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

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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.

Signature : …………………….

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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Particularly, I would like to express my deepest gratitude to Mr Azhar and Mr Junaidi assistants who always guide me handling the experiments. They also give idea how to improvement the procedure in order to get better result.

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).

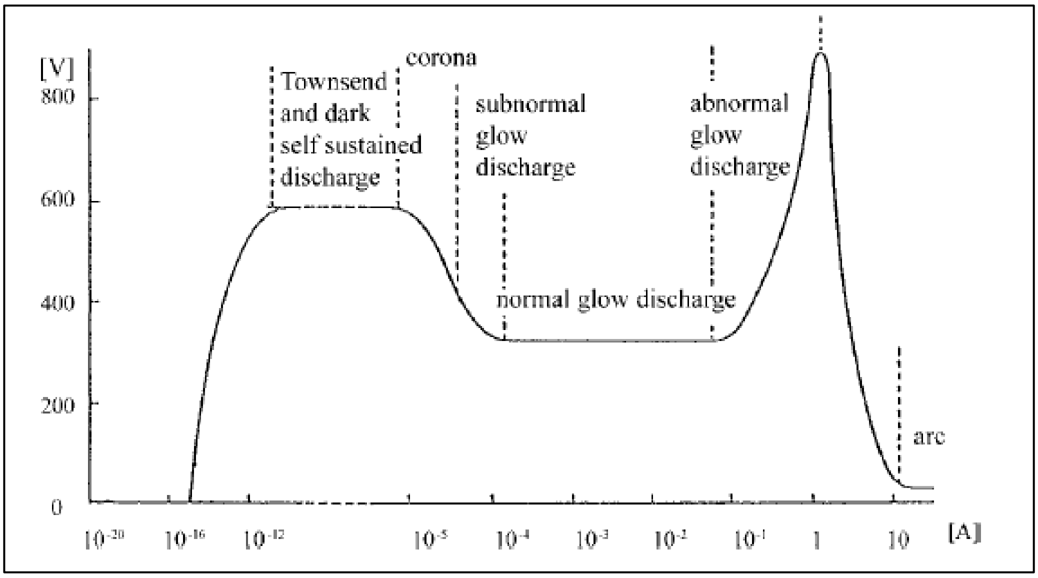

Figure 2.1: Various type of discharges depending on applied voltage and discharge current.[13]

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.

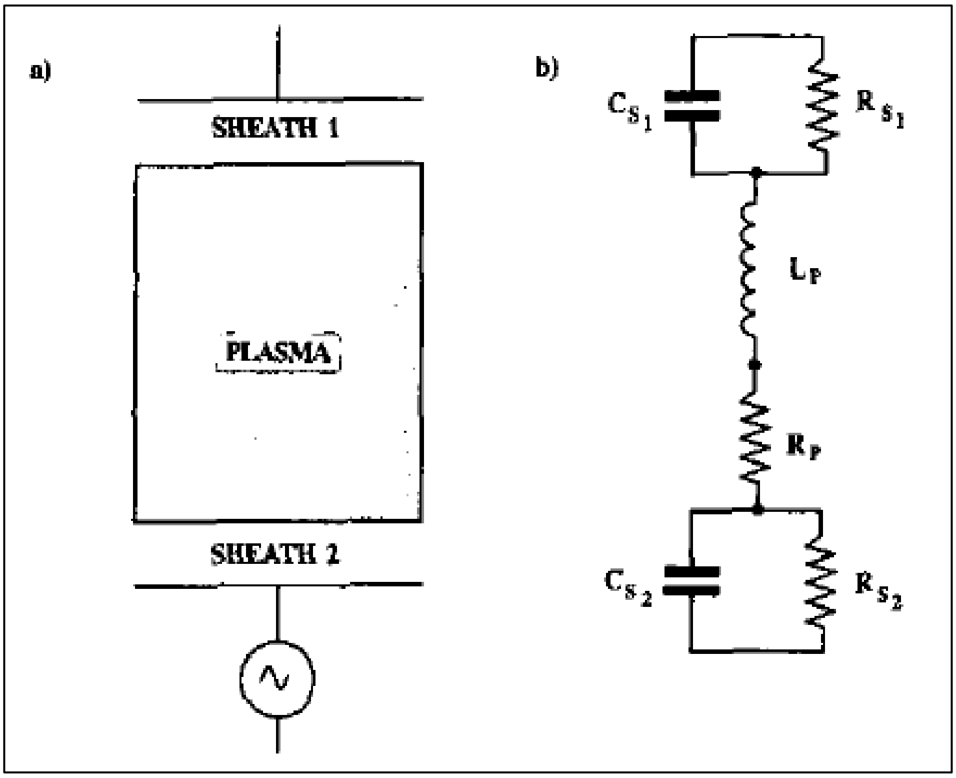

Figure 2.2: (a) Basic model of capacitively coupled discharge (CCD)

(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]