UNIVERSTI TEKNIKAL MALAYSIA MELAKA
FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : **DIELECTRIC SENSING (CAPACITIVE) ON COOKING OIL'S TPC LEVEL**

Sesi Pengajian :

1	5	/	1	6

Saya ………..........**MUHAMMAD AMIR USAMAH BIN CHE MOOD** ………….......…………………..
(HURUF BESAR)

mengaku membenarkan Laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (√) :

☐ **SULIT*** *(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

☐ **TERHAD**** **(Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

☐ **TIDAK TERHAD**

Disahkan oleh:

___________________________ (TANDATANGAN PENULIS)

___________________________________ (COP DAN TANDATANGAN PENYELIA)

Tarikh: ………………………..

Tarikh: ………………………..

DIELECTRIC SENSING (CAPACITIVE) ON COOKING OIL'S TPC LEVEL

MUHAMMAD AMIR USAMAH BIN CHE MOOD

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

"I hereby declare that the work in this project is my own except for summaries and quotations which have been duly acknowledge."

Signature : ....

Author : MUHAMMAD AMIR USAMAH BIN CHE MOOD

Date : 15 JUNE 2016

"I acknowledge that I have read this report and in my opinion this report is sufficient in term of scope and quality for the award of Bachelor of Electronic Engineering (Industrial Electronics/ Computer Engineering/ Electronic Telecommunication/ Wireless Communication)* with Honours."

Signature : ....

Supervisor's Name : KHAIRUN NISA BT. KHAMIL

Date : ....

DIELECTRIC SENSING (CAPACITIVE) ON COOKING OIL'S TPC LEVEL

MUHAMMAD AMIR USAMAH BIN CHE MOOD

This Report Is Submitted In Partial Of Requirements For The Bachelor Degree of Electronic Engineering (Industrial Electronic)

Faculty of Electronic Engineering and Computer Engineering

University Teknikal Malaysia Melaka

JUNE 2016

“I hereby declare that the work in this project is my own except for summaries and quotations which have been duly acknowledged.”

Signature : ....

Author : MUHAMMAD AMIR USAMAH BIN CHE MOOD

Date : 15 JUNE 2016

"I acknowledge that I have read this report and in my opinion this report is sufficient in term of scope and quality for the award of Bachelor of Electronic Engineering (Industrial Electronics/ Computer Engineering/ Electronic Telecommunication/ Wireless Communication)* with Honours."

Signature : ....

Supervisor's Name : KHAIRUN NISA BT. KHAMIL

Date : 15 JUNE 2016

ACKNOWLEDGEMENT

In preparing this thesis and finished this project, I dealt with many people and they have a great contribution towards my understanding and thoughts.

I would like to express my special thanks of gratitude to my supervisor for this final year project, Madam Khairun Nisa Bt. Khamil who gave me the golden opportunity to do this interesting research, for the guidance and encouragement upon completion on this project. Particularly, I would like to express my sincere appreciation to, Dr. Kok Swee Leong, who is willing to spend his precious time to give some ideas and suggestion towards this project.

My appreciation also goes to all my family who has been so accommodating and supporting me all these times. Thousand of thanks for their encouragement, love and emotional supports that they have given to me.

Furthermore, special appreciation dedicated to my members who were on same supervisor as me as their views, tips, supports, and assistance in various conditions are useful indeed. They are Chin Kah Yin, Lee Jian Dyer and Lee Hee Nian. Besides, my appreciation to all my housemates and classmates for their encouragement that they gave to me.

ABSTRACT

Total Polar Compound (TPC) is a chemical parameter which reflects the deterioration of the high temperature of cooking oil. The repeated use of cooking oil at high temperatures result in undesirable substances are generated, which may cause health problems. This project is to design a sensor based on capacitive (dielectric sensing) using interdigitated electrode structure in order to detect the TPC level of cooking oil obtained from the experiment using a probe to measure the electrical properties and related it to the TPC level of the oil samples. A total of 15 samples of 150 ml palm oil was heated at 150 up to 15 hours. For each one hour interval, one sample was moved out from the laboratory oven. The expected result determined the levels of TPC in cooking oils that are obtained from the experiments and relate it capacitance of the samples. The dielectric properties of oil samples were investigated in the frequency range of 0.1-10 kHz. The best frequency chosen gave the capacitance was increasing linearly with heated time. The results analysis of significant correlation between the electrical capacitance of the oil sample with TPC against heated time with R2 ranged from 0.805 to 0.852.

ABSTRAK

Jumah kompaun polar adalah parameter kimia yang mencerminkan kemerosotan minyak masak pada suhu yang tinggi. Penggunaan berulang minyak masak pada suhu yang tinggi menyebabkan bahan-bahan yang tidak diingini dihasilkan, yang boleh menyebabkan masalah kesihatan. Projek ini adalah untuk mereka bentuk sensor berdasarkan kapasitif (sensing dielektrik) menggunakan struktur elektrod interdigitated untuk mengesan tahap TPC minyak masak yang diperolehi daripada eksperimen menggunakan probe untuk mengukur sifat-sifat elektrik dan yang berkaitan ke tahap TPC sampel minyak. Sebanyak 15 sampel 150 minyak ml sawit dipanaskan pada 150 sehingga 15 jam. Bagi setiap selang satu jam, satu sampel telah dipindahkan ke luar dari ketuhar makmal. hasil yang diharapkan telah dipilih tahap TPC dalam minyak masak yang diperolehi dari eksperimen dan mengaitkannya dengan kapasitan sampel. Sifat-sifat dielektrik sampel minyak telah disiasat dalam julat frekuensi 0.1-10 kHz. Kekerapan terbaik yang dipilih memberikan kemuatan semakin meningkat secara linear dengan masa dipanaskan. Analisis keputusan hubungan yang signifikan antara kemuatan elektrik sampel minyak dengan TPC terhadap masa dipanaskan dengan R2 antara 0.805 hingga 0.852.

CONTENTS

LIST OF TABLE

LIST OF FIGURE

LIST OF ABREVIATION

TPC	Total Polar Compound
TDR	Time Domain Reflectometry
FLS	Free Line Sensing
EM	Electromagnetic Moisture
SM	Soil Moisture
FD	Frequency Domain
SOG	State of Ground
CPO	Crude Palm Oil
PCB	Printed Circuit Board
IDE	Interdigitated Electrode
SNR	Signal-to-Noise Ratio
TPM	Total Polar Meter
ADC	Analog-to-Digital

CHAPTER I

INTRODUCTION

1.0 Project Background

Total polar compound is a chemical parameter which describes the deterioration of the high temperature of cooking oil and is regarded to be one of the most important tests for evaluating degrading oils. This project is to design a sensor based on capacitive (dielectric sensing) in order to detect the TPC level of cooking oil.This study will determine the levels of TPC in cooking oils obtained from the experiment using a probe designed based on capacitive sensing to measure the electrical properties of the oil samples using the dielectric sensing method. The sensor is used to measure the electrical properties of the oil and related it to TPC level. The discrimination between different heated hours of oil samples were examined and the results were compared to their physico-chemical properties such as TPC's level and the capacitances for each of the heated samples. The expected result is succeeding in designing a prototype of sensing probe to measure the electrical capacitance of the oil samples. Besides, can determine the levels of TPC in cooking oils that are obtained from the experiments and relate it capacitance of the samples.

In the next section, we will have a view of the problem statement, objective of study, scope of work, significant of study and thesis organization.

1.1 Problem Statement

Nowadays, many people do not concerned about health. Usually, they just think about saving their money and not the future. In this case, the repeated usage of the common frying oil at high temperature can cause the health problems. The unwanted substances are generated when the oil is used repeatedly at high temperature. It has been proven hazardous due to the degradation process by chemical reactions that lead to changes in the quality of the oil. Many projects were conducted to check the total polar compound in the oil and most of them were successful. However, many of the criteria should be emphasized especially on the cost of the product. The projects those were conducted before, mostly high cost such as for the TPC meter to check the total polar compound in the oil.

1.2 Objective of Study

The objectives of this project are :

a) To design a sensing probe, which can measure the electrical capacitances of the oil samples.

b) Analyzed the electrical properties by correlated it with the sample TPC's level.

1.3 Scope of Work

The scope of this project:

a) Used of dielectric sensing (capacitive) to detect the TPC level of cooking oils.

b) Only cooking oils will be used in this project.

c) Capacitance sensor is used to detect the TPC level of cooking oils.

d) Three brands of oil, and each of the oils was separate into five samples of 150ml each; 3 hours heated, 6 hours heated, 9 hours heated, 12 hours heated, and 15 hours heated.

e) All measurements were taken at a constant temperature 40-45.

f) The TPC level received from the TPC meter and compare with the reading from the sensing probe for each heated samples.

1.4 Significant of Study

This project is to develop a sensor that is good potential for a simple and inexpensive way of determining the quality of the cooking oil. Besides, the sensor also is easy to fabricate and do not take much time on doing that. The purpose of using the dielectric sensing method is because the data analysis is simple and the sensor also highly resistant to contaminants. Besides, the sensor can be brought all along as it is portable and small in size. Thus, this project will help the people to be aware of the quality of the frying oil whether the oil still can be used or should change with new oil.

1.5 Thesis of Organization

This report contain of five chapters. The summary of each chapter will be explained as follows:

Chapter 1 will described about the introduction of the effect of the repeated usage of frying oil at high temperature. It also discusses the problem statement of the project to be carried out, the objectives of the project, scope of work, significant of study and thesis organization.

Chapter 2 of the dissertation as includes a literature review which related to the project as per referred to previous studies and result obtained by researchers before. Various methods and approaches that related to this project have been discussed and reviewed.

Chapter 3 explains about a methodology in how the project is carried out in sequence. Details of the whole project flow are described and explanations are provided in this chapter.

Chapter 4 explains about the results and findings of the project. The simulation result is analyzed and studied.

Finally, chapter 5 present overall conclusions of the project. Some recommendations for future work are also presented in this chapter.

CHAPTER II

LITERATURE REVIEW

2.0 Overview

This chapter will discuss in details on the background research which is related to this project. A brief explanation about the perspective and methods used in the previous research is presented in this chapter. At the end of the chapter, there will be shown how this project is related to the available research and how it is different from the others.

2.1 Previous Research on Development and Evaluation of Sensors Based on Dielectric Sensing Method and Other Technique

Many methods Have been introduce in making a sensor to sense a sensitivity or changing in a certain criteria that need to be analyzed. From previous research, there are some methods and technique that can be related to this project, which is about dielectric sensing (capacitive) on cooking oil's total polar compound (TPC) level. Although from the previous research do not relate to the sensing of frying oil, but there are other criteria that can be accepted on doing this project.

Takeoka *et al* proposed the effect of heating on the frying oils based on characteristics and chemical composition. Repeatedly using of cooking will generate several unwanted substances which can cause health problems. Various chemical process occurred during frying such as hydrolysis, polymerization and thermal oxidation. The reason is because of the presence of water produced during frying the food, high temperature and oxygen lead to the breakdown of the food which badly effect the flavor and color. The observed effects range from weight loss, growth suppression, increased liver and kidney weights to cellular damage to the liver, thymus, epidydimides, and testes are happening when the highly oxidized and heated oils are fed to laboratory animals [15].

2.1.1 Sensor Based On Dielectric Sensing to Assess Cooking Oil's TPC Level

Mostly in homes, restaurants, cafeterias and food service, they consider when to change the frying oil is when there is too much of smoke, greased texture, the oil becoming dark and strong of odor. Nevertheless, all of these changes may only obviously when the oil totally unusable. They do not consider about total polar compound (TPC) of the frying oil is one of the proper indicator for evaluating the oil quality during frying. Khaled *et al* developed a sensor probe using impedance spectroscopy technique. The development of sensor is to assess the cooking oil quality. The research is totally with the measurement of impedance of the heated cooking oil with the TPC value of various frequencies. Planar-interdigitated electrodes are used for the sensor [1]

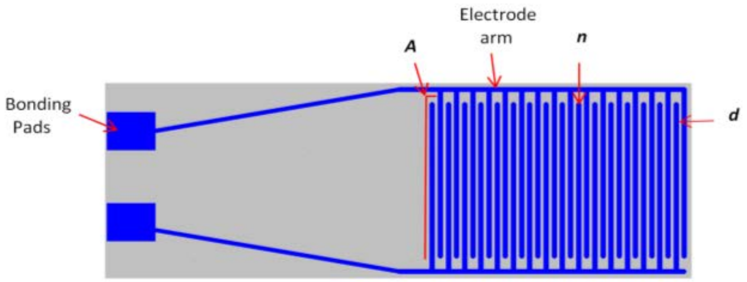


Figure 2.1.1 : Schematic of the impedance sensor

Khaled *et al* state that there are a lot of instruments and kits that can be used to determine oil degradation such as Vibro Viscometer, Testo 270 and Ebro FOM 310 but have some limitations with the current devices such the suitability for different type of oil and complex calibration. The capacitive sensor is designed based on interdigitated electrode (IDE). The variables of the sensor are including the electrodes number N, electrode width w, electrode spaces, and the electrode length L, with dimension of 41, 100 lm, 60 lm, and 8 mm, respectively. Every other electrode finger iselectrically connected together through a common electrode arm [3].

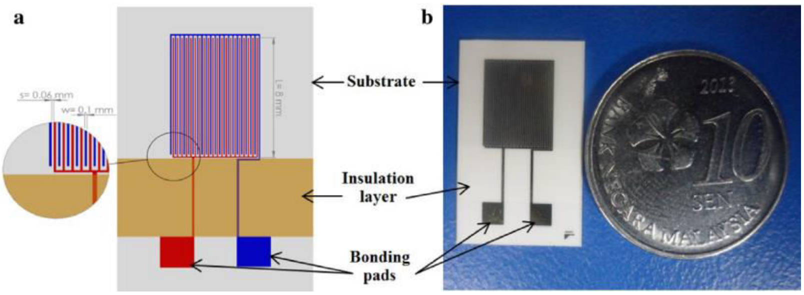


Figure 2.1.2 : (a) Illustration of capacitance sensor probe

(b) Prototype of the device

Hampikyan *et al* indicates that frying of foods nowadays is one of the famous ways that have been used either at home or restaurants. TPC determination is one of the best methods of monitoring the changes in quality of oils and fats during the process of frying. The amount of the TPC is determined by Testo 265,Testo Inc., USA on 200 frying oil samples that obtain from various cafeterias, restaurants, and canteens. The recurred use of cooking oils can cause high of TPC values. Various chemical reactions, such as hydrolysis or polymerization occur in the continuously and repeatedly used cooking oil at high temperatures from 150 up to 200°C. The hazardous compounds can give a harmful to consumer's health that occurred from the undesirable reactions [5].

2.1.2 Sensor Based On Dielectric Sensing to Assess Other Than Frying Oils

Marx *et al* state that any mechanical system that contain of rotating hardware, where there are contact between the moving parts, lubricant must be used to retain the integrity of the system. Micro-sensor is being developed to detect the oil degradation or contamination in the presence of additives such as water or other fluid in the system. Micro-sensor is based on Electrochemical Impedance Spectroscopy (EIS). Impedance measurements are made with a Gamry EIS 300 system and system impedance of an EG&G/Perkin Elmer by using Power Suite software. All experiments were performed using two electrodes set-up in a Faraday cage at room temperature. This sensor was put in the various oils, with and without additives, and the open circuit potential (OCP) was measured. It provides a non-destructive method for probing the nature and interactions of the oils and their additives [7].

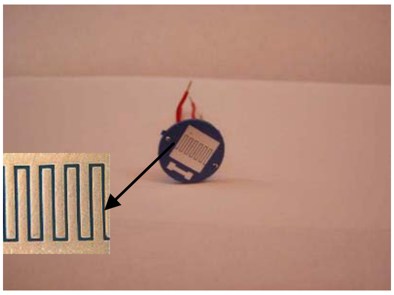


Figure 2.1.3 : The constructed sensor with leads connected

Markus *et al* presents dielectric sensors for determining soil and snow moisture. Dielectric methods are good for a precise measurement. For soil sensor (Electromagnetic Moisture), all of the developments are based on the determination of the dielectric properties of the material, which are largely affected by the moisture due to the high dielectric permittivity of water. The *TAUPE* sensor uses the Time Domain Reflectometry (TDR) Technique to drive the moisture of a material and the Free-Line-Sensing (FLS) technique measures the amplitude and phase changes of Electromagnetic Moisture (EM) waves on electrical transmission lines by the surrounding material. Sensors and techniques presented has been thoroughly tested in the field. The measurements were evaluated and the results were presented such as the soil moisture (SM) profiling method via access tubes with *LUMBRICUS* which uses Frequency Domain (FD) Technique that use capacitance to measure the dielectric permittivity of a surrounding medium and operate at a single measurement frequency. Besides, use of *TAUPE* sensors to determine the snow parameters such as density or liquid water content, and the characterization of the soil surface with the

State of Ground (SOG) sensor or large-scale SM interpretation with the FLS technique [8].

Figure 2.1.4 : Sensor mat for SOG detection

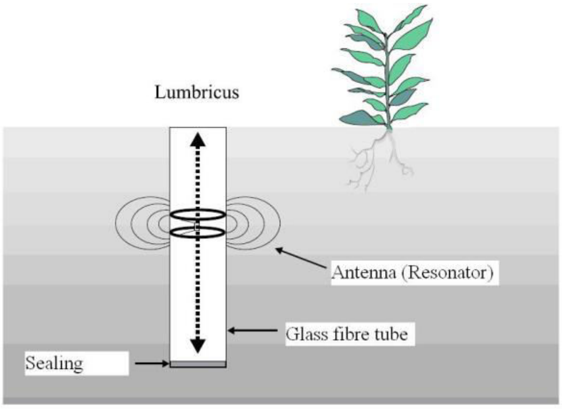


Figure 2.1.5 : 'LUMBRICUS' FD sensor

Fizura *et al* study about the effect of the contamination on capacitance values of crude palm oil (CPO). In order to monitor diesel contamination in crude palm oil, dielectric technique (capacitive sensing technique) is used. AD7746 capacitance to digital converter is the main idea which is the low cost of capacitive sensing. The two capacitive input channels of AD7746 are used for capacitive measurement. In this study, higher diesel contamination level in the CPO produced lower density mixture. It shows that the diesel pollution in CPO gives a significant effect on the capacitance values of the mixture [2].

Figure 2.1.6 :Head of sensor for AD7746 (Capacitance to Digital Converter)

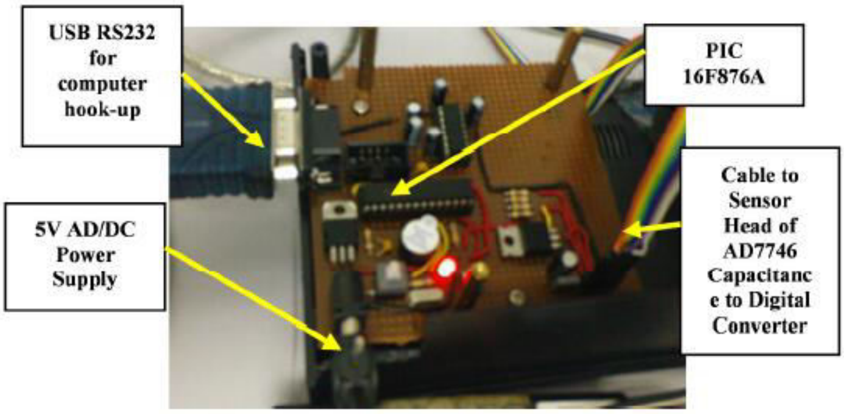


Figure 2.1.7 : AD7746 Capacitance to Digital Converter

Minasamudram *et al* proposed a simulation of a capacitive sensor which is used for wear metal analysis of industrial oils by using COMSOL Multiphysics. Oil analysis is used to detect and quantify the presence of wear metals and other contaminants in industrial oils which has focused on lubricant oil. It is a test that helps to determine the condition of a mechanical system's wear mode. The method is by detecting the change in capacitance between two plates of a capacitor because of wear metal contaminants in oil is present. Polarity of oil changes due to presence of conducting metal debris inside it, which in turn leads to change in dielectric constant of oil and can be detected using the capacitive sensors [8].

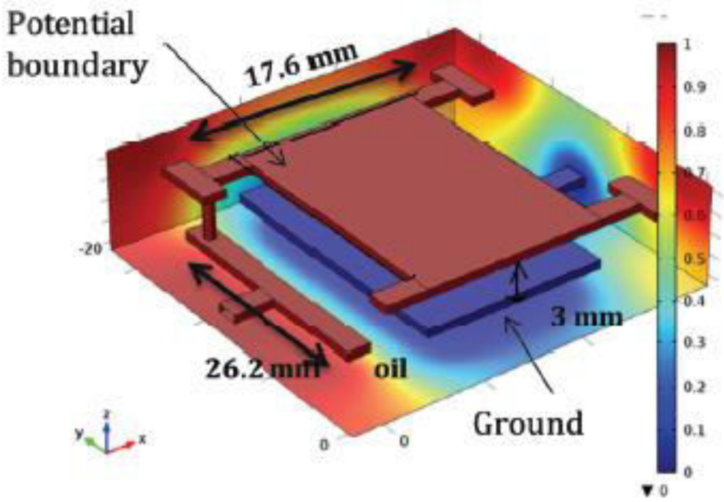


Figure 2.1.8 : Model of parallel plat capacitor

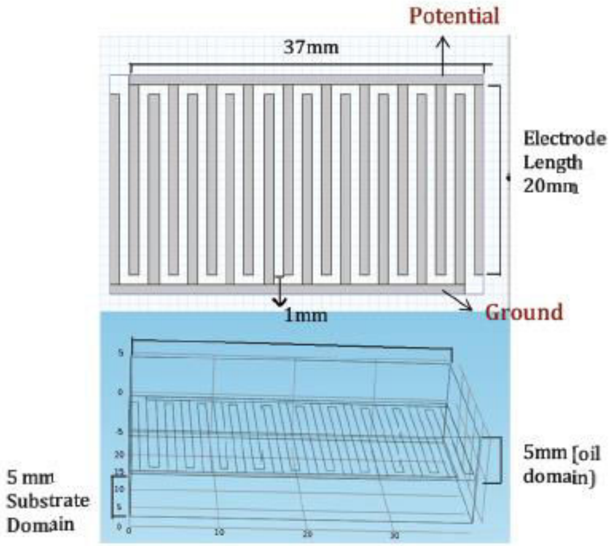


Figure 2.1.9 : Model of interdigitated capacitor

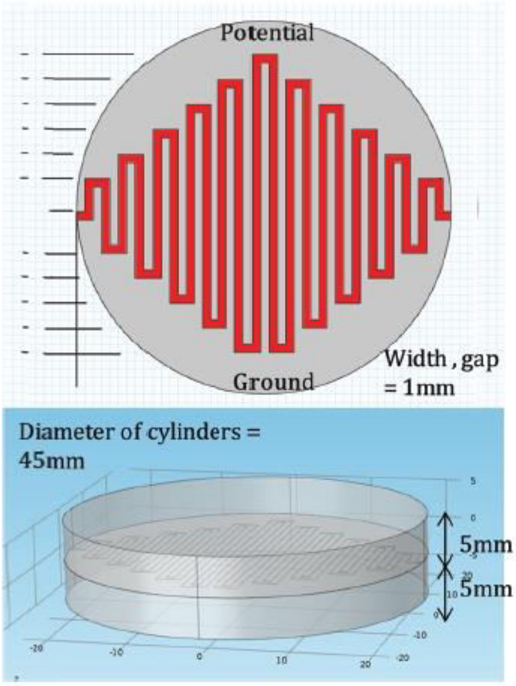


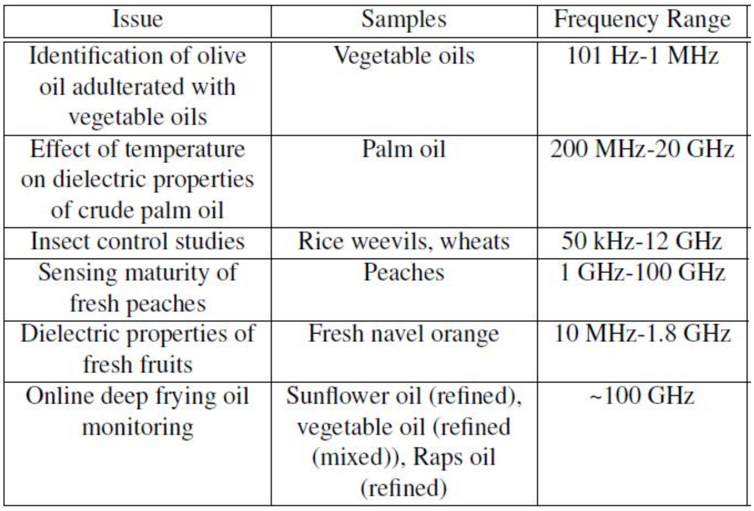
Figure 2.1.10 : Model of Meandering capacitor

Shah *et al* proposed a study of dielectric properties of vegetable oils such as corn oil and cotton seed oil. The study is about to use the vegetable oil as a new transformer oil based on the comparison results. The dielectric spectra exhibited a general plateau. As dielectric dispersion occurred, the dielectric spectra diminished and there is a slight monotonous decrease of έ values of vegetable oils with the increase in frequency [10].

Perez *et al* proposed a real time oil quality monitoring techniques in order to minimize the downtime, reduce maintenance costs and protect important industry assets. Lubricants impedance monitoring is an important tool to detect the state of the oils. The sensor is dedicated to monitors changes on the impedance of the sensing electrodes at high frequencies. The circuit provides an output voltage related to the dissipation factor. Therefore, it provides an indication of the oil condition as the dissipation factor tends to increase with the increasing presence of contaminants in lubrication oil. The proposed sensor shows three important characteristics: it is a very low cost design, it can be custom calibrated for a specific lubricant and it provides effective detection oil quality[4].

2.1.3 Dielectric Spectroscopy

Spectroscopy is the study of the interaction of electromagnetic radiation (EMR) with atoms and molecules to provide physical (structural) information, qualitative and quantitative chemical which is contained within the wavelength or frequency spectrum of the energy absorbed or emitted [13]. Dielectric spectroscopy is the study of the frequency dependence of dielectric parameters [13]. The key to the dielectric parameters are the dielectric constant and the dielectric loss factor. It is known as a fast, non-destructive and simple measuring technique where it provides the information about the dielectric response of materials to electromagnetic fields [13]. The following table showed the dielectric spectroscopy technology that has been used in previous studies for determining dielectric characteristics of respective samples:



Issue	Samples	Frequency Range
Identification of olive oil adulterated with vegetable oils	Vegetable oils	101 Hz-1 MHz
Effect of temperature on dielectric properties of crude palm oil	Palm oil	200 MHz-20 GHz
Insect control studies	Rice weevils, wheats	50 kHz-12 GHz
Sensing maturity of fresh peaches	Peaches	1 GHz-100 GHz
Dielectric properties of fresh fruits	Fresh navel orange	10 MHz-1.8 GHz
Online deep frying oil monitoring	Sunflower oil (refined), vegetable oil (refined (mixed)), Raps oil (refined)	~100 GHz

Table 2.1.3 : Past study on frequency range of variance sample

CHAPTER III

METHODOLOGY

3.0 Introduction

Figure 3.1 shows the flowchart of methodology and approach of the project. The project is divided into two parts which are hardware and software. For the software execution, it is more to the designing of the hardware by using Minitab for optimization (Taguchi Method) and COMSOL software to design the hardware (photomask of the probe). Meanwhile, hardware implementation involves the etching process of interdigitated electrode of PCB board and encapsulation of the copper etching. After these parts were complete, the next part was the testing of the hardware by doing some experiments. Each part of the project will be discussed in details in this chapter.

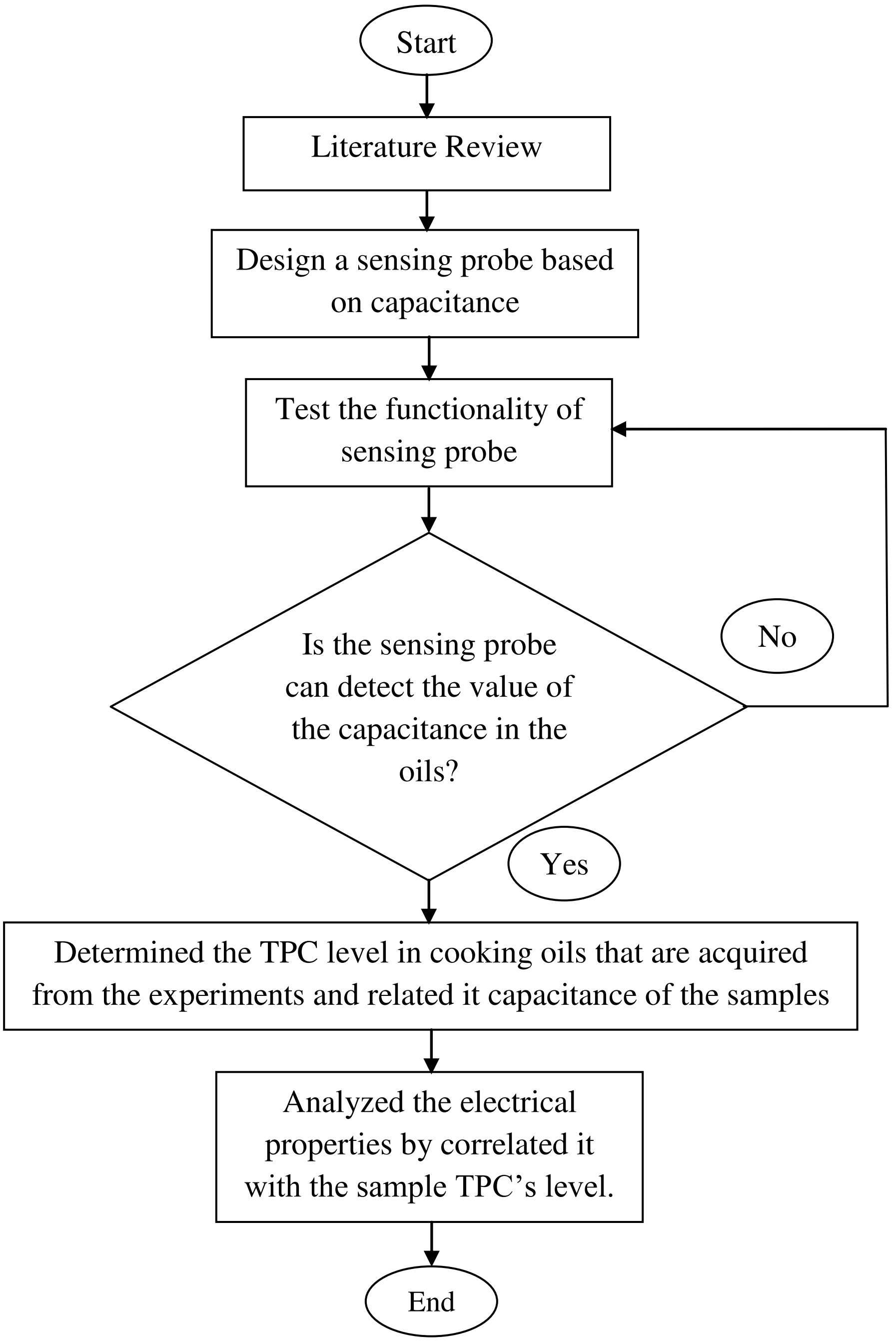


Figure 3 : Flow Chart of the Project

3.1 Optimization by Taguchi Method

Taguchi method is used to optimize the data of the interdigitated electrode (IDE). From the optimization, the best data to produce a better design is obtained. The capacitive sensor is designed based on the IDE. The sensor plan is designed by using the COMSOL software before photomask of the probe was formed. This step is to make sure the materials used to create the IDE are suitable in making the photomask of the probe. The data that obtained from the optimization by Taguchi Method are being used in the making of the design in COMSOL software. Data that is used in the Taguchi Method are obtained from previous studies and previous journal on the online website. From all the journal, the data for each measurement are recorded and doing some analysis before optimize by this method. The equation that is used to optimize each of the data is as follows:

The equation of the electrical capacitance [3]:

$$\boldsymbol{C = \frac{\varepsilon_0 \varepsilon_r A}{s.N - 1}}$$

$\boldsymbol{\varepsilon_r}$: Relative dielectric constant of oil 3.5

$\boldsymbol{\varepsilon_0}$: Permittivity of free space 8.854 pF/m

$\boldsymbol{S}$: Electrode space ($\boldsymbol{\mu m}$)

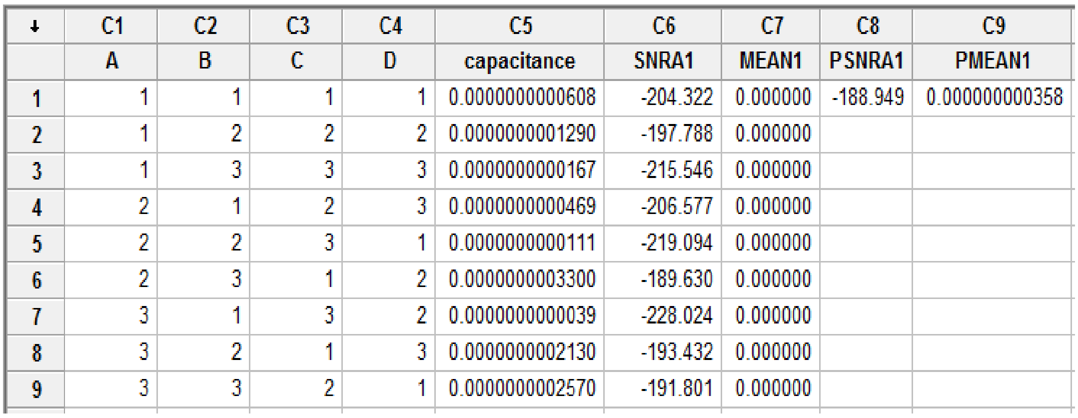
$\boldsymbol{N}$: Number of electrodes

$\boldsymbol{A}$: Area of the sensor

$$A = L \cdot (\omega \cdot N)$$

L : Length of electrode measured by (mm)

ω : Electrode width (μm)



↓	C1	C2	C3	C4	C5	C6	C7	C8	C9
	A	B	C	D	capacitance	SNRA1	MEAN1	PSNRA1	PMEAN1
1	1	1	1	1	0.0000000000608	-204.322	0.000000	-188.949	0.000000000358
2	1	2	2	2	0.0000000001290	-197.788	0.000000		
3	1	3	3	3	0.0000000000167	-215.546	0.000000		
4	2	1	2	3	0.0000000000469	-206.577	0.000000		
5	2	2	3	1	0.0000000000111	-219.094	0.000000		
6	2	3	1	2	0.0000000003300	-189.630	0.000000		
7	3	1	3	2	0.0000000000039	-228.024	0.000000		
8	3	2	1	3	0.0000000002130	-193.432	0.000000		
9	3	3	2	1	0.0000000002570	-191.801	0.000000		

Figure 3.1.1 : Table of optimization of Taguchi Method From Minitab Software

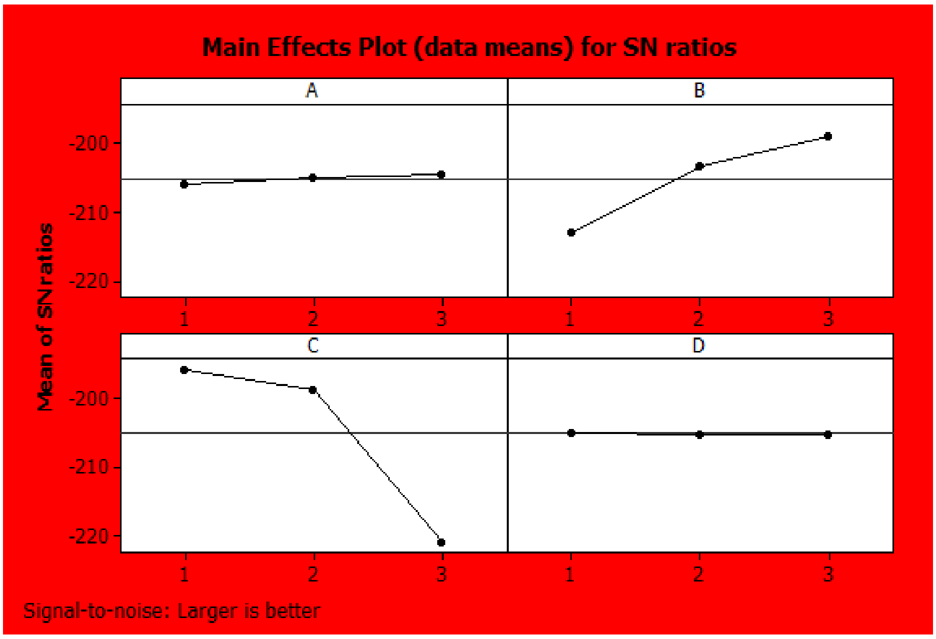


Figure 3.1.2 : Graph of main effect plot for SN ratios from Taguchi Method

Larger is better is using for the signal-to-noise ratio (SNR) because the result that should have obtained is to maximize the sensitivity of the sensor. The equation for the SNR larger is better is as follows:

$$S/N = -10 \times \log(\sum(\frac{1}{Y^2})/n)$$

The S/N ratio that obtained from the Taguchi Method is equal to -188.949 dB.

From the optimization, the value get from each measurement are as follow :

Electrode Length (L)	Electrode Width (W)	Electrode Space (s)	Number of teeth electrode (N)
13mm	0.5mm	0.5mm	30

Table 3.2 : Value of each measurement after optimization by Taguchi Method

3.2 Designation of Interdigitated Electrode (IDE)

The data obtained from the optimization of Taguchi method is then used to create a design by using COMSOL software. COMSOL is a simulation environment which designed with real-world applications in mind and as closely as possible, effects that are observed in reality. There are basely on an engineering or scientific context and need of Multiphysics. COMSOL is one of the software used for designation in two dimensions (2D) and also in three dimensions (3D). The result of Taguchi method is used in the designation of the IDE by using this software. For the first step, the design of the IDE on COMSOL is in 2D because it is much simpler than in 3D. Every measurement that has been optimized by Taguchi Method is used such as for the length and width of the electrode. All about the shape of the design is used of the rectangle. For the interdigitated electrodes, all of them are the same size in length and width. The distance between each of the electrodes are the same to another. The connection between the electrode to electrode is the electrode arm for positive and negative connection. After a complete design in 2D, the design is then converted to 3D by extrude. The thickness of the electrodes has to be specific and based on the previous journal, the thickness of 0.03mm is given. The thickness of the IDE is based on copper etching and also include of encapsulation of the copper to prevent from being rusted. The thickness of the Printed Circuit Board (PCB) is designed based on the size in the market, but specifically thinner than usual lab used to make sure the sensitivity of the sensor does not effect at all.

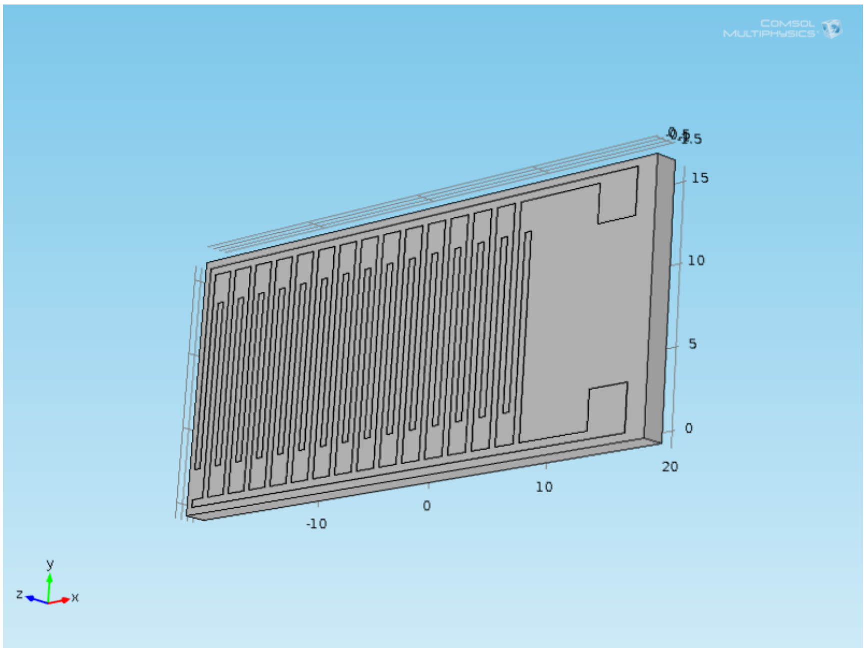


Figure 3.2 : IDE design sensor using COMSOL software

3.3 Designation of Capacitive Sensor (Hardware) and Methods

The materials used to develop the sensor were the standard copper used in fabrication student's lab. The mechanism of this sensor is that when the oil oxidatively and thermally breaks down during frying, there will be an increase in the number of polar molecules, which directly increases the dielectric constant. While an electric field is enforced across the IDEs interface, the dipole and molecular charges in the testing of the frying oil are forced out from their equilibrium locations, and those dipole charges laid up through the electrodes of the detector. Thus, as long as the frying oil yield polar molecules through different chemical reactions during frying the more charges will be laid up in the electrodes. The sensor based on dielectric sensing (capacitive) was designed in order to determine the electrical capacitance of the frying oil and compare to its TPC. The sensor, designed in COMSOL software then transferred to Coreldraw to be printed and fabricate it on printed circuit board (PCB).

Figure 3.3 : Sample of IDE sensor on PCB

3.3.1 Sample Experiment

The frying oil was bought from a Mydin Mall in Ayer Keroh, Melaka, Malaysia. Three different brands of oil were divided into5 samples each, into the beaker contained of 150 ml. All samples were heated in an oven at the temperature of 150°C.The samples were heated from 1 up to 15 hours, where one sample was taken out from the oven at each hour. After done heating, all of the samples were kept until reach approximately 40- 45 °C for further analyses.

3.3.2 Electrical Capacitance and Total Polar Compound (TPC)

The difference between each heated oil sample was analyzed by measuring its electrical capacitance and TPC. The electrical capacitance was measured using the custom built IDE sensor immersed into the oil samples. The sensor was connected to an LCR meter with Kelvin clip leads. The LCR meter has a frequency range from 10 Hz and to100 kHz. Before starting the measurements using the LCR meter, calibration was performed following the standard procedure of the instrument operation manual. Then, each of the samples was measured using a tester (Testo 270, InstruMart lnc, Germany) to get the value of TPC. Before TPC measurement, the oil tester was calibrated using the reference oil supplied with the device which has a TPC value of 6.5± 0.5%. The reference oil was heated to approximately 50for 10 min. Then, the oil tester was immersed in the reference oil and adjusted to get the reference value.

3.3.3 Sensor Calibration

The sensor was calibrated by using distilled water to get the dielectric constant of the distilled water in room temperature ranges from 70-80 using the equation of impedance (1):

$$Z = \frac{s(N-1)}{2\pi f \mathcal{E}_0 \mathcal{E}_r A} \qquad (1)$$

ε_r: Relative dielectric constant of distilled water in room temperature, 70-80

ε_r: Permittivity of free space, 8.854 pF/m

S : Electrode space

N: Number of electrodes

A: Area of the sensor

f: Frequency

The value of calibration of this sensor was approximately 70. If the sensor does not achieve the value of 70, a modification will take part in adjusting the parameter measurement of the sensor. Basically, the main parameter that considered the most was the space gap between the electrode. After that, the process of fabrication will take part again and calibration will do the same until get the calibration value of the sensor.

3.4 Experimental Procedure

Firstly, three (3) brand of oil samples were divided into 5 beakers each and each of it contain 150 ml. Each brand was heated directly in the microwave in the lab by 150℃for 15 hours. Each three hours, the oil sample will be removed from the microwave.

Figure 3.4.1 : Microwave used to heat the oil samples

After that, the oils were left to cool down until reached the temperature ranged from 40-45. Then, the value of TPC of the oils was measured by using Testo 270. After that, the electrical capacitance of the oil samples was measured using the IDE sensor designed by connecting directly to the LCR meter by Kelvin clip leads as shown in Fig. (3.5.2) . The IDE sensor was immersed in the oil samples and the measured value of capacitance were recorded for varying frequency adjusted at LCR meter ranged from 100-10kHz.

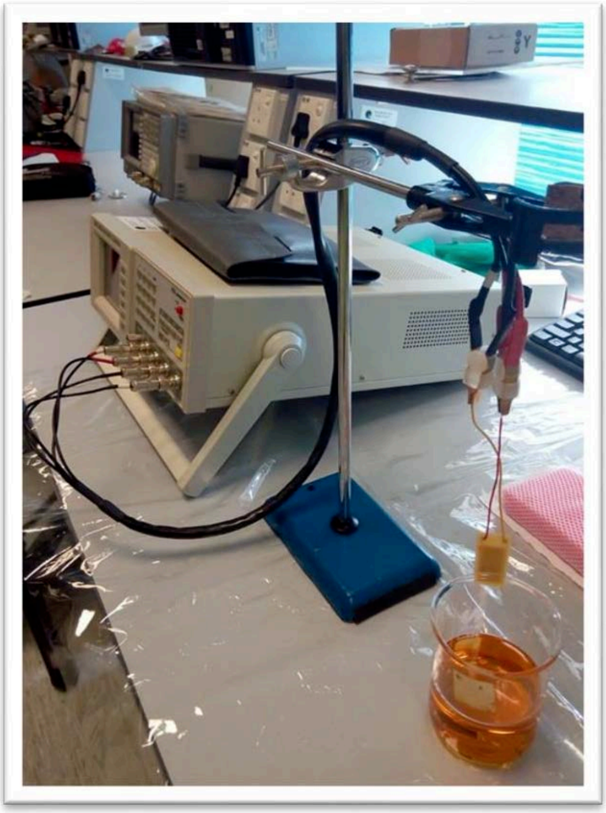


Figure 3.4.2 : The setup for measuring capacitance of oil samples

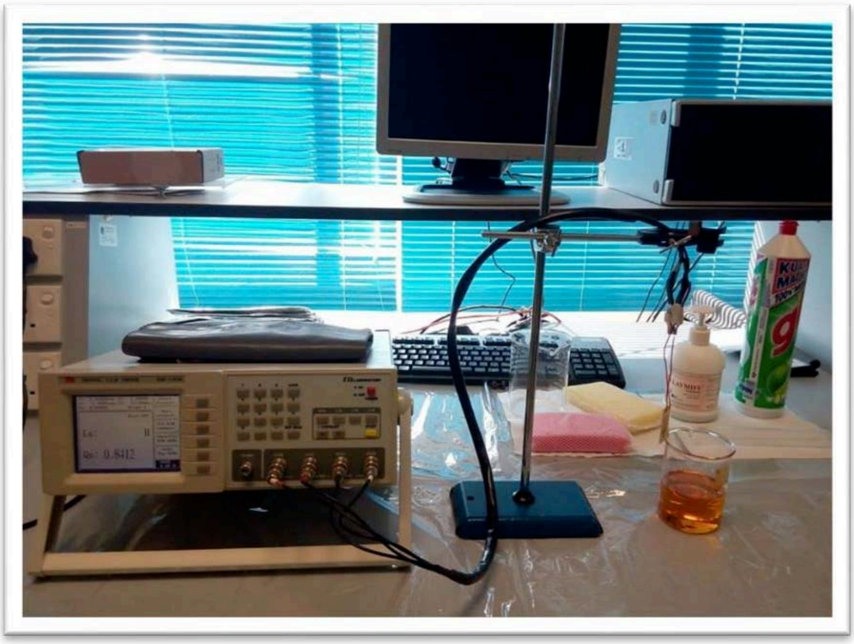


Figure 3.4.3 : Measured value from LCR meter

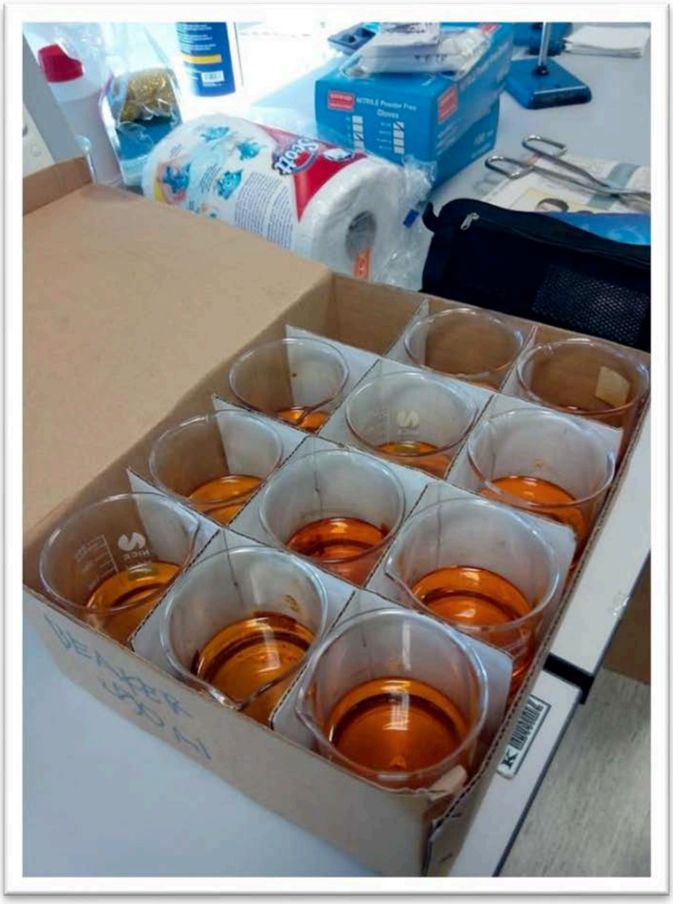


Figure 3.4.4 : Oil samples kept in the box after doing measurement

CHAPTER IV

RESULT AND DISCUSSION

4.0 Introduction

This chapter explains about the results achieved in the project and a few discussions on problem solving during the process and experiment of completing this project. All the data and analysis are based on a reading of TPC meter and the sensor of interdigitated electrode (IDE). The data collection of the IDE sensor was based on a reading of LCR meter which focussed on capacitance.

4.1 Results and Discussion

The value of capacitance measured each of three (3) hours heated were recorded and tabulated in the tables for variable frequency.

Heating Time (h)	Oil sample 1	Oil sample 2	Oil sample 3
		Capacitance Value (F)	
0	1.44E-12	1.20E-12	1.10E-12
3	1.45E-12	1.20E-12	1.10E-12
6	1.20E-12	1.10E-12	1.10E-12
9	1.10E-12	1.10E-12	1.10E-12
12	1.10E-12	1.10E-12	1.10E-12
15	1.10E-12	1.10E-12	1.10E-12

Table 4.1 : Value of capacitance of oil samples at 100Hz

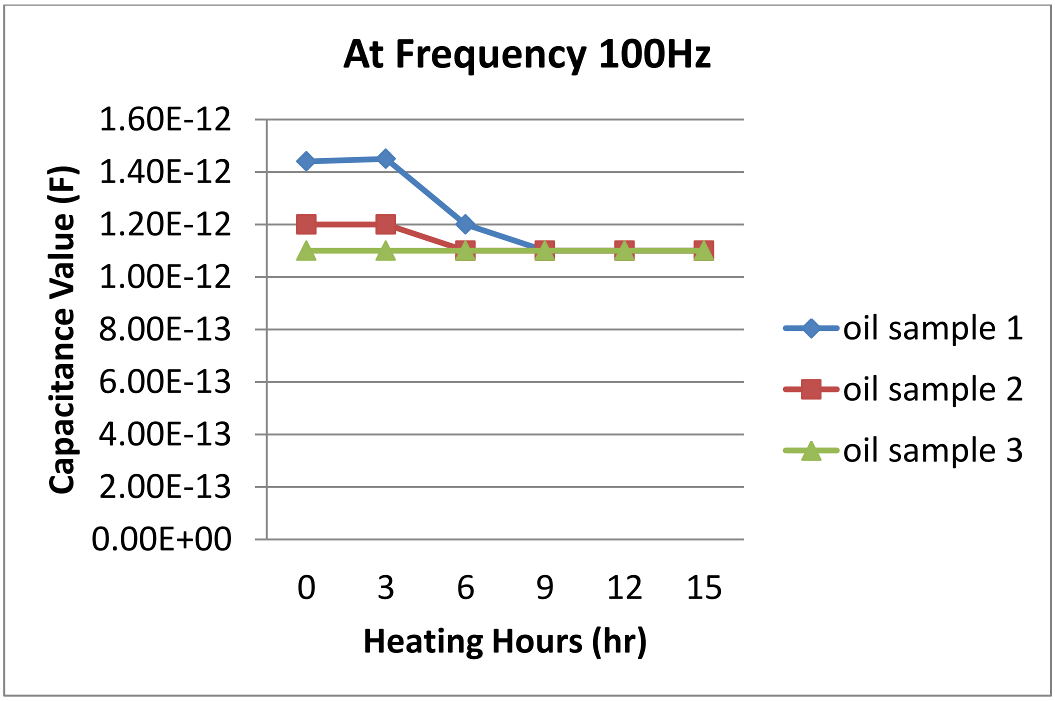


Figure 4.1 : Graph of capacitance value at 100 Hz

Heating Time (h)	Oil sample 1	Oil sample 2	Oil sample 3
		Capacitance Value (F)	
0	1.73E-12	1.73E-12	1.73E-12
3	1.74E-12	1.74E-12	1.73E-12
6	1.71E-12	1.74E-12	1.72E-12
9	1.75E-12	1.74E-12	1.72E-12
12	1.75E-12	1.75E-12	1.73E-12
15	1.75E-12	1.75E-12	1.74E-12

Table 4.2 : Value of capacitance for oil samples at frequency 1 kHz

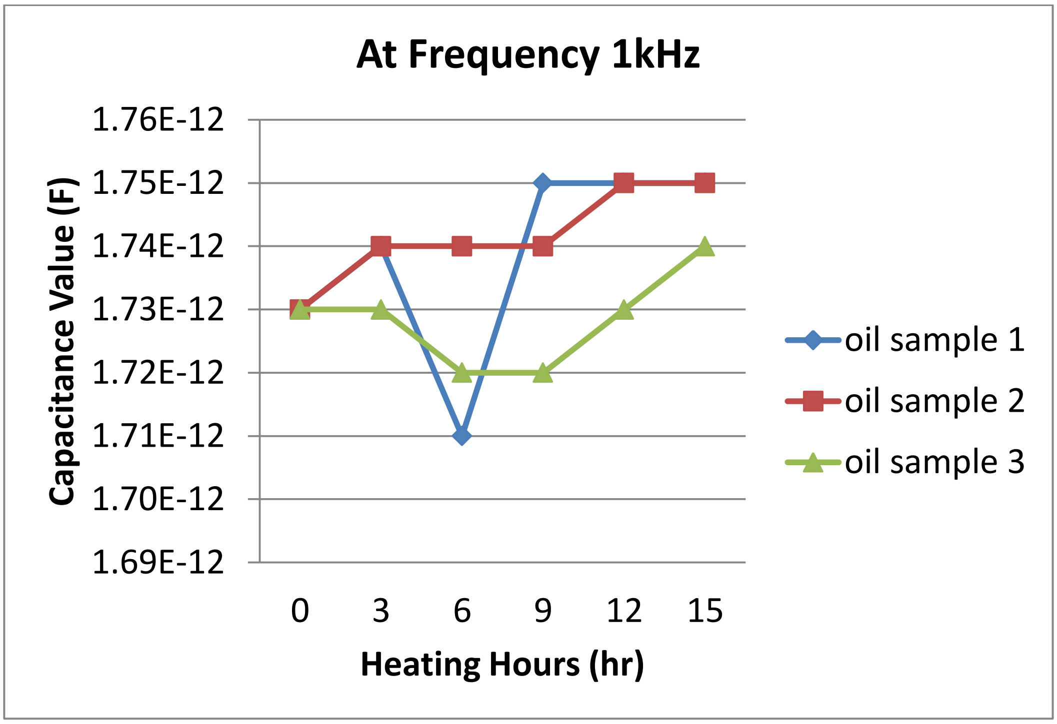


Figure 4.2 : Graph of capacitance value at frequency 1 kHz

Heating Time (h)	Oil sample 1	Oil sample 2	Oil sample 3
		Capacitance Value (F)	
0	2.09E-12	2.09E-12	2.06E-12
3	2.10E-12	2.10E-12	2.06E-12
6	2.02E-12	2.06E-12	2.07E-12
9	2.07E-12	2.07E-12	2.07E-12
12	2.07E-12	2.06E-12	2.07E-12
15	2.06E-12	2.06E-12	2.07E-12

Table 4.3 : Value of capacitance for oil samples at frequency 10 kHz

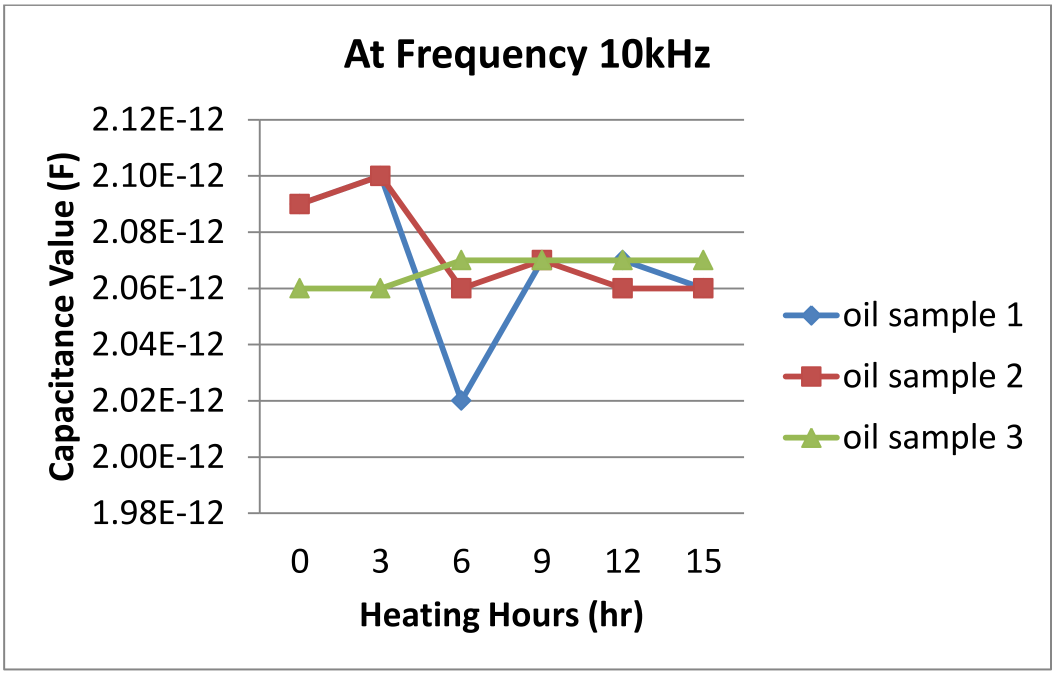


Figure 4.3 : Graph of capacitance value at frequency 10 kHz

Then, the value for TPC of sample oils were measured and tabulated in the table by classifying each of the samples by different heated time.

Heading Time (h)	Sample 1 TPC (%)	Sample 2 TPC (%)	Sample 3 TPC (%)
3	13	14	19
6	14.5	20	26
9	17	23.5	29.5
12	24	25	31
15	28	28.5	32

Table 4.4 : Value of capacitance for oil samples at frequency 10 kHz

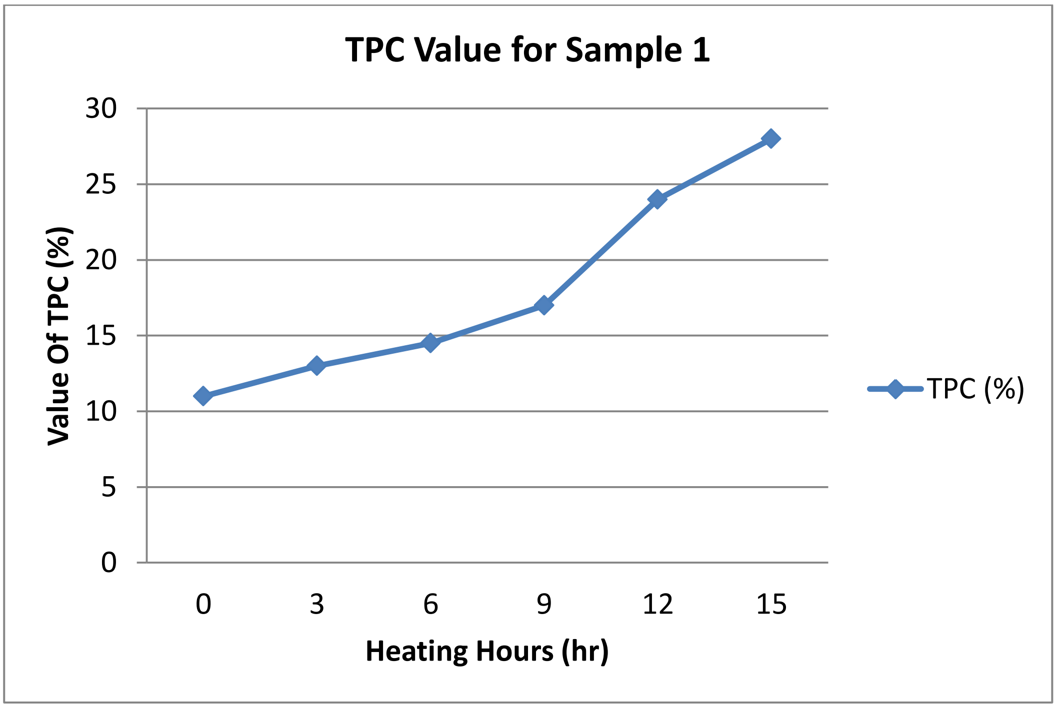


Figure 4.4 : Graph of TPC value for oil sample 1

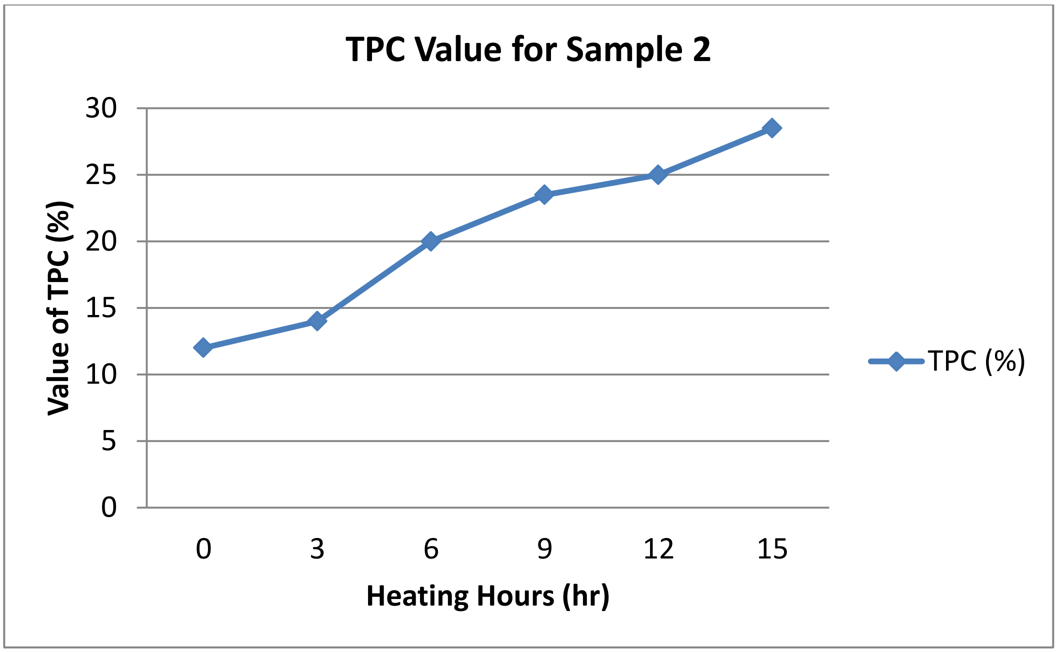


Figure 4.5 : Graph of TPC value for oil sample 2

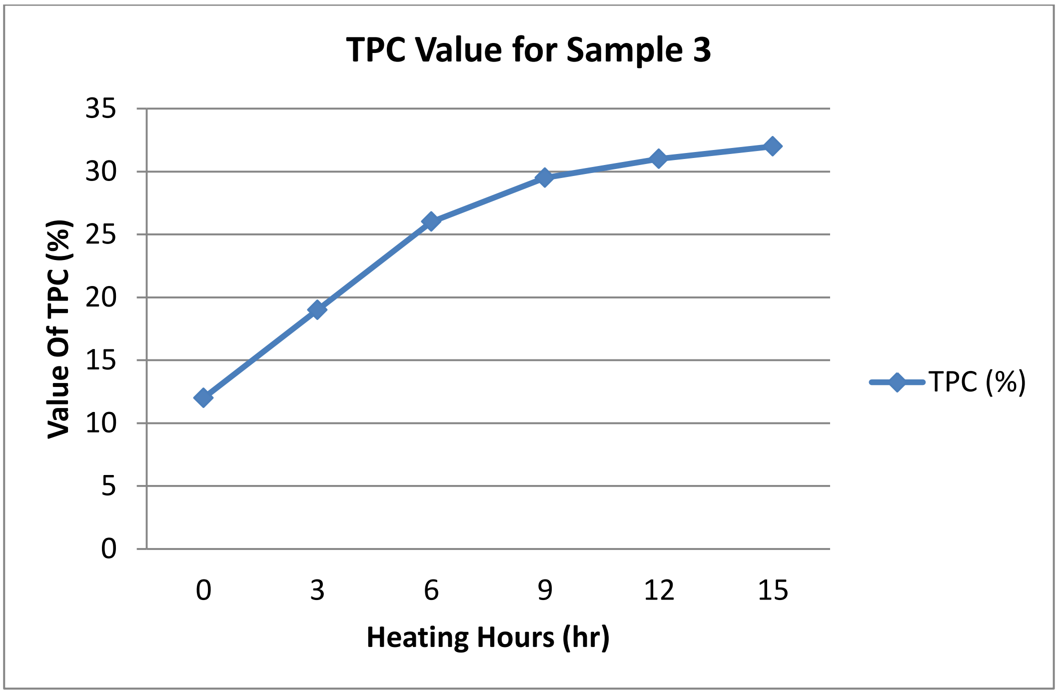


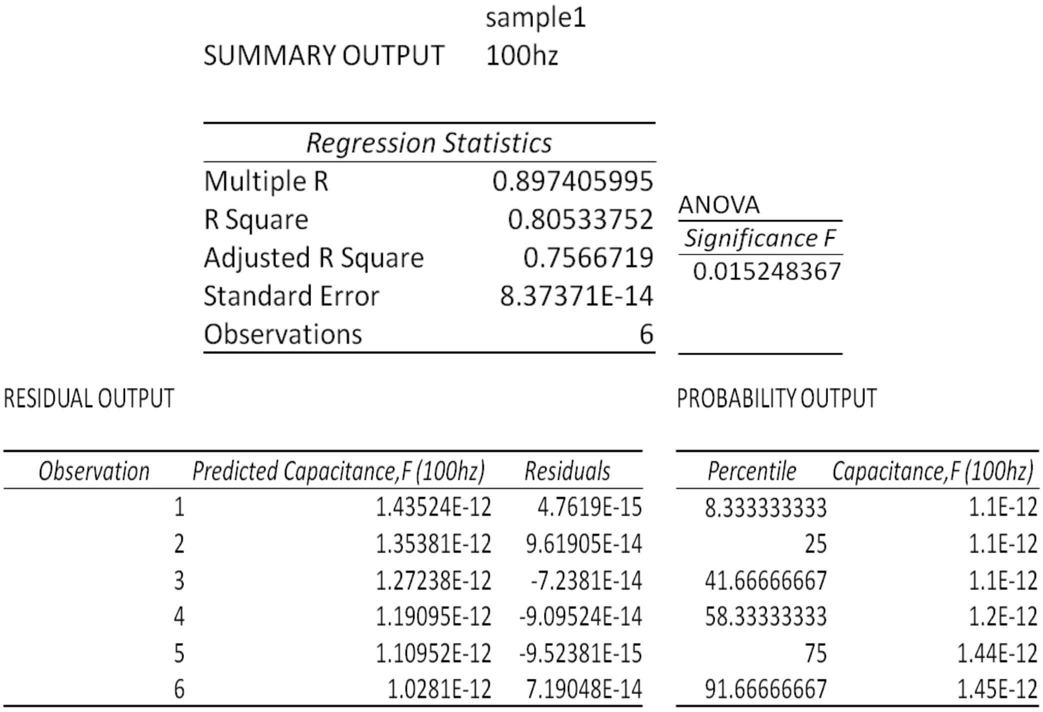
Figure 4.6 : Graph of TPC value for oil sample 3

4.1.1 Relationship between capacitance measurements and TPC measurements

The capacitance measurement data were analyzed to evaluate the deterioration of the quality of frying oil. Overall, the capacitance of frying oil increased as the heating time increased. In this result, the trend of measured capacitance by the IDE sensor followed the same trend of TPC measured using Testo 270 but not slightly the same. The capacitance of the frying oil samples increased linearly with the heating hours. However, the fluctuation in the capacitance results might be caused by changes in temperature of the oven during the conducted experiments.

4.2 Statistical Analyses

Regression analysis was performed to assess the relationships between degradation indices of TPC with the capacitance of the heated oil samples.



SUMMARY OUTPUT sample1 100hz

Regression Statistics	
Multiple R	0.897405995
R Square	0.80533752
Adjusted R Square	0.7566719
Standard Error	8.37371E-14
Observations	6

ANOVA

Significance F
0.015248367

RESIDUAL OUTPUT

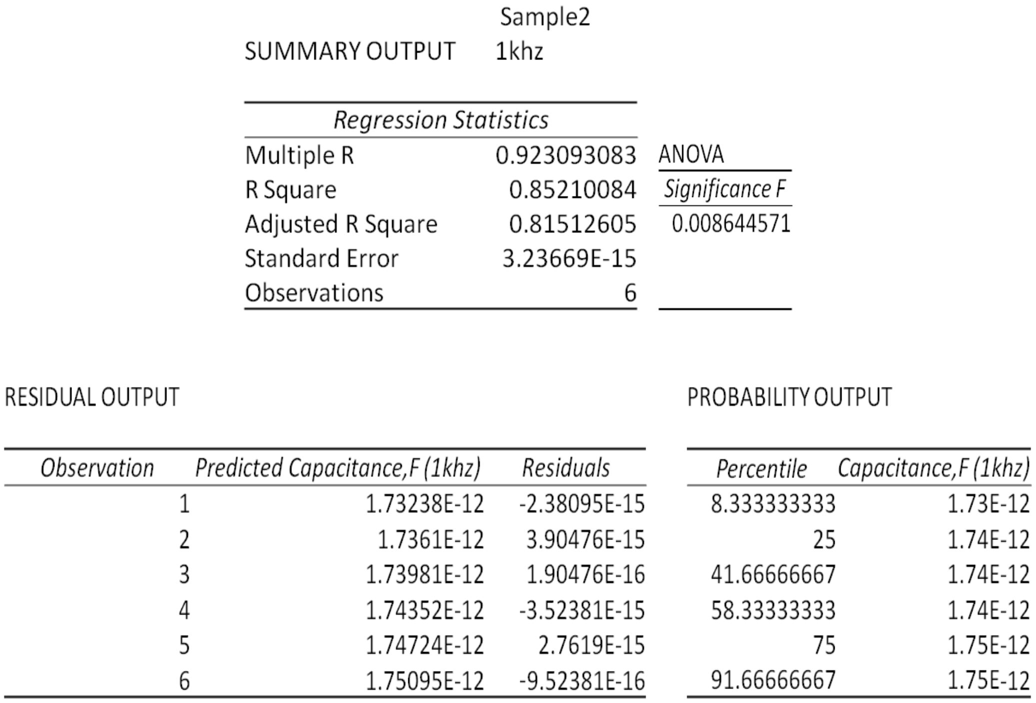
Observation	*Predicted Capacitance,F (100hz)*	*Residuals*
1	1.43524E-12	4.7619E-15
2	1.35381E-12	9.61905E-14
3	1.27238E-12	-7.2381E-14
4	1.19095E-12	-9.09524E-14
5	1.10952E-12	-9.52381E-15
6	1.0281E-12	7.19048E-14

PROBABILITY OUTPUT

Percentile	*Capacitance,F (100hz)*
8.333333333	1.1E-12
25	1.1E-12
41.66666667	1.1E-12
58.33333333	1.2E-12
75	1.44E-12
91.66666667	1.45E-12

Table 4.2.1 : Regression analyses for sample oil 1 at frequency 100 Hz

The coefficient of determination was found to be 0.805 when linear model was used for the frequency at 100 Hz. Meanwhile, the significance F was 0.0152 which was below than 0.05 and this proved that this result were reliable (statistically significant).



SUMMARY OUTPUT Sample2 1khz

Regression Statistics	
Multiple R	0.923093083
R Square	0.85210084
Adjusted R Square	0.81512605
Standard Error	3.23669E-15
Observations	6

ANOVA

Significance F
0.008644571

RESIDUAL OUTPUT

Observation	*Predicted Capacitance,F (1khz)*	*Residuals*
1	1.73238E-12	-2.38095E-15
2	1.7361E-12	3.90476E-15
3	1.73981E-12	1.90476E-16
4	1.74352E-12	-3.52381E-15
5	1.74724E-12	2.7619E-15
6	1.75095E-12	-9.52381E-16

PROBABILITY OUTPUT

Percentile	*Capacitance,F (1khz)*
8.333333333	1.73E-12
25	1.74E-12
41.66666667	1.74E-12
58.33333333	1.74E-12
75	1.75E-12
91.66666667	1.75E-12

Table 4.2.2: Regression analyses of oil sample 2 at frequency 1 kHz

The coefficient of determination was found to be 0.852 when linear model was used for the frequency at 1 kHz. Meanwhile, the significance F was 0.008 which was below than 0.05 and this also proved that this result were reliable (statistically significant).

CHAPTER V

CONCLUSION AND RECOMMENDATION

In this chapter, we will discuss the conclusion of all findings and results from dielectric sensing (capacitive) on cooking oil's TPC level. Finally, we will give suggestions and recommendations that can be applied in order to improve this project in future.

5.1 Conclusion

The objective of this project is to develop a sensor based on dielectric method (interdigitated electrode) using capacitive sensing to measure the electrical properties of the frying oil samples. The sensor design is to detect the capacitance value in the frying oil that have been used and compare to the value of the total polar compound (TPC) in the oil.

Secondly, the objective is to analyze the electrical properties by correlated it with the sample TPC's level. The value of capacitances of the oil is measured using an LCR meter by connecting the sensor directly to the LCR meter using cable clip. Then, the TPC of the oil is measured using a total polar meter (TPM), Testo 270. Both of the measurement are recorded in the table and compare to each other. The value of the capacitance is increasing linearly proportional to the heated hours as of the TPC value of the oil.

5.2 Recommendation

In order to improve this project, there are some recommendation that can be implemented in the future work :

1) To make the sensor is portable and easy to bring anywhere, the sensor should combine with the analog to digital (ADC) device such as an AD7747 Evaluation Board.

2) In order to get a more accurate value of capacitance read by the sensor, signal conditioning circuit need to be implemented to make sure that there are no noise can interrupt the measured/reading value.

3) The drawback of this type of technique are interferences by moisture since only a few pF was observed as sensor response, therefore a more extensive research on this area is recommended.

REFERENCES

[1] A. Y. Khaled, S. A. Aziz, F. Z. Rokhani, "Development and evaluation of an impedance spectroscopy sensor to assess cooking oil quality", *International Journal of Environmental Science and Development,* vol. 5, No. 3, pp. 299-302, 2014.

[2] C. H. Fizura, S. A. Aziz, S. Hafizan, "Effect of diesel contamination on capacitance values of crude palm oil", *Journal of Engineering Science and Technology*, vol. 9, No. 3 pp.286- 292, 2014.

[3] A. Y. Khaled, S. A. Aziz, F. Z. Rokhani, "Capacitive sensor probe to assess frying oil degradation", *Journal of Information Processing In Agriculture 2,* pp.142–148, 2015.

[4] A. T. Pérez and M. Hadfield, " Low-cost oil quality sensor based on changes in complex permittivity", *Journal of MDPI, Basel, Switzerland, Sensors*, No. 11, pp.10675-10690, 2011.

[5] H. Hampikyan, H. Colak, M. Akhan and I. Turgay, " Determination Of Total Polar Compound (TPC) Levels In Frying Oils", *Journal of Food, Agriculture & Environment,* Vol. 9, No. 2, pp. 142-144,2011.

[6] M. Stacheder, F. Koeniger and R. Schuhmann, " New dielectric sensors and sensing techniques for soil and snow moisture measurements", *Journal of MDPI, Basel, Switzerland, Sensors*, No. 9, pp.2951-2967, 2009.

[7] B. M. Marx, M. Luke, and D. P. Butt, "Micro-sensor for monitoring oils", *Department of Material Science and Engineering,Boise State University, Boise, ID* , pp.45-46, 2006.

[8] R. Minasamudram, P. Agarwal, and P. Venkateswaran, "Simulation of a capacitive sensor for wear metal analysis of industrial oils", *Proceedings of the 2013 COMSOL Conference, Bangalore* , pp.1-6, 2013.

[9] G. R. Takeoka, G. H. Full, and L. T. Dao, "Effect of heating on the characteristics and chemical composition of selected frying oils and fats", *Journal of Agriculture, Food and Chemistry*, No.45, pp.3244-3249, 1997.

[10] Z. H. Shahand Q. A. Tahir , "Dielectric properties of vegetable oils",*Journal of Scientific Research*, No.3, pp.481-492, 2011.

[11] S.M. Huang, C.G. Xie and M.S. Beck, "Design of sensor electronics for electrical capacitance tomography", *IEE Proceedings-G*, Vol. 139, No. I , February 1992.

[12] E. Terzic, "Capacitive Sensing Technology", *A Neural Network Approach to Fluid Quantity Measurement,* pp.11-37,2012.

[13] C.N.G. Scotter,"Non-destructive spectroscopic techniques for the measurement of food quality",*Trends in food science & technology*, 8(9): pp.285–292, 1997.

[14] C. Inoue, Y. Hagura, M. Ishikawa, and K. Suzuki, "The Dielectric Property of Soybean Oil in Deep-Fat Frying and the Effect of Frequency", *Journal Of Food Science*, Vol. 67, No. 3, pp.1126-1129, 2002.

[15] H. Lizhi, K. Toyoda, I. Ihara, "Discrimination of olive oil adulterated with vegetable oils using dielectric spectroscopy", *Journal Of Food Engineering 96,*pp.167–171, 2010.

[16] R. Minasamudram, P. Agarwal, and P. Venkateswaran, "Simulation of a Capacitive Sensor for Wear Metal Analysis of Industrial Oils", *Proceedings of the 2013 COMSOL Conference in Bangalore,* 2013.

[17] N. J. Djermanova, J. G. Kiss'ovski and V. A. Vatchkov, "Portable Arduino - Based LCR – Meter", *Annual Journal Of Electronics,* pp.170-173, 2014.

[18] A. Y. Khaled, S. A. Aziz, F. Z. Rokhani, W.I. Ismail, "Capacitive Sensing System for Frying Oil Assessment During Heating", *IEEE International Circuits and Systems Symposium,* pp.137-141, 2015.

[19] J. Wang, "Design and Implementation of an Impedance Analyzer Based on Arduino Uno", *Degree Project In Medical Engineering, Second Level Stockholm, Sweden,* 2015.

[20] E. Choe And D.B. Min, "Chemistry of Deep-Fat Frying Oils", *Journal Of Food Science,* Vol. 72, No. 5, pp.77-86, 2007.