THERMAL DISTRIBUTION OF COPPER ELECTRODE POST-PLASMA DISCHARGE IN AIR AT ATMOSPHERIC PRESSURE BY USING MICROWAVE

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A report submitted

in fulfilment of the requirements for the degree of

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DECLARATION

I declare that this project report entitled " Thermal distribution of copper electrode post-plasma discharge in air at atmospheric by using microwave" is the result of my own work except as cited in the references.

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Name : MUHAMMAD NAFIS BIN ADBUL NASIR

Date : …………………….

APPROVAL

I hereby declare that I have read this project report 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.

Signature :……………………….

Supervisor's Name :DR. FADHLI BIN SYAHRIAL

Date :……………………….

DEDICATION

To my beloved mother and late father

ABSTRACT

Plasma is the forth state of matter after gas which created when energy was continuously supplied to neutral gas and charge carries were formed. Microwave plasma is one the method for hydrogen gas production which the zero-emission energy. However, the process considered costly and all the process done at low pressure condition. Thus, in this study a 2.45 GHz conventional microwave oven was used to generate plasma in air at atmospheric pressure. The effect of lengths of copper electrode on plasma generation and power output of microwave on temperature distribution at each electrode were investigated using Thermal Imaging Camera FLIR. Copper electrode with 3 cm, 6 cm and 18 cm was prepared. For the case of power output effect on temperature distribution, 17% (low), 33% (medium low) and 55% (medium) of power output mode were investigated. Plasma generation at tip of the copper electrode in air at atmospheric pressure was observed. It showed that plasma was generated at 6 cm and 18 cm length of electrode. Meanwhile, the higher the power output the higher the temperature at tip of the electrode. However, at 6 cm in length, the temperature of electrode was higher than that of 18 cm in length at the same power output mode and the stable plasma generation was observed. Thus, plasma can be generated when the lengths of electrode were at 1/2 and 3/2 of wavelength. Moreover 6 cm in length of electrode could be considered the most ideal and promising dimensions for the applications in decomposition of waste materials and synthesis of nanomaterials using microwave plasma discharge

ABSTRAK

Plasma merupakan keadaan ynag ke empat dari keadaan jisim selepas gas yang tercipta apabila tenaga secara berterusan dibekalkan kepada neutral gas dan membentuk cas pembawa. Plasma gelombang mikro merupakan salah satu kaedah untuk penghasilan gas hidrogen yang merupakan sejenis tenaga sifar pengeluaran.Walaubagaimanpun,, proses tersebut dianggap mahal dan kesemua proses dijalankan pada keadaan tekanan rendah. Oleh itu, dalam kajian ini, ketuhar gelombang mikro dengan 2.45 GHz frekuensi digunakan untuk menjana plasma di udara dengan tekanan udara atmosfera.Kesan panjang elektrod tembaga terhadap penjanaan plasma dan kuasa output dari gelombang mikro terhadap pengedaran suhu pada setiap elektrod disiasat mengunakan Thermal Imaging Camera FLIR. Elektrod tembaga dengan panjang 3 cm, 6 cm dan 18 cm disediakan. Untuk kes kesan kuasa output pada taburan suhu, 17% (rendah), 33% (sederhana rendah) dan 55% (sederhana) daripada keseluruhan tenaga gelombang mikro telah dijalankan kajian. Plasma hanya terbentuk pada hujung elktrod tembaga pada udara di tekanan udara atmosfera diperhatikan. Ia menunjukkan plasma hanya terbentuk pada 6 cm panjang elektrod dan juga 18 cm panjang elektrod.Walau bagaimanapun, semakin tinggi kuasa semakin tinggi suhu pada hujung elektrod. Namun, pada 6 cm panjang elektrod, suhu elektrod lagi tinggi dariapada 18 cm panjang pada kuasa output yang sama dan kestabilan penjanaan plasma diperhatikan. Oleh itu, penjanaan plasma hanya berlaku pada elektrod tembaga yang mempunyai 1/2 dan 3/2 daripada panjang gelombang. Oleh tu, 6 cm panjang elektrod boleh dipertimbangkan sebagai panjang ideal dan mejanjikan untuk diaplikasikan dalam penguraian bahan terbuang dan juga sintesis bahan nano menggunakan plasma gelombang mikro.

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Special thanks to all my peers, my late father, beloved mother and my brother for their moral support in completing my degree. Lastly,, thank you for those who had taken part in realization of this project.

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LIST OF ABBREVIATIONS

T_i	Ion temperature
T_e	Electron temperature
RF	Radio frequency
MHz	Megahertz
ICP	Inductively coupled plasma
CCP	Capacitively coupled plasma
AC	Alternate current
DC	Direct current
CO_2	Carbon Dioxide
MW	Microwave
ECR	Electron cyclotron resonance
UHR	Upper hybrid resonance
FCC	Face-centered-cubic
BCC	Body-centered-cubic
DBTT	Ductile-to-brittle-transition-temperature
V_{en}	Velocity of neutral particles
V_{ei}	Velocity of iron

CHAPTER 1

INTRODUCTION

1.1 Background of Study

As all known, state of matter consist of three state which are solid, liquid and gas. Realize or not, there is fourth state of matter called plasma. Plasma can be defined as an electrically conducting medium consist of neutral atom, positively charged iron and negatively charged iron [1]. Meanwhile, by supplying enough energy to neutral gas, plasma will generate from the formation of charge carriers. Electron and ions in the gas phase gain enough energy and collide with the neutral atoms and molecule [2], [3].

Most popular method of generating plasma is through electric fields. By applying electricity, electrical breakdown of neutral gas will occur. Microwave plasma consider as one of electrical discharge. When 2.45 GHz microwave radiation supplied from electrode, the plasma will generate [4], [5]. Normally, plasma generated in condition under atmospheric pressure. Natural plasma that occur at atmosphere also happen under low pressure condition. So, the subject now is that plasma can be generate at atmospheric pressure without any catalyst?

Nowadays, metal become the most important in engineering materials. Properties of metal make it satisfy to be applied in variety of design requirement. Due to that, manufacturing process for them already developed many years ago. Copper and tungsten example of metal that exist in this world. Pure copper appear in reddish coloured and tungsten appear in steel-grey to tin-white metal.

Both metal have their own properties whether physical, chemical or properties [6]. When this type of metal applied as electrode for plasma generation process, what will happen? Does differences in properties affecting the plasma generation?

1.2 Problem Statement

In plasma generation, there are several main part that need to be highlighted in order to generate plasma. In the previous research, most of the plasma generation conducted in low pressure condition [7], [8] with only a few conducted at atmospheric pressure. So, the issue now can the plasma generation occur at atmospheric condition without any catalyst use by using microwave oven. Existing of electrode in plasma generation also main factor. Configuration of electrode need to be study also with the effect of different material on thermal distribution which will contribute on plasma generation.

1.3 Objectives

The objectives of this study are:

1. To generate plasma in air at atmospheric pressure by using conventional microwave oven.
2. To determine the temperature distribution of the electrode post-plasma generation

1.4 Scope of Study

The study covers the plasma generation by using conventional microwave oven. Meanwhile, three proposed length for copper electrode are 3 cm, 6 cm and 18 cm for plasma generation. Besides that, the variation power of microwave oven are 17%,33% and 55%of maximum power 700W. This percentage following the configuration setting of the microwave oven.

CHAPTER 2

LITERATURE REVIEW

2.1 Plasma

2.1.1 Theory of Plasma

Plasma plays an increasingly important role in many sectors like industrial, commercial and domestic environments, as well as in space and fusion research. The research and development towards plasma already done many years ago and that's why, nowadays influence of plasma technology in human activity already penetrates during the last few years.

Nature of material once the material temperature rises, its condition changes from solid to liquid and then to gas. However, if the temperature is further risen, a huge number of gas atoms will be ionized and the gaseous high - temperature state, in which the charge numbers of ions and electrons are almost equal and the charge neutrality on a macroscopic scale is fulfilled, will be achieved. [9]

In general, plasma is a collection of a very huge number of individuals charged particles, all interacting through mutual Coulomb forces and through the electric current associated with their motion, while simultaneously interacting with any electromagnetic fields of external origin.

The plasma science includes space plasma, kinetic plasma and technological plasma and ranges from huge variations in parameters such as pressure, distance and energy. From all the variation, one method to distinguish them is as thermal (hot) and non-thermal (cold) plasma (Table 2.1), [10]. Each class applied at different field depending on the relative value of ion temperature T_i to electron temperature T_e.

Table 2.1: Temperature and pressure ranges of hot and cold plasma

Low-temperature thermal cold plasma	Low-temperature non-thermal cold plasma	High-temperature hot plasma
$T_e \approx T_i \approx T < 2 \times 10^4$ K	$T_i \approx T \approx 300$ K $T_i \leq T_e \leq 10^5$ K	$T_i \approx T_e > 10^6$ K
Arcs at 100 kPa	Low pressure ~ 100 Pa glow and arc	Kinetic plasma, fusion plasma

2.1.2 Plasma Generation

Theoretically, generation of plasma occur when energy continuously supply to a neutral gas which leads to the formation of charge carries. Elastic impacts (in which the impulse is retained) and inelastic shocks are the mechanism by which energy is transferred from electrons in an electric field to neutral particles and forms plasma. There are various field to supply the energy to the neutral gas such as through thermal energy, adiabatic compression, energetic beam and by applying the electrical field. From that field, number of methods used to ionize the gas like, combustion, flames, electrically heated furnace, electric discharges (corona, spark, glow, arc, microwave discharge, plasma jet and radio frequency plasma) and shocks (electrically, magnetically and chemically driven.[11].

The most popular method of plasma generation is by using electric fields, which the low-temperature plasma can be maintain purposely for technological and technical application.[12]. This method applies DC electric discharges, alternating current (AC) and known as direct coupling method since its need presence of electrode to transferring the energy.

In general, when electric field supply to natural gas that contain small number of electron and ion, it will trigger the free charged particle and increase the acceleration of that free charged. As result the free charged will collide with the atom and molecule in the gas or with the surface of electrode which lead to the plasma generation. However, there are several type of discharge types that generate different plasma which all this depending on the voltage applied and discharge current. (Figure 2.1).

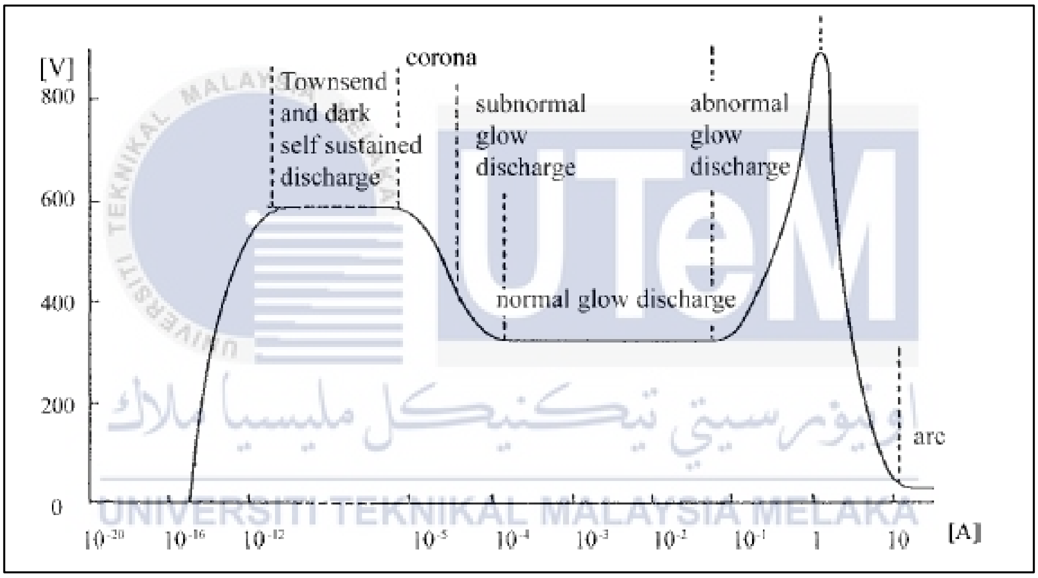

Figure 2.1: Various type of discharges depending on applied voltage and discharge current.[13]

Relationship between voltage and current characteristic widely used to characterize the main areas of discharge in terms of measurable factors, voltage and current, and refers to the occurrence of discharge, but does not include the effects of current density, gas pressure or frequency [14]. Based upon the graph, it gives a clear view on how plasma behaviour changes over a wide range of current. Discharge current can be divided into 3 different regions which are Townsend Region, Glow Region and Arc region. Townsend region exist at low discharge current in between 10^{-12} to 10^{-5}. At this region, all the electron will accumulate at the anode and charge multiplication occur.

Glow region can be achieved with medium discharge current in between 10^{-4} until 1 A and happen below atmospheric pressure. Under glow region, there are 3 stages which are subnormal, normal and abnormal stage. At subnormal stage, the current density at the cathode is low and the discharge is diffuse. Abnormal stage, the current value restraint by the cathode size but in some condition its limit by the anode size. For Arc region, the current discharge value about 1 to 10^{4} A. At this region, its archive thermal equilibrium and have characteristic of high currents and current densities.[11].

Indirect coupling discharged is a process obtaining the plasma without constrain of electrode [14]This process needs the presence of high frequency sources like radio frequency (RF) and microwave replacing the electrode to transfer the energy and generate plasma. Interest towards this method increasing for technical and industrial application due to the availability of high frequency power sources using electronic valve. Magnetic field play the role to control the performance of plasma precisely by delaying its transit. Both high-energy densities and charged particles can be obtained when magnetic field line surround by electric field and even can occur at very low-pressure condition. The RF discharge commonly operates at frequency range 1-100 MHz with correspond wavelength 3-300 m larger than the dimension of reactor [12]. Indirect coupled discharged divide into 2 method which the first one is inductively coupled discharged and second is the capacitively coupled discharged.

Inductively coupled plasma (ICP) applied the concept of a transformer when the plasma excited acting as single turn and RF current induced alike the secondary coil of transformer.

There are several geometrical features of ICP [15]: -

i. Helical inductive couplers – cylindrical plasma
ii. Helical resonator – cylindrical plasma
iii. Spiral inductive couplers – planar plasma
iv. Immersed inductive couplers
v. Transformer – coupled plasma

Plasma electron accelerate when the magnetic field changing and induces the electric field. Secondary coupled acting to the density of magnetic flux and frequency. Although it has several types of geometrical features but the typical one in shape of helical or spiral conductive. In order to obtain the RF driving frequency, an electrical reactance was added which role function as tuner to the inductor. This will help to allow huge RF current flow into inductive element and finally the generated magnetic flux transferred to adjacent discharge region. By applying Faraday's Law, the "inductive" electric field cause the acceleration of free electron in the discharge and sustains the plasma.

As expected, high potential will exist in the arrangement since ICP is driven by the electrical resonance. This potential then will lead to the capacitive coupling another approach of indirect coupling process. Capacitive coupled plasma (CCP) perform similar way of direct coupled discharge at high frequencies. But the different is each electrode alternate act as cathode and anode during one RF cycle.[16] This resulting high-potential and time dependant sheaths form at each end of discharge. The basic structure of CCP made up of two electrodes covered by layer of insulation and there is space between them which the plasma energy will generate at the space.

The insulator plays three main role which are acting as element stabilizer, reducing the discharge to narrow and lastly protect the electrode from evaporate [14]. For CCD to operate there are operating regimes: - [17]

i. "Wave riding" (α) regime: collisional regime, which electrons 'surf' on the sheath fields and gaining energy from the sheath expansion and equilibrating the energy with plasma electrons. Absent of electrode is possible for CCD operation.

ii. "Secondary emission" (γ) regime: like the DC glow discharge, discharge process maintained by electrons excited by cathode and accelerated through the sheaths.

iii. "Positive column" (pc) regime: an electric field that fixed in space but changing to time enable the electrons gain the energy.

iv. "Electron-sheath collision" (ESC) regime: Expansion of sheaths resulting they gained of momentum and energy by the electron.

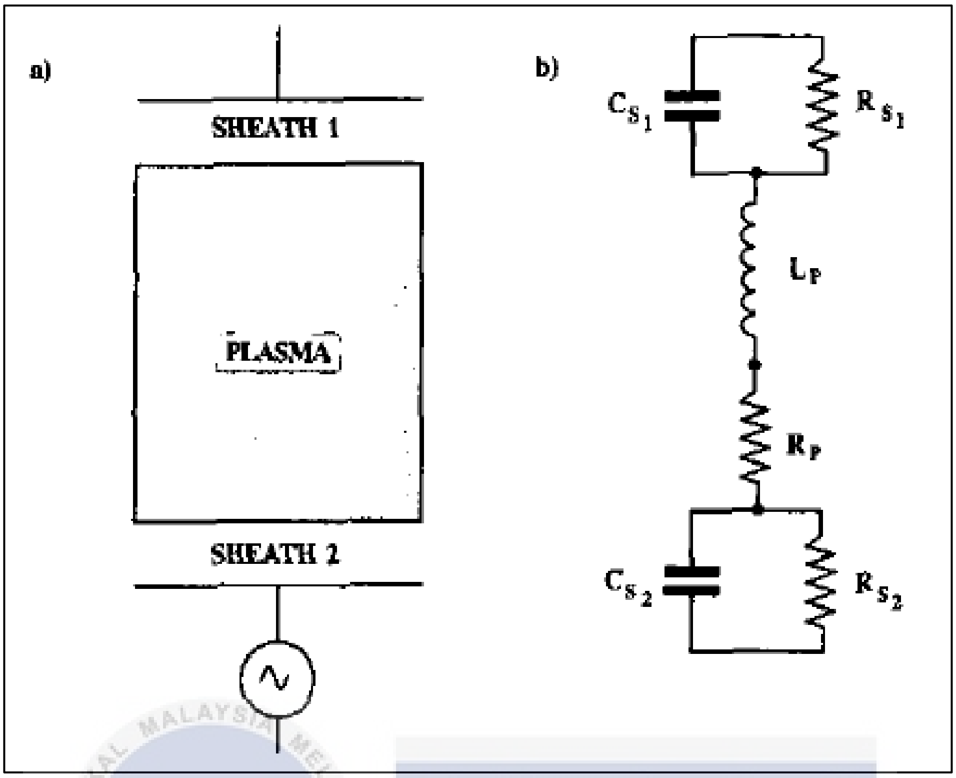

Figure 2.2: (a) Basic model of capacitively coupled discharge (CCD)

(b) Equivalent circuit

- R_{s1}, R_{s2}, are sheath resistance and C_{s1}, C_{s2} are sheath capacitances
- R_p plasma resistance and L_p plasma inductance

2.1.3 Application of Plasma

Since development of plasma already started many years ago, the usage of plasma already penetrates almost every aspect of human life. In plasma technology, a permanent electric arc is generated by passing electric current through a gas in a process known as an electrical breakthrough and produce ionised gas stream that been use in plasma technology [18]. As mention earlier, plasma can be distinguished into two which are thermal plasma and non-thermal plasma. The application also different for each type of plasma.

(i) Thermal Plasma

One of the advantages of thermal plasma is it can operate at high temperature and that's why thermal plasma always applied at heavy industries. As example in thermal plasma use in treatment of wastes in purpose to destruct the hazardous wastes. Mention by [18], thermal plasma better than other thermal treatment for because it can maintain steady state condition due to high flux densities at reactor boundaries. This result in rapids start-up and shutdown time.

Another example of thermal plasma application is generation of electricity by nuclear fusion at nuclear power plant. Process recombining nuclei to form new nuclei and release large amount of energy is called nuclear fusion and plasma produced during the mixing procedure help heat from current up to 5 MA [14]. In order to increase the power density, RF power coupling and injection of high-power beam is use during the process. For a certain nuclear fusion, there necessary condition is needed, firstly high temperature (up to 10^7 K), second high density and lastly prolonged stability.

Next, plasma arc welding also one of the famous thermal application nowadays. Arc

welding use in major industrial fabrication method from the simple AC or DC manual welding to the complex high-frequency process. But now, modern power supplies used like high frequencies inverters or electronic ignition and current control either AC or DC. Typically, for DC arc welding, cathode is represented by a connected electrode and the workpiece connected as anode. The power density of anode normally lower than at cathode but power dissipated at anode higher resulting magnetic flux high along axis of discharge [19]

(i) Non–Thermal Plasma

For non-thermal plasma the application can be classified into two category which are non-thermal operate at low-pressure discharges and the other one operates at atmospheric discharges. Operation at low-pressure still can achieve charge equilibrium but with high energy supply into plasma. Semiconductor industry applied the low-pressure glow discharge to manufacture electronic especially the computer memory chips. In this modern world, everything become smaller in size like silicon-based integrated circuits contain up to 10^9 transistors on single computer chip. Low-pressure plasma gas discharge is used in 12 different process. Separation between the component (etched) less than 0.2 µm and that etched required high definition that why ion plasma widely used in this area. [14]

In general, non-thermal plasma also can be applied towards environment like exploit the carbon dioxide CO_2 to change it to valuable hydrocarbon. Combustion of fossil fuel will emit CO_2 which will lead to greenhouse effect like global warming that why level of CO_2 must be lower. Non-thermal plasma can apply for indirect conversion of CO_2 into syngas which can be use in fertilizer production or as solvent. Non-thermal plasma has been reflected as substitute method for syngas production.[20]. The suitable method to carried out this process through silent discharge to form syngas from CO_2 and reforming methane [21]One of the benefits of this process, it can be carried out ad ambient temperature but high yield total.

2.2 Microwave Plasma

2.2.1 Theory of Microwave (MW)

Microwave is an electromagnetic wave that have a frequency range starting from around 0.3 GHz to 300 GHz and have corresponding wavelength approximately between 0.001m to 1m. Refer figure below:

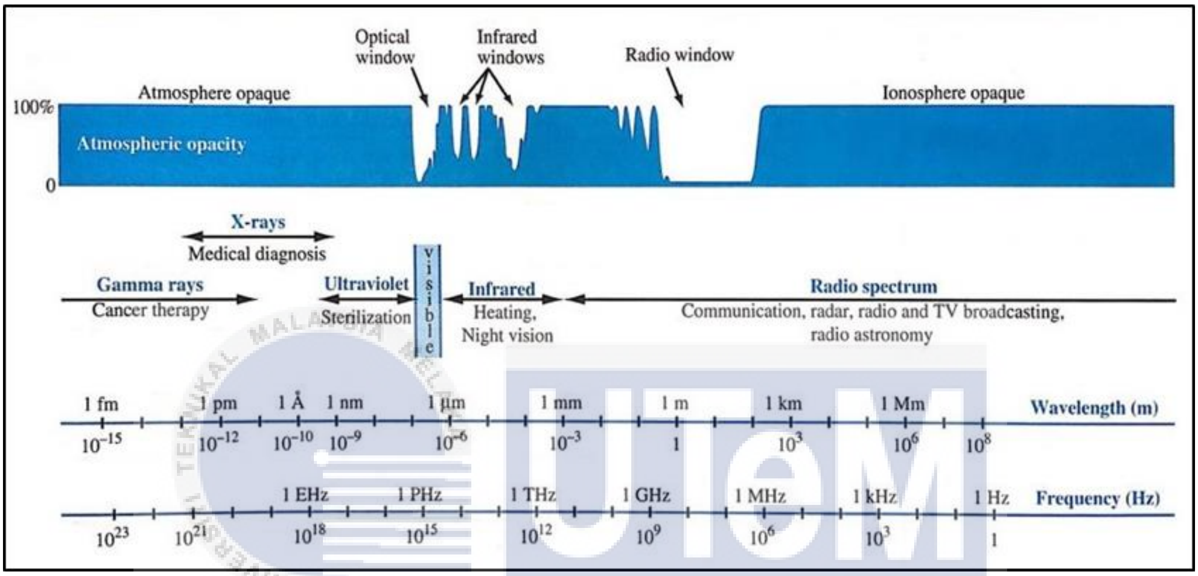

Figure 2.3: Electromagnetic spectrum [22]

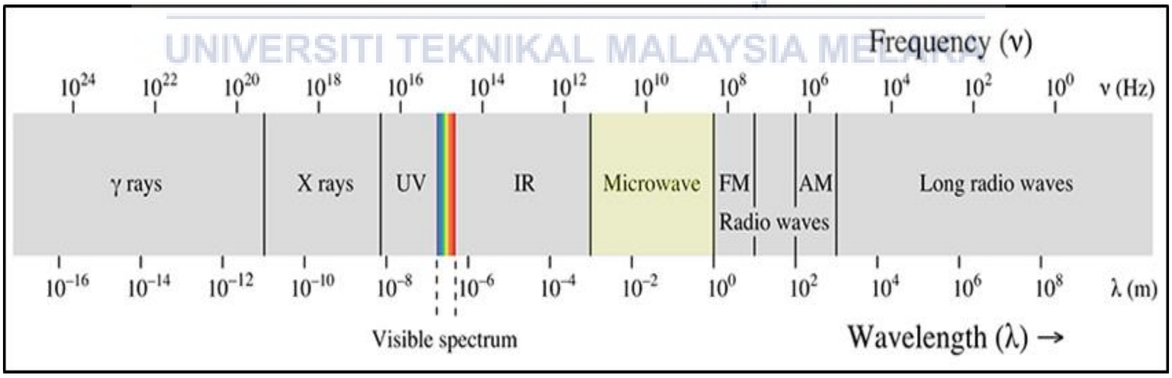

Figure 2.4: Location of microwave frequency band

Microwave are intelligible and captivated as it opposed to the visible waves. Since microwave obey the laws of optics, it has characteristic to be transmitted, absorbed or reflected depending on the type of material. In addition, obeying law of optic (Snell's law & law of reflection) being the key point when considering on how microwave operates.

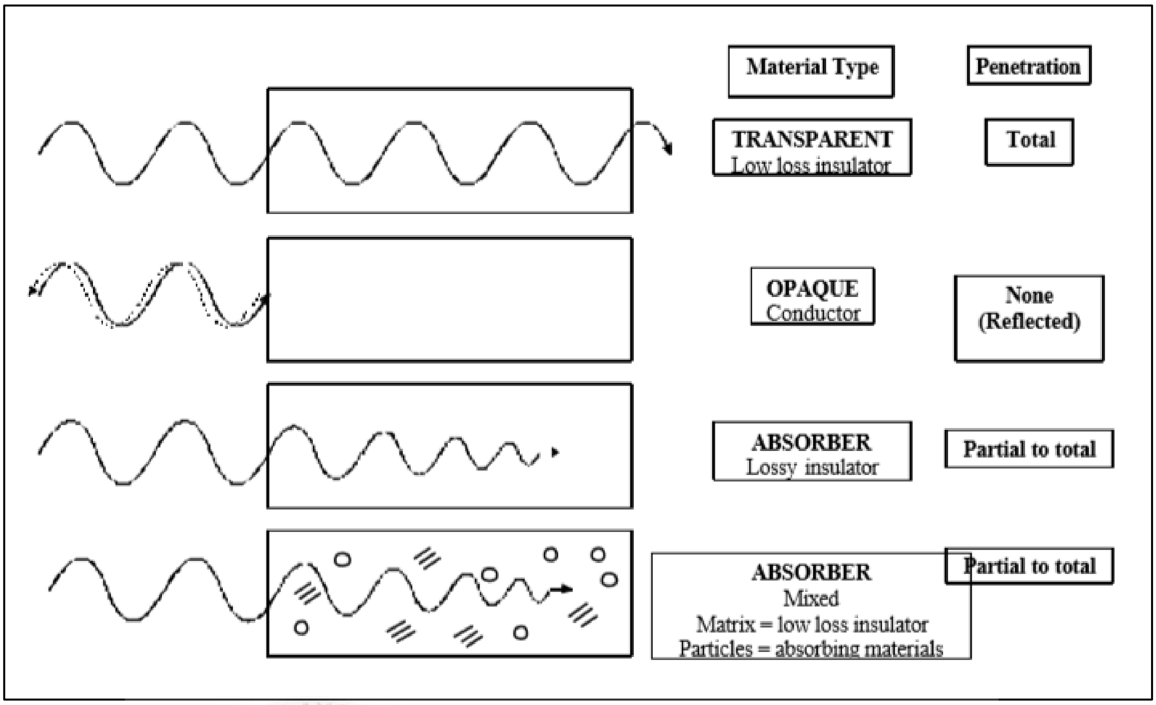

Figure 2.5: The interaction of microwave with different material [23]

The adaptability of the application of microwave has been long recognized in variety of areas. The most application of microwave is in communication field which function to transmit the information through multichannel communication both long distance and local [24]. Other than that, microwave also been applied in material processing field like ceramics, composites and metals. Application of microwave much better than normal heating because it have less cycle time and also eco-friendliness process [25]. At consumer level, microwave oven one of the famous applications of microwave.

2.2.2 Microwave Heat Transfer

Microwave heating is better than conventional heating as it short time taken to complete the process and also produce high yield under milder reaction conditions.[26] Heat transfer occur in three method which are conduction, convection and radiation. Microwave heat transfer apply radiation method since microwave exist in electromagnetic waves. Material that exposed directly or indirectly to the electromagnetic radiation will be heated up.

In conventional microwave oven, electrical energy that had been supply convert to microwaves by a part called magnetron. The transfer occur through short, high-frequency waves. Material that absorb the microwave will cause the element vibrates fast and creating heat. According to [27], one of advantages of microwave heat transfer is it able to penetrate and couple with material resulting in gain controlled and precise heating.

2.2.3 Theory of Microwave (MW) Plasma

As discuss before, plasma source can be obtaining from various type including the microwave itself. Typically, microwave operate at 2.45 GHz with corresponding wavelength 12.24 cm at short time taken to excite microwave field [12]. Besides that, MW plasma also can operate both at higher and lower pressure condition but assist from magnetic field needed in order to generate plasma at lower pressure [28]. According to [29] at atmospheric pressure, MW plasma can rise the electron temperature about 4000-10000 K and also increasing temperature of particle between 2000-6000 K.

Categorization of microwave discharges depending on the type of microwave field applicator or wave launcher. Normally, during process design of applicator several term need to be consider which are the characteristic of the wave, excitation frequency, pressure of medium (gas or liquid), plasma density, existing of external magnetic field and lastly boundary conditions [28]. In addition, absorption of microwave power by electron can be in two different mode whether collisional or resonant resulting to MW plasma generation.

As all know, MW plasma widely used nowadays because of it provide lot of advantages. Generally, present of electrode being compulsory which play role to maintain the plasma for dc discharge. MV plasma can provide zero corrosion problem as well as reduce the gas contamination [30]. Other than that, MW plasma also consider as lower cost reactors since microwave source like microwave oven already mass-produced. In term of economical, this will lead to a stronger economic potential for MW plasma sustain.

Apart from the advantages, MW plasma also have its own disadvantages which could happen for certain cases. When electrode applied in MW plasma equipment, to allow the plasma generation some procedure need to be taken. This causes the equipment become complex, hard to handle and become expensive [31]. Furthermore, MW plasma system tend to lose their impedance when the parameter changing affect the power coupling. Last but not least, microwave including in high frequency band which could lead to radiation hazard [30].

2.2.4 Microwave (MW) Plasma Generation

Microwave plasma generation included in group of plasma production using electric field with electromagnetic wave produce the electrical discharges. The microwave wavelength should correspond to the microwave frequencies used in industrial, medical and scientific application. Commonly used frequency for microwave is 2.45 GHz with wavelength 12.24 cm [32], [33]As mention before, MW plasma can be generated over wide range of pressure. At low pressure (below atmospheric pressure), it called as magnetoactive plasma (presence of magnetic field) and for high pressure condition, absence of external magnetic field it called isotropic plasma.

In general, creation of plasma come from ignition of applied electric field strength that higher enough to breakdown the working gas [34]. Formation of MW plasma occur when the ionize gas absorb the microwave energy. Three basic absorption mechanism that highlighted are collisional absorption, collision less absorption and nonlinear absorption. Collisional absorption mean collision that occur between electron with ions and with neutral particle [35]. This phenomenon can be categorized into three condition that summaries in the table 2 below.

Collisionless absorption occur in condition when $v/\omega < 1$ satisfied, where ω is the angular frequency of the microwave. This type of collision changed by depending on the resonance frequency of transverse electromagnetic [36]. Three important resonance are plasma resonance, electron cyclotron resonance (ECR) and upper third hybrid resonance (UHR).

Table 2.2: Condition of pressure and the predominant collision

Condition	Predominant collisions
Pressure ≥ 10^3 Pa	$V_{en} > V_{ei}$
Pressure < 10^3 Pa	$V_{ei} \approx V_{en}$
Pressure < 1 Pa	$V_{ei} > V_{en}$

* V_{en} = Velocity of neutral particles

* V_{ei} = Velocity of ion

For nonlinear absorption, occur when high microwave powers being supply to plasma. In addition, this kind of absorption is called anomalous due to being connected to instabilities parametric.

Apart from that, MW plasma generator typically include of several components with specific function. Table below explain the component with its individual role. The last component of MW plasma generator which is MW-to-plasma applicator being the most important part in MW plasma generator. Beside levels of minimal and maximal plasma power, MW-to-plasma applicator also play the role to recognise the plasma generator efficiency (amount of incident power absorbs in plasma). Furthermore, it also define bandwidth of the system and also the structure of MW field [37].

Table 2.3: Component of MW plasma generator with its function

No	Component	Function
1	Magnetron generator	Microwave power source
2	Circulator	Protecting MW from reflected
3	Standing wave ratio meter	Measure standing wave ratio
4	Matching circuit	Matching the signal from source to load
5	MW-to-plasma applicator	Levels of minimal and maximal plasma powers

2.2.5 Application of MW Plasma

Currently, various type of technologies use plasma being widely applied in various field like industrial application, materials processing, medical and others. Industrial field are the most popular field implement microwave plasma in their process like photoresist stripping process. Stripping or also known as etching of organic is an important procedure in microelectronics production. Influenced of various parameter make the dry etching process become difficult. However, the amount of free radical equal to the etching rate and the radical may transferred from plasma chemical reaction. There where microwave plasma play role with high radical source for an ideal high rate of etching process [38]

Other than that, MW field can reach high strength over the breakdown field strength which make it very suitable to ignite plasma. Result from that, MW plasma widely use in thermal treatment like treat waste gas become useful gas. This method very interesting because it can operate without combustible material. Moreover, it consider eco-friendly when zero emission of exhaust gas and can provide high and stable working temperature [39]. As example waste gas is ammonia. Ammonia can be decomposed by thermally which next produce hydrogen and nitrogen gas. Hydrogen gas nowadays very useful as source of energy.

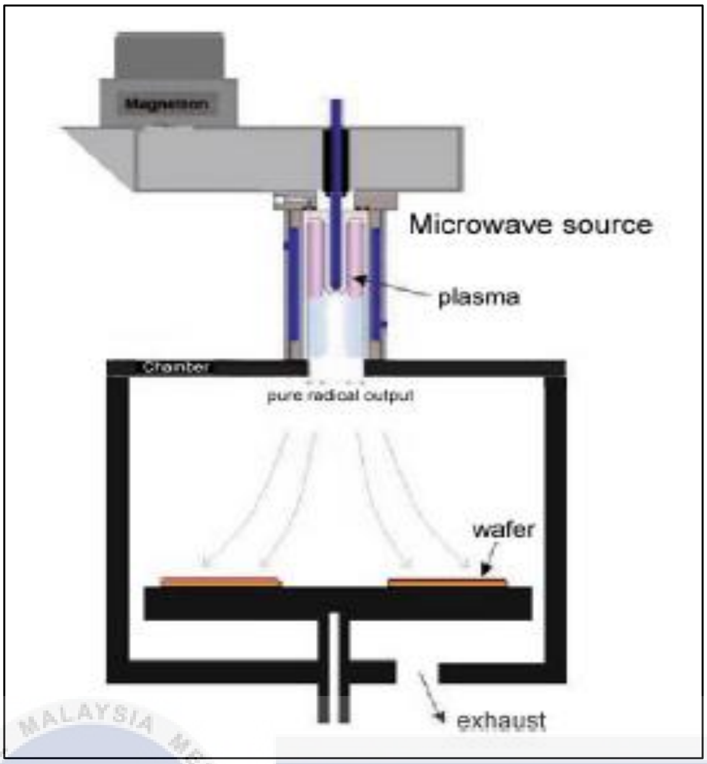

Figure 2.6: Microwave mobile plasma as radical source

Automobile industry also one of famous field that applied MW plasma in production process. MW plasma being used for photo curing especially for luxury car production which very precise on the finishing quality of product including the coating quality and final surface of the car. Typically, UV light being used for this method, but the problem come when curing at rough edges, holes and undercut. To solve that problem, MW plasma been used to replace the UV light. At excitation state, the photon will play the role to cure the photo [40], [41]. Plasma generated contain high density of excited neutral that have characteristic of long lifetime in MW plasma pulsed.

2.3 Copper Metal

2.3.1 Theory of Copper Metal

Copper was one of the early metals that discovered by human which give a huge contribution towards the human civilization. Cooper tool have been made about 5500 B.C and helped the civilization that time out from Stone Age. Copper classified as non-ferrous metals and consider as heavy non-ferrous metal with medium melting temperature [42]. In addition, copper is an electrolytically metal with impurities contain up to 0.5 % and commonly use as electrode for decomposition process.

Furthermore, the crystal structure of copper is in face-centered cubic (FCC) with an atom at each corner of the cube and six atom locate at each face of the cube [43]. FCC structure have the atom packed tightly which determine the mechanical properties of copper. In periodic table, copper can be found at group 11 together with silver and gold. In term of electron structure, copper have one s-orbital electron that will also determine the properties of copper itself.

Copper have a good electrical conductivity and consider the best among other metal except for silver. The resistance in copper is small that helped the electric current to flow easily without much loses [44]. Besides that, copper also good in heat conductivity second after silver. Cooper thermal conductivity around 401 W/(m.K) resulting in temperature rising at short period. This physical characteristic due to its lattice structure of free electron which allow the thermal vibration and the heat flow become faster. Moreover, copper have high boiling point about 1084.62 ºC [45]. Apart from that, copper also have other properties like corrosion resistance, ductile, malleable and easy to alloy.

2.3.2 Copper alloy

Copper performance can be increase by alloying them into a new metal but copper as the main component. Addition of one or more material to the pure copper within small quantities in order to achieve certain properties without alter the basic character of copper [46].

Totally, there are about 400 copper alloy with different combination to fulfil the requirement of industrial and environments. From that 400-copper alloy, there can be distinguished into 5 major classes as listed below [46], [47] :-

i. Brass

   Combination of copper with zinc (up to 45%). Brass always be the first choice for heat exchangers purposes because of the great thermal conductivity. In term of electrical conductivity, brass capability increases about 23% – 44% of pure copper.

ii. Nickel brass

   Combination of copper with zinc and nickel. Nickel brass normally silver in colour due to that it also known as nickel silver. In addition, nickel brass also frequently uses as base metal for cutlery and kitchenware replacing the silver since it has excellent corrosion resistance.

iii. Bronze

   Traditionally, bronze consist of copper-tin combination. But now in modern technologies, bronze can be combination of other element like aluminium and manganese. Normally bronze use in making coin and weapons.

iv. Tin Bronze

   The first copper alloy expands by mankind long time ago. Typically, fraction of tin in this combination are 4%, 6% and 8%. Addition of phosphorus to tin bronze will reduce the electrical conductivity from the pure copper. But this combination produces high yield strength which give quality contact force.

v. Beryllium-Copper

This combination is the hardest and strong among other copper alloy. Comparing to steel, beryllium-copper have similarities in mechanical properties but in term of corrosion resistance, this combination is better than steel.

2.3.3 Application of Copper and Copper Alloy

According to U.S Geological Survey [48], trend demanding on copper and copper alloy increasing for the last 25 year. Resulting from that, copper world production also rises their production to satisfies the demand. From that statement, it can be concluded that copper and copper alloy widely use in various application worldwide.

One of the copper and copper alloy application is in nuclear industry which copper alloy use as fusion reactor materials. Copper-based alloy have been selected to be use as material for certain part of nuclear reactor which are for first wall, limiter and stabilizers. Those part of reactor absolutely needed kind of material that have properties can withstand high temperature, create shielding from high electrical-conductivity and stabilize the position when surround by plasma. Copper-alloy chosen as it characteristic of high thermal conductivities greater than 316 stainless steel [49]. That characteristic helps a lot for the process including heat transfer and less the thermal stress which avoid from thermal fatigue.

Meanwhile, copper alloy also semiconductor industry to electroplating bath for microelectronic. Integrated circuit consist of interconnected in group of device and connected by a path that separated by dielectric layer. Delay in electrical signal propagation between device effect the performance of integrated circuit. Through research, copper alloy has been used as interconnect lines replacing the aluminium alloy. Copper alloy resistivities (range 1.7 to 2.0 μΩcm) lower than aluminium alloy (3.0 to 3.5 μΩcm) [50].

In general, due to its properties, copper and copper alloy always be chosen to be used in various field. Basically, copper usage can be breakdown into 5 main industry as listed in table 2.4.

Table 2.4: Breakdown of annually copper consumption for 5 main field area [51]

No	Field area	Annually consumption (%)
1	Building industry	47
2	Electronic products	23
3	Transportation	10
4	Consumer products	11
5	Industrial machinery	9

As can see, building industry consume copper the highest value among the other. In building industry, copper and copper alloy been applied to multiple part like for electrical wiring, roofing, heating system and so on. For addition information nowadays, consumption copper worldwide already reaches 18 million tonnes annually.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In general, this chapter will explain methodology used for this study according to the scope of study and general methodology briefly explain in previous chapter. A few step need to be taken starting with review on literature. Next, set up the experiment with first step start with preparation of electrode. The step continues with the plasma generation. After that, the data need to be collected using specific device. Correspond to data collected, the data need to be analysis. At last, documentation of research in report writing.

3.2 Electrode Preparation

In this research, copper material is chosen as the electrode. This material is chosen because of its frequently use in the industry especially come to heat or electrical application. Other than that, copper also have its own thermal properties and it purposely to study the effect on plasma generation. In addition, used of copper electrode also support by the inexpensive price which lead to the cost saving.

Table 3.1: Thermal properties copper

Copper	Thermal properties
0.38	Specific heat (J/kg.K)
24.44	Molar heat capacity (J/mol.k)
401.00	Thermal conductivity (W/m.k)
283.70	Enthalpy (kJ/mol)
16.50	Thermal expansion (µm/m.k)

Three different electrode sample is prepared, there are 3 cm, 6 cm and 18 cm. By using steel ruler, the length is marked by using marker pen and cut with a hacksaw. The purpose of different length copper electrode is to study the ideal length for microwave (MV) plasma generation, and this factor will fully discuss in chapter 4. Afterward, the electrode tip had been shaped into bullet shape at both end. Purposely for accumulation of heat at the top of the bullet shape and ease for plasma generation. Flat surface will effect on the plasma generation since heat will distributed along the large area and stand drill machine is used together with chisel for this procedure. At last, the electrode been bent inward to meet up both end together. It believe that, each end will play role as anode and cathode during plasma generation. The length of the electrode was based on the total length of electrode from end to another one. Figure 3.1 show example length dimension of 6 cm in length.

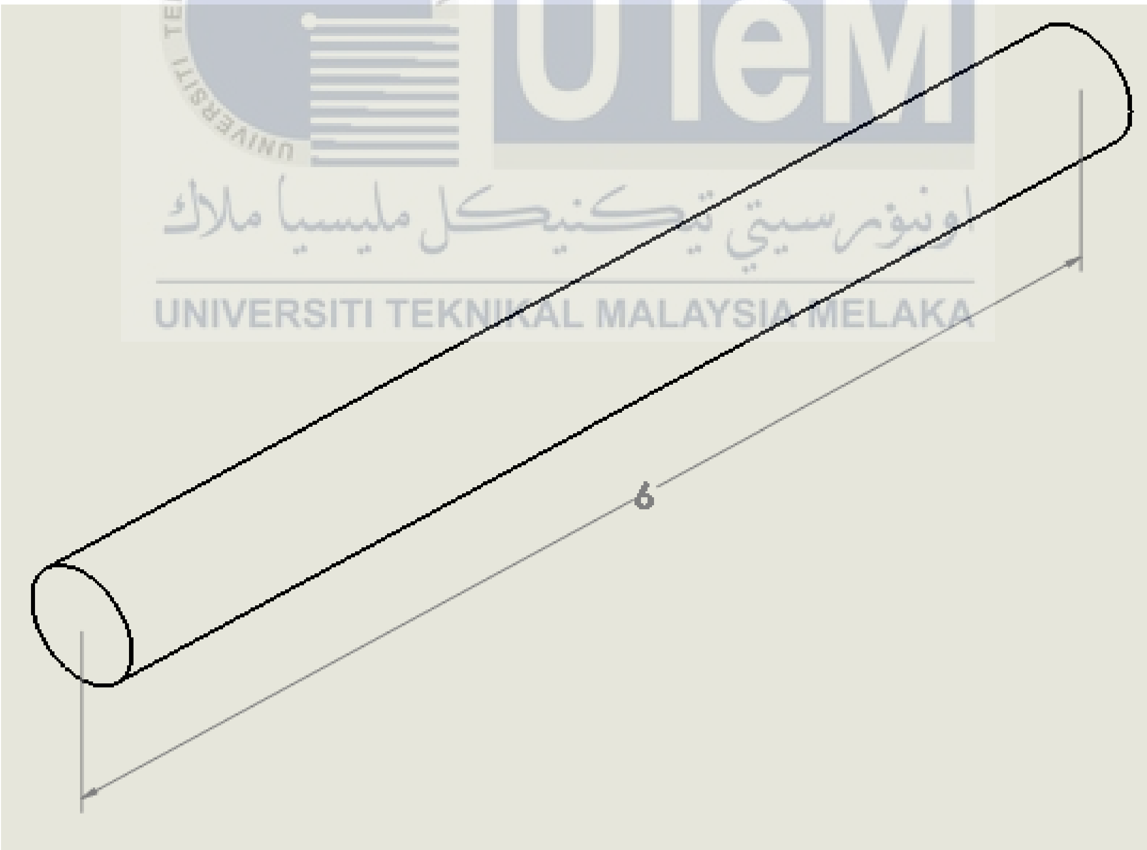

Figure 3.1: Example dimension for 6 cm in length

3.3 Platform Preparation

A platform is fabricated to hold the copper electrode during the plasma generation process. Mild steel plate with thickness 4mm is cut into round shape with diameter 90mm by using CNC plasma cutter. Then, the round mild steel plate then bring to CNC milling machine to make slot at the centre as housing for the copper electrode. CNC milling machine is used to get accurate slot with width 3mm and length 12mm. It’s vital to ensure the electrode hold at its position along the plasma generation process.

Figure 3.2: Platform

3.4 Plasma Generation

Plasma generation can be various method but for this research microwave (MW) plasma is chosen. By using conventional microwave oven plasma generated from the magnetron. Microwave oven typically will provide 2.45 GHz frequency. For observation purpose, the power will be change in range starting from 17% ,33% and 55% of the maximum power. The maximum power is 700W.

Before starting the plasma generation, the electrode needs to be clean from any deposited effected from oxidation of the electrode by using sandpaper. This to make sure that electrode free from any deposited that will affect the plasma generation process.

Figure 3.3: Apparatus set-up

Figure 3.4: Electrode and platform position in microwave oven

3.5 Data Collection

This procedure consider as the vital part since any mistake will effect the data collection. Every sample undergo each variation of power and the data collected for period 1min, 2min, 3min, 4min and 5min from first spark started (plasma generated). By using thermal imaging camera (FLIR A615), the temperature taken right after end of each period and the picture of the contour also taken for further discussion.

3.6 Data Analysis

Data collected are transferred into graphic presentation like line graph which easier for analysis. Comparison temperature between each sample are done in order to look for plasma effect on temperature. In addition, with comparison temperature the ideal length for plasma generation can be identify. FLIR tools provided contour for thermal distribution analysis.

Qualitative analysis was done for the first part which to determine the best electrode configuration that capable generated plasma. Calculation also done to determine the microwave wavelength and that wavelength will be used to come out with proposed electrode length.

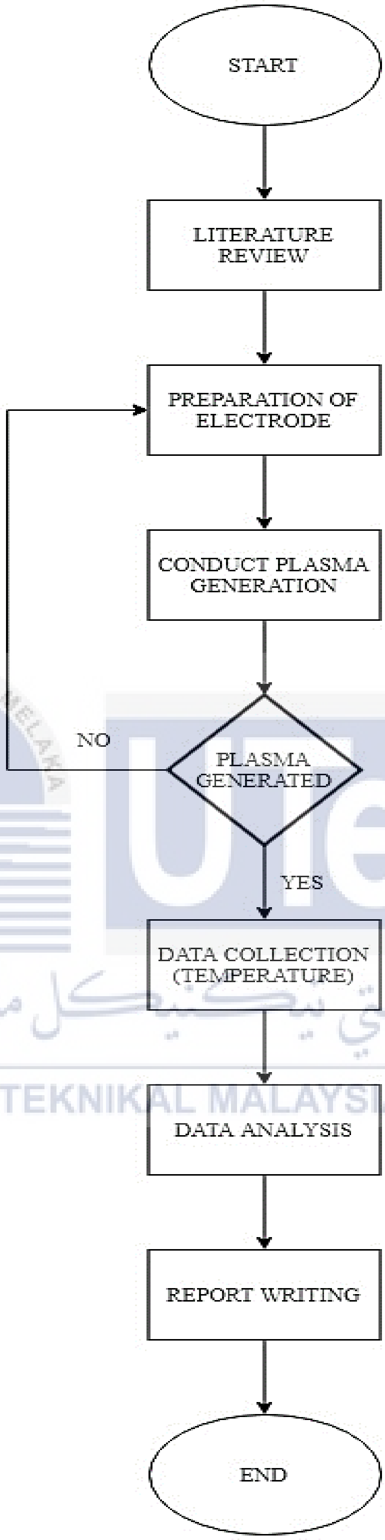

Figure 3.5: Flowchart of methodology

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this chapter, data extracted from Thermal Imaging camera and FLIR tool will be analysed and discuss in detailed. The main purpose of using Thermal Imaging camera is to capture and record the temperature distribution around the electrode tip at the initial and after the plasma generation. FLIR tool use to execute the thermal contour and temperature which this data transferred to Microsoft Excel to generate graphical graph for further analysis.

This study focusing temperature distribution at region around electrode after the plasma generated using conventional microwave oven. Discussion on this study divide into four main sections. Firstly, the qualitative analysis on the plasma generation on different electrode shape. Secondly, based on the theory and calculation the length of electrode is proposed to be used in plasma generation. Thirdly, comparing between length to study the effect of electrode temperature on plasma generation. It's follow with the finding of the ideal length of electrode for plasma generation.

4.2 Electrode Configuration

Consider as early stage of the experiment, qualitative analysis was done to identify electrode configuration that will generate plasma. Two different shape of electrode was prepared which are the first one was a straight electrode and second one ring shape electrode. Straight electrode only have single bullet tip while ring shape have two-bullet tip which both of that tip meet together. Length for both electrode was fixed to 6 cm since length not the concern at the first stage of this study.

Both electrode was tested for 1 minute in conventional microwave with low, medium low and medium power. The step was repeated twice for each electrode and presence of spark (plasma) was observed.

Table 4.1: Spark observation of straight electrode and ring shape electrode

Power/Electrode shape	**Straight electrode**		**Ring shape electrode**	
Low	No spark	No spark	Spark	Spark
Medium Low	No spark	No spark	Spark	Spark
Medium	No spark	No spark	Spark	Spark

After conducting the experiment, the result show that none of the trial from straight electrode produce spark or on the other word plasma was not generated from straight electrode. Meanwhile, ring shape electrode produce spark for all 6 trials which indicated that plasma can be generated from electrode that is in ring shape.

As mention before, ring shape electrode have two bullet tip that meet together. It's believed that that two-bullet tip play role one as the anode and the other one as the cathode. Presence of anode and cathode allowed the flow of electron from cathode to the anode. When the density of electron high enough, strike from microwave will excite visible light (spark) which is the plasma. This phenomenon also helped by the accumulation of heat at the bullet tip.

Straight electrode with one single bullet tip does not have anode and cathode terminal. Anode and cathode may can exist at both end, but plasma cannot be generated due to it large distance. Even though, microwave continuously strike the bullet tip, but ignition still not occur due to lack number of electron because transportation of electron does not occur at absence of anode and cathode.

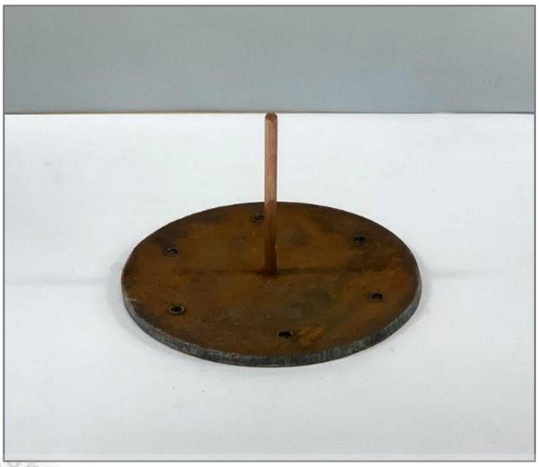

Figure 4.1: Single straight electrode

Figure 4.2: Single ring shape electrode

4.2 Proposed Length for Electrode

Beside the configuration of the electrode, another factor that affect plasma generation is the length of electrode. Before this, a lot of study conducted focusing on the conductive of the electrode, but length also play important role for plasma generation.

The length of electrode can be relate to the wavelength λ of the electromagnetic wave of the microwave. Frequency of microwave is not necessarily 2.45 GHz since it can be various depending on the model, but typically it should 2.45 GHz frequency. In this study, 2.45 GHz was used. A formula is used to determine the wavelength of electromagnetic wave [31], [52]

$$\lambda = \frac{c}{f} \cdot \frac{1}{\sqrt{\varepsilon_r}} \qquad (1)$$

From that formula, c is the speed of light in a vacuum condition, f is the oscillating frequency and ε_r is the relative permittivity of the working solution (medium). In this study, the value c is constant which equal to 3×10^8 m/s. Microwave used have oscillating frequency 2.45 GHz and the relative permittivity of air is 1.000 [53]. After completing the equation, the wavelength λ in air inside the conventional microwave oven used is 12.24 cm.

To find the best length for the electrode in generating plasma, three sample of length that related to the calculated wavelength λ were proposed which are $\frac{\lambda}{4}$ which equal to 3 cm, $\frac{\lambda}{2}$ corresponding to 6 cm and $\frac{3}{2}\lambda$ same to 18 cm in length. From previous research, it believed that length that near to the half of wavelength, 6cm will be the best length to generate plasma at optimum rate. To prove it, an experiment focusing on the temperature distribution was conducted.

Figure 4.3: 3 cm electrode

Figure 4.4: 6 cm electrode

Figure 4.5: 18 cm electrode

4.3 Temperature Distribution of Three Sample Electrode Length

Beside using the ring shape with 3 different length, this study also scope three different power which were low, medium low, medium and each power supply 17%,33% and 55% of the 700W maximum power. Power variation is on purpose to look effect on plasma generation and temperature produce on different power supply. Each sample will run for 5 minutes test for each power variant and at every one-minute average temperature of electrode will be recorded. Besides that, present of spark also been observed and recorded together with the temperature.

<u>3 cm electrode length (λ/4)</u>

Table 4.2 : Temperature and plasma generated for 3 cm electrode

Time/Power	Low		Medium Low		Medium	
	Temp, °C		Temp, °C		Temp, °C	
1 min	36.8	X	37.8	X	43.8	X
2 min	41.7	X	52.5	X	56.3	X
3 min	49.2	X	67.1	X	90.1	X
4 min	52.9	X	80.0	X	101.5	X
5 min	53.9	X	86.4	X	103.8	X

***** / = Spark produced X = No spark produced**

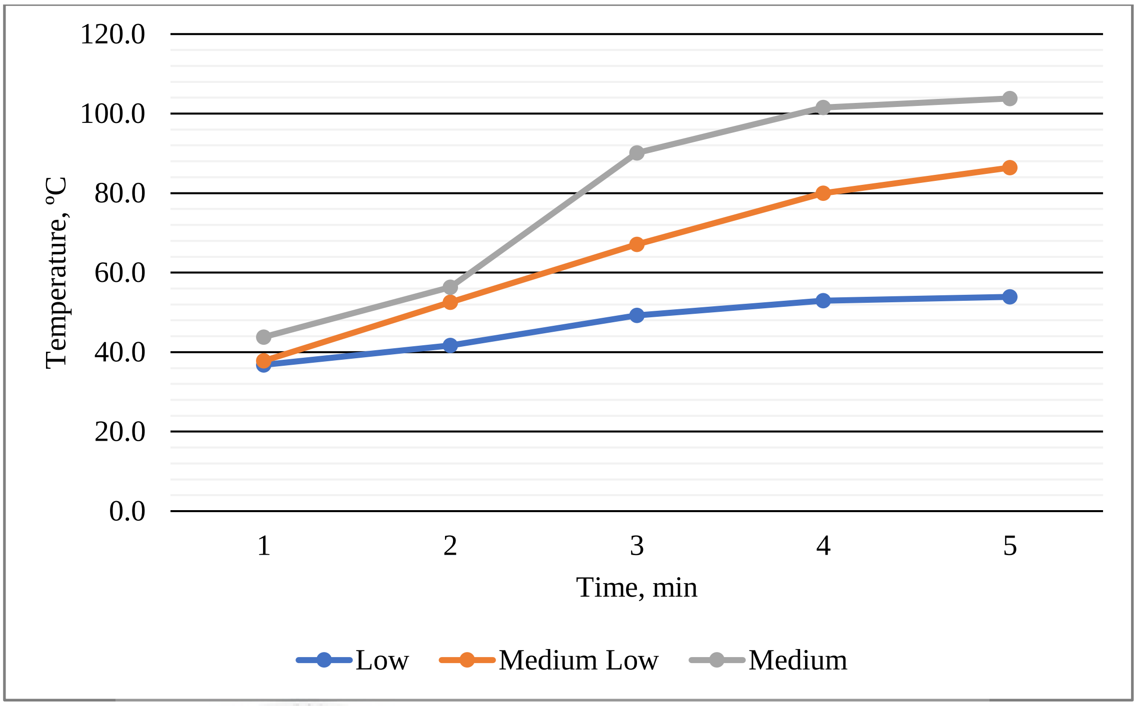

Figure 4.6 : Temperature distribution at 3 cm electrode

From the table above, at lower power mode until at 5 minutes time taken there still no spark produced even the temperature already reached 53.9 °C. The situation continue at medium low temperature when 86.4 °C produced at 5 minutes but still no present of spark. At medium mode, the temperature recorded 43.8 °C at first minute of the test and rise to 103.8 °C at the end of 5 minutes, but still no spark produced.

Overall temperature recorded show that the temperature will increase from first minute to the end of 5 minutes. In term of power mode, basically medium mode will produce larger temperature than other. This is because more power been supply to magnetron so that larger amount of microwave release to the vessel. Since no spark produce at any trial, it can be concluded that 3 cm length electrode not suitable length to generate plasma. The reason is wavelength of the microwave do not propagate continuously at the electrode tip since 3 cm length slightly short.

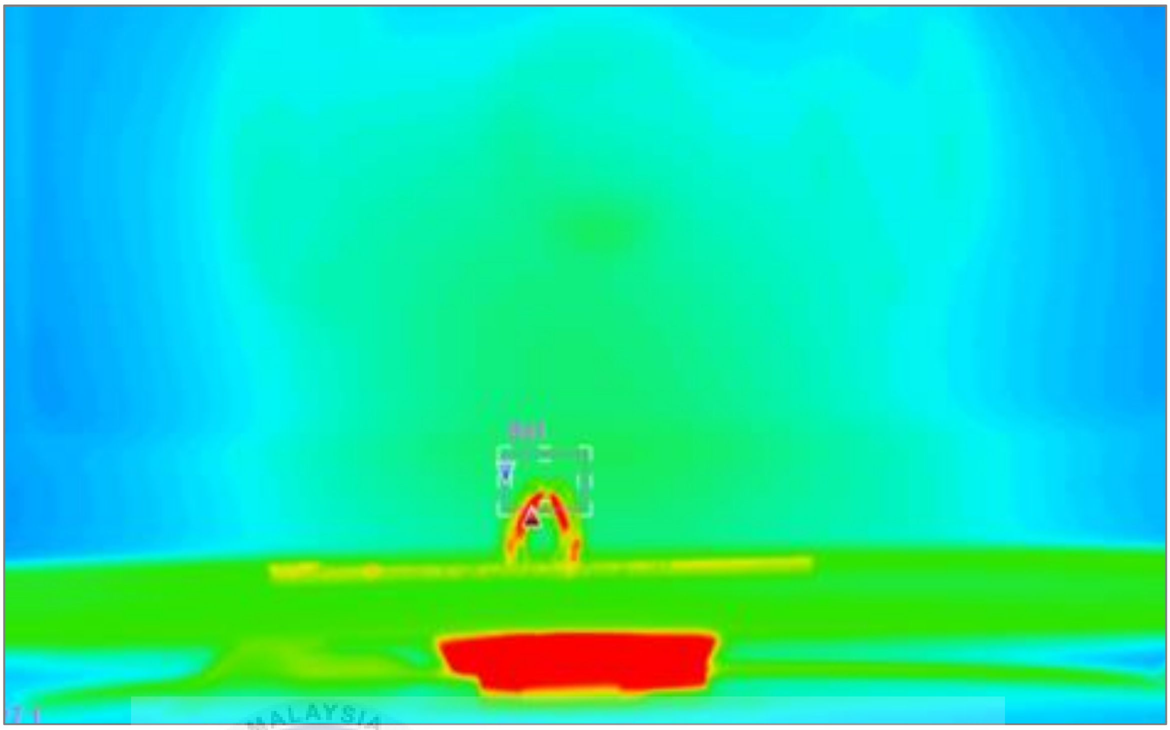

Figure 4.7: Example contour for 3 cm electrode length from FLIR tools

6 cm copper electrode (λ/2)

Table 4.3 : Temperature and plasma generated for 6 cm electrode

Time/Power	Low		Medium Low		Medium	
	Temperature, °C					
1 min	40.8	/	52.3	/	62.2	/
2 min	55.0	/	69.3	/	103.4	/
3 min	64.0	/	85.8	/	120.3	/
4 min	68.0	/	103.2	/	160.2	/
5 min	69.8	/	119.9	/	182.0	/

***** / = Spark produced X = No spark produced**

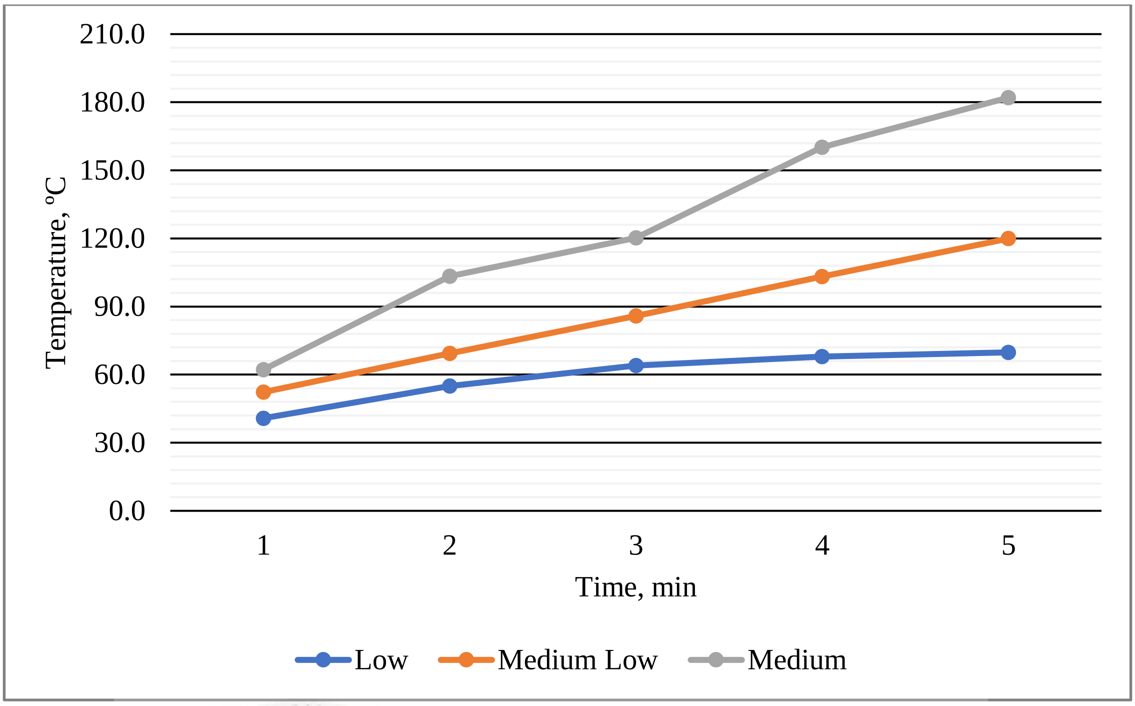

Figure 4.8 : Temperature distribution at 6 cm electrode

At low power mode starting from 40.8 ºC at first minute the spark already exist. The temperature keep rise until reach 69.8 ºC at the end of 5 minutes and spark also generated. Move to medium low power mode the situation still same. At all-time interval, the spark present until it's maximum temperature at 5 minutes reach 119.9 ºC. Medium low power show temperature increase significantly when at first minutes,, it's already at 62.2 ºC with the present of spark. 182.0 ºC was recorded at the 5 minutes time taken with a huge and stable spark.

From the graph it's clearly show that the temperature increase quite uniform. Other than that, the temperature recorded also quite high like when at medium mode, at second minutes the temperature already pass 100 ºC. This is because, huge and stable spark been produced during the test. It believed that, that plasma generated give effect on the temperature increasing. Wavelength from microwave propagate uniformly at the tip of the electrode and generate plasma with a huge and stable ignition.

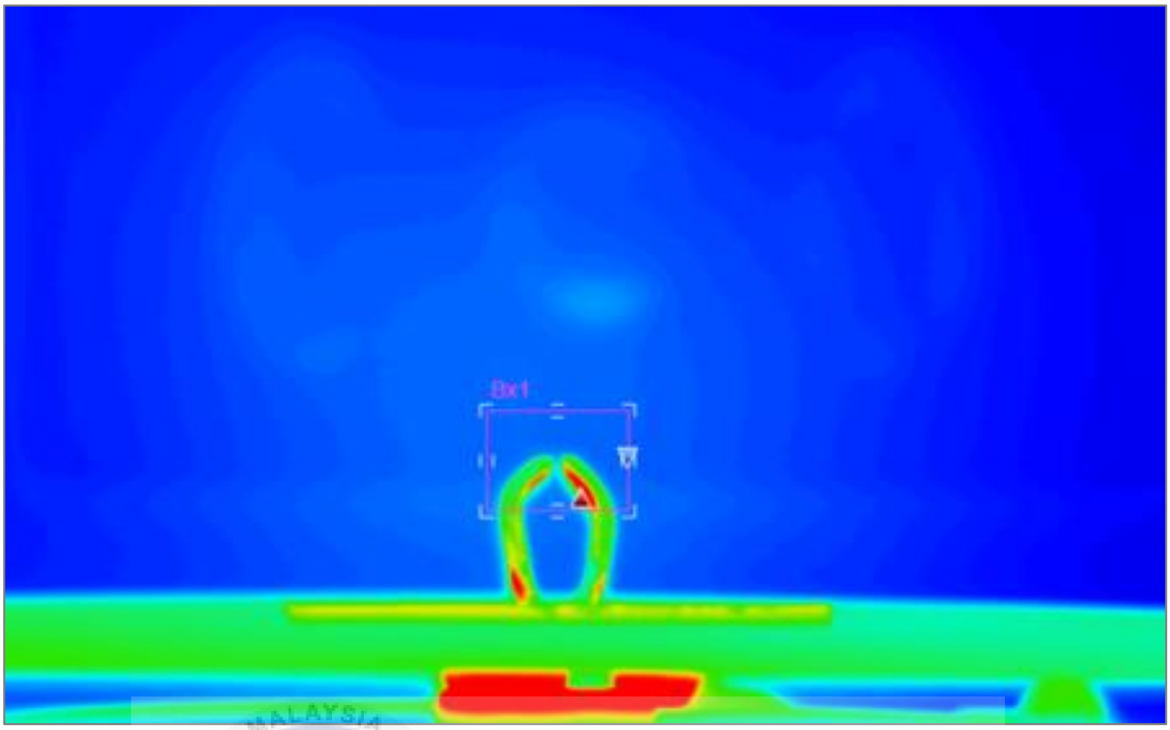

Figure 4.9: Example contour for 6 cm electrode length from FLIR tools

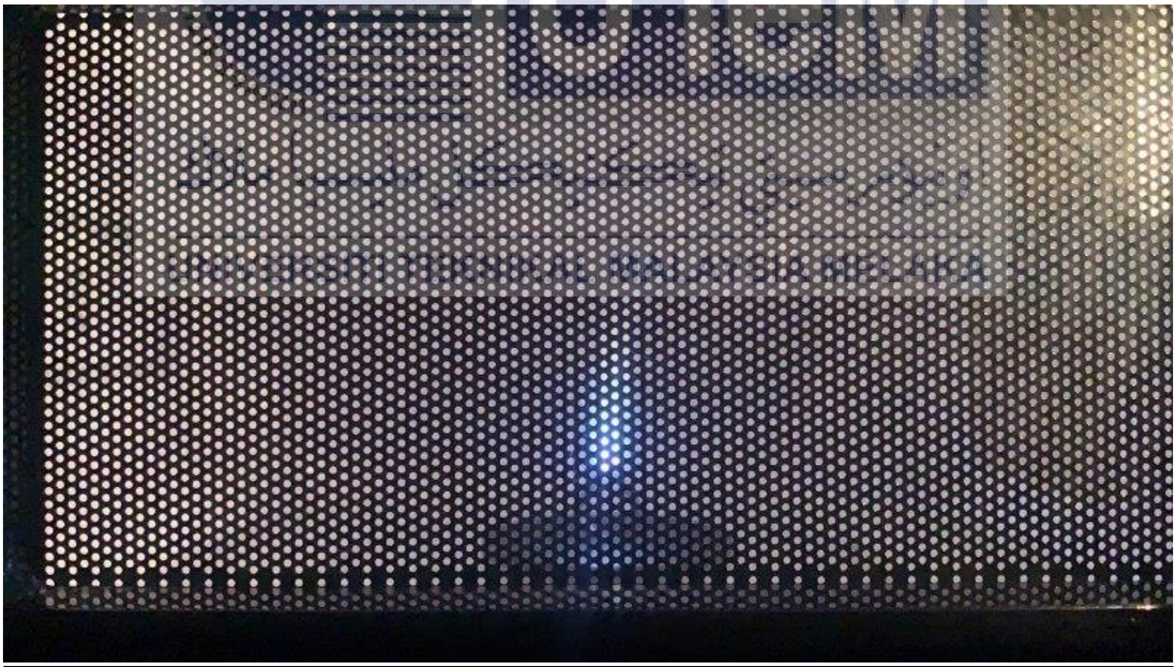

Figure 4.10: Spark during the experiment

18 cm copper electrode (3/2 λ)

Table 4.4: Temperature and plasma generated for 18 cm electrode

Time/Power	Low		Medium Low		Medium	
	Temperature, ºC					
1 min	37.4	X	34.9	/	71.4	/
2 min	39.8	X	47.9	/	75.8	/
3 min	51.7	X	71.4	/	91.9	/
4 min	56.2	X	82.1	/	107.8	/
5 min	61.4	X	84.8	/	118.4	/

***** / = Spark produced X = No spark produced**

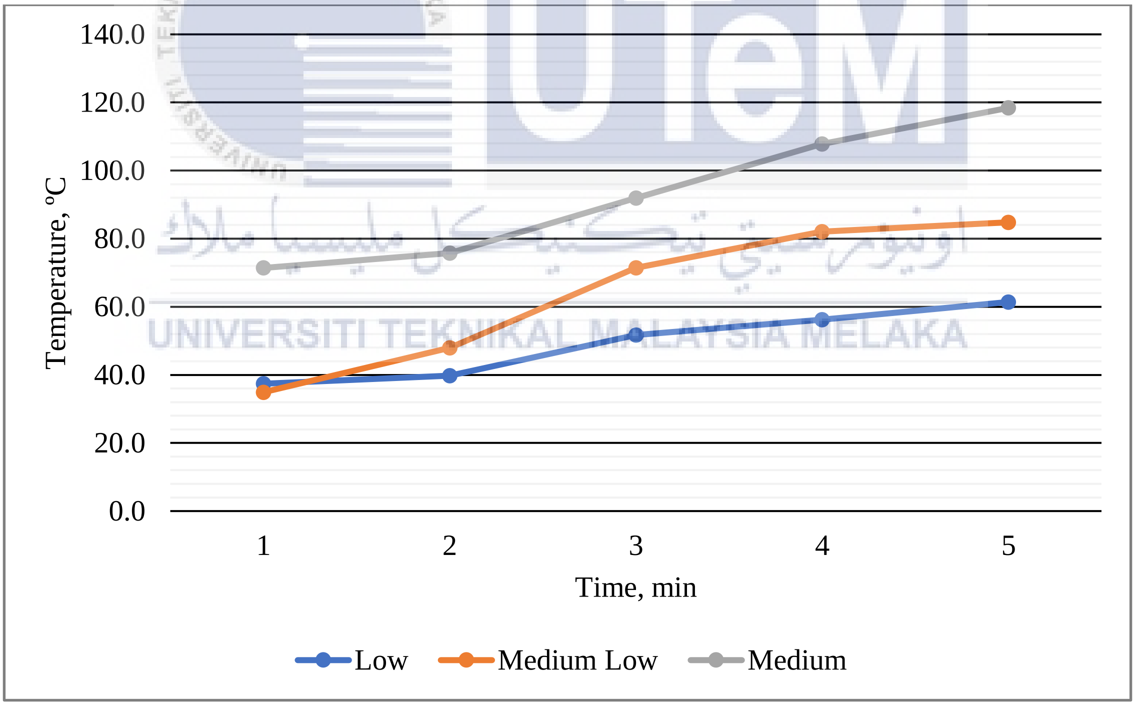

Figure 4.11: Temperature distribution at 18 cm electrode

Result from 18 cm electrode length show some mixing data. At the low power mode, at all 5 trial from first minute until 5 minutes no spark been produced. At the end of 5 minutes, it’s recorded temperature of 61.4 ºC when it initially at 37.4 ºC at first minute of test. When move to medium low mode, all the trial success to produce the spark with temperature slightly lower at first minute, 34.9 ºC. The temperature then rise to 84.8 ºC at final due to present of plasma. The situation same goes to medium mode when all 5 trials produced spark with final temperature at 5 minutes recorded at 118.4 ºC.

At the low mode power, the temperature rises not significant since there was absent of spark. But, as present in the graph, for both medium low and medium mode, the temperature rise quite significant and this due to generation of plasma. Plasma that produce heat up the electrode and result in rise of temperature. In term of plasma generation, for 18 cm electrode length the plasma cannot be generated at low power mode. The reason is less wavelength from the microwave propagate with the electrode tips since 18 cm is a long electrode.

Figure 4.12: Example contour for 18 cm electrode length from FLIR tools

4.4 Effect of Plasma on The Electrode Temperature

From the recorded data before, it clearly show that λ/4 or 3 cm electrode length was unable to generate plasma meanwhile, λ/2 or 6 cm electrode length was suitable in generating plasma at all power mode. Hence, this part will make comparison between both electrode length and discuss all possibilities of differences.

Focusing on medium power mode, from the **Figure 4.12** it show that the temperature of 6 cm electrode always higher than temperature of 3 cm electrode from the first minute of testing till the end of 5 minutes. For the first minute, 6 cm electrode make reading 62.2 ºC while 3 cm electrode recorded 43.8 ºC of temperature. At this time interval, spark only generated at 6 cm electrode and not at 3 cm electrode. Temperature of 6 cm electrode higher than 3 cm electrode because the generation of plasma heat up the electrode and rises the temperature.

Table 4.5: Temperature and plasma generated for 3 cm and 6 cm at medium power mode

Time/Electrode length	3 cm		6 cm	
	Temperature, ºC			
1 min	43.8	X	62.2	/
2 min	56.3	X	103.4	/
3 min	90.1	X	120.3	/
4 min	101.5	X	160.2	/
5 min	103.8	X	182.0	/

*****   / = Spark produced   X = No spark produced**

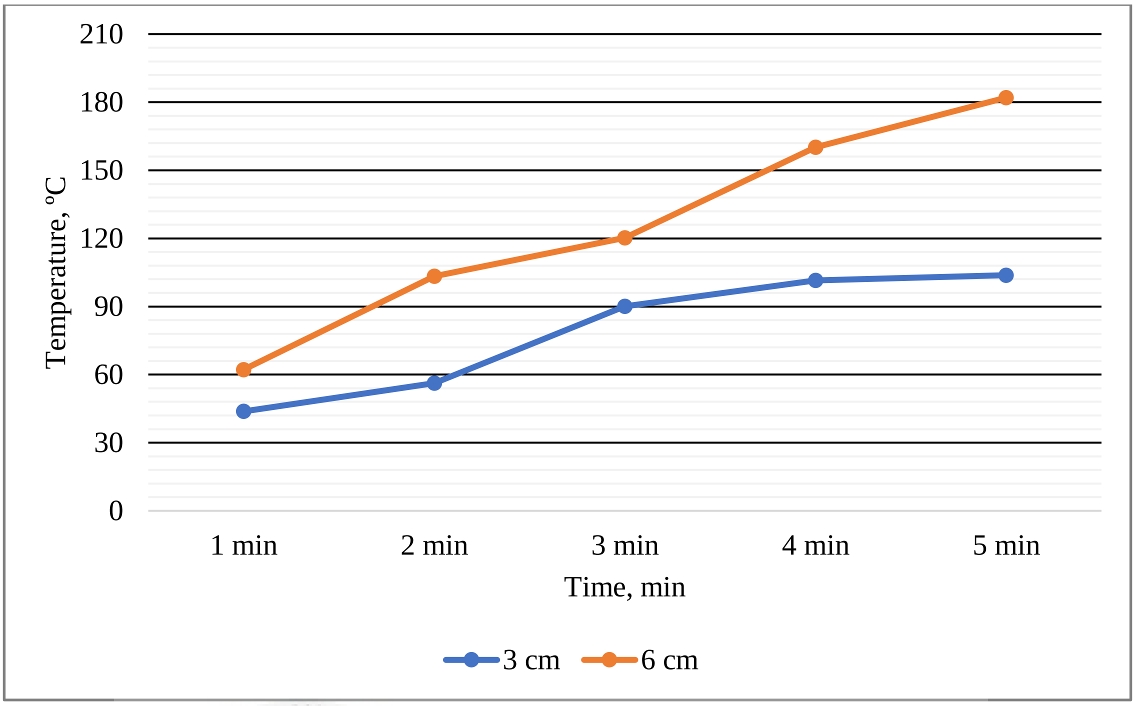

Figure 4.13: Temperature distribution of 3 cm and 6 cm electrode at medium power mode

The situation same at the 5 minutes time interval when 6 cm electrode produce 182.0 ºC and 3 cm electrode recorded temperature 103.8 ºC. Plasma continuously in 5 minutes get energy from the microwave frequency propagation resulting in collision of electron that absorb that microwave energy. Plasma itself increase in temperature and the heat was transferred from plasma to the electrode continuously resulting rises of the electrode temperature.

Microwave heat transfer also take place in this study. Microwave heat up the electrode through radiation mode and this phenomenon occur for all length at all power mode. Other than that, copper very good in thermal conductivity as it have 401.00 W/m.K. Heat transfer through material with good heat conductivity will occur faster.[54] This can related when plasma generated, 6 cm electrode increase in temperature higher than 3 cm electrode as it get heat from microwave and plasma itself.

In addition, plasma generated also can caused corrosion to happen at the electrode. Corrosion occur due to some factor like pH, concentration of corrosive material and temperature.[55] In this case, corrosion occur due to high temperature affected by the plasma toward electrode. Corrosion on electrode will disturb the stability of plasma generation and at certain time, plasma cannot generate at all due to the corroded have covered the electrode surface. After the experiment conducted, corrosion only occur at 6 cm electrode due to the plasma generated. 3 cm electrode does not have any corrosion since plasma does not exist at all.

Figure 4.14: No corrosion at 3 cm electrode length

Figure 4.15: Corroded at 6 cm electrode length

4.5 Ideal Length of Electrode for Plasma Generation

Both 6 cm electrode length λ/2 and 18 cm electrode length (3/2 λ) succeed generating the plasma. Unfortunately, 18 cm electrode length only capable generated plasma at medium low and medium power mode. Meanwhile 6 cm electrode length able generate plasma from low power mode to medium power mode. This section will find out which electrode length will be the ideal one in plasma.

Table 4.6: Plasma generated at 6 cm and 18 cm electrode length

	Low		Medium Low		Medium	
	6 cm	18 cm	6 cm	18 cm	6 cm	18 cm
1 min	/	X	/	/	/	/
2 min	/	X	/	/	/	/
3 min	/	X	/	/	/	/
4 min	/	X	/	/	/	/
5 min	/	X	/	/	/	/

*** / = Spark produced X = No spark produced

At medium power mode

Table 4.6 summarize the present of spark or generation of plasma at both 6 cm and 18 cm electrode length. Spark only present medium low and medium power mode for 18 cm electrode length meanwhile, spark was present for all at 6 cm electrode length. From this observation it's really can say that, for microwave wavelength 12.24 cm, the ideal length for plasma generation is 6 cm electrode length or length that nearly to the half of wavelength.

Table 4.7: Temperature and plasma generated for 6 cm and 18 cm at medium power mode

Time/Electrode length	6 cm		18 cm	
	Temperature, ºC			
1 min	62.2	/	71.4	/
2 min	103.4	/	75.8	/
3 min	120.3	/	91.9	/
4 min	160.2	/	107.8	/
5 min	182.0	/	118.4	/

*** / = Spark produced X = No spark produced

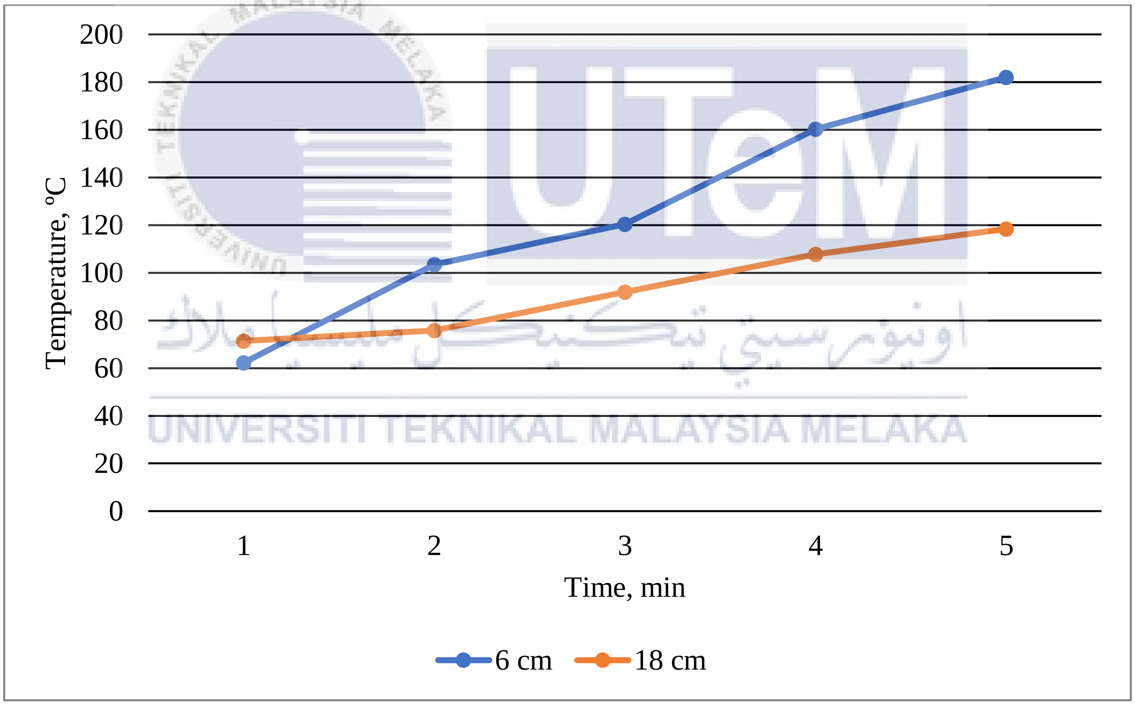

Figure 4.16: Temperature distribution of 6 cm and 18 cm electrode at medium power mode

This inference supported by observation conducted during the experiment was carried out. Plasma generated at 6 cm electrode length more stable it's ignition compared to 18 cm electrode length. 6 cm electrode length continuously produce plasma within certain period at each time interval. Meanwhile, spark at 18 cm electrode length not continuously appear within period at each time interval. When look to the temperature as well, temperature produce by 6 cm electrode length greater than 18 cm electrode length as example at 5 minutes medium power mode, 182.0 º C was record for 6 cm length and 118.4 ºC for 18 cm length.

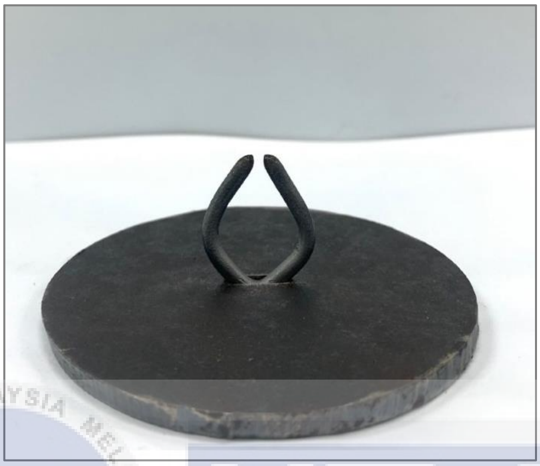

Figure 4.17: Corroded at 6 cm electrode length

Figure 4.18: Corroded at 18 cm electrode length

According to [31], a stable plasma only generated at λ/2 with ± 3mm. Other length cannot generate a stable plasma at ring shape because present of anode and cathode create electric field between the both end and microwave resonance occur smoothly at that electrode length. Besides that, in this case both 6 cm and 18 cm electrode undergo corrosion since plasma generated at both length. But, from observation the effect of corrosion was more at 6 cm electrode due to its stability producing plasma. Corrosion on 18 cm electrode only happen at the tip of the electrode and it can be concluded that 6 cm electrode undergo rate of corrosion higher that 18 cm electrode because the stability of plasma generated.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Nowadays, research towards development of plasma technology frequently done by human. They realize the advantages of using plasma energy to a various application like example production of hydrogen. Theoretically, application of plasma energy consider as cost effective. Furthermore, it now proved that plasma energy can be generated at atmospheric pressure environment after a lab scale experiment by using a conventional microwave oven and electrode, plasma can be generated.

To generate plasma at atmospheric pressure physical of the electrode is vital part. The ring shape electrode with two bullet end capable to spark plasma since each of the bullet tip act as anode and cathode that allow charge movement. Next, not all length are suitable for plasma generation. The length must related to the calculated wavelength of microwave using a formula. To find suitable length, three sample electrode with different length was tested and only 6 cm and 18 cm electrode length are able generate plasma.

Optimization always the key for any process. From the observation on the plasma generated, clearly show that electrode nearly half wavelength in length, 6 cm considered as optimize length for plasma generation. 6 cm electrode produce stable plasma at certain period along the time interval. In addition, 6 cm electrode is able produce spark at all power variant. Temperature comparison between 6 cm and 18 cm electrode show 6 cm produce higher temperature than 18 cm which can achieve 180.0 ºC after 5 minutes tested at medium power mode.

As mention before, length electrode always related to the wavelength of the microwave. Thus, it's not a fix length since the microwave frequency can be changed when it's come to customize microwave reactor. However, the ideal length for plasma generation will be always nearly half the wavelength. Beside, plasma present give corrosion effect to the electrode due to its high temperature. It believed that 6 cm electrode undergo higher rate of corrosion compared to 18 cm electrode due to its optimization in generate plasma.

5.2 Recommendation

For further study, used of other material of electrode is recommended to look for the effect on plasma generation on material with different thermal properties. The material can be tungsten and aluminium or other material which suitable. Other than that, corrosion that occur will effect on plasma generation. Hence as study on corrosion rate also recommended. Find out the corrosion rate and come out with solution to overcome the problem. Beside that, instead of using single electrode, it's suggest using multiple electrode for plasma generation. Theoretically, multiple electrode will generate more plasma. Lastly, from the observation in this study, position of electrode angle from the microwave source seem important to produce stable plasma. Hence it's recommended to do research on different electrode angle to find it's best angle in generating plasma.

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