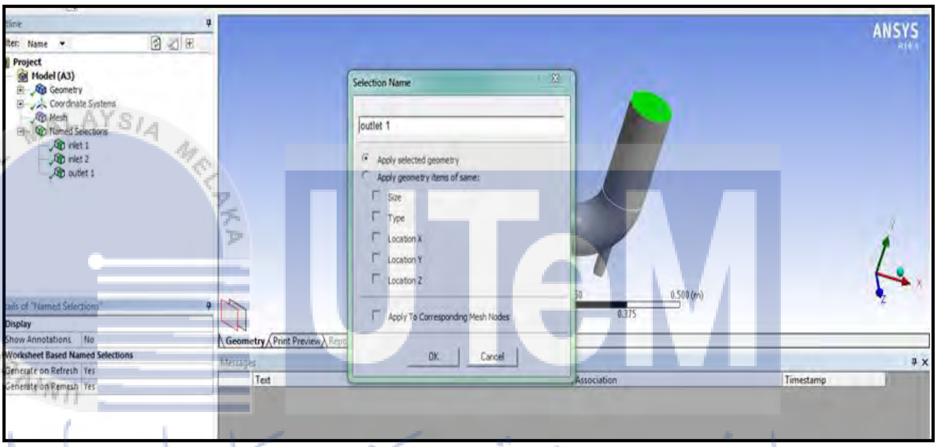


2. Elbow geometry was created by using ANSYS DesignModeler.



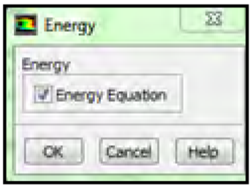
3. ANSYS Meshing was used to create the computational for geometry Then, naming each inlet and outlet.





4. Set up the CFD simulation in ANSYS FLUENT, which includes:

- Energy equation was turned on



- Material properties and boundary condition was set for a turbulent forced convection problem

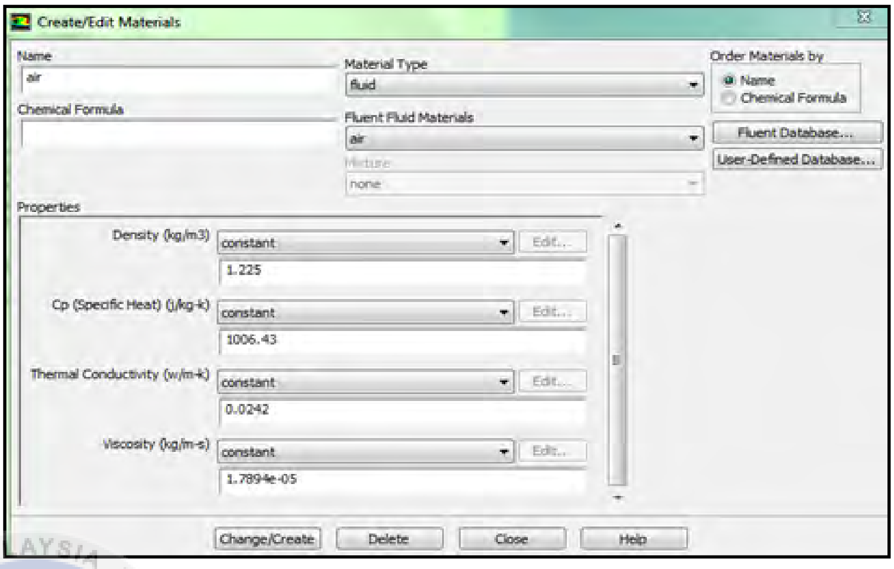


Figure 2.10: Create or edit material

- Setting parameter for each inlet and outlet

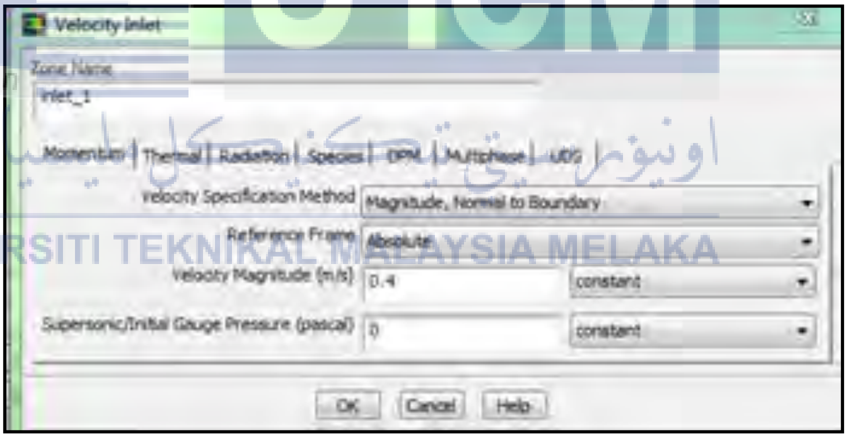


Figure 2.11: Parameter for inlet

5. Used ANSYS FLUENT Visually to examine the flow and temperature using
6. Step 3 to step 6 was repeated by using others material.
7. Result

APPENDIX B : GANTT CHART FYP 1

TASK/WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FYP TITLE SELECTION															
TITLE DISCUSSION AND ANSYS SOFTWARE															
TUTORIAL USING ANSYS															
PRESENTATION ABOUT WORK PROGRESS															
DEVELOP CFD MODEL															
STUDY AND ANALYSIS HEAT FLOW IN MODEL															
PREPARING POSTER AND SUBMISSION															
PREPARING REPORT AND SUBMISSION															
PRESENTATION															

APPENDIX C : GANTT CHART FYP 2

APPENDIX D: FAN BLOWER MEASUREMENT

1. Anemometer equipment

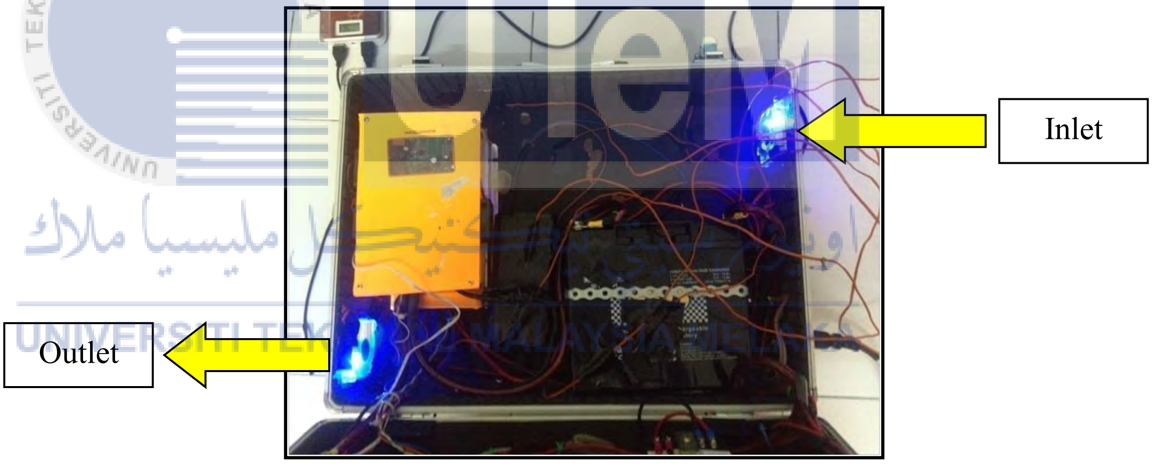
2. Inlet fan velocity measurement

3. Outlet fan velocity measurement

APPENDIX E : EXPERIMENTAL

1. Discharge experiment run with stand fan as a load

2. Inlet fan, outlet fan experiment



APPENDIX F: EXPERIMENTAL DATA

1. Data of inlet closed, outlet closed experiment for discharged

Time	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
Minutes	°C	°C	°C	°C	°C	°C	°C	°C
0	33.56	34.13	33.73	33.97	34.78	35.11	34.82	34.55
5	33.43	34.33	33.71	34.14	35.13	35.53	35.25	35.08
10	33.28	34.67	33.71	34.49	35.78	36.3	36.03	36.05
15	33.27	34.98	33.66	34.8	36.31	36.91	36.63	36.86
20	33.32	35.26	33.74	35.08	36.76	37.42	37.12	37.53
25	33.28	35.5	33.71	35.33	37.12	37.82	37.52	38.07
30	33.2	35.69	33.63	35.51	37.41	38.16	37.83	38.5
35	33.24	35.86	33.68	35.72	37.69	38.44	38.1	38.84
40	33.25	36.02	33.7	35.87	37.92	38.69	38.33	39.13
45	33.23	36.18	33.7	36.03	38.13	38.92	38.55	39.38
50	33.21	36.31	33.73	36.15	38.32	39.11	38.74	39.61
55	33.07	36.43	33.58	36.27	38.51	39.3	38.9	39.81
60	33.07	36.56	33.58	36.39	38.67	39.47	39.06	39.98
65	33.15	36.67	33.65	36.48	38.8	39.61	39.2	40.14
70	33.15	36.75	33.64	36.58	38.92	39.72	39.3	40.26
75	33.16	36.82	33.64	36.64	39.01	39.82	39.39	40.36
80	33.09	36.88	33.57	36.71	39.09	39.9	39.45	40.45
85	33.03	36.94	33.49	36.76	39.15	39.96	39.51	40.52
90	32.99	36.99	33.43	36.81	39.2	40.01	39.56	40.58
95	32.97	37.04	33.4	36.86	39.23	40.05	39.59	40.63
100	32.9	37.07	33.31	36.87	39.27	40.08	39.62	40.66
105	32.9	37.09	33.31	36.86	39.29	40.09	39.64	40.68
110	32.95	37.09	33.36	36.9	39.29	40.08	39.61	40.66
115	33	37.13	33.39	36.94	39.3	40.1	39.63	40.67
120	33.06	37.16	33.43	36.93	39.31	40.12	39.64	40.69
125	33.14	37.16	33.5	36.96	39.32	40.12	39.63	40.71
130	33.1	37.19	33.46	37.01	39.33	40.14	39.65	40.73
135	33.06	37.23	33.41	37.02	39.36	40.15	39.67	40.73
140	33.07	37.24	33.41	37.04	39.32	40.13	39.61	40.75
145	33.09	37.23	33.42	37.01	39.24	40.06	39.51	40.71
150	33.2	37.21	33.52	37	39.18	40	39.45	40.67
155	33.16	37.2	33.47	36.97	39.13	39.95	39.4	40.61
160	33.1	37.18	33.39	36.96	39.08	39.89	39.34	40.57
165	33.02	37.15	33.31	36.94	39.02	39.84	39.27	40.51
170	33.08	37.14	33.36	36.91	38.99	39.79	39.24	40.47
175	33.09	37.13	33.36	36.91	38.94	39.74	39.18	40.43
180	33.22	37.12	33.48	36.87	38.9	39.7	39.14	40.39

2. Data for inlet closed, outlet closed experiment for charging

Time	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
Minutes	°C	°C	°C	°C	°C	°C	°C	°C
0	33.16	33.85	33.1	33.67	34.06	38.64	33.69	33.9
5	33.22	34.43	33.13	34.21	34.43	38.05	34.01	34.66
10	33.2	36.58	33.13	36.26	35.88	39.01	35.11	36.95
15	33.29	37.43	33.22	37.13	36.54	40.19	35.63	37.77
20	33.16	37.98	33.09	37.59	36.94	40.84	35.98	38.26
25	33.24	38.34	33.18	37.94	37.25	41.31	36.28	38.62
30	33.18	38.6	33.11	38.22	37.54	41.67	36.54	38.94
35	33.18	38.83	33.1	38.47	37.78	41.98	36.77	39.22
40	33.23	39.02	33.15	38.68	38	42.26	36.97	39.5
45	33.1	39.19	33.03	38.88	38.2	42.51	37.13	39.74
50	33.08	39.34	33.02	39.03	38.32	42.68	37.25	39.92
55	33.54	39.44	33.1	39.1	38.42	42.79	37.34	40.04
60	33.28	39.58	33.09	39.16	38.5	42.86	37.41	40.13
65	33.26	39.57	33.13	39.22	38.56	42.89	37.47	40.21
70	33.2	39.67	33.08	39.3	38.6	42.91	37.55	40.29
75	33.12	39.74	33.01	39.37	38.66	42.99	37.57	40.35
80	33.08	39.76	32.99	39.43	38.73	43.04	37.62	40.41
85	33.11	39.83	33.02	39.45	38.72	43.05	37.65	40.41
90	33.01	39.81	32.93	39.37	38.74	42.99	37.67	40.39
95	32.84	39.81	32.77	39.34	38.72	42.97	37.68	40.4
100	32.83	39.85	32.76	39.36	38.76	43.01	37.71	40.42
105	32.77	39.9	32.72	39.39	38.82	43.09	37.76	40.48
110	32.86	39.92	32.81	39.42	38.83	43.09	37.76	40.5
115	32.91	39.93	32.85	39.41	38.82	43.06	37.76	40.49
120	32.87	39.93	32.81	39.4	38.82	43.07	37.77	40.5
125	32.96	39.99	32.91	39.46	38.85	43.13	37.78	40.55
130	32.88	40.11	32.83	39.57	38.92	43.27	37.84	40.64
135	32.9	40.12	32.85	39.57	38.96	43.29	37.84	40.66
140	32.92	40.07	32.89	39.54	38.93	43.22	37.84	40.64
145	32.94	40.09	32.9	39.55	38.93	43.23	37.85	40.65
150	32.94	40.12	32.91	39.59	38.97	43.28	37.86	40.68
155	32.74	40.15	32.72	39.6	38.98	43.31	37.88	40.71
160	32.71	40.21	32.68	39.63	38.98	43.36	37.89	40.73
165	32.78	40.25	32.75	39.67	39	43.39	37.91	40.77
170	32.78	40.27	32.76	39.71	39.06	43.45	37.96	40.79
175	32.76	40.31	32.73	39.72	39.1	43.47	37.98	40.82
180	32.77	39.96	32.74	39.41	38.9	43.06	37.9	40.53

3. Data of inlet open, outlet closed experiment for discharge

Time	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
Minutes	°C	°C	°C	°C	°C	°C	°C	°C
0	31.48	33.76	31.51	27.98	31.81	31.71	31.21	31.74
5	31.96	33.93	31.77	28.02	32.25	32.25	31.73	32.34
10	32.78	34.24	32.26	28.24	33.01	33.18	32.62	33.36
15	33.44	34.5	32.65	28.45	33.64	33.93	33.33	34.16
20	33.98	34.71	32.99	28.65	34.16	34.53	33.9	34.8
25	34.42	34.89	33.29	28.84	34.59	35.01	34.36	35.3
30	34.78	35.04	33.52	28.99	34.95	35.41	34.74	35.71
35	35.07	35.15	33.71	29.03	35.23	35.72	35.03	36.03
40	35.31	35.25	33.88	29.23	35.48	35.99	35.29	36.3
45	35.51	35.33	34.03	29.18	35.68	36.22	35.5	36.53
50	35.69	35.39	34.15	29.26	35.86	36.41	35.68	36.71
55	35.83	35.45	34.25	29.3	36.01	36.57	35.82	36.85
60	35.95	35.5	34.34	29.37	36.14	36.71	35.95	36.98
65	36.05	35.54	34.4	29.33	36.24	36.81	36.05	37.09
70	36.13	35.57	34.46	29.31	36.33	36.91	36.14	37.17
75	36.19	35.6	34.52	29.42	36.41	36.99	36.2	37.26
80	36.24	35.62	34.56	29.33	36.47	37.05	36.27	37.31
85	36.28	35.64	34.57	29.31	36.52	37.1	36.32	37.36
90	36.31	35.64	34.59	29.54	36.55	37.13	36.35	37.38
95	36.34	35.66	34.6	29.58	36.58	37.15	36.36	37.4
100	36.36	35.66	34.61	29.76	36.6	37.17	36.39	37.42
105	36.35	35.66	34.61	29.71	36.61	37.18	36.41	37.43
110	36.37	35.67	34.63	29.47	36.62	37.19	36.43	37.43
115	36.37	35.67	34.63	29.52	36.62	37.2	36.44	37.43
120	36.36	35.66	34.6	29.66	36.61	37.18	36.43	37.41
125	36.34	35.64	34.61	29.88	36.59	37.15	36.41	37.39
130	36.33	35.64	34.61	29.88	36.57	37.13	36.39	37.37
135	36.33	35.65	34.62	29.92	36.58	37.13	36.4	37.37
140	36.33	35.64	34.62	29.98	36.58	37.14	36.41	37.38
145	36.32	35.64	34.61	29.87	36.58	37.13	36.41	37.37
150	36.32	35.64	34.59	29.77	36.58	37.14	36.41	37.37
155	36.32	35.66	34.59	29.76	36.58	37.14	36.42	37.36
160	36.31	35.66	34.58	29.74	36.57	37.12	36.4	37.35
165	36.3	35.66	34.58	29.76	36.56	37.11	36.39	37.33
170	36.19	35.65	34.5	29.69	36.49	37.06	36.33	37.25
175	36.23	35.65	34.53	29.69	36.49	37.03	36.32	37.24
180	36.23	35.67	34.54	29.7	36.49	37.03	36.33	37.26

4. Data inlet open, outlet closed experiment for charging

Time	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
Minutes	°C	°C	°C	°C	°C	°C	°C	°C
0	31.53	32.84	31.64	30.24	32	33.42	31.58	31.72
5	33.38	32.85	32.27	30.29	32.54	33.55	31.95	33.02
10	35.17	33.05	33.13	30.27	33.7	35.25	32.56	34.15
15	36.05	33.33	33.3	30.33	34.42	36.4	33	34.82
20	36.69	33.59	33.49	30.41	34.98	37.15	33.37	35.3
25	37.14	33.83	33.65	30.37	35.42	37.69	33.68	35.72
30	37.52	34.05	33.88	30.42	35.77	38.13	33.95	36.07
35	37.84	34.27	34.01	30.42	36.11	38.53	34.18	36.38
40	38.06	34.47	34.21	30.31	36.38	38.89	34.39	36.66
45	38.25	34.66	34.34	30.33	36.58	39.13	34.55	36.93
50	38.37	34.84	34.52	30.32	36.73	39.29	34.68	37.13
55	38.45	35	34.63	30.37	36.85	39.4	34.79	37.29
60	38.53	35.15	34.71	30.37	36.94	39.42	34.88	37.44
65	38.62	35.3	34.88	30.51	37.04	39.51	34.98	37.56
70	38.7	35.44	34.98	30.56	37.14	39.6	35.03	37.67
75	38.77	35.59	35.07	30.62	37.23	39.7	35.12	37.78
80	38.79	35.71	35.13	30.38	37.25	39.72	35.17	37.87
85	38.84	35.84	35.21	30.47	37.32	39.79	35.23	37.94
90	38.91	35.96	35.28	30.5	37.38	39.85	35.28	38.03
95	38.96	36.08	35.37	30.5	37.44	39.9	35.32	38.11
100	38.99	36.19	35.34	30.44	37.44	39.93	35.34	38.14
105	39.05	36.3	35.42	30.48	37.5	39.97	35.4	38.24
110	39.08	36.42	35.53	30.48	37.53	40.03	35.42	38.3
115	39.05	36.53	35.56	30.55	37.56	40.01	35.45	38.32
120	39.09	36.63	35.68	30.46	37.58	40.02	35.49	38.37
125	39.13	36.75	35.64	30.5	37.58	40.04	35.5	38.4
130	39.19	36.85	35.73	30.5	37.59	40.1	35.53	38.48
135	39.17	36.95	35.8	30.45	37.55	40.06	35.54	38.45
140	38.85	37	35.83	30.42	37.34	39.74	35.48	38.29
145	38.64	37.04	35.86	30.45	37.18	39.46	35.42	38.15
150	38.51	37.06	35.83	30.4	37.06	39.31	35.36	38.06
155	38.44	37.09	35.82	30.37	36.99	39.18	35.32	38.03
160	38.35	37.11	35.88	30.18	36.89	39.09	35.27	37.94
165	38.24	37.12	35.79	30.08	36.79	38.96	35.2	37.86
170	38.16	37.15	35.78	30.17	36.73	38.86	35.18	37.79
175	38.13	37.17	35.76	30.11	36.67	38.82	35.14	37.74
180	38.09	37.19	35.77	30.2	36.64	38.78	35.09	37.69

5. Data of inlet closed, outlet open experiment for discharge

Time	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
Minutes	°C	°C	°C	°C	°C	°C	°C	°C
0	32.09	33.48	32.21	31.85	32.11	32.17	31.56	32.27
5	32.53	33.73	32.5	32.38	32.57	32.75	32.04	32.87
10	33.17	34.22	32.97	33.11	33.22	33.67	32.7	33.75
15	33.65	34.5	33.27	33.63	33.69	34.26	33.19	34.37
20	34.37	34.84	33.75	34.35	34.43	35.03	33.91	35.22
25	34.86	35.14	34.12	34.85	34.9	35.59	34.37	35.76
30	35.28	35.39	34.39	35.27	35.31	36.06	34.78	36.23
35	35.63	35.61	34.66	35.64	35.68	36.48	35.1	36.66
40	35.94	35.8	34.89	35.96	35.98	36.83	35.37	37
45	36.22	35.97	35.08	36.25	36.27	37.15	35.59	37.32
50	36.48	36.14	35.29	36.51	36.54	37.44	35.82	37.56
55	36.67	36.26	35.42	36.68	36.7	37.63	35.96	37.75
60	36.81	36.35	35.53	36.82	36.83	37.78	36.1	37.9
65	36.98	36.45	35.64	36.99	37.03	37.98	36.26	38.14
70	37.14	36.57	35.78	37.15	37.18	38.15	36.34	38.25
75	36.7	36.51	35.59	36.7	36.69	38.08	35.35	37.81
80	36.19	36.24	35.18	36.23	36.1	37.75	34.52	37.29
85	36.92	36.44	35.58	36.91	36.97	37.9	35.97	37.99
90	37.11	36.55	35.74	37.11	37.18	38.09	36.06	38.18
95	37.23	36.65	35.83	37.24	37.29	38.21	36.16	38.29
100	37.32	36.72	35.9	37.33	37.37	38.29	36.21	38.37
105	37.41	36.79	35.97	37.41	37.47	38.4	36.3	38.49
110	37.49	36.84	36.03	37.49	37.55	38.49	36.43	38.59
115	37.56	36.91	36.07	37.55	37.61	38.58	36.53	38.68
120	37.63	36.96	36.16	37.63	37.68	38.65	36.59	38.76
125	37.7	37.02	36.21	37.68	37.75	38.73	36.66	38.82
130	37.75	37.06	36.25	37.73	37.81	38.79	36.72	38.89
135	37.81	37.11	36.32	37.79	37.87	38.84	36.78	38.94
140	37.87	37.17	36.35	37.84	37.91	38.9	36.83	39.01
145	37.91	37.21	36.38	37.87	37.96	38.94	36.89	39.05
150	37.96	37.25	36.44	37.93	38.01	38.99	36.91	39.08
155	38	37.29	36.48	37.96	38.05	39.03	36.95	39.09
160	38.03	37.33	36.53	38.01	38.1	39.07	36.99	39.16
165	38.07	37.37	36.56	38.05	38.13	39.1	37.02	39.19
170	38.11	37.41	36.58	38.08	38.16	39.13	37.07	39.23
175	38.14	37.44	36.62	38.12	38.2	39.17	37.09	39.26
180	38.17	37.48	36.67	38.16	38.24	39.2	37.1	39.28

6. Data of inlet closed, outlet open experiment for charging

Time	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
Minutes	°C	°C	°C	°C	°C	°C	°C	°C
0	32.1	30.97	31.84	32.6	31.55	32.2	31.37	32.59
5	32.98	31.09	32.52	33.53	32.05	33.89	31.74	33.48
10	34.22	31.37	33.32	34.71	32.78	35.97	32.28	34.64
15	35.06	31.65	33.77	35.46	33.29	37.02	32.59	35.41
20	35.64	31.92	34.09	36.01	33.72	37.67	32.81	35.99
25	36.11	32.17	34.33	36.48	34.09	38.18	33	36.47
30	36.52	32.41	34.55	36.83	34.4	38.6	33.14	36.84
35	36.78	32.63	34.74	37.07	34.66	38.85	33.19	37.13
40	37.03	32.84	34.99	37.33	34.86	39.08	33.27	37.39
45	37.28	33.05	35.26	37.54	35.07	39.31	33.39	37.65
50	37.46	33.25	35.33	37.75	35.23	39.52	33.47	37.86
55	37.64	33.44	35.55	37.92	35.43	39.7	33.52	38.07
60	37.82	33.63	35.68	38.12	35.56	39.87	33.53	38.28
65	38.04	33.82	35.8	38.36	35.74	40.16	33.63	38.52
70	38.19	34	36.08	38.53	35.87	40.34	33.61	38.7
75	38.29	34.18	36.15	38.61	35.97	40.46	33.64	38.83
80	38.41	34.35	36.35	38.39	36.11	40.51	33.6	38.95
85	38.52	34.52	36.43	38.84	36.23	40.62	33.79	39.06
90	38.62	34.68	36.62	38.97	36.28	40.74	33.73	39.17
95	38.71	34.85	36.73	39.1	36.37	40.86	33.64	39.3
100	38.82	35.01	36.86	39.21	36.43	40.95	33.45	39.4
105	38.87	35.15	36.95	39.28	36.47	41.01	33.58	39.46
110	38.82	35.29	36.93	39.15	36.41	40.99	33.58	39.42
115	38.51	35.4	37.03	38.69	36.26	40.48	33.48	39.05
120	38.29	35.47	37.06	38.46	36.09	40.11	33.51	38.86
125	38.15	35.54	37.09	38.33	36.03	39.89	33.51	38.72
130	38.04	35.61	37.06	38.24	35.97	39.74	33.6	38.63
135	37.97	35.66	37.05	38.17	35.89	39.65	33.83	38.55
140	37.92	35.72	37.02	38.14	35.87	39.6	33.78	38.51
145	37.9	35.79	37.03	38.11	35.84	39.56	33.88	38.48
150	37.89	35.85	37.03	38.12	35.81	39.54	33.79	38.46
155	37.87	35.91	37.05	38.13	35.84	39.53	33.79	38.45
160	37.89	35.98	37.07	38.14	35.86	39.54	33.98	38.46
165	37.85	36.04	37.1	38.09	35.86	39.53	34.08	38.42
170	37.69	36.09	36.98	37.84	35.78	39.28	33.99	38.21
175	37.58	36.12	36.89	37.71	35.69	39.06	33.98	38.09
180	37.49	36.15	36.84	37.65	35.63	38.94	33.95	38.01

7. Data of inlet fan, outlet open experiment for discharge

Time	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
Minutes	°C	°C	°C	°C	°C	°C	°C	°C
0	32.57	33.08	32.65	32.4	32.55	32.8	32.71	32.65
5	33.3	33.29	32.93	33.23	33.19	33.5	33.2	33.62
10	33.95	33.59	33.26	33.86	33.76	34.17	33.79	34.47
15	34.4	33.84	33.55	34.3	34.18	34.65	34.19	35.02
20	34.73	34.01	33.76	34.63	34.49	35	34.45	35.44
25	34.98	34.18	33.94	34.87	34.73	35.27	34.66	35.7
30	35.17	34.3	34.08	35.06	34.93	35.47	34.8	35.94
35	35.3	34.4	34.18	35.19	35.05	35.6	34.91	36.05
40	35.42	34.49	34.28	35.32	35.18	35.73	34.96	36.23
45	35.49	34.56	34.36	35.39	35.24	35.79	34.99	36.26
50	35.57	34.63	34.42	35.47	35.33	35.87	35.05	36.4
55	35.59	34.68	34.45	35.49	35.34	35.88	35.04	36.42
60	35.67	34.75	34.5	35.57	35.43	35.97	35.11	36.44
65	35.68	34.78	34.52	35.58	35.44	35.98	35.13	36.49
70	35.73	34.84	34.54	35.64	35.51	36.05	35.21	36.5
75	35.75	34.86	34.55	35.66	35.54	36.07	35.24	36.57
80	35.79	34.92	34.57	35.7	35.59	36.11	35.28	36.59
85	35.81	34.94	34.58	35.73	35.62	36.14	35.31	36.66
90	35.83	35	34.63	35.74	35.63	36.15	35.29	36.63
95	35.84	35.02	34.65	35.75	35.65	36.17	35.3	36.69
100	35.85	35.06	34.69	35.76	35.64	36.16	35.28	36.65
105	35.88	35.1	34.71	35.79	35.68	36.19	35.31	36.72
110	35.86	35.12	34.72	35.77	35.66	36.16	35.3	36.66
115	35.89	35.16	34.76	35.8	35.69	36.19	35.29	36.71
120	35.87	35.17	34.78	35.77	35.65	36.16	35.25	36.68
125	35.9	35.21	34.75	35.8	35.7	36.2	35.3	36.65
130	35.88	35.22	34.76	35.79	35.69	36.18	35.3	36.68
135	35.89	35.25	34.77	35.79	35.69	36.18	35.3	36.65
140	35.89	35.26	34.76	35.8	35.7	36.19	35.29	36.68
145	35.9	35.29	34.77	35.8	35.7	36.2	35.29	36.63
150	35.89	35.3	34.79	35.8	35.71	36.19	35.29	36.69
155	35.85	35.3	34.76	35.75	35.65	36.13	35.26	36.62
160	35.84	35.31	34.74	35.74	35.66	36.13	35.22	36.64
165	35.81	35.31	34.73	35.7	35.6	36.08	35.16	36.59
170	35.82	35.34	34.74	35.71	35.62	36.09	35.17	36.55
175	35.8	35.34	34.71	35.69	35.6	36.07	35.19	36.57
180	35.8	35.35	34.72	35.69	35.6	36.07	35.21	36.56

8. Data of inlet fan outlet open experiment for charging

Time	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
Minutes	°C	°C	°C	°C	°C	°C	°C	°C
0	31.69	32.39	31.78	31.12	31.74	31.62	31.67	31.65
5	32.23	32.44	31.89	31.56	31.8	32.28	31.84	32.41
10	32.94	32.56	32.05	32.11	32.02	33.62	32	33.16
15	33.28	32.68	32.17	32.33	32.16	34.16	32.11	33.49
20	33.48	32.79	32.26	32.47	32.27	34.4	32.22	33.7
25	33.61	32.9	32.34	32.5	32.35	34.52	32.35	33.84
30	33.7	32.99	32.4	32.55	32.41	34.6	32.43	33.94
35	33.79	33.09	32.48	32.63	32.46	34.69	32.46	34.05
40	33.85	33.18	32.53	32.69	32.53	34.76	32.46	34.13
45	33.91	33.29	32.59	32.79	32.57	34.81	32.53	34.2
50	33.98	33.4	32.65	32.89	32.62	34.88	32.59	34.28
55	34	33.52	32.7	32.88	32.66	34.91	32.59	34.31
60	33.98	33.63	32.75	32.85	32.64	34.83	32.61	34.28
65	33.95	33.73	32.77	32.82	32.61	34.75	32.56	34.24
70	33.88	33.83	32.79	32.79	32.57	34.65	32.53	34.17
75	33.81	33.91	32.8	32.75	32.52	34.52	32.5	34.1
80	33.77	33.97	32.79	32.68	32.5	34.45	32.46	34.07
85	33.75	34.05	32.82	32.66	32.48	34.42	32.43	34.05
90	33.74	34.13	32.84	32.64	32.46	34.39	32.49	34.03
95	33.7	34.21	32.86	32.61	32.48	34.33	32.42	33.98
100	33.67	34.29	32.87	32.6	32.44	34.25	32.38	33.95
105	33.63	34.35	32.88	32.56	32.42	34.18	32.37	33.9
110	33.61	34.43	32.9	32.57	32.39	34.13	32.44	33.88
115	33.59	34.49	32.91	32.61	32.37	34.1	32.44	33.86
120	33.58	34.56	32.93	32.58	32.37	34.06	32.41	33.83
125	33.57	34.62	32.94	32.59	32.37	34.05	32.42	33.81
130	33.56	34.68	32.97	32.57	32.37	34.04	32.47	33.81
135	33.55	34.73	32.99	32.52	32.39	34.03	32.45	33.79
140	33.55	34.79	33	32.54	32.39	34.03	32.49	33.79
145	33.55	34.84	33	32.57	32.37	34.02	32.49	33.78
150	33.55	34.9	33.03	32.61	32.38	34.01	32.48	33.78
155	33.55	34.95	33.04	32.57	32.39	34.01	32.46	33.78
160	33.55	35.01	33.07	32.54	32.41	34.02	32.47	33.79
165	33.57	35.07	33.11	32.56	32.43	34.03	32.48	33.8
170	33.61	35.11	33.09	32.53	32.44	34.06	32.51	33.81
175	33.66	35.16	33.1	32.59	32.49	34.08	32.52	33.85
180	33.73	35.24	33.13	32.67	32.59	34.09	32.4	33.96

9. Data of inlet open, outlet fan experiment for discharge

Time	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
Minutes	°C	°C	°C	°C	°C	°C	°C	°C
0	32.29	32.32	32.09	31.35	32.1	32.32	32.2	32.39
5	32.73	32.53	32.32	31.29	32.41	32.8	32.41	32.94
10	33.34	32.84	32.69	31.38	32.92	33.47	32.74	33.72
15	33.79	33.07	33	31.43	33.32	33.96	32.96	34.27
20	34.13	33.25	33.25	31.47	33.63	34.33	33.11	34.67
25	34.47	33.45	33.5	31.47	33.97	34.69	33.25	35.09
30	34.72	33.61	33.71	31.56	34.22	34.96	33.33	35.37
35	34.89	33.71	33.84	31.65	34.35	35.11	33.37	35.49
40	35.01	33.78	33.97	31.66	34.45	35.21	33.43	35.36
45	35.14	33.87	34.07	31.71	34.57	35.33	33.47	35.44
50	35.2	33.95	34.15	31.67	34.64	35.41	33.51	35.53
55	35.25	33.98	34.18	31.64	34.68	35.43	33.38	35.56
60	35.29	34.02	34.2	31.55	34.7	35.44	33.42	35.53
65	35.36	34.08	34.27	31.58	34.77	35.51	33.47	35.62
70	35.42	34.16	34.31	31.52	34.8	35.53	33.51	35.63
75	35.47	34.23	34.37	31.64	34.83	35.56	33.52	35.65
80	35.49	34.26	34.41	31.68	34.87	35.58	33.47	35.64
85	35.47	34.29	34.41	31.6	34.86	35.56	33.38	35.65
90	35.44	34.3	34.4	31.55	34.84	35.54	33.33	35.64
95	35.42	34.31	34.37	31.49	34.83	35.52	33.33	35.62
100	35.41	34.34	34.37	31.62	34.84	35.52	33.33	35.6
105	35.39	34.36	34.37	31.71	34.84	35.52	33.33	35.62
110	35.39	34.39	34.37	31.69	34.83	35.49	33.34	35.59
115	35.39	34.41	34.38	31.64	34.82	35.47	33.34	35.57
120	35.4	34.45	34.4	31.59	34.82	35.46	33.33	35.53
125	35.4	34.48	34.4	31.58	34.83	35.46	33.32	35.55
130	35.39	34.51	34.4	31.53	34.82	35.44	33.29	35.54
135	35.39	34.53	34.41	31.49	34.8	35.43	33.3	35.52
140	35.39	34.55	34.41	31.48	34.8	35.41	33.28	35.48
145	35.38	34.57	34.42	31.46	34.8	35.4	33.25	35.5
150	35.36	34.58	34.41	31.49	34.78	35.37	33.24	35.48
155	35.35	34.6	34.4	31.55	34.77	35.36	33.23	35.47
160	35.34	34.6	34.4	31.59	34.76	35.34	33.21	35.44
165	35.35	34.63	34.4	31.57	34.77	35.34	33.23	35.43
170	35.34	34.63	34.4	31.52	34.76	35.33	33.22	35.44
175	35.34	34.65	34.4	31.55	34.75	35.31	33.21	35.43
180	35.32	34.65	34.38	31.42	34.73	35.29	33.18	35.41

10. Data of inlet open, outlet fan experiment for charging

Time Minutes	Channel 1 °C	Channel 2 °C	Channel 3 °C	Channel 4 °C	Channel 5 °C	Channel 6 °C	Channel 7 °C	Channel 8 °C
0	31.08	31.5	31.11	30.41	30.86	31.02	31.03	31.04
5	31.03	31.42	30.98	30.34	30.84	31.18	31.11	31.17
10	31.9	31.58	31.39	30.38	31.35	32.12	31.41	32.6
15	32.04	31.67	31.51	30.41	31.16	33.63	31.54	33.56
20	32.25	31.8	31.67	30.43	31.23	34.21	31.62	33.96
25	32.41	31.9	31.79	30.59	31.3	34.46	31.69	34.2
30	32.5	32	31.88	30.69	31.36	34.6	31.74	34.33
35	32.61	32.08	31.94	30.69	31.39	34.66	31.76	34.42
40	32.69	32.15	32.01	30.8	31.43	34.7	31.82	34.5
45	32.76	32.22	32.07	30.89	31.46	34.78	31.84	34.56
50	32.78	32.29	32.11	30.86	31.5	34.88	31.88	34.63
55	32.84	32.37	32.16	30.89	31.55	34.97	31.91	34.68
60	32.88	32.44	32.2	30.89	31.59	35	31.92	34.71
65	32.87	32.51	32.24	30.96	31.64	34.98	31.94	34.71
70	32.88	32.56	32.27	31	31.66	34.98	31.93	34.68
75	32.91	32.61	32.3	30.94	31.72	34.96	31.93	34.69
80	32.91	32.66	32.33	30.88	31.75	34.94	31.93	34.65
85	32.91	32.7	32.36	30.84	31.76	34.94	31.93	34.64
90	32.92	32.74	32.39	30.85	31.78	34.94	31.92	34.62
95	32.93	32.78	32.43	30.77	31.8	34.95	31.92	34.61
100	32.96	32.82	32.44	30.78	31.86	34.91	31.92	34.62
105	32.95	32.85	32.49	30.83	31.88	34.92	31.92	34.62
110	33	32.91	32.52	30.87	31.92	34.93	31.92	34.65
115	33.1	33	32.56	30.85	31.9	34.89	31.93	34.65
120	33.25	33.14	32.66	30.91	31.89	34.96	31.96	34.63
125	33.44	33.17	32.82	30.98	31.95	34.93	31.9	34.72
130	33.47	33.35	32.85	30.9	32.04	34.8	31.96	34.71
135	33.43	33.45	32.89	30.82	32.07	34.74	32.04	34.71
140	33.43	33.5	32.91	30.94	32.11	34.75	32.07	34.7
145	33.4	33.55	32.91	30.97	32.18	34.7	32.06	34.7
150	33.38	33.57	32.9	30.94	32.19	34.7	32.06	34.7
155	33.38	33.6	32.93	30.96	32.22	34.71	32.05	34.73
160	33.36	33.6	32.93	30.89	32.23	34.73	32.01	34.76
165	33.36	33.62	32.93	30.9	32.24	34.73	32.01	34.78
170	33.38	33.64	32.95	31.01	32.23	34.75	32.02	34.82
175	33.32	33.65	32.95	30.87	32.19	34.63	31.99	34.69
180	33.31	33.65	32.93	30.88	32.19	34.56	31.97	34.7

11. Data of inlet fan, outlet fan experiment for discharge

Time	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
Minutes	°C	°C	°C	°C	°C	°C	°C	°C
0	31.58	31.98	31.57	30.64	31.41	31.55	31.58	31.81
5	31.69	32.2	31.7	30.83	31.53	31.66	31.7	31.71
10	31.89	32.43	31.91	30.95	32.18	32.25	32.5	31.31
15	32.1	32.74	32.14	31.06	32.71	32.89	33.22	30.92
20	32.25	32.95	32.33	31.13	33.08	33.35	33.72	30.63
25	32.37	33.12	32.48	31.1	33.36	33.69	34.07	30.4
30	32.45	33.26	32.63	31.03	33.62	33.98	34.38	30.13
35	32.52	33.38	32.75	31.01	33.79	34.21	34.59	30.04
40	32.58	33.46	32.85	30.96	33.9	34.35	34.72	29.93
45	32.58	33.51	32.91	31.04	33.99	34.47	34.82	29.87
50	32.59	33.56	32.94	31.04	34.04	34.54	34.88	29.83
55	32.65	33.62	33.01	31.2	34.11	34.61	34.96	29.67
60	32.7	33.72	33.08	31.16	34.28	34.77	35.13	29.63
65	32.71	33.75	33.13	31.17	34.26	34.79	35.13	29.63
70	32.67	33.76	33.15	31.04	34.25	34.79	35.13	29.5
75	32.71	33.81	33.18	31.02	34.32	34.85	35.19	29.53
80	32.71	33.83	33.2	31.12	34.3	34.84	35.16	29.54
85	32.7	33.83	33.21	31.1	34.29	34.83	35.14	29.52
90	32.65	33.84	33.18	31.13	34.28	34.82	35.14	29.51
95	32.64	33.88	33.18	31.06	34.34	34.86	35.19	29.39
100	32.6	33.89	33.18	31.12	34.31	34.85	35.17	29.48
105	32.58	33.9	33.16	31.12	34.29	34.82	35.14	29.46
110	32.58	33.92	33.18	31.17	34.32	34.84	35.16	29.34
115	32.57	33.93	33.19	31.03	34.32	34.85	35.16	29.39
120	32.51	33.91	33.18	30.96	34.28	34.81	35.12	29.4
125	32.49	33.91	33.17	30.95	34.27	34.79	35.11	29.3
130	32.49	33.94	33.18	30.96	34.29	34.81	35.12	29.35
135	32.47	33.93	33.16	30.98	34.26	34.77	35.1	29.35
140	32.47	33.93	33.16	31.03	34.25	34.76	35.09	29.27
145	32.49	33.97	33.15	31.02	34.3	34.8	35.14	29.28
150	32.48	33.97	33.12	31.05	34.27	34.78	35.13	29.16
155	32.49	33.96	33.1	31.05	34.25	34.76	35.12	29.11
160	32.49	33.99	33.12	31.1	34.31	34.8	35.17	29.1
165	32.49	33.97	33.12	31.03	34.26	34.77	35.14	29.14
170	32.49	33.97	33.11	31.14	34.24	34.76	35.12	29.18
175	32.53	34	33.14	31.04	34.31	34.8	35.17	29.13
180	32.55	33.99	33.16	30.92	34.28	34.79	35.15	29.15

12. Data of inlet fan, outlet fan experiment for charging

Time	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
Minutes	°C	°C	°C	°C	°C	°C	°C	°C
0	31.85	32.18	31.92	31.04	31.89	31.95	31.91	31.98
5	31.98	32.36	32	30.9	31.99	32.03	32.14	31.92
10	32.3	32.44	32.14	31.13	31.99	32.11	32.16	31.95
15	32.39	32.5	32.22	31.17	32.16	33.02	32.68	30.8
20	32.52	32.68	32.35	31.42	32.62	35.42	33.64	29.15
25	32.78	32.9	32.51	31.41	32.88	36.69	34.1	28.46
30	33.02	33.1	32.86	31.38	33.19	37.39	34.62	28
35	33.23	33.3	33.15	31.35	33.44	37.9	34.89	27.76
40	33.33	33.48	33.32	31.29	33.56	38.14	35.04	27.54
45	33.39	33.63	33.42	31.29	33.66	38.28	35.16	27.36
50	33.4	33.78	33.51	31.33	33.72	38.36	35.26	27.28
55	33.39	33.92	33.59	31.52	33.77	38.42	35.33	27.23
60	33.32	34.05	33.65	31.39	33.82	38.49	35.38	27.2
65	33.24	34.18	33.68	31.5	33.86	38.55	35.45	27.19
70	32.95	34.3	33.6	31.45	34.14	38.6	35.56	27.27
75	32.92	34.42	33.58	31.55	34.28	38.62	35.6	27.28
80	32.89	34.53	33.57	31.5	34.31	38.63	35.61	27.28
85	32.87	34.63	33.57	31.42	34.31	38.66	35.63	27.25
90	32.88	34.74	33.58	31.41	34.31	38.68	35.64	27.21
95	32.83	34.84	33.59	31.43	34.32	38.69	35.64	27.18
100	32.85	34.94	33.62	31.35	34.35	38.72	35.65	27.14
105	32.88	35.04	33.65	31.39	34.35	38.76	35.67	27.09
110	32.88	35.13	33.68	31.37	34.37	38.79	35.69	27.04
115	32.88	35.22	33.71	31.37	34.35	38.83	35.7	27.01
120	32.85	35.29	33.67	31.34	34.16	38.65	35.6	27.15
125	32.74	35.35	33.61	31.4	34.01	38.3	35.77	27.15
130	32.89	35.45	33.78	31.46	34.29	38.5	35.84	26.98
135	32.83	35.44	33.82	31.48	34.35	38.69	35.91	26.9
140	32.86	35.41	33.86	31.45	34.36	38.75	35.95	26.86
145	32.89	35.35	33.89	31.39	34.36	38.73	35.94	26.87
150	32.87	35.34	33.89	31.28	34.27	38.68	36.02	26.94
155	32.75	35.33	33.8	31.3	34.08	38.28	35.82	27.28
160	32.7	35.29	33.73	31.35	33.94	37.91	35.65	27.49
165	32.65	35.28	33.69	31.25	33.84	37.72	35.54	27.58
170	32.64	35.28	33.67	31.3	33.81	37.63	35.48	27.63
175	32.63	35.25	33.66	31.3	33.77	37.58	35.45	27.64
180	32.56	35.24	33.64	31.32	33.72	37.53	35.39	27.67