TEMPERATURE DISTRIBUTION ON LIQUID BASED ON MICROWAVE ENERGY

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TEMPERATURE DISTRIBUTION ON LIQUID BASED ON MICROWAVE HEATING

NURATIQAH BINTI ALIAS

A report submitted

in fulfillment of the requirement for the degree of

Bachelor of Mechanical Engineering

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DECLARATION

I declare that this project report entitled "Temperature distribution on liquid based on microwave energy" is the result of my own work except as cited in the references

Signature	:	…………………….
Name	:	…………………….
Date	:	…………………….

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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	:	……………………..
Name	:	……………………..
Date	:	……………………..

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DEDICATION

To my beloved mother and father

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ABSTRACT

Plasma is seen as an electrically neutral ionized gas and highly reactive gas mixture. Plasma also are a quasi-neutral atoms which contains equal number of positively charged ions and negatively charged electrons. Plasma discharge generated by the microwave is one of the applications of plasma for various materials processes. Microwave plasma is used in industry for growth of diamond structure, growth of carbon nanotubes, silicon etching and others. However, the waves generated in custom made microwave are differs with a conventional microwave as it cannot propagates waves properly. Thus, this study focuses on the generation of plasma in air and in liquids by using a 2.45 GHz conventional microwave oven at atmospheric pressure. The temperature distributions of copper electrode and liquid on plasma generation with variation of microwave powers were investigated by using Thermal Imaging Camera (FLIR A516). The liquids used are water, waste engine oil and waste cooking oil. The variation of powers used in conducting the experiment is 17% (low), 33% (medium low) and 55% (medium) power outputs. Plasma generation at the tip of the electrode in air and in liquids was observed. In liquids, the temperature distribution of liquids shows a higher value compared to the electrode according to the increasing microwave power. Waste cooking oil shows the highest value of temperature distribution of electrode and liquids in all microwave powers. Plasma was generated in air but not in liquids. Moreover, the temperature distribution of electrode in air was twice the value of temperature distribution of electrode in liquids.

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ABSTRAK

Plasma dilihat sebagai gas terionis neutral elektrik dan campuran gas yang sangat reaktif. Plasma juga merupakan atom kuadratik yang mengandungi bilangan ion positif yang sama banyak dengan elektron bercas negatif. Pelepasan plasma yang dihasilkan oleh gelombang mikro adalah salah satu aplikasi plasma untuk pelbagai proses sintesis bahan. Plasma gelombang mikro digunakan dalam industri untuk pertumbuhan struktur berlian, pertumbuhan nanotube karbon, etsa silikon dan lain-lain. Walau bagaimanapun, gelombang yang dijana dalam gelombang mikro dibuat khas berbeza dengan gelombang mikro konvensional kerana ia tidak dapat menyalurkan gelombang dengan betul. Oleh itu, kajian ini memberi tumpuan kepada penjanaan plasma dalam udara dan dalam cecair dengan menggunakan ketuhar gelombang mikro konvensional 2.45 GHz pada tekanan atmosfera. Pengagihan suhu elektrod tembaga dan cecair pada penjanaan plasma dengan variasi kuasa gelombang mikro telah disiasat dengan menggunakan Kamera Pengimejan Termal (FLIR A516). Cecair yang digunakan ialah air, sisa minyak enjin dan sisa minyak masak. Variasi kuasa yang digunakan dalam menjalankan eksperimen ialah 17% (rendah), 33% (sederhana rendah) dan 55% (sederhana) output kuasa. Penjanaan plasma pada hujung elektrod dalam udara dan dalam cecair diperhatikan. Dalam cecair, taburan suhu cecair menunjukkan nilai yang lebih tinggi berbanding dengan elektrod mengikut peningkatan daya gelombang mikro. Sisa minyak masak menunjukkan nilai tertinggi pengedaran suhu pada elektrod dan cecair di semua kuasa gelombang mikro. Plasma dihasilkan di udara tetapi tidak di dalam cecair. Selain itu, pengedaran suhu elektrod di udara adalah dua kali ganda nilai pengagihan suhu elektrod berbanding di dalam cecair.

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LIST OF ABBREVIATION

AC	Alternate Current
DC	Direct Current
CVD	Chemical Vapor Deposition
K	Kelvin
TPCVD	Thermal Plasma Chemical Vapor Deposition
ECR	Electron Cyclotron Resonance
UHR	Upper Hybrid Resonance
GHz	Giga Hertz
MHz	Mega Hertz
RF	Radio Frequency
Pa	Pascal

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Often thought as a subset of gases, plasma is a state of matter which behave very differently compared to gases. Plasma has no fixed shape or volume like gases and they are less dense than solids or liquids. According to [1], around this universe, most of the visible matter are in plasma state. For example, the stars, the sun and all visible interstellar matter are in plasma state too. Other than that, plasma also can be divided into two main groups of laboratory plasma which is fusion plasma (high temperature plasma) and gas discharge plasma (low temperature plasma).

In 1879, Crookes found out the importance of plasma after investigated the electrical discharges in gas [2]. Today, applications of plasma have made a big impact especially in electronics industry and as well as materials preparation, diamond synthesis and materials modification in polymer treatments. According to [3], the treatment of surfaces is the fastest expanding areas of plasma applications in these recent years. Through the process of nitridation or deposition of polymers, yielding anticorrosion or dielectric coating, the surface treatment field includes the processing substrate in semiconductor manufacturing such as deposition, oxidation, etching and encapsulation process plus the hardening and protection of metal surfaces.

[4] added the method use to generating plasma can be a method that used AC or DC high voltages or a method that used microwaves.

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Using microwave for CVD plasma can produce highly dense plasma and also films formation at high speed. However, plasma can be generated at high atmospheric pressure which enables faster formation of films than plasma CVD. This is because high atmospheric pressure plasma has high molecular density and the generation of plasma is easy to start and maintained. According to [3], radio frequency and microwave produced plasma can be referred as high frequency plasma. High frequency plasma helps removing electrode corrosion problems, reduce gas contamination and have lower cost of discharge tubes and reactor.

Thus, this study focuses on the method of generating microwave plasma using electrode in microwave oven. [4] added that this method have lower cost and have the ability of oscillating high-power microwaves. Microwaves in the waveguides are not capable of propagating properly and it is differs from the microwaves produced in the microwaves oven. This is because the waves in the microwaves oven distributed the waves uniformly to heat object in the oven. [5] also stated that in vacuum conditions, microwave plasma at atmospheric pressure may allow lower facility and process cost for a variation of plasma processing and manufacturing techniques. Providing the suitable conditions for dissociating molecules in abatement systems, for burning out the chemical and biological warfare agents and for atomizing and synthesizing materials in carbon nanotubes is examples of what high density plasma can do to forming a product.

1.2 Problem Statement

Plasma usually can be generated in atmospheric pressure or naturally in space. Plasma also can be generated when subjected to inert gases such as argon, nitrogen and others as catalyst. Despite this, plasma can be difficult to generate in water or in liquid. However, plasma provides a lot of application as it have high temperatures up to 4000 K. In Malaysia, there are abundant of waste engine oil and waste cooking oil produced every

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day. This often creates many problems as people would dispose it improperly and causing pollution into the environment. Disposal of waste oils are also would cost a lot of money. Instead of disposal of waste oils, it would be a better idea to convert the oil wastes into something useful. The high temperature of the plasma can be used in liquid to convert oil wastes into energy, water treatment or others.

1.3 Objective

The objectives of the study are:

1. To determine temperature distribution of in different liquids.
2. To generate plasma in liquid.

1.4 Scopes

The scopes of the study are:

1. The types of medium/liquid used in the experiment which are water, waste engine oil and waste cooking oils
2. The variation of microwave power used in the experiment which is low, medium low and medium power.

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CHAPTER 2

LITERATURE REVIEW

2.1 Plasma

2.1.1 Theory of plasma

Plasma is the fourth state of matter after solid, liquid and gas. According to [6], plasma is a phase of matter which were assumed and viewed as an electrically neutral ionized and highly reactive gas mixture. Most plasma are quasi-neutral as they contains equal numbers of positively charged ions and negatively charged electrons. Although plasma often appears in the form of gases, plasma has charges which causing them to behave differently from the three states of matter: solid, liquid and gases as plasma also highly affected by electric and magnetic field. [6] also stated that to obtain a plasma radiation, a strong electric field needs to be applied at the gas mixture. This condition then causing energetic collision between the charged ions and electrons to formed into gas state.

2.1.2 Types of plasma

There are two types of plasma, which is thermal and non-thermal plasma. [7] stated that the thermal plasma are identify by the thermodynamic equilibrium. This can be defined as the electrons, ions and neutral species have the same temperature or energy. As for the temperature, [8] stated that a thermal plasma can reach up to 20 000˚C or more if electrically generated. Next, according to [7], the non-thermal plasma are identified by a thermal non- equilibrium between the temperature of the electrons and the ions. Non-thermal plasma or also called cold plasma have lower degree of ionizations.

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They are also classified by lower energy density and a huge dissimilarity between the temperature of the electrons and the heavier particles. The temperature of non-thermal plasma is stated that it can reach up to around 300 to 1000 K.

Normally, a non-thermal plasma are often the favors in the industry rather than a thermal plasma. This is because the electrons in non-thermal plasma can achieved the temperature up to 10000 to 100000 K (1-10 eV) while the gas temperature can constantly as low as room temperature [9]. [10] also stated that a non-thermal plasma required less power and are obtained at lower pressures. Technically, as non-thermal plasma have low temperature and medium pressure attracts some particular interest industrially as they are also do not require extreme conditions to work on.

2.1.3 Plasma generation

There are many types of plasma generation. Plasma generation can be produce by using electric field and using beams. By using electric field, [11] stated that by maintaining the electric field on temporal basis, discharges can be categorized as dc discharges, ac discharges and pulsed discharges. In the other hand, the other types of discharges are rf and microwave discharges, microwave discharges and dielectric barrier discharges. As for the plasma generation by using beams, it is often achieved by the usage of electrons beams and laser beams. Plasma generation by using beams also generated when there is the interaction between an electron beams with the gas medium

Different discharges and plasma can be produce by relying on the applied voltage and the discharges current. For example, the ion energy at the cathode are approximately high as for dc discharges and the power source are well developed and widely available. However, dc discharges required interior electrodes and needs to consider the possibility of reactions with reactive and corrosive gases. As for rf and microwave discharge, they can

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be operated without the need of electrodes which is also called electrodes-less. Electrodes-less are useful because it can generate plasma that over a various range of pressure which then producing high density plasma.

2.1.4 Application of plasma

Different field have different types of application of plasma. For example in the modification of fibers for textile production, a wide usage of plasma treatment is applied [6]. According to [12], in biomedical industry, plasma is used in medical application in sterilizations, wound healing, blood coagulation, gene transfection and tissue regeneration. However, the application of plasma depends on the type of plasma. This is because thermal plasma and non-thermal plasma have different characteristic which their usage is differs with each other.

Cold plasma plays the important roles in innovations of semiconductor manufacturing [12]. [13] also stated that in food industries, cold plasma applications include food decontamination, food quality improvement, toxin degradation and surface modifications of packaging materials. Next, [13] added that cold plasma plays a huge roles in the polymer and electronic industry for surface modifications and functionalization of different polymers.

For thermal plasma, its applications includes in coating technology, synthesis of fine powders, waste destruction, spherodization with densification of powders and in slag metallurgy [14]. [8] also added that thermal plasma applications applies to a wide range of application especially in thermal plasma surface treatment technology such as coating techniques, such as plasma spraying, wire arc spraying and thermal plasma chemical vapor deposition (TPCVD), synthesis of fine powders in the nanometer size range, metallurgy

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which including clean melting and re-melting applications in large furnaces, extractive metallurgy including smelting operations and the destruction and treatment of hazardous waste materials.

2.2 Microwave plasma

2.2.1 Theory of microwave plasma

Microwave are electromagnetic wave which its frequency range between 300 GHz to 300 MHz and have wavelength range between 1 mm to 1 m respectively [7]. In industry, microwave frequency used is 0.915 GHz with a wavelength of approximately 32 cm which found in mobile phones and food processing while a frequency of 2.45 GHz with approximate 12 cm wavelength is usually found in kitchen microwave or microwave sterilization. According to [15], if a material is radiated with microwaves, the material temperature can be directly increased whether by dipolar polarization or interfacial polarization. The temperature also can indirectly increased by heat transfer by the plasma discharges surrounding of the material. Microwave heating also can be more rapid and energy reduction method of heating compared to conventional heating due to decreased path of the heat transfer.

Apart for heating materials, microwave also can be used as energy sources for discharging plasma for various material processes. [7] stated that compared by using other types of electrical excitation, using microwave energy can obtained higher degree of ionization and dissociation. Despite reduces the activation energy, higher degree of ionization and dissociation also enhances the kinetic to initiates a chemical reaction. Microwave plasma sources can also inject large power densities which causes active species of interest achieving high population densities [5]. At atmospheric pressure,

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microwave plasma enables lower facility and process costs for several of plasma processing and manufacturing techniques when executed under vacuum condition.

According to [7], a microwave plasma consists of neutral gas species, dissociated gas together with ions and free electron and also precursor molecules for the suitable chemical reactions. Consequently, the collisions between the charged electrons and ions and also the uncharged species such as molecules, atoms and particles have an effect to the energy transfer to the particles. The energy transfer equation of the microwave plasma is given by the energy (E), which then transferred to a charged species of mass (m) in an oscillating electrical field with frequency (f) is proportional to its charge (Q), and inversely proportional to its mass (m) and the measure of the temperature is given by frequency to the power of two (f^2). Meanwhile, (z) is the collision frequency.

$$E \propto \frac{Q}{m}\frac{z}{f^2 + z^2} \quad (1)$$

2.2.2 Types of microwave plasma reactors

There are three types of microwave plasma reactor which is discharged produced in closed structures, in open structures and in resonance structures with a magnetic field. According to [11], the plasma chamber in closed structures is surrounded by metallic walls. At high pressure, it allows an easy ignition of discharges by the resonant cavity of high quality with their high electric field. Next, microwaves torches, slow wave structures and surfatrons are the examples of discharges in open structures types of microwave plasma reactor.

For resonance structures with a magnetic field, the typical example is the Electron cyclotron resonance (ECR) plasmas. [16] stated that ECR microwave plasma sources is operated by using two ways which is using magnetrons or by solid-state generators.

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ECR heating mechanism is very efficient at very lower pressure such as pressure range between 10^{-2} to 1 Pa. When the electron frequency is small compared to the angular frequency of the applied electric field, the energy collected by the electrons is mostly the one imparted during collision in the collisional system of ECR mechanism.

The work of an electron on a full period of the applied microwave field also could be zero without the magnetic field. In ECR, when an electron has the biggest chance to obtain maximum energy of the electric field while having maximum probability to have a collision on the period of the wave is called the maximum transfer efficiency obtained. The duration between two collisions is high when at low pressure which means that the probability to collect maximum energy of the electric field is high but the probability to have a collision is low. Meanwhile, due to high collision frequency at high pressure, the probability to collect energy of the electric field is low but the probability to have a collision during a period of the wave is high. In application, it is commonly preferable to work at moderately lower pressure depending on the gas to ease the diffusion of plasma species and thus increase the penetration depth of the electromagnetic wave in plasma.

2.2.3 Generation of microwave plasma

An optically generated plasma and Radio Frequency (RF) generated plasma have the similarity with the microwave generated plasma [17]. In centimeter range, the wavelength of the microwave plasma is longer compared to the wavelength of the optical waves in nanometer scale while smaller compared with the wavelength of the RF plasma. [11], [17] stated that, the wave of microwave radiation are in the form of rectangular waveguides. The effect of the absorption of microwave energy in an ionized gas causing the excitation of microwave plasma. There are three basic absorption mechanisms which is collisional absorption, collisionless absorption and non-linear absorption.

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The collisional absorption happens when the collision of electrons with ions (v_{ei}) together with neutral particles (v_{en}) [18]. Higher predominant collisions are when the collisions of electrons with neutral particles are more than collisions with ions ($v_{en}>v_{ei}$) which occurs at pressures of about 10^3 Pa. However, when pressure is lower than 10^3 Pa, both of the collision of electrons with neutral particles and ions are approximately equals to each other ($v_{en}\approx v_{ei}$) and if the pressure is lower than 1 Pa, the collisions of electrons with ions are higher than neutral particles ($v_{ei}>v_{en}$). In plasma, the collisionless absorption is dominant because it satisfy the conditions of $v/w < 1$ which w is the angular frequency of the microwaves. This collisionless absorption surfaces at various resonance frequencies of transverse electromagnetic waves. These waves then are strongly slowed down here with their phase velocity is on the level with thermal velocity of electrons (v_{Te}) and the energy of transverse waves is very effectively transferred into short-wavelength plasma waves which strongly absorbed in the plasma. The most important resonances involves in this absorption are the plasma resonance, the electron cyclotron resonance (ECR) and the upper hybrid resonance (UHR).

When high microwave powers are delivered into a plasma, that is when a non-linear absorption surfaces at arbitrary pressures [18]. Comparing with the previous types of absorption, the non-linear absorption is abnormal. This is due to it is connected with an excitation of different types of instabilities which usually comes with the lack of parametric stabilities. The absorption due to the developing of parametric instabilities surfaces when certain condition is satisfied. The first condition is when $v_E/v_{Te} \geq 0.1$ which v_E is the ac drift velocity and v_{Te} is the thermal velocity of the electrons. This abnormal absorption also starts at certain threshold values of the electric field intensity.

The another way of generating plasma by microwave is the excitation of surface waves [11]. [5] also added as waveguide-based, atmospheric plasma sources driven by

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