TEMPERATURE DISTRIBUTION ON LIQUID BASED ON MICROWAVE ENERGY

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TEMPERATURE DISTRIBUTION ON LIQUID BASED ON MICROWAVE HEATING

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A report submitted

in fulfillment of the requirement for the degree of

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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 : ……………………..

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 : ……………………..

DEDICATION

To my beloved mother and father

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.

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

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.

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 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.

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.

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 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 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, 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.

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

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.

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.

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 surface waves are compact, electrodeless, economical, easy to operate and an attractive way to a classical sources. Surface waves driven microwave plasma sources also very multipurpose because it can operate over a wide range of operation conditions and geometries. According to [19], surface waves plasma can be divided into two types which is dielectric-bounded type and metal-bounded type. For the dielectric-bounded type which the surface waves propagate along the dielectric and plasma interfaces while for metal-bounded type, it employing microwave sheath-voltage combination plasma where surface waves propagate along the plasma and sheath interfaces.

2.2.4 Application of microwave plasma

Industrial demand for large scale plasma surface processing requires for plasma sources with increased performance in terms of control, density and uniformity over a wide area of operation. According to [15], in the year of 1983, microwave plasma system is used by M. Kamo et al. to grow diamond structure on non-diamond substrate. While in the year 2000, the growth of carbon nanotube is reported by C. Bower et al. by using microwave plasma-enchanced chemical vapor deposition (CVD). As for Z. Zang et al, microwave plasma system could be applied for doping of films such as cuprous oxide films nitrogen doping. S. Tachi et al. also reported in the year of 1987 that microwave plasma system also can be used in the etching of silicon and now it has been adopted in semiconductor industry.

For microwave plasma assisted chemical vapor deposition (CVD), the deposition of the films possibly more efficient than plasma assisted CVD. This is due to the low efficiency of forming active species inside the plasma [18]. Microwave plasma assisted CVD also can be categorized into two types of groups which is one group is using the isotropic while the other using magnetoactive plasma. Microwave plasma assisted CVD is used for the creation of a metal oxide films. However, this was based on the capability of a certain metal-organic compounds to absorb energy from the microwave plasma which than causes decomposition occurs. For microwave plasma assisted CVD using magnetoactive plasma, it focuses only on ECR plasma deposition which means the absorption of microwave energy at the ECR.

Etching is one of the most vital steps in microelectronic. According to [20], the rate of etching in organic is the main process step and has high impact on productivity in micromechanics although the layers to be stripped in electronics are comparably thin. The rate of etching has a relationship with the amount of free radicals which it will transfer the organics through plasma reactions into the gas state. Although the radical energy is not automatically highest in plasma but there is an advantage that helps to keep away from too much energy load to the organic surface in the afterglow. The after effect of this phenomenon would cause crosslinking within the microstructure of the resist and results an extreme decrease of the rate of etching. Thus, for a high rate etching process, the ideal source to be used is a remote plasma radical source with a high radical density considered.

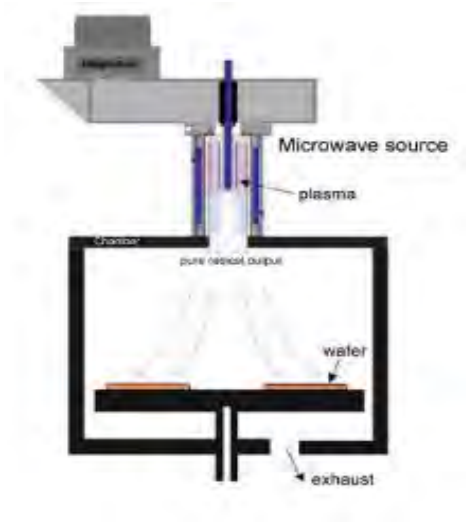

Figure 2.1: Plasma reaction with free radicals in microwave source [20]

2.3 Liquid Permittivity

Permittivity or dielectric permittivity can be defined as the combination of polarization and conduction of a material. Polarization of a material is the potential of a material to store electrical charges and conduction of materials is the ability of the electrical charges move through a material (Permittivity & Content, 2018). Dielectric permittivity, ε, also served as the function of frequency. The ratio of the complex dielectric permittivity (ε) to the free space dielectric permittivity ($\varepsilon_{\circ}$) is known as relative dielectric permittivity, $\varepsilon^*(\omega)$, which ω is the angular frequency. Relative dielectric permittivity also can be called as the dielectric value or dielectric constant. The dielectric value can be denoted in form of real part and imaginary part. Hence, the dielectric value is equals to $\varepsilon^* = \varepsilon'(\omega) - j\varepsilon''(\omega)$, where ε' represent the real part of dielectric value and ε'' represent the imaginary part of dielectric value.

Next, the effect of dielectric is the result of the polarization in a medium (Fig. 2.2). This phenomenon gives rise to a reverse field where the force between two charges is reduces and the potential difference between the charged plates of a condenser is also reduces. This then allows the capacitance increases which given by charge or the potential difference inside the medium [21]. There are several causes of why polarization could happen. Polarization could be the result of either the permanent dipoles alignments, for examples the water molecules (Fig. 2.3) or either charge separation which forming the induced dipoles (Fig. 2.4). This is why relative permittivity is significant in alternating current electricity as due to its impact on capacitance in any medium.

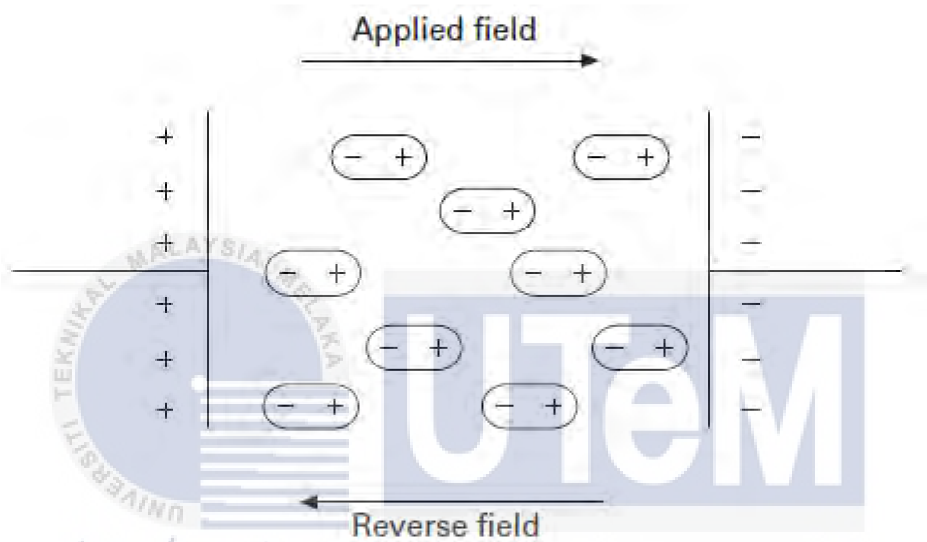

Figure 2.2 : Polarization in a medium [21].

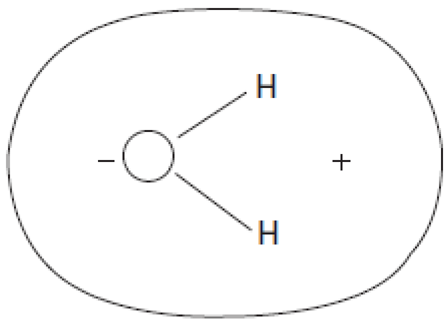

Figure 2.3 : Permanent dipoles of water molecules [21].

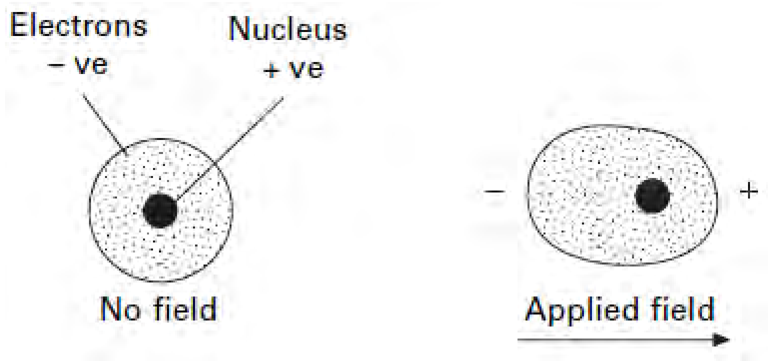

Figure 2.4 : The induced dipoles distortion around nucleus of an atom [21].

CHAPTER 3

METHODOLOGY

3.1 Medium

The medium or liquids used in the experiment are waste cooking oil, waste engine oils and water as the datum. Waste cooking oils are obtained from nearest restaurant while waste engine oils are obtained from the nearest car workshop in UTeM Technology campus, Melaka. The reason why those medium are chosen for the experiment is because of its dielectric constant values and all can be renewable sources. The dielectric constant value for waste cooking oil is 3.254. Meanwhile, the dielectric value of waste engine oils can be varied in the range of 2.1 to 2.4 by depending on its viscosity, density, relative paraffin, and the additive package of the oil [22]. Meanwhile, water has the permittivity of 80.4 at temperature 20˚C and 10 at temperature 360˚C, respectively [23].

3.2 Electrode preparation

Copper electrode is used in this experiment. The electrode first is measured approximately 6 cm with a plus minus 0.5 cm in length by using a ruler. According to [24], setting the length of the electrode is a must so that electric field can be maximized at the tip of the electrode. After the electrode is cut using hacksaw, the flat surface of the electrode is grind to produce a bullet shaped tip using drill machine and chisel. The pressure applied by the chisel need to be in consistent pressure during the rotation of the drill in order to produce a smooth surface of the electrode.

During this process, precaution steps also need to be taken seriously to avoid any injuries occurs. Wearing a google and keeping a safe distance between the machines is performed during this process. Bullet shaped surface is produced because flat surface will causing low heat accumulation as more heat need to be distributed along the flat surface. The thermal conductivity of the electrode metals also affected the heat accumulation at the tip of the electrode. In the experiment, copper electrode have the thermal conductivity of 386 W/m K at temperature of 20˚C [25] is used. After obtaining bullet shaped tip on both end of the electrode, the electrode is bent within both ends thus creating a positive and negative like tip.

Figure 3.1: 6cm electrode

3.3 Platform preparation

The material used for the electrode platform is mild steel. A mild steel with a thickness of 0.4 cm is cut to a round shape by using plasma cutter. The mild steel is cut approximately 10 cm of diameter. The platform surface then is finishes by using chisel. After making sure the platform surface is smooth, a capsule shaped hole are drill at the middle of the platform. This process involving the use of Lathe CNC machine to ensure the accuracy of the hole parallel with electrode. The capsule shaped hole was drill at a width of 0.3 cm and 1.2 cm in length.

Figure 3.2: Electrode platform.

3.4 Plasma generation

Microwave is one type of plasma generation sources. In this experiment, microwave plasma generation method is applied. Using a microwave with the power of 700 W, the power knob is adjusted to a certain percentage as below. This percentage power is used as the variable during the experiment.

Table 3.1: Variation of percentage power supply

Power knob	Percentage power
Low	17%
Medium low	33%
Medium	55%

Before experiment can be conducted, the electrode is polished using sand paper to remove any deposited dust from fabrication processes. The electrode surface must be in shinning state or otherwise it will affect the generation of plasma. For generation of plasma in air, the polished electrode is put on the platform. The specimen then is put into the microwave and once microwave power is turned on, the experiment is conducted with the variation of the percentage power. The time taken for the experiment is 2,4 and 6 minutes of time intervals. The experiment is started with 2 minutes intervals and once done, the temperature of the tip of the electrode is measured by using thermal imagine camera (FLIR A516). Before proceeding the experiment with 4 and 6 minutes, the electrode needs to be polished to remove any deposited cause by the corrosion of electrode. The experiment then is repeated for 4 and 6 minutes with every variation power and data is collected.

For generation of plasma in liquid, the polished electrode is put into the platform and both of the electrode and the platform is put into a glass container. The liquid is measured in a beaker with the volume of 280ml before pouring it into the glass container. While pouring the liquid into the glass container, the level of the liquid must be a bit lower than the tip of the electrode to ensure the temperature of the electrode can be measured. The type of liquid used for the first experiment is water. The glass container then is put into the microwave and the experiment is started with low power. The time taken to observe the generation of the plasma in the liquid is 2,4,6,8 and 10 minutes. After 2 minutes of the experiment with low power microwave, the temperature of the electrode and the temperature of the liquid are measured by using thermal imaging camera (FLIR A516). Once the data of the experiment is recorded, the glass container containing the electrode is cool down for 1 minutes before proceeding the experiment with 4,6,8 and 10 minutes. The experiment is repeated with every power variation for waste cooking oil and waste engine oil with the same time taken and the data is collected.

Figure 3.3: The plasma generation in air set up.

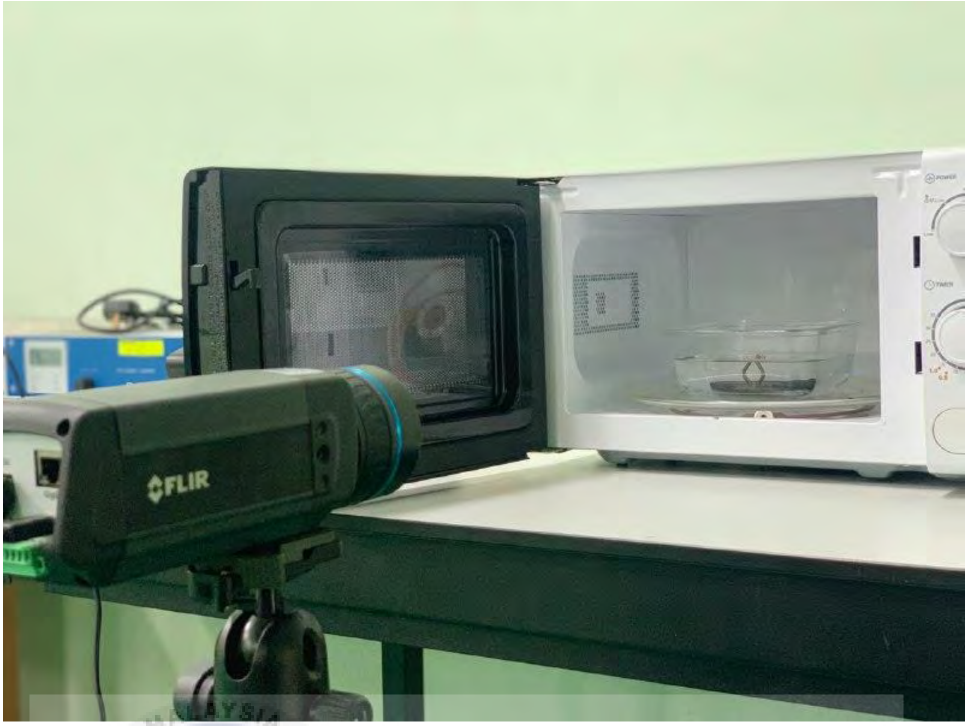

Figure 3.4: The plasma generation in liquid set up.

3.5 Data collection and data analysis

Upon collecting the data by using thermal imaging camera (FLIR A516) for all the experiment, the data is collected from the FLIR software. The data is arranged in a table for systematic data collection. There are four tables of data representing the experiment which is the table of the electrode temperature in air, the table of the electrode and the liquid temperature in water, the table of the electrode and the liquid temperature in waste cooking oil and the table of the electrode and the liquid temperature in waste engine oil. The experiment is repeated two times to obtain the accurate data thus the average data is taken for data analysis. Table 3.2 shows the examples of tables used during collecting the data.

The data collections then are analyzed in form of graphs. There are 6 graphs in total representing the temperature distribution in various liquids and the temperature distribution between liquid and electrode in water, waste cooking oil and waste engine oil.

Every temperature distribution contains 3 graphs each describing the data collected from the experiment. The graph representing the temperature of the electrode vs the microwave power and the temperature of the electrode and the temperature of the liquids vs the microwave power for each type of the liquids.

Table 3.2: Data collection table

Power/Time (min)	Low		Medium Low		Medium	
Temperature (˚C)	Electrode	Liquid	Electrode	Liquid	Electrode	Liquid
2 min						
4 min						
6 min						
8 min						
10 min						

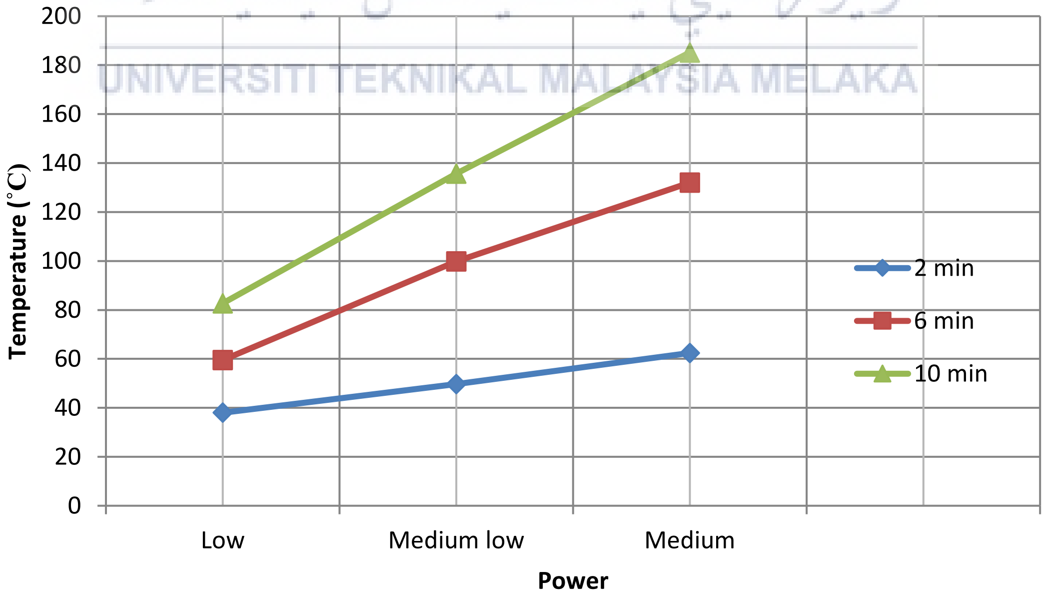

Figure 3.5: The temperature distribution for one type of liquid.

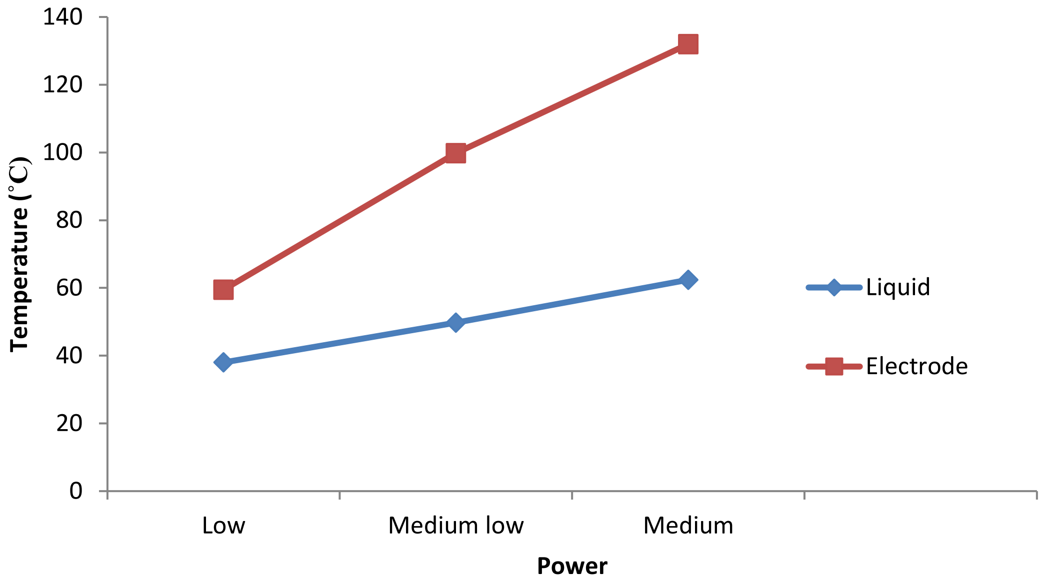

Figure 3.6: The temperature distribution between liquid and electrode for one type of liquid.

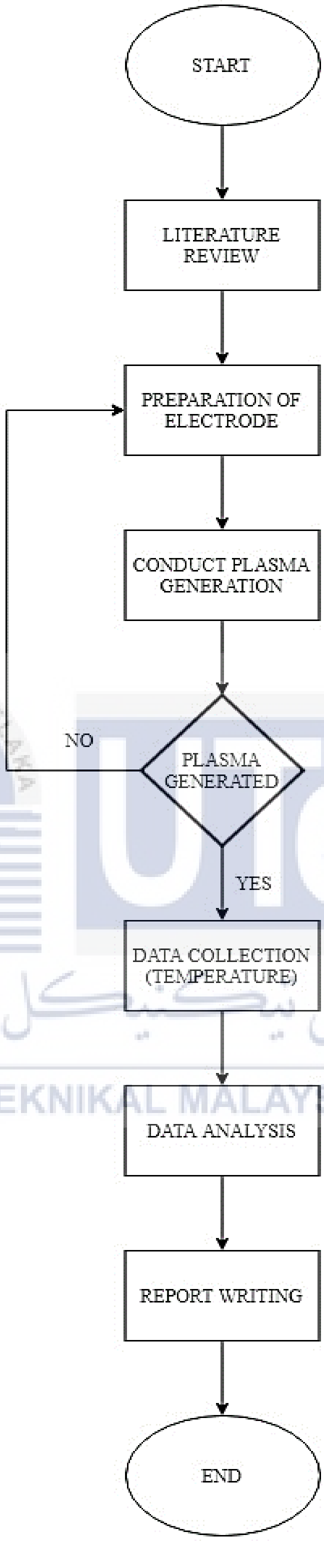

Figure 3.7: General methodology flow

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter discussing on the result and discussion of the experiment conducted. The experiment conducted is to determine the temperature distribution in different solutions and to generate plasma in liquid. The experiment is done in four types of medium, which is in air, water, waste engine oil and waste cooking oil. The result of the experiment is analyzed in form of tables and graphs followed by the detailed discussion of the experiment in every subchapter. The subchapters on this chapter are categorized into four main sections. The first section discussing on temperature distribution in water followed by the second sections which discussing on temperature distribution in various liquids. Next, third subchapter discussing on temperature distribution between liquid and electrode in water, waste engine oil and waste cooking oil. Lastly, the subchapter will discussing on the temperature difference between in liquid and in air cases.

4.2 Temperature Distribution in Water

The first objective of the experiment is to determine the temperature distribution in different liquids. The term of temperature distribution in the context is the temperature of the electrode in water with the time taken of 2,4,6,8 and 10 minutes per experiment. The experiment started with low microwave power then continues with medium low and medium microwave power. Table 4.1 shows the data recorded during the experiment.

Table 4.1: Temperature of electrode in water.

Time (min) / Power	Low	Medium low	Medium
	Temperature (˚C)		
2	33.4	37.9	44.5
4	37.5	49.7	67.7
6	42.9	58.7	73.8
8	46.7	62.8	73.8
10	50.5	65.4	72.7
Volume of water left after 10 minutes (ml)	240	160	80

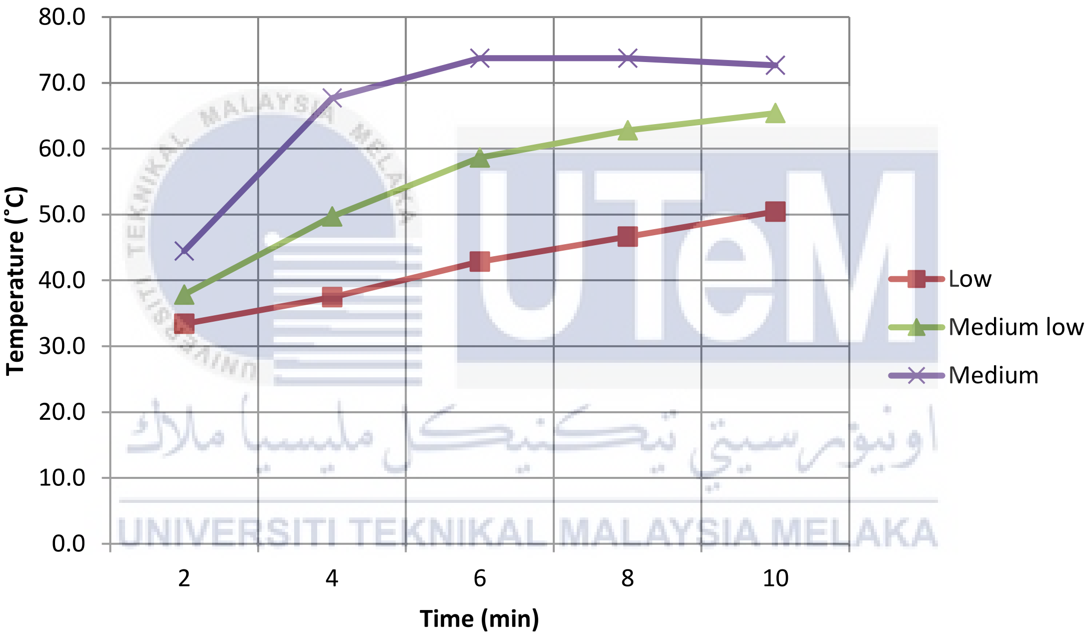

Figure 4.1: Temperature distribution in water.

Based on Figure 4.1, the data shows the temperature of the electrode is increases proportionally with time and the microwave power. At each power and every time interval, the temperatures are slightly increases indicating a small temperature difference between the each power and each minute. However, at medium microwave power, the electrode temperatures become constant at the time of 6, 8 and 10 minutes. The electrode temperatures are at constant temperature during 6 and 8 minutes which then become slightly decreases with a temperature difference of 1.1˚C at 10 minutes.

Table 4.2: Temperature of liquid and electrode in water.

Power	Temperature (˚C)						Volume of water left after 10 minutes (ml)
	Electrode			Liquid			
	6 min	8 min	10 min	6 min	8 min	10 min	
Low	42.9	46.7	50.5	57.3	63.7	67.8	240
Medium low	58.7	62.8	65.4	82.2	85.0	91.5	160
Medium	73.8	73.8	72.7	90.9	89.2	90.1	80

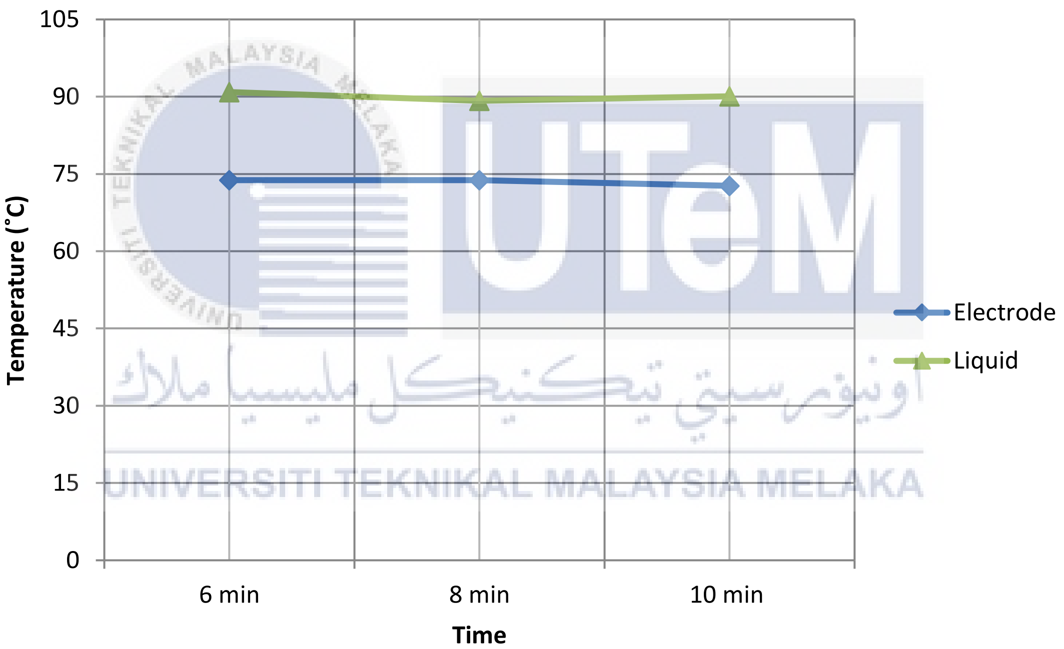

Figure 4.2: Temperature of liquid and electrode in water for medium power.

During conducting the experiment, some observation also can be made. The observation of water level left in the container is recorded in Table 4.1. The initial volume of water used in the experiment is 280 ml for every microwave power. However, at low microwave power, the volume of the water decreases to 240 ml after 10 minutes ends. Similar case happens at medium low and medium microwave power which the volume of the water decreases into 160 ml and 80 ml respectively after 10 minutes ends. According to Figure 4.2, the temperature of the liquid and the electrode are constant at medium power microwave given time 6, 8 and 10 minutes.

The initial volume of water is reduced at every stage of power indicates that evaporation process occurs during the experiment. Evaporation means the process of converting a liquid state to a vapor state [26]. Water contains hydrogen atom and oxygen atom. According to [27], the hydrogen bond in water are always formed and broken down as passing each water molecules. The process of breaking is mainly due to kinetic energy of the water molecules when heat is subjected into the system. If a high heat is subjected to the system, it will cause a high kinetic energy thus the hydrogen bond will completely breaks and produces vapor state. Water also have lower boiling point which enable a faster evaporation process. As for the experiment, the temperature of the liquid is increasing with time at each variation power. A higher variation power indicates a stronger microwaves ability to heat up the specimen. This is why the water is evaporated during experiment since continuous heat had been supplied.

Water has boiling point of 100˚C. From Figure 4.2, the temperature of the liquid is at a constant of 90˚C approaching to 100˚C. This is because, the temperature of the liquid will not rise until all the liquid change it state to gas while obtaining its boiling point [28]. [28] added, some water molecules can obtain sufficient kinetic energy to be released from the liquid to atmosphere when the water is heated at a constant pressure. Thus, this brings more heat energy needed to release the other molecules in form of gas state. This is the process where the temperatures of the liquids become lower than the boiling point of the water.

In order to increase the temperature of the water from constant temperature, the water molecules need to have sufficient energy to transform into gaseous state. Based on the phenomenon, the constant temperature of the liquid also affected the temperature of the electrode during the experiment. The liquid cannot supply enough heat to the electrode thus causes the temperature to stay constant.

4.3 Temperature Distribution in Various Liquids

Referring to the first objective, the aim is to determine the temperature distribution in various liquids. The temperature distribution of the electrode is recorded during the experiment with three types of different liquids. The liquids used are water, waste engine oils and also waste cooking oils. Three variation of power is applied which started with low, medium low and medium power. Table 4.3 shows the data recorded during the experiment with the time taken of 2, 6 and 8 minutes.

Table 4.3: Temperature of electrode in various liquid for 2 minutes.

Power/Liquid	Water	Engine oil	Cooking oil
Low	33.4˚C	36.3 ˚C	37.6 ˚C
Medium Low	37.9 ˚C	41.5 ˚C	50.2 ˚C
Medium	44.5 ˚C	46.8 ˚C	61.7 ˚C

Figure 4.3 shows the temperature distribution of electrode in various liquids for 2 minutes. At low microwave power, the temperature of the electrode in water, waste cooking oil and waste engine oil are near from each other values. While at medium low microwave power, the temperature values of electrode in water and waste engine oil shows a slightly difference values meanwhile an increase of temperature can be seen in waste cooking oil. The temperature of electrode in waste cooking oil at medium microwave power also shows that there is an absolute rise in the temperatures values compared to in water and waste engine oil. Water and waste engine oil shows very low temperature

difference at medium microwave power.

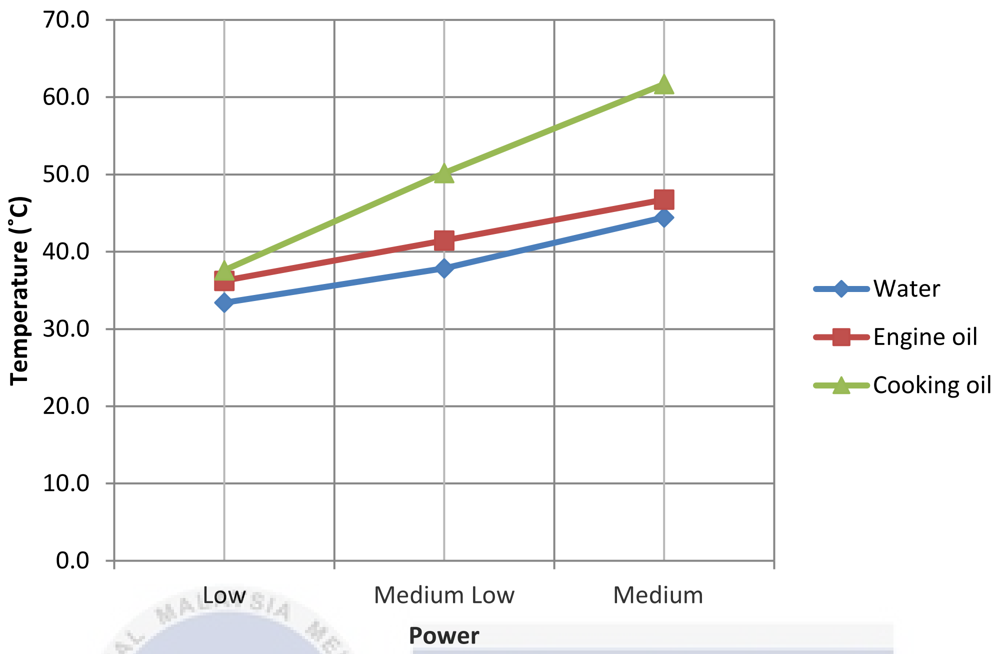

Figure 4.3: Temperature distribution in various liquids for 2 minutes.

Table 4.4: Temperature of electrode in various liquids for 6 minutes.

Power/Liquid	Water	Engine oil	Cooking oil
Low	42.9˚C	44.2˚C	58.5˚C
Medium Low	58.7˚C	71.4˚C	100.6˚C
Medium	73.8˚C	117.2˚C	132.3˚C

Figure 4.4 shows the temperature distribution of electrode in water, waste engine oil and waste cooking oil for time 6 minutes. Based on the graph, the temperature of electrode in water and waste engine oil are nearly similar at low microwave power while the temperature of electrode in waste cooking oil is slightly higher. For medium low microwave power, the temperatures of electrode in all type of liquids are increasing. However, at medium microwave power, the temperature of electrode in waste engine oil is

showing a sudden increase but does not overpass the temperature of electrode in waste cooking oil. The temperature of electrode in waste cooking oil is the highest compared to in water and waste engine oil for all microwave power.

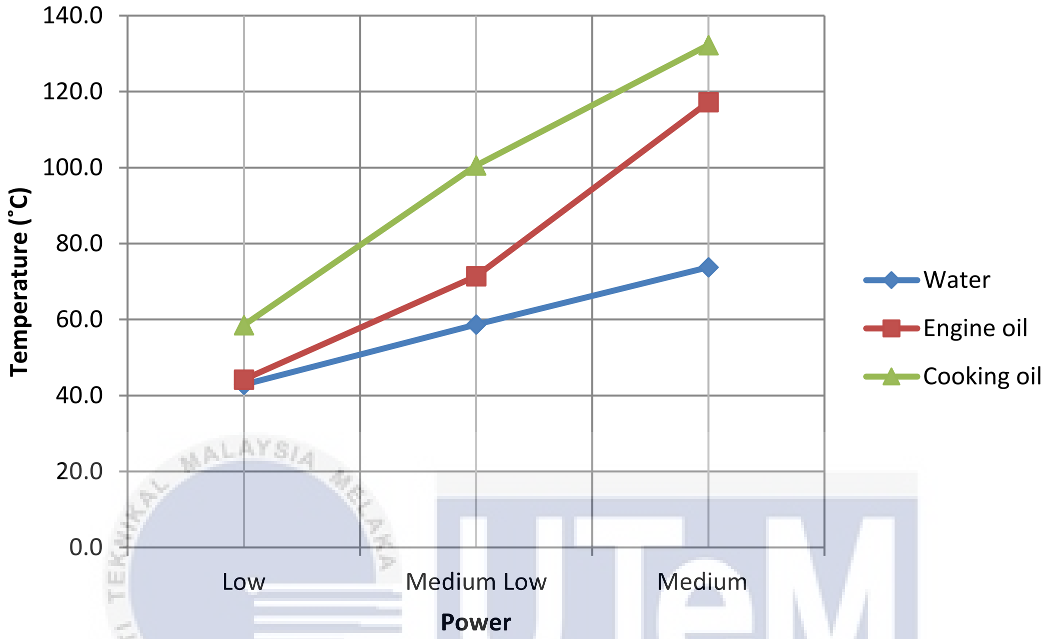

Figure 4.4: Temperature distribution in various liquids for 6 minutes.

Table 4.5: Temperature of electrode in various liquids for 10 minutes.

Power/Liquid	Water	Engine oil	Cooking oil
Low	50.5˚C	57.4˚C	80.7˚C
Medium Low	65.4˚C	103.4˚C	136.2˚C
Medium	72.7˚C	132.7˚C	179.2˚C

Figure 4.5 shows the temperature distribution of electrode in various liquids for 10 minutes. The temperature of electrode in water and waste engine oil at low microwave temperature displays a small temperature difference compared to in waste cooking oil. At medium low and medium microwave power, the temperature of electrode in all types of liquids shows an increasing value of temperature. The highest electrode temperature in all

microwave power is in waste cooking oil.

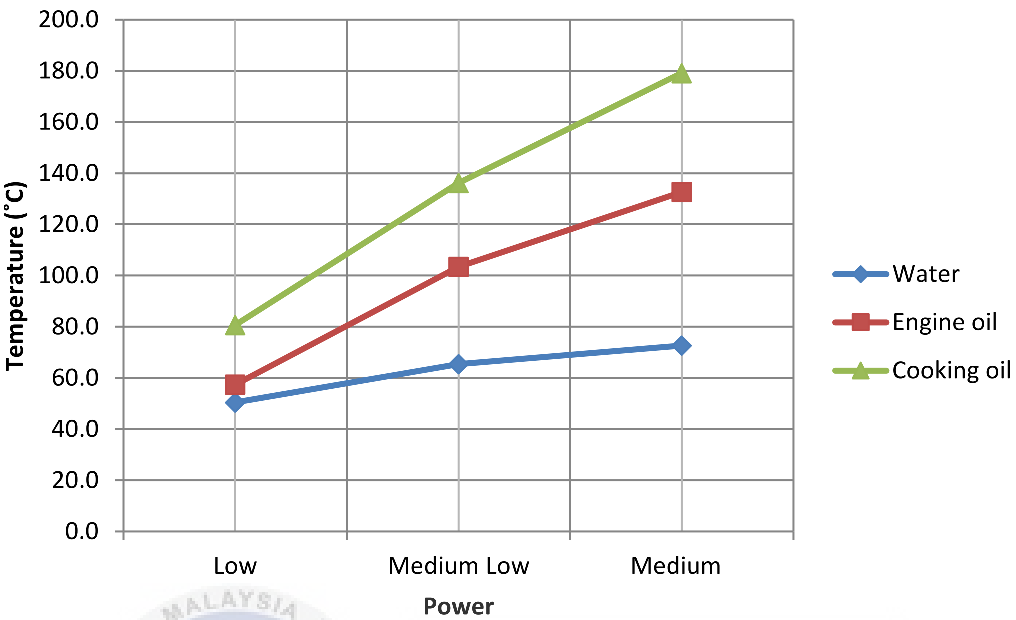

Figure 4.5: Temperature distribution in various liquids for 10 min.

The temperature of the electrode in waste cooking oil is the highest in every variation power given 2, 6 and 10 minutes. This is because of specific heat capacity and the thermal conductivity of the waste cooking oil. Waste cooking oil has the specific heat capacity ranging from 1.29- 5.26 J/g.K for the temperature ranging from 10 to 80˚C [29]. In the experiment, the specific heat capacity of waste cooking oil is 1.861 J/g.K. Meanwhile, for water and waste engine oil, the specific heat capacity is 2.944 J/g,K and 4.186 J/g.K respectively. Thermal conductivity of water, waste engine oil and waste cooking oil are 0.6 W/m.K, 0.145 W/m.K and 0.1721 W/m.K respectively.

Specific heat capacity is the amount of heat energy required to raise the temperature of a substance per unit of mass. According to [30], the transfer of heat energy more efficiently can be achieved by the oils which has the larger thermal conductivity. However, water incapable of transferring more heat energy because of the presence of evaporation process during the experiment. For a given amount of heat absorption, oils with a larger value of specific heat capacity will requires a smaller temperature rise. Comparing to all types of liquids, waste cooking oils which have lowest value of specific heat capacity are capable in rising the liquid temperature easily since it requires less heat to raise. In the experiment, the temperature of the electrode is affected by the temperature of the liquids as the liquids conducted heat to the electrode by convection process.

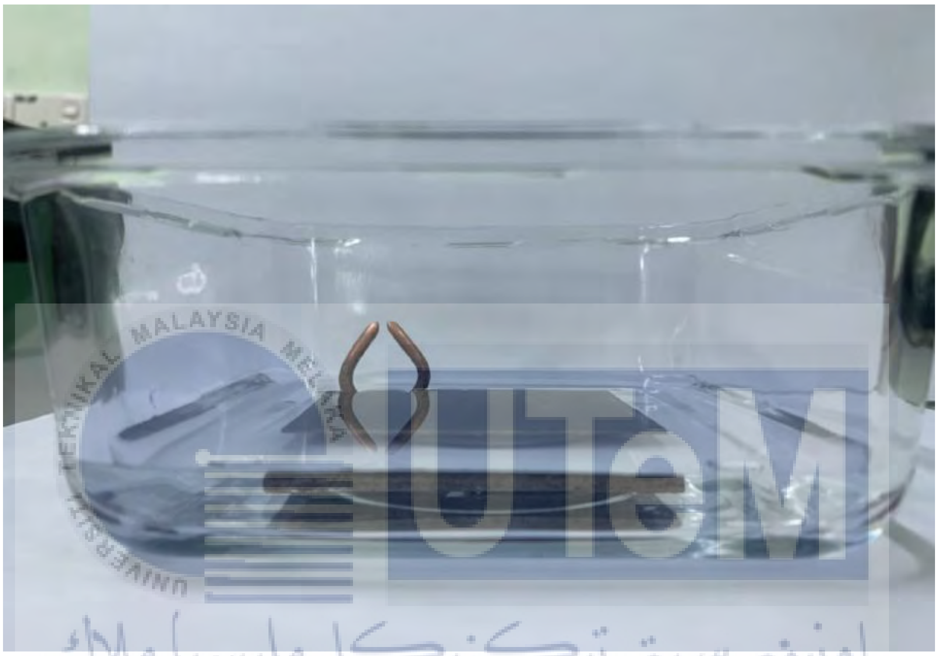

Figure 4.6: The electrode and water liquid after the experiment.

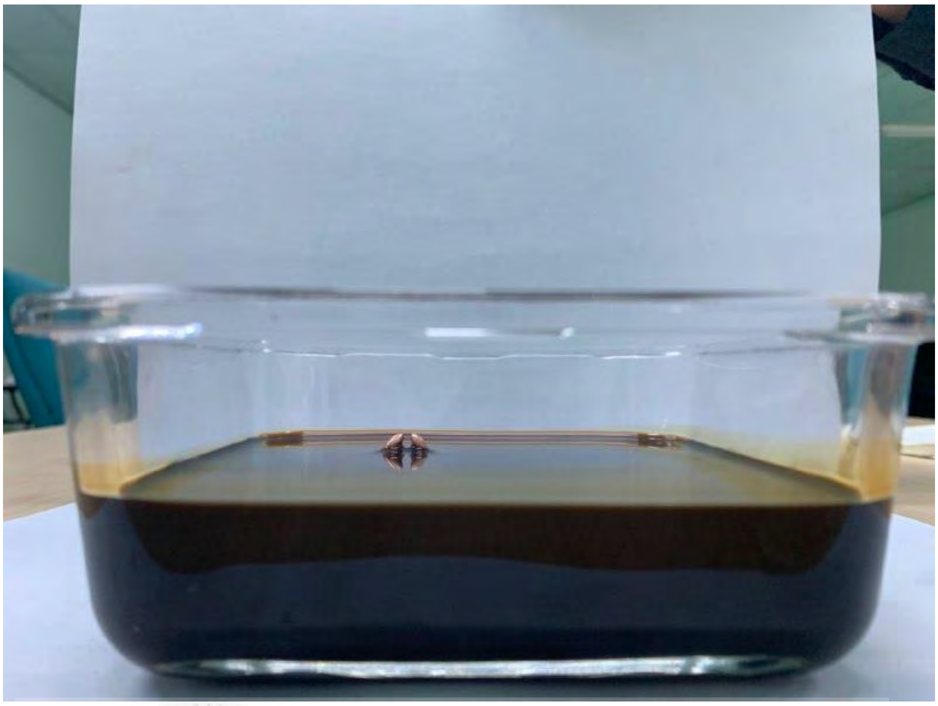

Figure 4.7: The electrode and waste engine oil liquid after the experiment.

Figure 4.8: The electrode and waste cooking oil liquid after the experiment.

4.4 Temperature distribution between liquids and electrode in water, waste engine oil and waste cooking oil

The result and discussion of temperature distribution between liquids and electrode in water, waste engine oil and waste cooking oil were based on the first objectives. The data of electrode and liquid temperature distribution in water, waste cooking oil and waste engine oils are recorded in Table 6. The time taken for the experiment is 2,4,6,8 and 10 minutes. However, the discussion of temperature distribution is discussed only at time 6 minutes as same results also occurs at time 2, 4, 8 and 10 minutes.

Table 4.6: The temperature of liquid and electrode in water for 6 minutes

Power/Temperature	Electrode	Liquid
Low	42.9	57.3
Medium Low	58.7	82.2
Medium	73.8	90.9

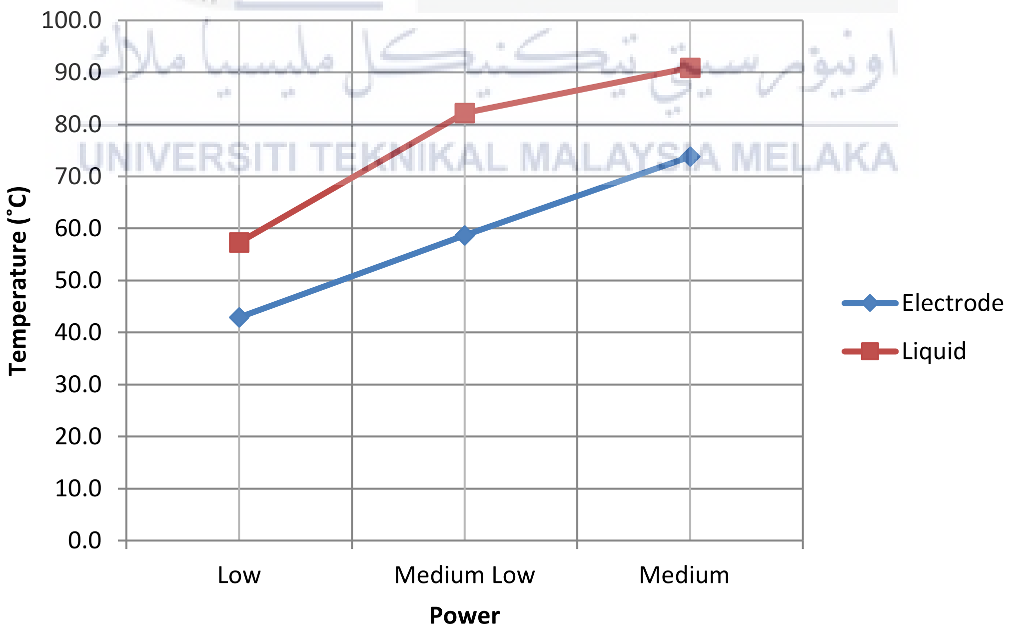

Figure 4.9: Temperature distribution between liquid and electrode in water for 6 minutes

Figure 4.9 shows the temperature distribution between liquid and electrode in water for 6 minutes. The temperature of the liquids is higher than the temperature of the electrode in low, medium low and medium microwave power. The temperature difference between electrode and liquid also can be observed referring to Figure 4.9. The temperature difference at each power can be seen constantly increasing at time 6 minutes.

Table 4.7: The temperature of liquid and electrode in waste engine oil for 6 minutes

Power/Temperature	Electrode	Liquid
Low	44.2	54.4
Medium Low	71.4	89.8
Medium	117.2	136.1

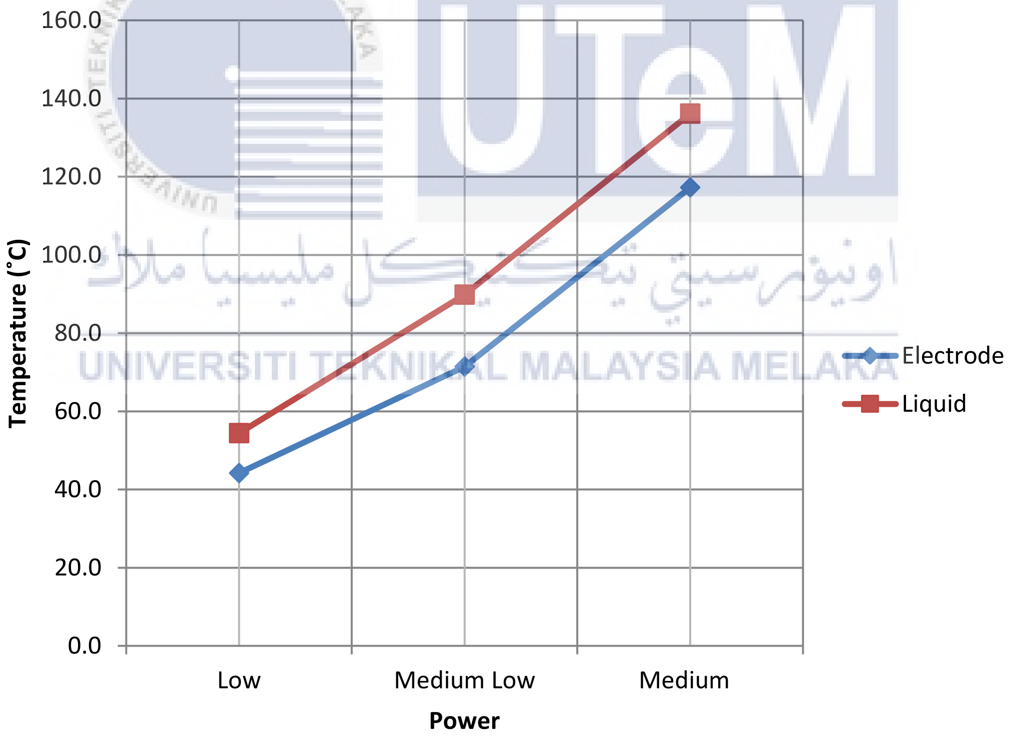

Figure 4.10: Temperature distribution between liquid and electrode in waste engine oil for 6 minutes.

The temperature distribution between liquid and electrode in waste engine oil for 6 minutes can be seen in Figure 4.10. Both temperature of liquid and electrode started at low temperature during low microwave power. However, at power of medium low and medium, the temperature of the liquid and the electrode are increasing respectively with slightly high temperatures compared to low microwave power. The temperatures of the liquids also are higher compared to the temperature of the electrode in all microwave power. The temperature difference between liquid and electrode are in constant rate at all microwave power.

Table 4.8: The temperature of liquid and electrode in waste cooking oil for 6 minutes

Power/Temperature	Electrode	Liquid
Low	58.5	70.6
Medium Low	100.6	132.6
Medium	132.3	177.6

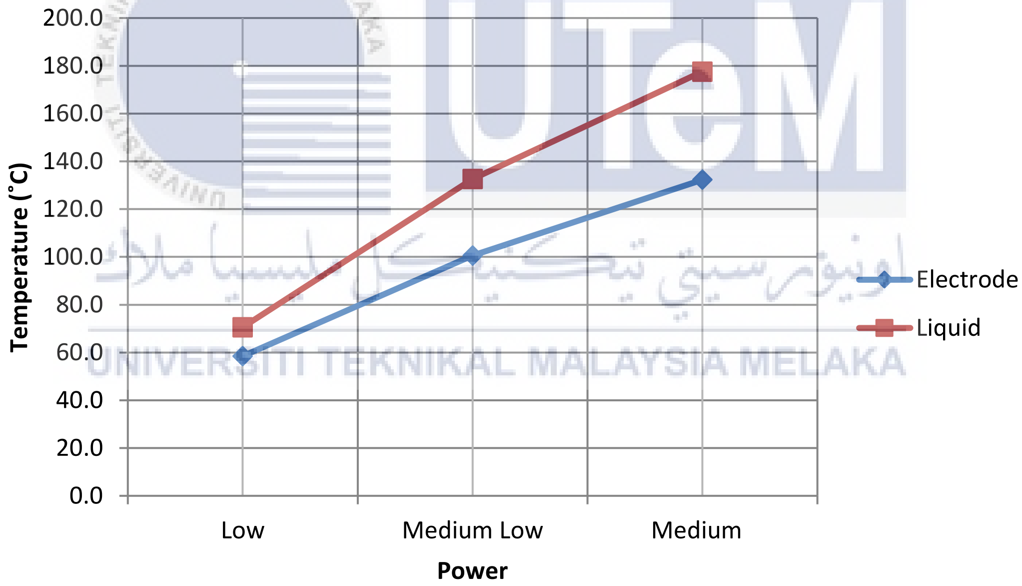

Figure 4.11: Temperature distribution between liquid and electrode in waste cooking oil for 6 minutes.

Figure 4.11 shows the temperature distribution between liquid and electrode in waste cooking oil for the time 6 minutes. At low microwave power, the temperature of liquid and the electrode are starting at small difference of temperatures. Meanwhile, a larger temperature difference between the liquid and the electrode temperatures can be observed at medium low and medium microwave power. Besides, both temperature difference of the liquid and the electrode at medium low and medium microwave power display a consistent increase of temperature at time 6 minutes.

As stated in the discussion of temperature distribution in various liquids, the thermal conductivity of water, waste cooking oil and waste engine oil are 0.6 W/m.K, 0.145 W/m.K and 0.1721 W/m.K respectively. The thermal conductivity for copper electrode is 397.48 W/m.K. Thermal conductivity is the heat transfer rate by conduction process within the material area especially when there is a temperature gradient escape perpendicular to the area. Theoretically, material that has high value of thermal conductivity will have a higher temperature compared to the material that has low value of thermal conductivity. In the experiment, the temperature of the electrode has the lowest value of temperature distribution despite of it has a high value of thermal conductivity. The temperature of the electrode has the lowest temperature distribution compared to the temperature of the liquids; water, waste engine oil and waste cooking oil.

At medium microwave power, the temperature of the electrode is the highest in waste cooking oil compared to waste engine oil and water. However, the temperature of waste cooking oil is higher than the temperature of the electrode. The phenomenon is due to a high absorption of heat energy in waste cooking oil. Similar to waste engine oil and water cases, the temperature of the liquid is higher than the temperature of the electrode due to high absorption of heat energy in the liquid. Thus, it is believe that the cooling effect affected the result of the experiment. Comparing the cooling effect for all types of the liquids, cooking oil has the lowest cooling effect between water and waste engine oil. This is because the temperature of the electrode is the highest in waste cooking oil which indicates a less effective cooling effect of the liquid during the process. Despite in water cases, water has an effective cooling effect as it absorb heat energy of the electrode without resulting in high temperatures outcomes.

4.5 Temperature difference between in liquid and in air cases.

The second objective of the experiment refers to generation of plasma in liquid. The experiment is conducted in different medium which is in waste oils and in atmospheric pressure (air). The same length and configuration of electrode is used during conducting the experiment. Table 4.9 display the data recorded regarding the temperature difference of the electrode between in liquid and in air cases.

Table 4.9: The temperature difference of electrode in waste oils and in air

Power / Time (min)		2	4	6	Plasma
Low	Engine oil	36.3	40.3	44.2	-
	Cooking oil	37.6	47.6	58.5	-
	Air	55.0	68.0	73.9	X
Medium Low	Engine oil	41.5	58.0	71.4	-
	Cooking oil	50.2	77.2	100.6	-
	Air	69.3	103.2	130.8	X
Medium	Engine oil	46.8	78.6	117.2	-
	Cooking oil	61.7	98.1	132.3	-
	Air	103.4	160.5	189.0	X

X = Plasma is present - = Plasma is not present

Figure 4.12.4.13 and 4.14 shows the temperature difference of the electrode between the liquid and air cases in all medium power. In low microwave power, the temperatures of the electrode in waste engine oil and in waste cooking oil are showing a greater difference between the temperatures of electrode in air. Similar to medium low and medium microwave power cases, the electrode temperature in air shows a higher temperature compared to the electrode temperature in waste engine oil and waste cooking oil. From Table 9, the air cases produces plasma at every power stages compared to waste engine oil and waste cooking oil cases. The waste engine oil and waste cooking oil cases shows no plasma is generated at any power stages at all.

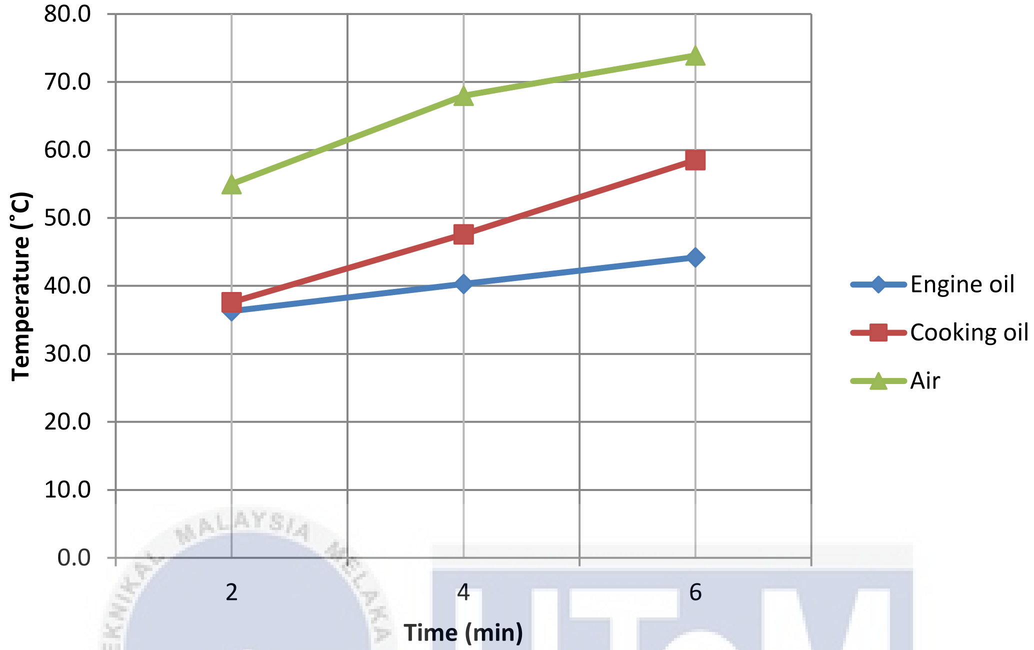

Figure 4.12: Temperature difference between liquid and air cases in low power.

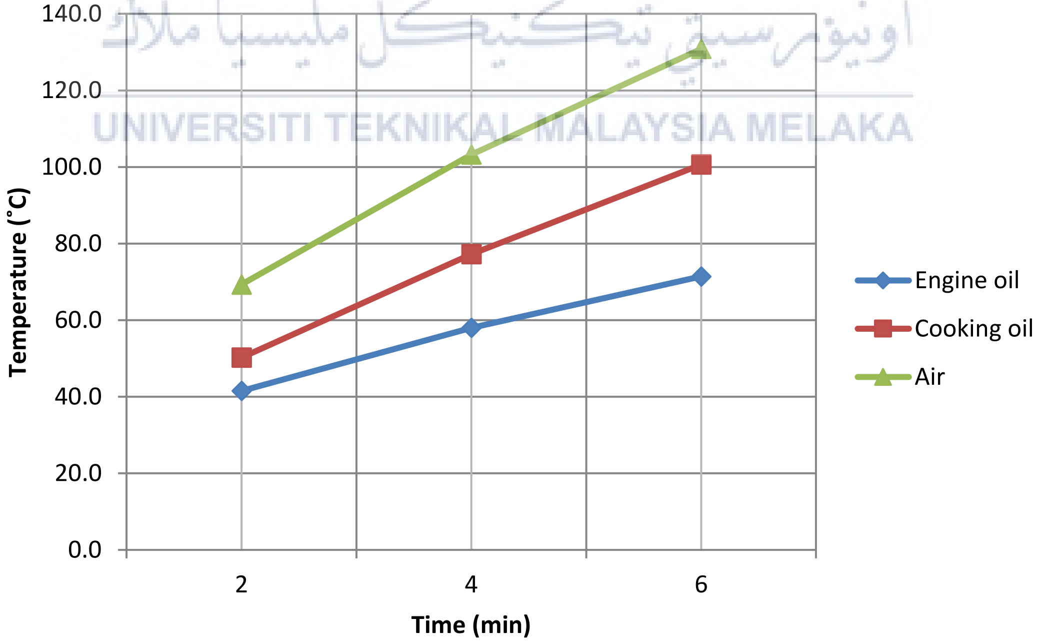

Figure 4.13: Temperature difference between liquid and air cases in medium low power

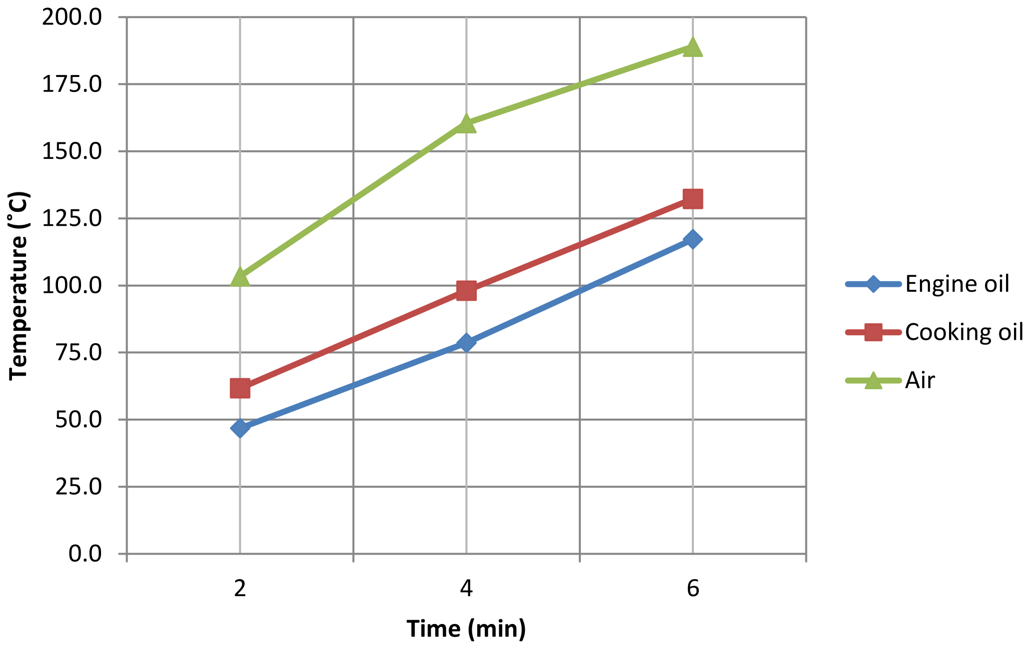

Figure 4.14: Temperature difference between liquid and air cases in medium power.

The temperature of the electrode is the highest in air cases compared to the liquid cases. The reason is because the presence of the plasma during the experiment. Plasma generated an amount of heat energy later transferred into the electrode. Meanwhile, the attempt to generate plasma in liquid was unsuccessful during the experiment. This is because according to [4], plasma cannot be generated when there is a presence of molecular structure which has electrical dipole moment because the liquid will absorbs the microwaves energy. The example of liquids that contains molecular structure with electrical dipole moment is water and alcohol. It is also believed that waste cooking oil and waste engine oil contains molecular structure with electrical dipole moment because plasma cannot be generated in both liquids including in water.

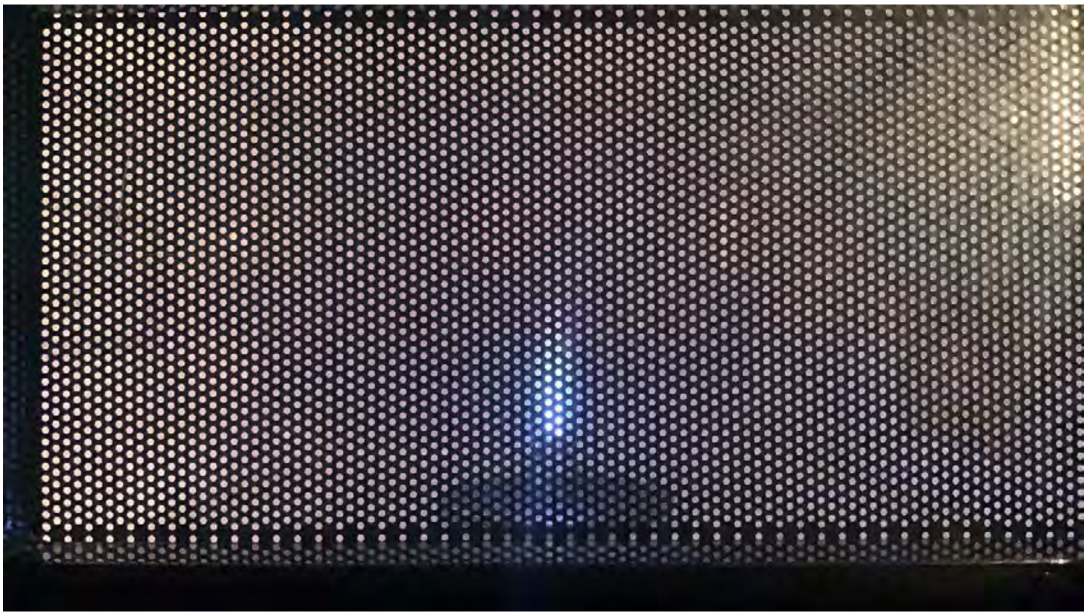

Figure 4.15: Plasma generation in air

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, the method of generating plasma can be done in liquid and air which the temperature distribution is investigated during the study. Through literature review done, it is found that there are a lot of methods in generating plasma including the generation of plasma in microwave. Plasma can be useful in this current technology as it contributed various applications for each industry. The vital part of plasma in contributing to the application is its properties that contain high temperature of electrons. Through the experiment, plasma is generated through atmospheric pressure and in liquids. Plasma successfully can be generated in atmospheric pressure while the attempt in generating plasma in liquids is failed. The generation of plasma then is discussed by comparing the temperature distribution of the electrode between in atmospheric pressure and also in liquids. The temperature distribution of liquids and electrode in liquids medium also is discussed in comparing why plasma cannot be generated while same parameters have been given similar to generation of plasma in atmospheric pressure. Hence, it is found that the thermal properties of the liquids are affecting the result of the experiments. Plasma generation in water, waste engine oils and waste cooking oils are affected by the evaporation process, specific heat capacity, thermal conductivity and also the molecular structure of the liquids. Comparing the thermal properties of air with water, waste engine oil and waste cooking oil, air or atmospheric pressure provide a lower value of those properties. This results in a successful generation of plasma in atmospheric pressure.

5.2 Recommendation

In further study, plasma generation in liquid can be done in a vacuum condition. Plasma generation also can be done once the reactor vessel is subjected to inert gases as the catalyst for plasma formation. The study on plasma temperature and also the electrode temperature can be done during the generation of plasma. Next, the configuration of the electrode should be studied further to investigate its effect on plasma generation. It is suggested to study on multiple electrode configuration affect in generation of plasma.

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