PERFORMANCE EVALUATION OF CHARCOAL BARBEQUE WITH AIR VENTILATION SYSTEM

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and, in my opinion, this thesis is adequate in terms of scope and quality for the award of degree of Bachelor of Engineering Technology in (Energy & Environmental) with Honors.

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ABSTRACT

The charcoal barbeque system developed in this project is a portable and compact barbecue set equipped with air ventilation system. The objective of this work is to analyses the heat transfer mechanism from barbequing process using this charcoal barbeque system. The main purpose of the air ventilation system is to avoid manual fanning. Besides that, some improvement features are added to reduce combustion time, safety, energy and quality of grilling with ease of use. The methodology involved the design stage of charcoal barbeque with air ventilation system prototype by using NX10 modelling. Subsequently, material selection and cost analysis have been done to identify ideal and cost-effective equipment and material based on price, size/dimension and quality. It followed by the fabrication of major components such as the body casing, charcoal port, hot rack and blower. After that, electrical part was commissioned to control the speed of blower. Three types of performance testing have been conducted to ensure the final product is well function. The blower performance testing proved that the higher the voltage, the higher the velocity. The minimum voltage supply set at 6.9V resulted velocity of blower at 17.7knott (9.1 m/s). Meanwhile maximum voltage 7.3V achieved blower velocity about 21.9knott (11.2m/s). In terms of best quality of charcoal for combustion, coconut shell charcoal is selected as more effective than mangrove wood charcoal as it capable to generate higher hot air temperature, flameless and smokeless. Theoretically, according to the heat transfer analysis, temperature difference throughout the barbecuing determines amount of heat transferred towards the food. This analysis demonstrated that heat is gradually transferred to the chicken meat throughout the barbecuing. The chicken meat received adequate heat at 74.4 °C when it is fully cooked.

ABSTRAK

Sistem barbeku arang yang dibangunkan di dalam projek ini ialah produk yang mudah alih, kompak dan dilengkapi dengan sistem pengudaraan. Objektif projek ini adalah untuk menganalisis mekanisme pemindahan haba daripada sistem barbeku yang masih menggunakan sistem arang. Tujuan utama pemasangan sistem pengudaraan adalah untuk mengelakkan sistem pengudaraan secara manual oleh pengguna. Di samping itu, sistem ini telah dilengkapi dengan beberapa ciri-ciri tambahan untuk mengurangkan masa pembakaran, ciri keselamatan, tenaga dan kualiti pembakaran makanan yang selamat untuk digunakan. Metodologi yang terlibat di dalam proses reka bentuk prototaip sistem barbeku yang dilengkapi sistem pengudaraan ini adalah menggunakan model NX10. Seterusnya, pemilihan material dan analisis kos telah dijalankan untuk menentukan alatan dan material yang ideal dan kos efektif berdasarkan harga, saiz/dimensi dan kualiti. Diikuti dengan proses fabrikasi komponen-komponen utama seperti permukaan luaran, bekas arang, rak pemanas dan juga kipas udara. Selepas itu, pemasangan komponen elektrik telah dijalankan untuk mengawal kelajuan kipas udara. Tiga jenis analisis prestasi telah dijalankan untuk memastikan produk yang dihasilkan berfungsi dengan baik. Ujian prestasi terhadap kipas udara telah membuktikan kelajuan udara semakin meningkat dengan peningkatan voltan. Voltan minimum yang telah disetkan adalah 6.9V dan menghasilkan kelajuan kipas udara 17.7knott (9.1 m/s). Manakala, voltan maksimum 7.3V menghasilkan kelajuan udara 21.9knott (11.2m/s). Di dalam aspek kualiti arang semasa pembakaran, arang daripada tempurung kelapa telah dipilih sebagai arang yang lebih efisien kerana menghasilkan udara panas yang bersuhu lebih tinggi, tidak bercela dan kurang berasap. Secara teori, berdasarkan analisis pemindahan haba, perbezaan udara sepanjang proses barbeku menentukan jumlah haba yang dipindahkan kepada makanan. Analisis ini menunjukkan bahawa haba telah dipindahkan kepada daging ayam secara beransur-ansur sepanjang proses barbeku. Daging ayam telah menerima haba yang secukupnya menunjukkan ia telah masak sepenuhnya pada suhu 74.4 °C.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Barbecuing is normally a social occasion and is a safe activity. In Malaysia, under Environmental Quality Act 1974 [Act 127] Environmental Quality (Prescribed Activities) (Open Burning) Order 2000 stated that open burning from outdoor grills, barbeques or fireplaces for the preparation of food which is not carried out at any peat soil area is allowed. Barbecuing is a great activity for bonding with family and friends. It is very popular event during leisure time. This prompts the idea to innovate a barbecue tools in this project.

A barbeque grill is a device that cook food by applying heat from below. Barbequing over charcoal grills is popular around the world. Every country has their own style of barbequing. It depends on the type of barbeque system. To that end, consumers are able to choose from a various type of charcoal grills that come in all shapes and sizes. Charcoal grills require approximately 30 minutes or more to heat the charcoal to a temperature suitable for safe and effective cooking (U.S. Patent No. 2008016897, 2008).

The grill sales trend in Figure 1.1 shows demand for barbeque products is increasing over years. Charcoal grill still being used for barbequing purpose, on top of infrared grills, kamados, gas grills and pallet grills. Thus, in 2014 data shows that 15% retailers are still using charcoal/smoker as their barbeque system.

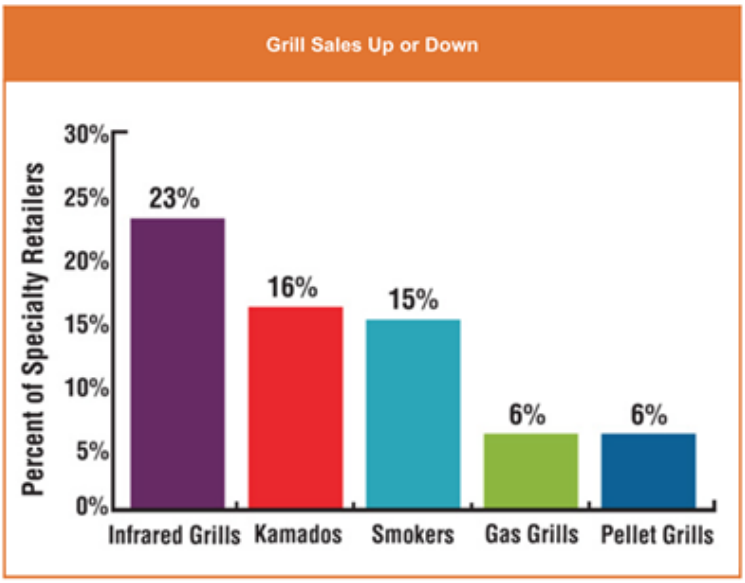


Figure 1.1: The Barbeque Grill Sales in United State 2014 (Wright, 2015)

Based on the previous research and market studies, gas and electric grills are not new after the charcoal grill. Table 1.1 provided the amount of shipments for three types of barbeque grills including charcoal, gas and electric from 2010 to 2013. Gas and electric grill shipments were increased while charcoal slightly decreased about 10.3%. People in North US were looking for other method instead of charcoal as they choose not to get expose to the smoke from charcoals. However, charcoal grill cooked meat has better acceptability, tenderness, juiciness, and flavor scores compared to those of gas and electrical grill-cooked (Choi, 2016). Moreover, people are still looking for a charcoal grill to get a smoky and natural taste of the barbecue.

Table 1.1: Shipments of Charcoal, Gas and electric Barbeque Grill Shipments in North US.

Year	Charcoal	Gas	Electric
2010	6,232,500	8,553,500	276,600
2011	6,047,000	8,445,000	288,000
2012	5,917,000	8,200,000	280,000
2013	5,590,000	8,053,000	302,000

Therefore, the charcoal grill needs to be improvised by providing a simple and easy to use device that generates an airflow that travels through the charcoals, allowing accelerated ignition and heating of the charcoal without creating potential contaminants or blowing ashes into the cooking food (U.S. Patent No. 2008016897, 2008). Thus, this project had improvised the design of conventional charcoal grill by developing a Charcoal Barbeque with Air Ventilation System as shown in Figure 1.2.

Throughout the project development, every important aspect has been considered such as the compatibility of the design with semi-auto portable concept, the air ventilation system at which the device is able to be produce and recycle heat, and the quality of barbecuing in aspect of environmental. In a nutshell, the barbeque set comes with special features that improve energy usage, time consumption, eco-friendly, ease at use and user safety.

Figure 1.2: The Charcoal Barbeque with Air Ventilation System

1.2 Problem Statement

Barbecue grills set have gained in popularity in recent years, grill manufacturers are continually striving to develop barbecue grill that will safely and efficiently cook meat or other foods while retaining the natural flavor of the food being cooked. Conventional charcoal barbeque has low energy efficiency and produce smoke emission. It requires longer times to produce heat and low in heat distribution.

The invention of gas and electric barbeque getting more popular over conventional barbecue. However, most gas and electric barbeque are non-flexible for indoor and outdoor usage. Furthermore, gas and electric grills were designed with attached permanent briquettes (Figure 1.3) to replace conventional grills which use combustible charcoal briquettes. Nevertheless, the permanent briquettes associated with current gas and electric grills tend to collect grease from food being cooked and thereby provide a cooking environment very susceptible to unwanted flaming which can burn and dry out meats or other foods being cooked.

Figure 1.3: Ceramic Briquettes inside a Gas Grill

In other hand, another disadvantage associated with conventional charcoal grills is the difficulty in cooking large pieces of meat which often require longer cooking times and tend to lose their natural juices during such prolonged cooking periods. Other than that, grease drippings will directly contact with the heat source and create uneven heat distribution toward the food.

Thus, the charcoal barbeque set is portable and easily carried, moved and flexible for indoor and outdoor usage. It will be installed with regulated air ventilation system that avoid human fanning and minimize grilling time consumption. The self-fabricated barbeque set prototype also eco-friendly which contribute less pollution towards the environment and safe for user.

1.3 Project Objectives

This project has been developed to achieve the following objectives:

1. To design and fabricate portable charcoal barbeque with air ventilation system.
2. To select the best charcoal in terms of temperature of hot air produced versus time.
3. To analyse the heat transfer from barbequing process

1.4 Project Scope

The project covers all aspects in the development of charcoal barbeque set installed with air ventilation system including the design and fabrication stage. This project was developed based on research from previous studies and several products available in markets in order to propose more efficient charcoal barbecue set. Several important elements of this charcoal barbeque set are the cooker, charcoal system and air ventilation with low smoke emission and hot rack. Generally, a sequence of process involves in the development of this project are:

1. Identification of the ideal equipment for the Charcoal Barbeque with Air Ventilation System by selecting the material based on price, size/dimension and quality.
2. Designing of Charcoal Barbeque with Air Ventilation System by using NX10 Modelling.

3. Fabrication of portable and flexible charcoal barbeque system equipped with cooker, charcoal port, blower to create proper heat distribution and hot rack to maintain food quality.
4. Performance testing to evaluate the functionality and effectiveness of the Charcoal Barbeque with Air Ventilation System.

As a project team leader, those specific job scopes have been conducted throughout this project to ensure the project meet with the specified project objectives:

1. The design works for ventilation path and major components such as the body casing, charcoal port, hot rack and blower.
2. The planning studies contribute to material selection, cost analysis and material purchasing.
3. Fabrication process of Charcoal Barbeque with Air Ventilation System and the commissioning of electrical part.
4. Undergo the performance testing to verify the effectiveness of the product.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Barbequing over charcoal grills is enormously popular the world over. To that end, consumers are able to choose from a seemingly endless array of charcoal grills that come in all shapes and sizes. In spite of great availability of charcoal grills these grills universally face one great setback. Charcoal grills require approximately 30 minutes or more to heat the charcoal to a temperature suitable for safe and effective cooking (U.S. Patent No. 2008016897, 2008).

Consequently, the transformation of barbecue technique has been improvised from time to time. Many researchers have improved the technology of barbecue in order to ensure the effectiveness of the barbecuing set and preserving quality of food. Gas and electric grills are not new after the charcoal grill. However, this study will focus on the improvement of charcoal grill in specific.

2.2 Overview of Barbecue Set

In this section, background study of barbecue is discussed including the barbecuing methods and style of barbecue. Various types of barbecue sets also have been investigated.

2.2.1 Methods and Style of Barbecue

There are numerous methods and styles of barbecuing that break down into two distinct cooking methods; direct and indirect methods. Direct cooking or grilling is where the heat source is directly put under the food to be cooked. The heat source effectively emanates from one direction so food cooked directly is cooked on one side at a time and will need turning to ensure that it is cooked on all sides. Whereby, indirect cooking on a barbecue uses convection heat like in a conventional oven. The primary

feature of indirect cooking is that there is separation between the food and the heat source by positioning of food in relation to the heat source or by a physical barrier (Paul, 2018).

Another usual term is roasting refers to a cooking method that uses dry heat, whether an open flame, oven, or other heat source. Roasting usually causes caramelization or mail lard browning of the surface of the food, which is considered a flavor enhancement. Roasting, as the word implies, is the working mechanism by which the food product material is thermally subjected into irreversible structural changes and reduction of moisture contents purposely to bring about digestible content for human consumption (Oke, 2013).

2.2.2 Typical Barbecue Sets

There are various types of barbecue sets which are put into use worldwide. These include electric barbecue machines, cell barbecue grill, barbecue grill netting, and barbecue machine (Gyansah, 2012). Most conventional barbecue set for an example, in Namibia all run on wood and undergoes the same principle; firewood is placed in a metal container and once the embers are ready for barbecuing the meat is placed on a grill rack above the embers (Lindberg, 2010).

In developing countries like India, barbecue sets mostly use by the local street vendors selling roasted corns operate seasonally, as per the availability of maize crops. Roasting of corn cobs is done by placing the maize on a glowing charcoal and then turning it occasionally to allow even distribution of heat. A hand fan is used by the vendor to blow the air so as to maintain the glowing of charcoal. The rate of heat transfer from the charcoal to the maize depends on how fast the hand fan blows the air current. The process is strenuous as the vendor is tired out with the time before the corn cob is completely roasted (Deepika, 2016).

While in China, Chinese style barbecue is very popular in Chinese charcoal barbeque restaurant. Before put on the table, food is initially baked in the charcoal burner range in kitchen. During the meal, a pot or plate that fueled with charcoal is set on each table to ensure that the food is always hot. Similar to hot pot, when the food is eating up, other dishes can load into the broth for further cook (Zhang, 2017).

Conversely, contemporary barbecues also exist out there such as regular barbecue using charcoal and a steel casing as in Figure 2.1 (a), the heat can fluctuate, which can either be positive or negative. Figure 2.1 (b) depicts the barbecue that uses propane gas that allows for easy temperature control but wood chips should be added in order for the food to taste smoky. Meanwhile, Figure 2.1 (c) shows a ceramic barbecue that stays warm more easily but is expensive and hard to handle. All three can be used with or without a lid and this has a lot of impact on the functionality (Taams, 2016). Most of the barbecues sold in Sweden are run on charcoal or Liquefied Petroleum Gas (LPG) (Lindberg, 2010).

(a)

(b)

(c)

Figure 2.1: (a) Regular Barbecue Using Charcoal and a Steel Casing (b) Barbecue That Uses Propane Gas (c) Ceramic Barbecue

2.3 The Innovation and Evolution of Barbecue Set

The needs for more energy efficient barbecues are alarming and urged many researchers to innovate and involve in the evolution of barbecue set. In this section, the reviews are referring to those invention from previous researchers. The subsequent content is divided into two, improvement of the conventional barbecue and high technology invention in barbecue set.

2.3.1 Basic Improvement of the Conventional Barbecue

One of the studies at the open markets in Namibia was initiated since firewood constitutes a large cost for the actors selling food at the market. Therefore, (Lindberg, 2010) had built a prototype called the EzyStove. The project was dedicated for a Creative Entrepreneurs Solution (CES) based in northern Namibia. The barbecue set is as an attempt to reduce the wood consumption, applying a concept of combining cooking and barbecuing. The most important finding during the field study was that it is common to use two or more fires at the same time to be able to both barbecue and cook in pots.

The design in barbecue set was improved further through barbecue stove design with features to minimize the stress on arms, probability of accidents and improving the performance of the stove. The cubical shape stove is insulated to avoid the direct contact of heat to the body and the provisions were made to avoid the contact of fire with the body part. A blower was attached to the model to reduce the stress produced by constant fanning (Deepika, 2016).

2.3.2 Advance Barbecue Invention with Technology

Moving forward, more sophisticated study devoted to barbecue set was developed by other inventors or researchers. As part of Senior Design Project that took place in the Department of Mechanical Engineering at Ohio University, Team OU BBQ were proposed a mobile grilling system to solve a problem with a mobile food vending

service. The problem presented to the group dealt with the customer running out of product because a large enough grill could not be transported on her truck. After researching food and road safety standards, the group designed and analyzed a system that could incorporate a much larger grill and still be transported on her truck with ease of use. The end product used a hydraulic lift system that attached to the back end of the truck and lowered the grilling system to the ground so the grill could be used wherever was convenient (Harris, 2010).

Another invention in barbecue set is a development of portable gas barbecue machine (Gyansah, 2012). The prototype has proven to be more efficient, serviceability, low cost, and has better heat radiation controllability when manufactured. Besides the primary objective to provide a portable barbecue set, this design also eliminates the health hazards associated with the use of charcoal in substitute of gas cylinder. Whereby, (Oke, 2013) has designed the multipurpose roasting machine made up of roasting chamber, heating chamber, two blowers, and power transmission mechanism. The roasting chamber houses ten food hangers use to hold the food items. The hangers were continuously rotated to perform uniform and smooth roasting.

Additionally, more sophisticated study devoted to barbecue set was developed by (Taams, 2016) and his team by deploying the Internet of Thing (IoT) concept. Pitmaster was created, that is barbecue support toolkit consists of temperature sensors, sensor tongs, timers and a base station. They had redesigned the barbecue experience using modern communication technologies into a smart barbecue toolkit that evolved from an iterative design process. One of the special features is a wireless-connected barbecue system where the user is possible to check the cooking progress from anywhere.

2.4 Special Features of Barbecue Sets

The latter emphasizes distinctive major features of the improved design of barbecue sets. Three major components are reviewed including the cooker, barbecue incorporated with fan and barbecue smoke reduction.

2.4.1 The Cooker

The barbecue cooker is a vital part in barbecue set. A variety of charcoal type cookers are conventionally available, and serve the functions of containing the fuel and generating the heat used for the cooking process.

Among the technology invention for barbecuing tools is the convection oven development (U.S. Patent No. 20110275023, 2010). The designed convection oven for cooking foods includes a housing having a fire chamber and a cooking chamber disposed generally above the fire chamber. A vessel is receivable in the fire chamber and is adapted to hold combustible material therein to generate heat and smoke for cooking food in the cooking chamber. Meanwhile, a blower is mounted on the housing to move air. Thus, the oven does not require supplemental heat from a burner or similar heating element. The convection oven illustration is provided in Figure 2.2.

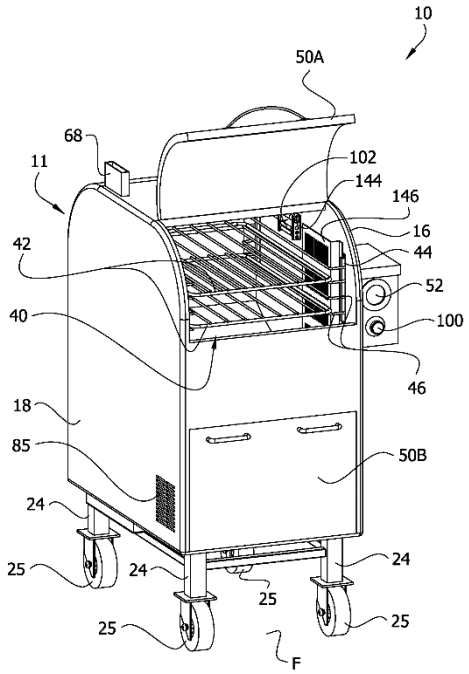


Figure 2.2: Convection Oven (U.S. Patent No. 20110275023, 2010)

2.4.2 Barbecue Incorporated with Fan

People are looking for a good barbecue that are energy efficient, less cooking time and user friendly. Ordinary barbecues require longer time to starts fire manually, however this activity is now taken over by the incorporated fan or blower in most barbecue set. Remarkably, a charcoal grill has been designed to provide a rapid ignition and heating of the charcoal, by means of an electric fan that is coupled to the body of the grill (U.S. Patent No. 2008016897, 2008). According to Figure 2.3, the installed fan decreases the overall time required to heat the charcoal to proper cooking temperature by increasing the flow of air provided to the charcoal. The increased airflow created by the incorporated fan accelerates the firing-up and heating of the charcoal by channeling air across and through the charcoal.

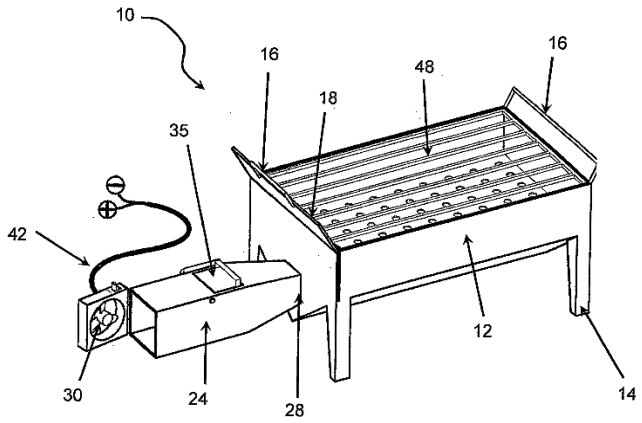


Figure 2.3: Portable Charcoal Grill with Incorporated Fan
(U.S. Patent No. 2008016897, 2008)

Likewise, forced air grill in Figure 2.4 utilizes a fan to force air through an air duct and into the lower chamber of the firebox, up through the charcoal. This grills temperature is controlled by the use of thermocouple to turn a fan on and off which supplies air to the fuel. The design of the grill makes it easy to add charcoal and clean out ashes. The removable tray gives an option to prevent flare-ups so user no need to constantly monitor the grill (U.S. Patent No. 20170238761, 2017).

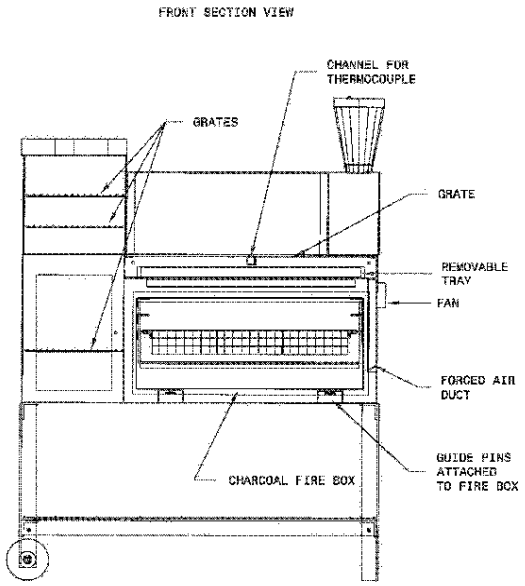


Figure 2.4: Forced Air grill (U.S. Patent No. 20170238761, 2017)

2.4.3 Barbecue Smoke Reduction

A by-product of the barbecue grill in a great many occasions is smoke which may result due to the high heat and meat being cooked on the barbecue grill. The direction of the smoke may vary depending on the wind direction and strength. Normally, the smoke is directed towards the cook. According to (Zhang, 2017), barbecue charcoal combustion could be an important source of emissions to the atmosphere with potential health risks. Thus, it would be desirable to be able to control the direction of the smoke in order to provide a more pleasant cooking experience and prevent health risks.

In another invention, a barbecue grill device has been designed attached with a base member to form a base for the barbecue grill device, a burner housing to be positioned on the base member and an airflow diverter to form an airflow between the user of the barbecue grill device and a burner housing (U.S. Patent No. 20140090634, 2014). Meanwhile, Figure 2.5 shows a vent created at the back side of the portable gas barbecue to allow circulation of air and flow out the excess smoke (Gyansah, 2012).

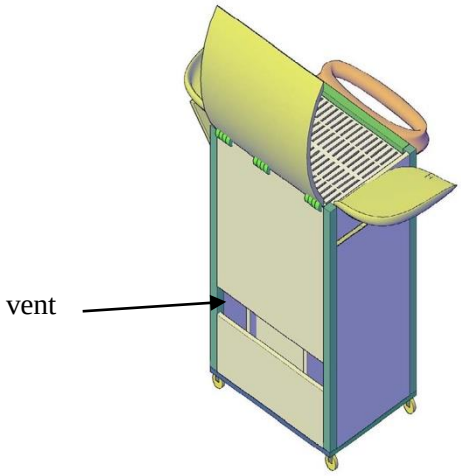


Figure 2.5: A Vent at the Back of Portable Gas Barbecue

2.5 Overview of Charcoal for Barbeque

Charcoal represents one of man's very first technological achievements; it was in use as early as 200,000 B.C. When wood is burned slowly without oxygen it produces charcoal. The charring removes the water and most of the flavor-producing chemical compounds of the wood, leaving a carbon-rich fuel that burns hot, cleanly, and efficiently. Charcoal also produces a more concentrated fire. No wonder the vast majority of the world's grill masters burn charcoal. But not all charcoals are the same. Common type of charcoals are lump charcoal, Charcoal briquettes, and coconut shell charcoal.

2.5.1 Types of Charcoal

Lump charcoal

Sometimes called char wood or natural lump charcoal, this is the original charcoal, made by burning trees or logs in a kiln, sealed cave, or even underground. Unlike briquettes, lump charcoal is pure wood—free of binders or petroleum-based accelerants. Lump charcoal burns hot, cleanly, and pure. You can refuel a lump charcoal fire with unlit charcoal without producing the acrid smoke associated with freshly lit briquettes. However, natural lump charcoal burns unevenly, hotter at the beginning, cooler at the end, and it burns out more quickly than charcoal briquettes. When you grill

with lump charcoal you'll need to refuel the grill more often than with briquettes, usually after 30 to 40 minutes. Avoid "lump" charcoal that comes in straight-edged rectangular blocks—it's made from lumber scraps, not logs. One excellent widely available brand is Royal Oak. For something a little more exotic.

Charcoal briquettes

These are designed to burn evenly and maintain a steady "broiling" temperature of at least 600 degrees F for 1 hour. Traditional briquettes contain wood scraps, sawdust, coal dust, borax, and petroleum binders, so it's not surprising that they emit an acrid-tasting smoke when first lit. Instant-light charcoal consists of briquettes saturated with lighter fluid. The acrid smoke disappears once the charcoal glows orange and begins to ash over, but you're still grilling over borax, coal dust, and petroleum binders. And, although the petroleum-based accelerants of instant-light charcoal burn off in theory, they can produce an oily taste when less than completely lit. "Natural" briquettes, which contain only wood scraps and starch binders, are meant to eliminate these problems.

Coconut shell charcoal

This sustainable charcoal is made from coconut shells, not wood. It is flavor neutral and generates virtually no smoke or ash. It is quick to light, hot burning, and sold in small pieces, it's the perfect charcoal for the small grills used by Asian street vendors. This charcoal burns up to 978°F, so you will never have issues getting beautiful grate marks on your food.

2.6 Heat Transfer Mechanism in Barbecuing Process

Heat transfer is the movement of heat across the boundary of the system due to temperature difference between the system and the surroundings. There are three modes of heat transfer between the two bodies explicitly conduction, convection and radiation. Knowledge of heat transfer processes is required for the construction of the charcoal barbeque with air ventilation System. The rate at which heat is transferred from heating medium to food by force convection, heat transfer by convection is measured by the equation:

$$Q = hA\ (T_f - T) \quad (1)$$

Where Q is the heat transferred per unit time, A is the area of the object, h is the heat transfer coefficient, T is the object's surface temperature and T_f is the fluid temperature (Oke, 2013).

The charcoal barbeque with air ventilation system operates when the blower is utilized to force air through an air duct and into the charcoal port. Charcoal is fired up inside the charcoal port when air is supplied by the blower. The blower effectively providing additional air for the fire, while allowing the air to circulate naturally and uniformly up through the charcoal (U.S. Patent No. 2008016897, 2008). During barbecuing process, the hot air will interact with the food and being recycled back to the hot rack inside the cooker to maintain the grilled barbeque food temperature and quality.

Heat transfer through conduction occurred when heat is transferred to the food by direct contact with the heat source. Thus, heat transfer mechanism during barbecuing could be observed through heat transfer analysis. During barbecuing, temperature and amount of heat transferred to the chicken could determine the ultimate cooking time. Specific amount of heat absorbed during barbecuing are calculated using the equation:

$$Q = mCp.\ \Delta T \quad (2)$$

Where Cp=the specific heat capacity, m= the mass of the substance, and ΔT is the change in temperature.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter elaborates further the methods and procedures that have been executed in order to achieve the objectives of this project. The chosen methods have been considered in every aspect so as to ensure a satisfying result of the performance of the Charcoal Barbeque with Air Ventilation System.

The methodology outline in this chapter is divided into methodology framework, designing process, material selection, fabrication process, electrical part commissioning and performance testing.

In conjunction with the methodology framework, the Charcoal Barbeque with Air Ventilation System mechanisms and specification are also being discussed in detail. Besides that, equipment used throughout the project development is included in this chapter as well.

3.2 Methodology Framework

The methodology framework for the development of Charcoal Barbeque with Air Ventilation System as shown in Figure 3.1.

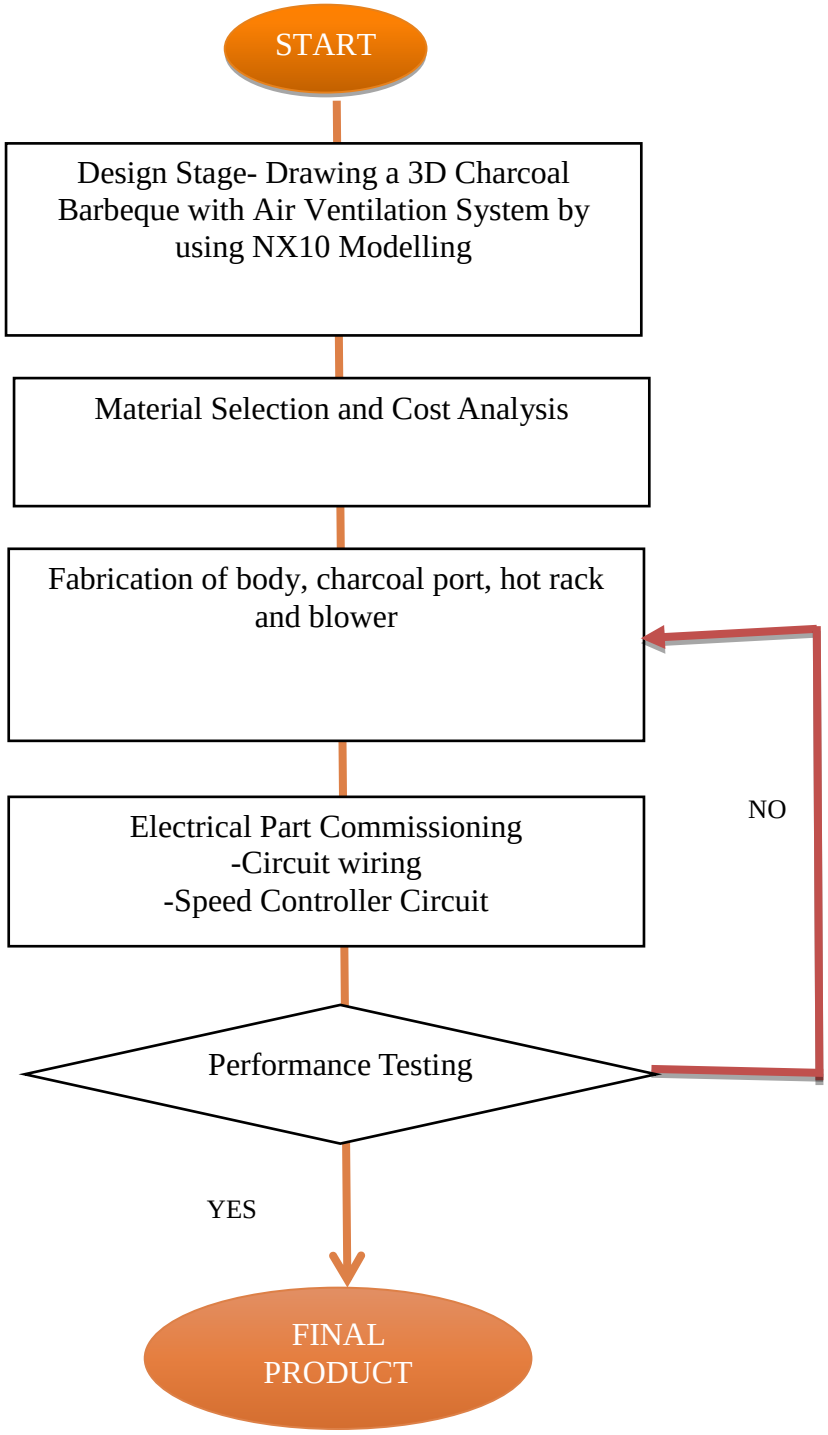


Figure 3.1: Methodology Framework

Firstly, the design of Charcoal Barbeque with Air Ventilation System prototype has been prepared by drawing a 3D sketch using NX10 modelling. Secondly, material selection and cost analysis has been done to identify ideal and cost-effective equipment and material based on price, size/dimension and quality. It followed by the fabrication of major components such as the body, charcoal port, hot rack and blower. After that, electrical part was developed to control the speed of blower. Finally, performance testing has been conducted to ensure the final product is well function.

3.3 The Charcoal Barbeque with Air Ventilation System Mechanism

This sub-chapter explained the theory of process behind the proposed Charcoal Barbeque with Air Ventilation System according to charcoal system and the cooker with air ventilation system.

The charcoal system mechanisms inside the charcoal system will go through these three steps. Firstly, charcoal need to be fired up inside the charcoal port. Secondly, blower function to allow air flow through the charcoal port. Air will interact with the hot charcoal and perform hot air distribution towards the system. Consequently, the hot air will be used as a medium for barbequing in cooker part. During barbecuing process, the hot air will interact with the food and being recycled back to the hot rack inside the cooker to maintain the grilled barbeque food temperature and quality. All these processes are summarized in Figure 3.2. Meanwhile, clear illustration of heat flow distribution can be viewed through Figure 3.3.

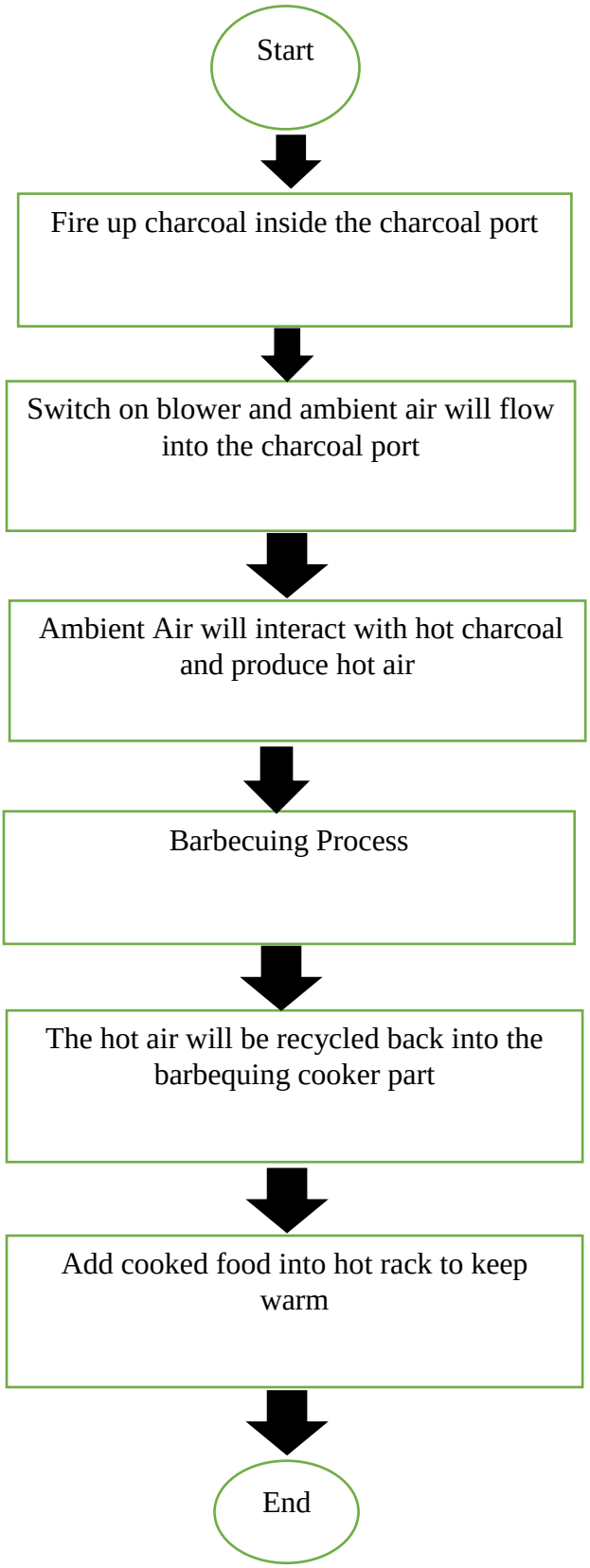


Figure 3.2: The Mechanisms of Charcoal Barbeque with Air Ventilation System

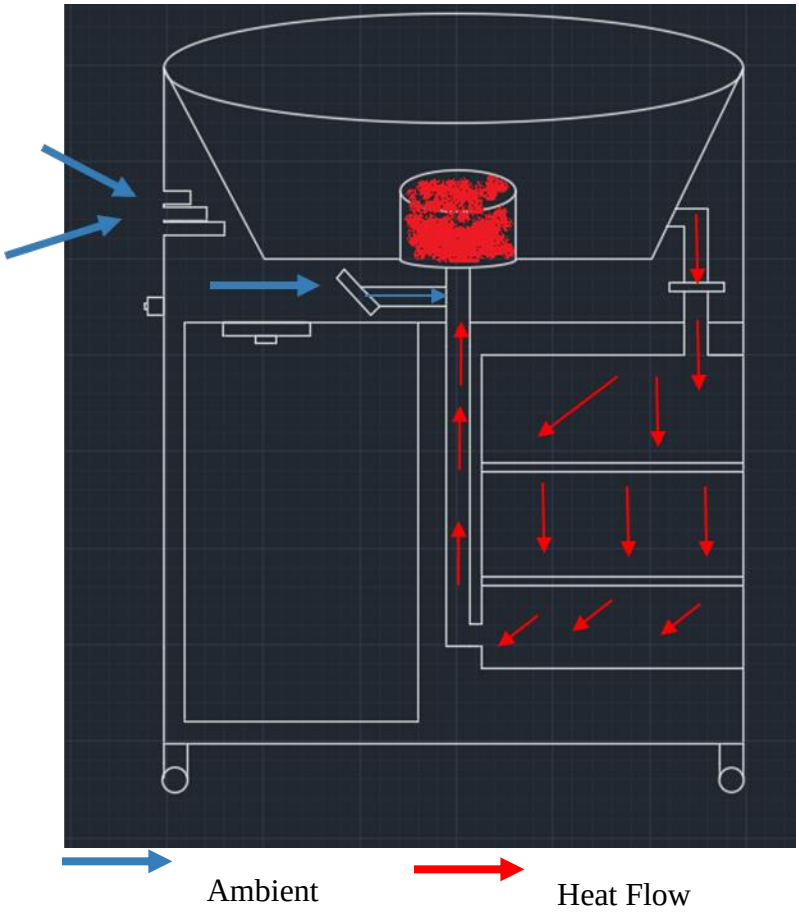


Figure 3.3: Heat Distribution Path (Cooker and Hot rack)

3.4 The Design Stage and Features of Charcoal Barbeque with Air Ventilation System

The design of a portable Charcoal Barbeque with Air Ventilation System focusses on three different parts, which is charcoal port system, the cooker with air ventilation and hot rack. The 3D drawing of the barbeque set was prepared using NX10 Modelling. Figure 3.4 shows front view of the proposed system while Figure 3.5-3.6 illustrated right, left and isometric view respectively.

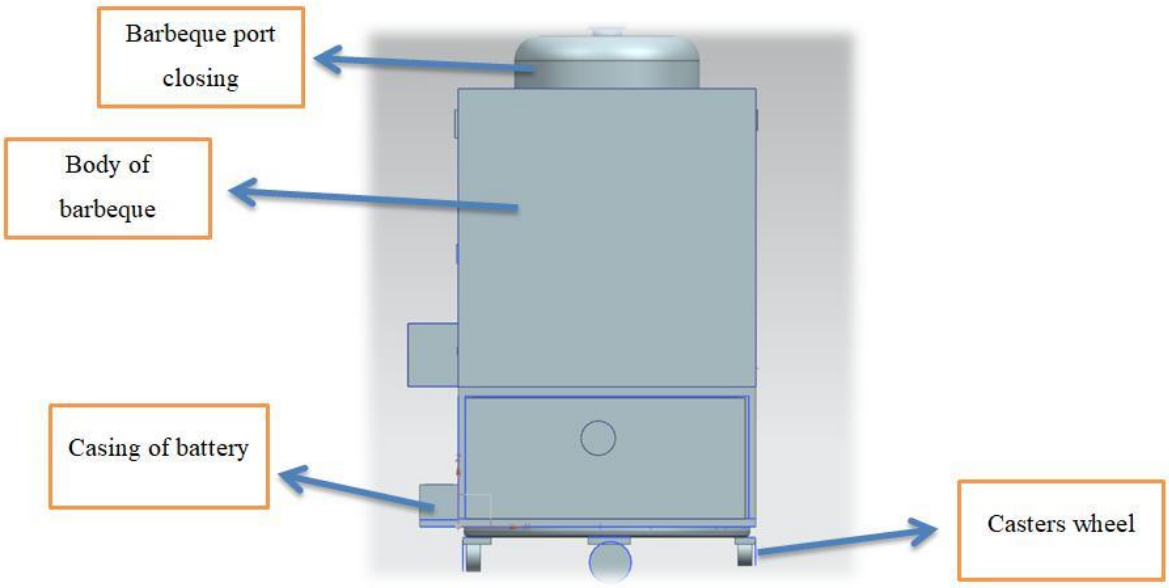


Figure 3.4: Front View of the Charcoal Barbeque with Air Ventilation System

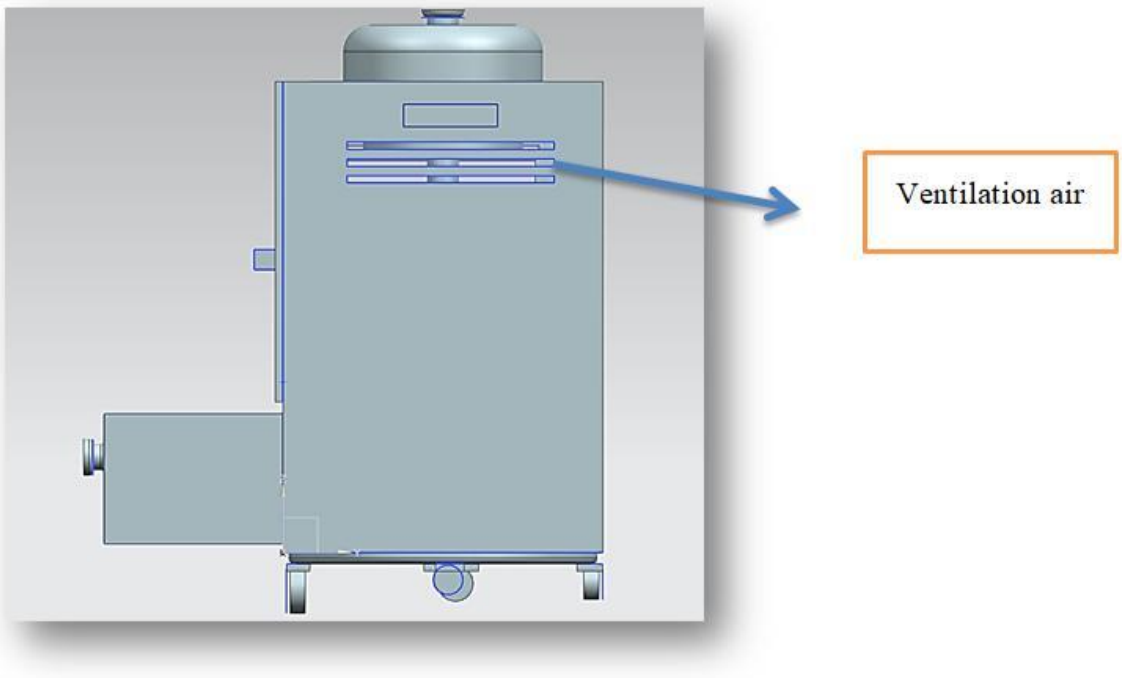


Figure 3.5: Right View of the Charcoal Barbeque with Air Ventilation System

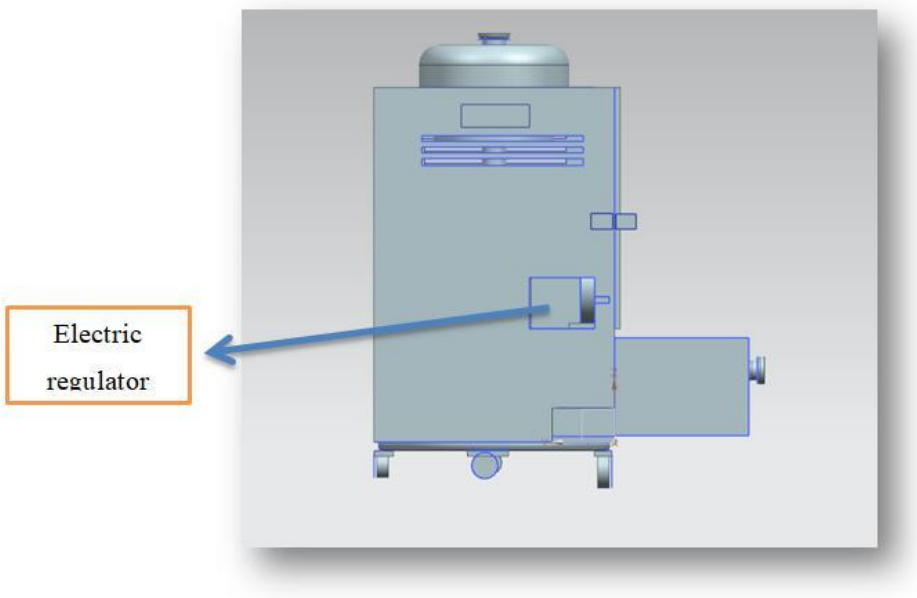


Figure 3.6: Left View of the Charcoal Barbeque with Air Ventilation System

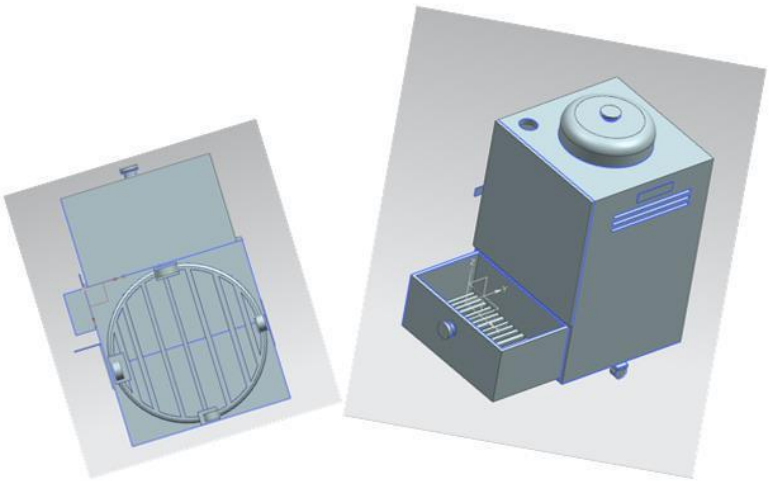


Figure 3.7: Isometric View of the Charcoal Barbeque with Air Ventilation System

Literally, the Charcoal Barbeque with Air Ventilation System was designed with special features as the following:

- Portable – Compact 36 cm length, 43 width and 38cm high.
- Simple to use – No manual fanning required.
- Safe – Exterior double-wall construction.
- Easy – Easy to assemble and cleaning.
- Healthy – Due to the special design of the charcoal port, excess fat cannot reach the charcoal.
- Eco Friendly- Use of Coconut Shell Charcoal

3.5 Material Selection

After completing the designing stage of Charcoal Barbeque with Air Ventilation System, material selection was carried out to identify ideal equipment for prototype assembly. Material selection is based on price, size/dimension and quality. List of selected materials are as in Table 3.1.

Table 3.1: Material for Charcoal Barbeque with Air Ventilation System

Material	**Quantity**
Zink	10kg
Barbeque bowl	1
Barbeque grill	1
Variable Speed Switch Control	1
Blower	1
Coconut Shell Charcoal	3kg
Casters Wheels 2"	4
Battery 12V	1

3.5.1 Cooker Set Selection-Stainless Steel

The selection of appropriate material for the cooker set is important to retain heat during barbecuing. According to Table 3.2, stainless steel was chosen over aluminum as a common cooking material based on the thermal diffusivity, α. Thermal diffusivity, α is the combination of the three properties: is the combination of the three properties:

$$\alpha = (k/\rho)\, Cp \qquad (3)$$

Where *k*=Thermal conductivity, ρ=density, *Cp*=Specific heat

A material with high α is characterized by a quick response to the changes in surrounding temperatures. A material with low α characterized takes longer to reach a steady state condition, but is excellent at retaining heat once heated.

Table 3.2: Properties of Common Cooking Materials.

	ρ (kg/m^3)	k (W/mK)	Cp(J/kgK)	α (10^{-6} m^2/s)
Aluminium	2780	170	880	70
Cast iron	7870	70	450	21
Copper	8900	400	385	117
Stainless steel	8000	15	480	3.7
Glass	2600	4	800	1.9

3.5.2 Charcoal Selection

In this project, charcoal is use to fuel the barbecue set. Right selection of charcoal determines its efficiency. Thus, a comparison has been done to decide the best charcoal. According to Table 3.3, the coconut shell charcoal can be considered as the best type of charcoal for grilling because of its cost, efficient, and burning process. However, the natural coconut shell charcoal having size unevenly bring negative effect to grilling quality. Therefore, the Coconut Charcoal Briquettes were then suggested to use on barbeques. This sustainable charcoal is made from coconut shells, not wood. It is flavor neutral and generates virtually no smoke or ash. It is quick to light, hot burning and can burns up between 500˚C to 600˚C for 3 to 4 hours (Jenner, 2017).

Table 3.3: Comparison of Types of Charcoal (Jenner, 2017)

Mangrove wood charcoal	**Coconut shell charcoal**
	
Expensive	Inexpensive
Less efficient	More efficient
Burn faster (1 hour)	Burn slower (3-4 hours)
Burns hottest (≥760°C)	Lower temperature (500˚C to 600˚C)
Pure natural hardwood	Natural
Size unevenly	Size either evenly or unevenly
Burning with strong flame and smoke	Flameless and smokeless

3.6 Fabrication Stage of Charcoal Barbeque with Air Ventilation System.

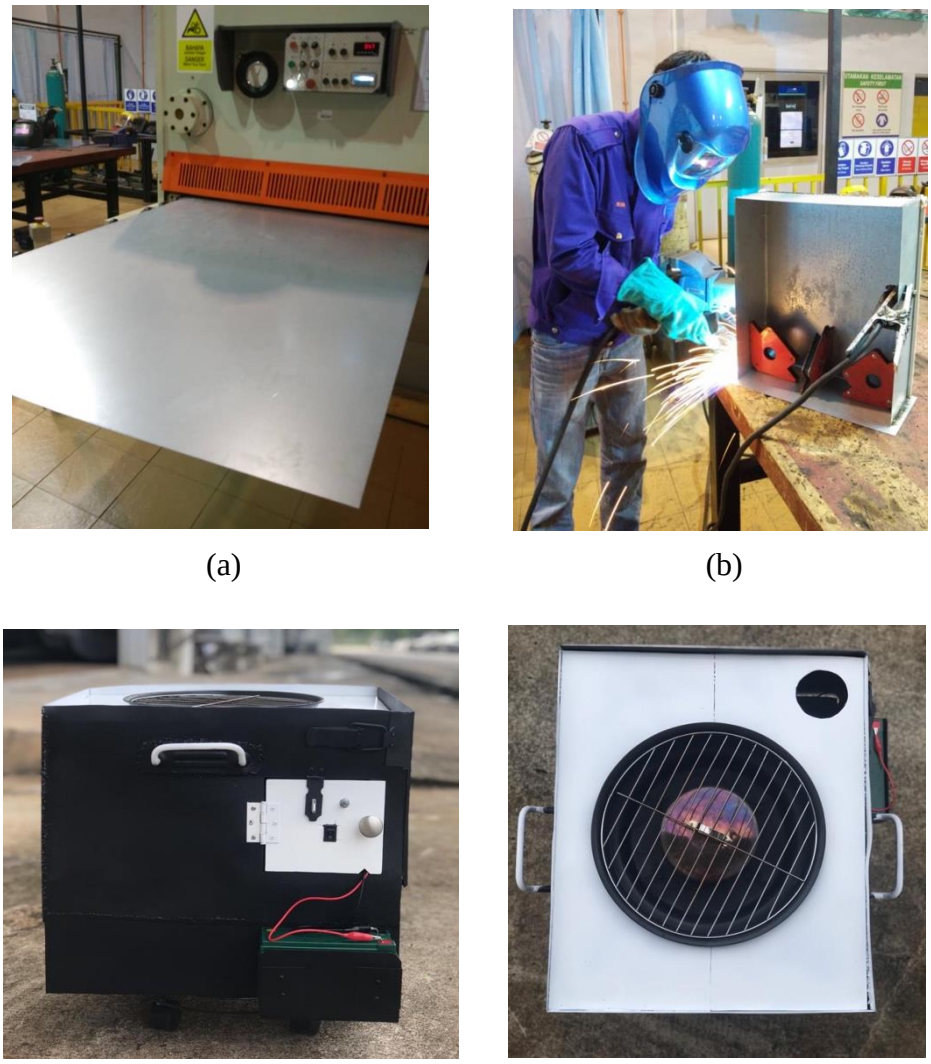
The fabrication of Charcoal Barbeque with Air Ventilation System prototype has been conducted in Engineering Technology Workshop in Faculty of Engineering Technology, UMP. It took about one month to finish the fabrication of the final product. The prototype was manufactured using zinc material for the body part as well as stainless steel for the cooker set. The structure has gone through dimensioning process to get the right sizing, cutting, joining and assembling processes. The tools deployed in the fabrication process are grinder, welding machine, solder and rivet. The sizing of major components is provided in Table 3.4.

Table 3.4: Sizing for Major Components

Components	**Sizing**
Body/Frame	Length-36cm, width-43cm, Height-38cm
Grill part	Diameter-26cm
Charcoal port	Diameter-11cm, Height-7cm
Hot Rack	Length-33cm, Width-40cm, Height 13cm

3.6.1 Fabrication of Casing Part

The construction procedures were done in stages starting from the construction of the body where the frame was constructed using zinc material. The square zinc was marked out accordingly and cut into pieces of different required size based on the design calculation (sizing: 36 cm length, 43 cm width and 38 cm height). The pieces were welded together for rigidity, support and stability. On top of the structure placed the charcoal port, while the front side is attached with hot rack functioning like a drawer. Figure 3.8 shows several photos during fabrication of casing part.



(a) (b)

(c) (d)

Figure 3.8: (a) Cutting of Zink (b) Fabrication of Body Casing (c) Side View of Body (d) Top View of Body with Charcoal Port

3.6.2 Fabrication of Charcoal Port

The charcoal container was constructed using stainless steel. The material was measured according to the design size. The charcoal chamber was perforated to allow air from the blower for effective supply of required heat. Charcoal port was constructed with size diameter 11cm at 7cm height. The appearance of charcoal port can be viewed from Figure 3.9.

Figure 3.9: The Charcoal Port

3.6.3 Fabrication of Blower

The blower in Figure 3.10 was measured and modified into desired shape for incoming air at the center of a spinning impeller. As the impeller turns, it accelerates the air outwards from the impeller. The air was channeled into pipes that had been welded and inserted into the charcoal port. The size of the blower is about 11cm in diameter. The increased airflow created by the blower accelerates the firing-up and heating of the charcoal by channeling air across and through the charcoal port.

Figure 3.10: The Blower

3.6.4 Fabrication of Hot Rack

The hot rack is a compartment for placing the food after cooked to keep it warm. The hot rack was designed as a drawer with a removable grill tray inside as in Figure 11. The hot rack placed in front of the barbecue set. The hot rack is constructed with sizing 33 cm height, 40 cm width and 13 cm height.

Figure 3.11: The Hot Rack

3.7 Electrical Part Commissioning

The electrical part commissioning was performed after the fabrication of prototype. The electrical part consists of one unit of battery and electric regulator. The battery used for the barbecue set is 12 voltage in capacity. Voltage is supplied by the battery to run the blower in order to generate air velocity. Meanwhile, electric circuit function to regulate the speed of blower. Apparently, Figure 3.12 shows the battery and electrical circuit consists of mosfet, potentiometer and motor with high RPM and torque.

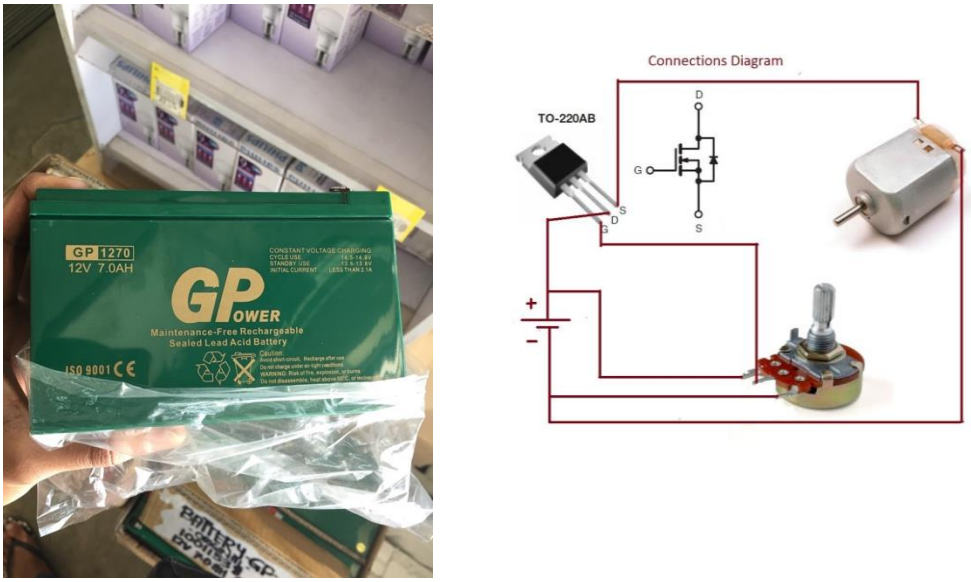
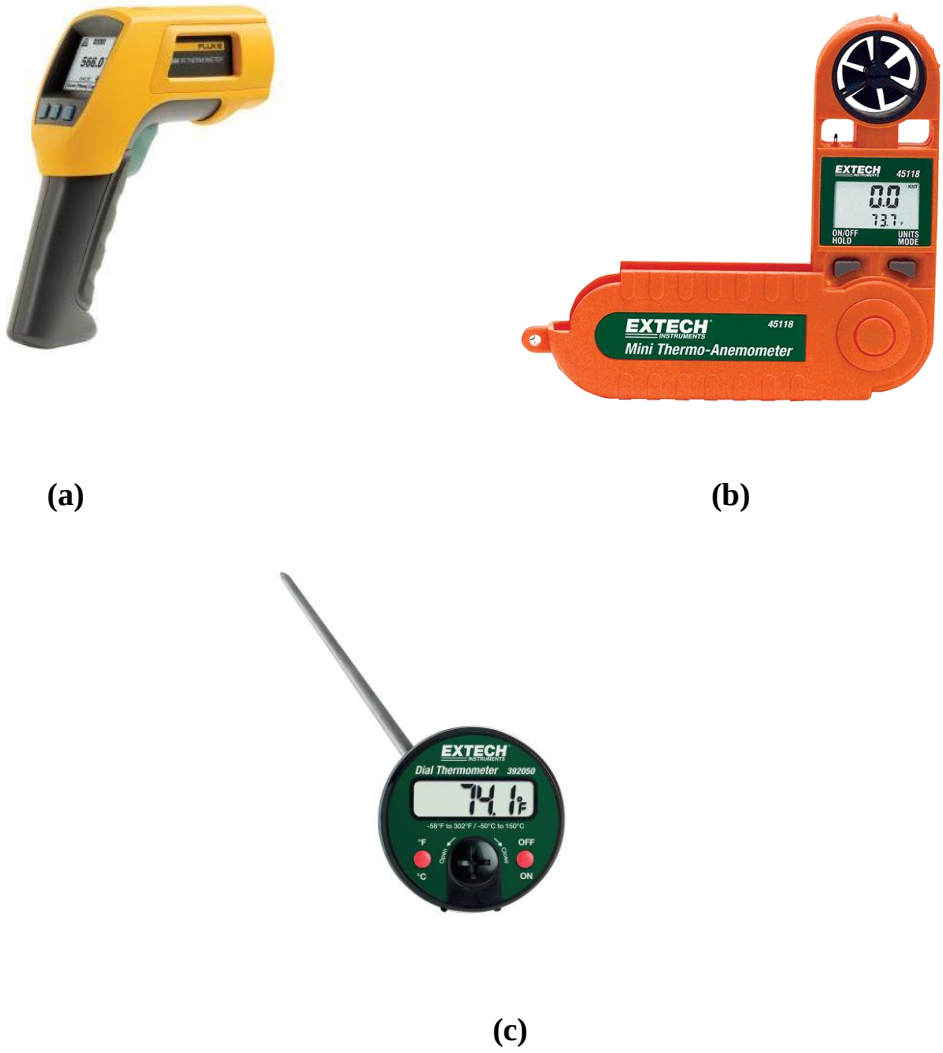


Figure 3.12: Battery, 12 Volt and Electrical Circuit

3.8 Performance Analysis

As the prototype completed, performance analysis was conducted in order to investigate blower performance, compared different type of charcoal performance and heat transfer analysis. Whereby, during performance analysis; there are few measurement devices have been utilized. Figure 3. 13 presented devices that being used including thermal infrared contact thermometer, mini anemometer as well as penetration stem dial thermometer.



(a) **(b)**

(c)

Figure 3.13: (a) Thermal Infrared Contact Thermometer (b) Mini Anemometer and (c) Penetration Stem Dial Thermometer

3.8.1 Blower Performance

Blower performance analysis has been done by regulate the supply voltage to control the velocity of blower. This analysis is to monitor the minimum and maximum velocity that can be produced by the blower. The heat produced by the charcoal can be controlled by using the velocity of air supplied from the blower.

3.8.2 Selection of Charcoal

Generally, the usage of charcoal as a fuel in barbecuing determines the quantity of hot air produced. In this testing, mangrove woods and coconut shell were compared to select the best charcoal in terms of temperature of hot air produced. The half-life of charcoal also being observed during this analysis. Subsequently, the selected charcoal is use to proceed the heat transfer analysis.

3.8.3 Heat Transfer Analysis

Heat transfer analysis was carried out to determine temperature and amount of heat transferred to the chicken. This analysis was conducted during barbecuing approximately 30 minutes period at constant velocity (9 m/s). Specific amount of heat absorbed through conduction heat transfer was calculated using equation in Section 2.6. The value taken for Cp= 3.68kJ/kg.K, m= 0.128 kg, and initial temperature = 28.9°C. The final temperature was obtained during barbecuing at every five minutes interval.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Blower Performance Analysis

Air blower is a machine used for generating flow of air at substantial pressure. The air flow generated in this barbecue set is used to heat up the coal. By controlling the fan, the temperature can be controlled. In this analysis, the supply voltage was regulated to control the velocity of blower to monitor the minimum and maximum velocity that can be produced by the blower. This analysis was repeated about three times to determine the average velocity of blower. The velocity data for different voltage are tabulated in Table 4.1.

From Figure 4.1, it can be seen that the higher the voltage, the higher the velocity. The minimum voltage supply set at 6.9V resulted velocity of blower at 17.7knott. Meanwhile maximum voltage 7.3V achieved blower velocity about 21.9knott. From this analysis, it can be concluded that the heat produced by the charcoal can be controlled by using the velocity of air supplied from the blower.

Table 4.1: Velocity (knott) of Blower at Different Voltage

Voltage	velocity$_1$	Velocity$_2$	velocity$_3$	Average velocity
6.9	17.8	17.3	18	17.7
7	18.6	19.2	19.1	18.9
7.1	19.6	20.3	20	19.9
7.2	20.9	21.6	21.2	21.2
7.3	21.6	22.3	21.9	21.9

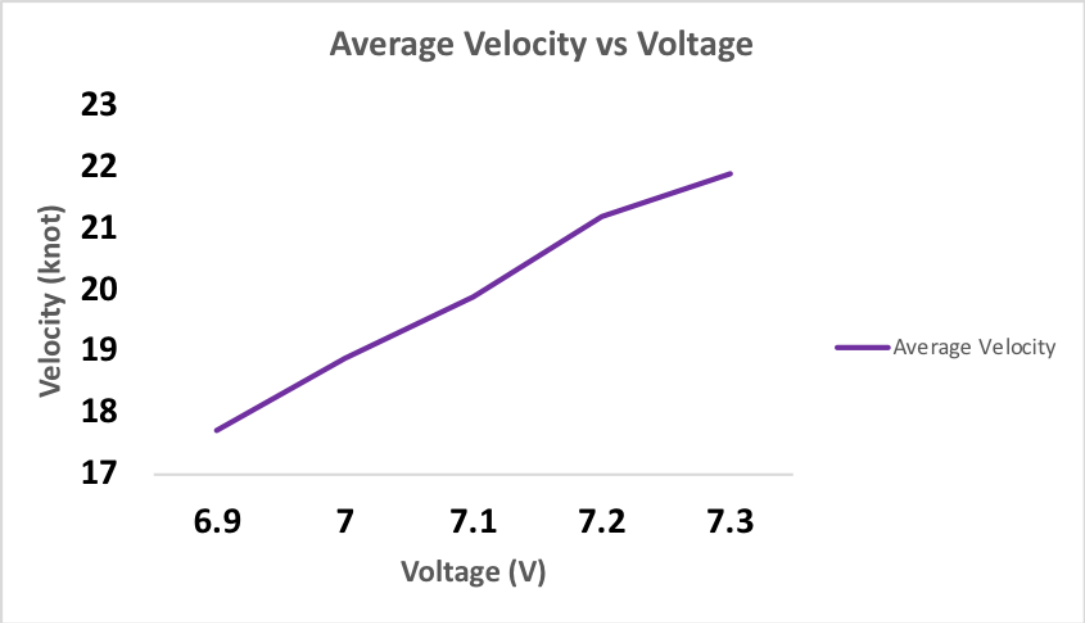


Figure 4.1: Average Velocity of Blower Vs Voltage

4.2 Performance Testing of Different Charcoal

The usage of charcoal as a fuel in barbecuing determines the quantity of hot air produced. The half-life of charcoal also being observed during this analysis. In this testing, mangrove woods and coconut shell were compared. Temperature of hot air for both charcoals were recorded at two minutes interval within 20 minutes time. From the observation, one charcoal port can contain about 420g to 450g charcoal and able to supply heat within 30 minutes.

Data for hot air temperature are tabulated in Table 4.2 and Table 4.3. As a result, coconut shell produces higher amount of hot air as compared to mangrove wood. Thus, coconut shell charcoal is selected to proceed with subsequent heat transfer analysis.

Table 4.2: Mangrove Wood Charcoal Testing

Time	Hot Air Temperature (Mangrove Wood Charcoal)		
	Test 1	**Test 2**	**Average**
2	65.8	66.7	66.2
4	65.4	66.6	66
6	64.2	65.3	64.7
8	59.4	64.9	62.1
10	57.7	64.7	61.2
12	56.4	63.7	60
14	54.6	62.9	58.7
16	53.4	61.6	57.5
18	52.8	59.8	56.3
20	48.5	59.2	53.8

Table 4.3: Coconut Shell Charcoal Testing

Time	Hot Air Temperature (Coconut Shell Charcoal)		
	Test 1	**Test 2**	**Average**
2	82.9	85.7	84.3
4	79.4	86.6	83
6	77.9	84.8	81.3
8	76.8	82.3	79.5
10	66	77.7	71.8
12	63.6	75.4	69.5
14	61.7	75.1	68.4
16	60.4	74.6	67.5
18	55.3	72.7	64
20	54.7	70.3	62.5

In addition to that, the plotted graph for those recorded data is showing in Figure 4.2. It clearly illustrates decreasing trend of hot air over time as the charcoal is fully combusted at the end of the barbecuing process.

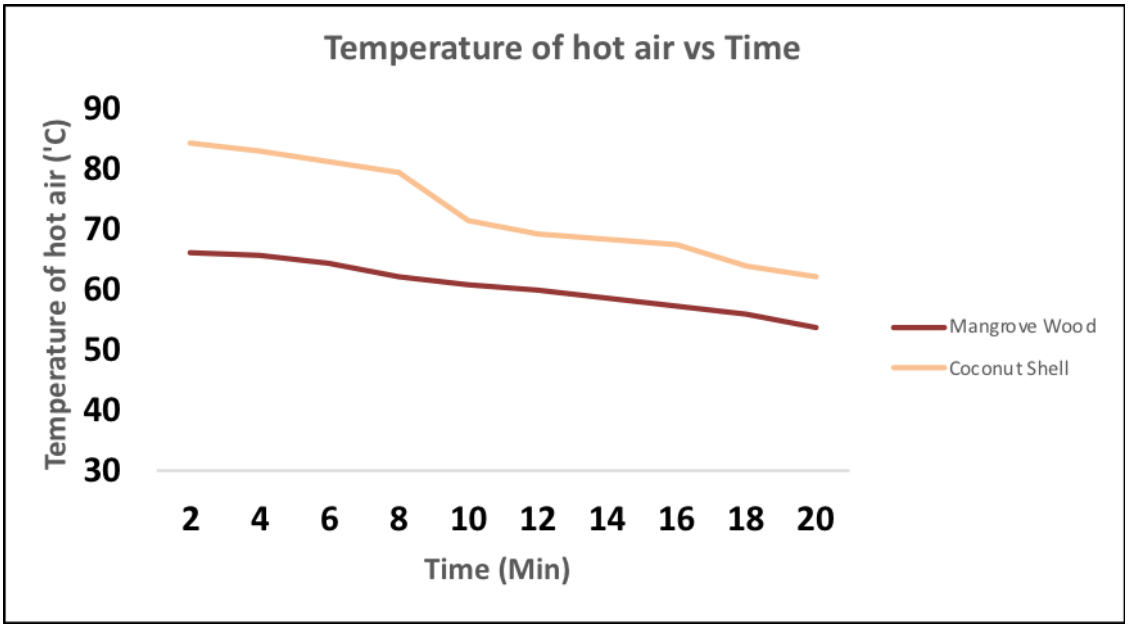


Figure 4.2: Comparison of Mangrove Wood and Coconut Shell Charcoal-Hot Air Temperature Vs Time

From this analysis, it can be concluded that coconut shell charcoal is more effective than mangrove wood charcoal as it capable to generate higher hot air temperature, flameless and smokeless.

4.3 Heat Transfer Analysis during Barbecuing

Heat transfer analysis was carried out during barbecuing using coconut shell charcoal. The objective of the heat transfer analysis is to determine temperature and amount of heat transferred to the food through the barbecuing process. This analysis was conducted during barbecuing of 277g chicken meat around 30 minutes at constant velocity (9 m/s). The amount of heat energy transferred during the barbecuing was calculated using equation $Q = mcp.\Delta T$, Where Cp= 3.68kJ/kg.K, m= 0.128 kg, and initial temperature, T1 = 28.9°C. The final temperature was obtained during barbecuing at 5 minutes interval. The calculated heat transfer data is tabulated in Table 4.2.

Table 4.4: Heat Transfer Analysis Data

Time	Temperature	Heat energy, Q
5	47.8	15.16
10	59.2	9.15
15	69.9	8.58
20	79.1	7.38
25	76.2	2.32
30	74.4	1.44

Next, the recorded data for temperature and amount of heat transferred to the chicken meat were plotted in Figure 4.3. Temperature difference throughout the barbecuing determines amount of heat transferred. This analysis proved that heat is gradually transferred to the chicken meat throughout the barbecuing. The chicken meat received adequate heat at 74.4 °C when it is fully cooked. The figure of sample chicken meat during the analysis shows in Figure 4.4.

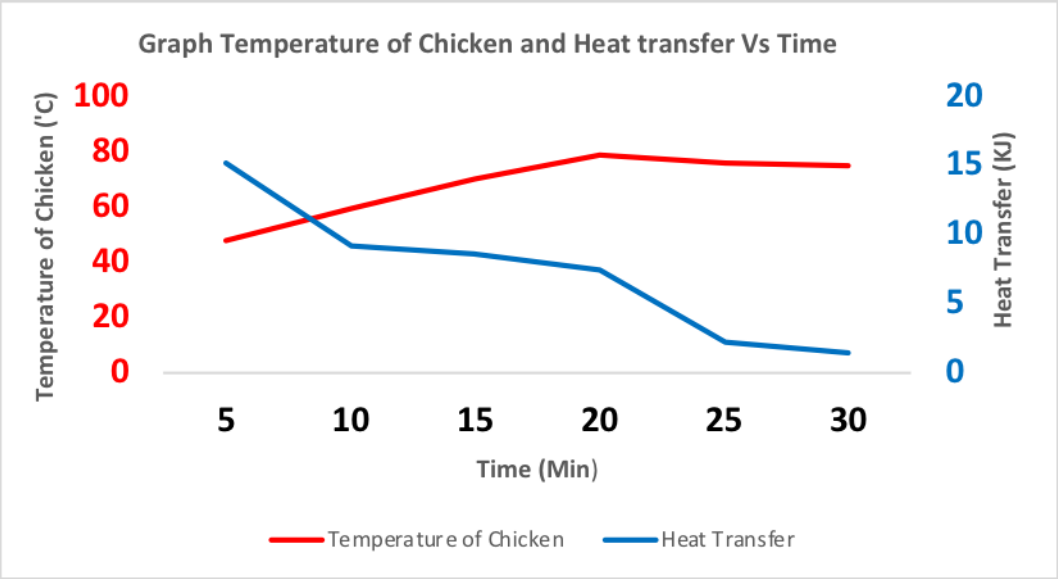


Figure 4.3: Temperature and Heat Transfer during Barbecuing

Figure 4.4: The Sample of Chicken Barbecue

From this analysis, it is concluded that coconut shell charcoal generates adequate heat to be transferred into the food during barbecuing. The chicken meat was perfectly and nicely cooked.

4.4 Time Management and Cost Analysis

In overall, time management is very crucial from the starting until the project finishing. Basically, the actual milestones are provided in Table 4.5 and Table 4.6 during the proposal preparation (SDP 1) and product development (SDP 2) of the Charcoal Barbeque with Air Ventilation System.

Towards the end, step by step processes and procedures in the methodology framework were accomplished. The fabrication process took about one month. Eventually, the final product was exhibited and evaluated during Senior Design Product (SDP) at the end of semester.

Table 4.5: Project Timeline Senior Design Project 1 (SDP 1)

	Activities	Week											
		1	2	3	4	5	6	7	8	9	10	11	12
1.	Group members recruitment												
2.	Supervisor approval												
3.	Discussion on the project and task distribution												
4.	Literature survey												
5.	Generate and analyze designs												
6.	Select & finalize the practical design												
7.	Material listing												
8.	Proposal's first draft preparation												
9.	Submission of the proposal's first draft												
10.	Project advisor's approval of the proposal's first draft												
11.	Prepare the presentation slides												
12.	Present the proposal												
13.	Improvisation of the proposal												
14.	Submission of the final proposal												

Table 4.6: Project Timeline Senior Design Project 2 (SDP 2)

	Activities	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Literature survey														
2.	Generate and analyze designs														
3.	Select & finalize the practical design														
4.	Material listing														
5.	Material Purchasing														
6.	Fabrication of Charcoal Barbeque with Air Ventilation System														
7.	Commissioning of Electrical Part														
8.	Performance Testing														
9.	Senior Design Project (SDP) Day														
10.	Thesis Writing														

In term of economics, the aim of this project is to develop an energy efficient barbeque set at the optimum cost of investment. Therefore, material selection has been proposed according to previous studies and product market reviews. Then, quotations for material purchasing were obtained from several local suppliers.

However, the challenge in the development of Charcoal Barbeque with Air Ventilation System is to work with a group budget allocated by the faculty. The project team was funded about RM450.00, so the team has done cost analysis prior to the material purchasing to make sure sufficient money expenditure for the whole prototype development. Table 4.7 provides cost breakdown for the material purchasing as a whole.

Table 4.7: Cost Breakdown for Material Purchasing

Material	Quantity	*Unit Cost	Total Cost
Zinc plate	10kg	RM23.14	RM23.14
Stainless steel bowl and grill	1	RM46.00	RM46.00
Electrical Component	1	RM12.00	RM12.00
DC Motor	1	RM30.00	RM30.00
Coconut Shell Charcoal	3kg	RM8.00	RM24.00
Casters Wheels 2"	1	RM10.00	RM30.00
Battery 12V	1	RM33.00	RM33.00
Blower	1	RM 25.00	RM 25.00
		TOTAL	**RM223.14**

4.5 Product Benefits and Marketability

Several product benefits have been cultivated from the charcoal barbeque with air ventilation system. Designed with a portable setup, it is basically a compact barbeque set with hot rack that easily to carry and move. The ventilation system installed in the barbecue set reduces human work where no manual fanning required. The design also can be dismantling part by part and easy for cleaning. In term of human health, the barbecue food is safe to eat as it could reduce the formation of polycyclic

aromatic hydrocarbons (PAHs), a cancer-causing chemical. Besides that, it is known as green device as the fuel material used is coconut shell charcoal that produces less ash to environment, flameless and smokeless.

Marketability is the competitive position of a brand, product or service with respect to a market. In order words, it is the potential for a product to sell. The marketability concern is important to ensure charcoal barbeque with air ventilation system charcoal is potential to be commercialized. Hence, according to the prior cost analysis, the expectation price for Charcoal Barbeque with Air Ventilation System is about RM 250– RM 300. The estimation price could compete with the existing barbecue set in market.

4.6 Ethical Consideration

Ethical considerations can be specified as one of the most important parts of any research project. Throughout the project implementation period, there are several ethical considerations have been adhered especially towards human, environment and economics. Correspondingly, this project has addressed the three pillars in sustainability aspects. It meets the needs of the improved barbecue set that is user friendly, safe to the environment at reasonable cost of production. The project design chosen is depending on the aims of the study, existing knowledge on the topic, and the perceived product benefits. This project has been designed scientifically and ethically sound as well-designed and well-executed project is necessary to produce satisfactory charcoal barbeque with air ventilation system. The product is original and not imitate the existing barbecue product.

Safety precaution while working in the workshop is very important to avoid accident or any unwanted circumstance. Personal protective equipment (PPE) is equipment worn to minimize exposure to hazard hazards that cause serious workplace injuries and illnesses. PPE like safety shoes, gloves, safety glasses, and welding mask were used at all times during the fabrication and testing processes. Most importantly, all the workshop rules and regulations have been adhered throughout the project implementation.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In a nutshell, the prototype for a Charcoal Barbeque with Air Ventilation System has successfully developed and tested. It is more advantageous as compared to conventional barbeque set. Indisputably, the charcoal barbeque with air ventilation system was designed with special features as the following:

- **Portable setup** = Compact barbeque set with hot rack that easily to carry and move.
- **Reduce work load** = No manual fanning required and easy cleaning.
- **Safe to eat**= Reduce polycyclic aromatic hydrocarbons (PAHs), a cancer-causing chemical.

  Eco- friendly = Material used (Coconut Shell Charcoal) produces less ash to environment

In the end, the project has performed the key element of the air ventilation system to avoid human manual fanning. As of the fuel selection, coconut shell charcoal is selected as it produced higher temperature hot air, smokeless, flameless and clean. If it going to be commercialized in the future, the expectation price for one complete set is about RM 250.00 to RM 300. 00. However, the existing product could be much more noteworthy if future improvement is being made.

5.2 Recommendation

In this subsection, such considerable recommendation is being made for the future remarks. For the next team, it is suggested to redesign the charcoal barbeque with air ventilation system barbecue using modern communication technologies. It will transform the barbecue as stand-alone device into a product-service. Several auxiliary features might be incorporated for user accessibility including:

1. Temperature sensor

The existing prototype needs the user to check manually of the food doneness. Eventually it might be convenient to be able to sense real time data of the food during barbecuing. The food sensor to be installed at the body of cooker and giving signal at certain temperature. Thermocouple is proposed to measure the the heat at the grill surface and the heat of the air inside the barbecue when the lid is closed. They will be accurate enough for the barbecue purpose but therefore they need to be able to release heat as well.

2. Timer

Timing in the barbecue is important to ensure quality of the barbecue. Being closely related to the temperature, time has to be managed accordingly and its role has not been limited to determine when the food is ready. With the right notifications or visualization, it could also help user maintain a more constant temperature. Thus, the installation of timer is proposed and connected to user's handphone or another device to make it more feasible.

3. Mapping tool

The food's cooking process may be tracked. Because the conditions may vary, it is known that the pieces of food can be tracked individually. To do this, a kind of mapping is required. Simulating the position of different pieces, the right progression can be associated with the right piece of food.

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