DETECTING CORROSION IN OIL PIPELINE USING CAPACITOR

By

GWENDOLIN DUMANG ANAK JAKOP

FINAL YEAR PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

December 2009

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

DETECTING CORROSION IN OIL PIPELINE USING CAPACITOR

by

Gwendolin Dumang anak Jakop

A project dissertation submitted to the
Electrical & Electronics Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Approved:

(Dr. Noohul Basheer Zain Ali)
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

December 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Gwendolin Dumang anak Jakop

ABSTRACT

Internal-pipeline corrosion is a serious issue in oil and gas industry. This project aims to build a capacitive sensor using aluminium plates and analyzed the effect on the output voltage when corrosion occurred in the pipeline which carries different viscosities of oil. Corrosion in the oil pipeline affects the quality of liquid in it and causes leakage which pollutes the environment. It is time and cost consuming to replace the pipeline and the operators find it difficult to assess the condition inside the pipelines. This project covers only the oil pipeline and three types of oil with different viscosity are used to demonstrate the working principle of the capacitive detector. Simulation was done to verify the effects of capacitance to the output voltage. Iron(II) ion and iron(III) ion which are the products of early stage corrosion and rusting process respectively were added into the oil and readings were taken and recorded for analysis. Experiments were conducted to analyze the effect of different levels of corrosion i.e. early stage and rusting stage towards the output voltage. Based on the results obtained, the output voltage across the capacitive plates decreases as more iron ion present in the oil. The outcome from the comparison between early stage of corrosion and rusting stage were also done and the outcome was that the output voltage across the capacitive plates is lower in the rusting stage. Thus it can be concluded that the more severe is the corrosion in the pipeline, the lower is the output voltage measured across the capacitive plates.

ACKNOWLEDGEMENTS

First and foremost, praises be to God for His tremendous blessing and wisdom upon the author throughout her whole life as a student and as a creature of His. Everything is possible through Him who gives her strength.

The author would like to express her greatest gratitude to her previous project supervisor, Dr. Abdallah Belal for his guidance and supervision. The idea of building a capacitive detector to detect corrosion in oil pipelines is indeed great and brilliant. Thank you for the time that you had spent to guide and supervise the author throughout the whole semester. To Dr. Noohul Basheer Zain Ali, thank you for your willingness to take over the responsibility to supervise the author as she continues to work on the project.

Special thanks are also conveyed to the Electrical and Electronics Engineering Final Year Project Committee and those technicians involved to ensure this project is a successful run. Not forgetting her beloved friends – Wanie Kenny, Michelle Tomato, Miki, Illi and many more, thank you for every help that you had given to the author. A friend is indeed someone who reaches out for your hands and touched your heart.

Last but never the least, the author would like to thank her superb parents whom had supported and motivated her in many kinds of ways. For always being there to lift up her spirit and provide her all the needs to complete this project. The author could not have done it without them.

Kind words can be short and easy to speak, but their echoes are truly endless.

-Mother Teresa-

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

PIG	Pipe Inspection Gauge
EMF	Electromotive Force
TX	Transmitter
RX	Receiver
RF	Radio Frequency
AM	Amplitude Modulation
FM	Frequency Modulation
RC	Resistor-Capacitor
AC	Alternating Current

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Internal-pipeline corrosion had become a critical issue in oil and gas industry as it does not only cause losses to the company involved but also reduce the plant availability [1]. It became an environmental concern when pipeline leakage happens due to prolong and unmonitored corrosion process occurred inside which result in severe consequences upon safety of personnel, environment and asset value. The cost of replacing those pipelines are indeed costly where it involves isolating the pipelines from process operation and pulling down the rate of production which influence the overall performance of the plant [1].

Corrosion refers to any process involving deterioration or degradation of metal components such as rusting of steel [1]. Accumulation of water and other corroding substances had provoked the corrosion process to occur mainly at the bottom part of the pipelines as generally water is denser than the oil. All metal pipelines exhibit a tendency to be oxidized in which the relative strength of this tendency is tabulated in the “Galvanic Series” [1].

Internal corrosion in oil pipeline can be detected by visual examination when it is being isolated and drained, external measurement of the pipe wall thickness with appropriate instruments or devices and through in-line inspection tool to identify areas of pitting or metal loss [2]. However, these techniques can only be carried out during isolation of the pipelines involved which consume more time compared to other live-corrosion-detection method.

Generally, capacitive detectors are being used for level measurement. By adopting the same concept, it is then possible to come out with a corrosion detector by comparing the capacitance values of the reference and measuring points without having isolation of pipelines. When corrosion occurs, the material of the pipe wall such as iron oxide (metal) will deteriorate and absorb into the flow of oil. As the metal mix with the oil, the permittivity is no longer the same and thus will change the capacitance and voltage values measured at another end of the pipeline.

1.2 Problem Statement

Corrosion on the internal wall of oil pipeline has created an issue to the oil companies as it causes leakage and up to the extent of rupturing the pipeline. This will cause financial and time loss to the companies [1]. Leakage of the pipelines does not only pollute the environment and endanger the health of personnel involved but also affects the process flow as the pressure drops and level decreases due to the holes formed at the pipe wall. The quality of liquid in the pipeline is also contaminated due to rusting process of the metal alloy and the operators find it difficult to assess the condition inside the pipelines.

Pigging (Pipe Inspection Gauge) process is not sufficient to monitor the corrosion as the main purposes of pigging are to clean and remove debris besides checking the dimension of the pipeline. Thus, it is crucial to have an with intelligent device that is able to detect corrosion even at early stage and attract the attention of the process and pipeline engineers to take appropriate corrective actions to avoid corrosion from continuing.

1.3 Objectives

The main objectives of this project are to build a capacitive detector using aluminium plates to detect corrosion in the oil pipelines and analyze the effect of adding Ferrous(II) Chloride Tetrahydrate into the oil which used to represent the Iron ion (Fe^{2+}) being released during the occurrence of corrosion in the pipeline. To further investigate the effect of corrosion in the oil pipeline, Ferric(III) Chloride Hexahydrate is used to represent the rust which is being produced due to oxidation of the precipitate at the first stage of corrosion process. Further explanation on this matter can be found in ***Section 2.1.2***. Different types of oil with different level of viscosity are used for the experiments to determine the relationship of output voltage and the viscosity of the oil at room temperature under atmospheric pressure.

The summary of the project objectives are as follow:

i) Build capacitive detector using aluminium plates which able to detect the changes of oil permittivity due to corrosion.

ii) Collect sufficient data to analyze the effect in the output voltage when Iron ion (Fe^{2+} and Fe^{3+}) is added into the oil by conducting experiments.

iii) Determine the relationship between different levels of corrosion i.e. early stage and rusting stage with the changes in output voltage.

iv) Determine the relationship between the oil viscosities and the output voltage of the sensor.

1.4 Scope of Project

The scope of the project is to design a capacitive circuit to detect corrosion in the internal wall of the *oil* pipeline. In this project, the corrosion process which refers to the uniform thinning that proceeds without appreciable localized attack is represented by adding Ferrous(II) Chloride Tetrahydrate into the oil as corrosion start to happen when pipeline which is made of metal alloy releases its Iron(II) ion (Fe^{2+}) and reacts with the corroding component such as water and oxygen. Rust will be produced when Iron(II) ion (Fe^{2+}) is further oxidized to produce Iron(III) ion (Fe^{3+}). Experimental work is done to relate the oil viscosities with the output voltage when increasing amount of Iron ion presents in the oil. The oil viscosities were measured using Brookfield DV-I+ Digital Viscometer and is done under atmospheric pressure with normal room temperature of 25°C.

This project is to be completed within two (2) semesters and the capacitive sensor circuit is the important part of the project which must be completed prior to the experimental works which involve determining the relationship between the oil viscosities and the changes in the output voltage. Capacitive sensor can be an accurate way of detecting changes in oil permittivity and thus can be the best solution in overcoming severe corrosion problem in oil pipelines.

The scope of this project is relevant to the electrical and electronics course as it utilizes the characteristics of a passive element – capacitor. The oil and gas industry is certainly in need of an innovative sensor to detect the level of corrosion for easy monitoring and maintenance handling.

CHAPTER 2
LITERATURE REVIEW

2.1 Corrosion in Oil Pipeline

Internal corrosion of pipeline is a real issue which happens in the oil and gas industry. According to source [3], corrosion in pipelines causes oil leakage which brings huge losses to the oil companies besides polluting the environment.

Generally, the corroding substances attack the lower parts of the pipeline as water droplets and other substances such as sulfur sink beneath the pipeline and stimulate the corrosion process [1]. When pipeline had been in serviced for certain period of time, it will be necessary to maintain line efficiency and aid in the control of corrosion. Cleaning of pipeline need to be done periodically and process flow can be manipulated to avoid corrosion process from occurring.

2.1.1 Classification of Corrosion

There is no standardize way of classifying corrosion as corrosion can be divided based on the appearance of corrosion damage, mechanism of the attack, industry section and ways of preventing it [15]. For example, in the oil and gas industries, the corrosion classification generally is based on the conditions which induced corrosion: sweet corrosion, sour corrosion, oxygen corrosion and electromechanical corrosion [15].

According to [1], corrosion can be classified into eight forms which are: Uniform attack, crevice corrosion, selective leeching, erosion corrosion, stress corrosion, intergranular corrosion, hydrogen damage and pitting corrosion. However, this classification is arbitrary as it was based on the visual characteristics of the morphology of attack.

2.1.2 Representation of Corrosion Processes

In the oil industries, pipelines are used to transport liquids from one point to another point. There are many ways of monitoring and controlling corrosion e.g. cathodic protection complimented with suitable dielectric coating. The coating system plays an important role by reducing the total protective current applied by the cathodic protection system during the operating life of the pipelines [16].

Corrosion is a process of deterioration or degradation of metal's properties such as its appearance and mechanical properties [14]. The process is an electrochemical reaction in which it involves two half-cell reactions that occur simultaneously: oxidation and reduction [1]. Since the reactions occur simultaneously on a metal surface, it creates an electrochemical cell as shown in Figure 1 below.

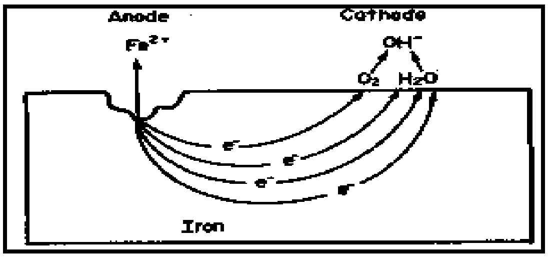


Figure 1 The electrochemical cell set up between anodic and cathodic sides on an iron surface undergoing corrosion [17].

The complete corrosion reaction of iron can be shown as follow:

Anode (oxidation): $2Fe(s) \longrightarrow 2Fe^{2+}(aq) + 4e^-$ (1)

Cathode (reduction): $O_2(g) + H_2O + 4e^- \longrightarrow 4OH^-(aq)$ (2)

Within the surface, the hydroxide ions can move inward to react with the iron (II) ions moving from the oxidation region. Iron (II) hydroxide is precipitated.

$$Fe^{2+}(aq) + 2OH^-(aq) \longrightarrow \underset{\text{(Solid precipitated)}}{Fe(OH)_2(s)} \quad (3)$$

Rust is then quickly produced by the oxidation of the precipitate.

$$4Fe(OH)_2(s) + O_2(g) \longrightarrow 2Fe_2O_3 \cdot H_2O(s) + 2H_2O \quad (4)$$

2.2 Capacitive Detector and Capacitance

Capacitive sensors are often used to measure the displacement (particularly level) of medium in a compartment where sight glass is inconvenience due to the pressure or composition of the medium. The effects of varying the physical or electrical characteristics of the medium which act as the dielectric component allow the capacitance value to change accordingly [4]. Any arrangement of two conductors separated at some distance with an electric insulator (dielectric) is a capacitor [5]. The dielectric constant is determined by the permittivity of the dielectric medium. When a material is exposed to an Electromotive Force (EMF), it will produce an electric flux which is termed as the permittivity [4].

Electrical charges deposited on first conductors will induce an equal charge with opposite polarity on the second conductor. Due to this phenomenon, an electric field exists between the two conductors and is directly proportional to the magnitude of the charge stored, Q [5].

Charge stored can be calculated using the following equation:

$$Q = CV \tag{5}$$

Where C = capacitance in Farad (F)

Q = electric charge in Coulomb (C)

V = voltage in volt (V)

Taking into account the plate area and the distance between the two plates, equation (5) can be rearranged and yield:

$$C = \frac{\varepsilon_o \varepsilon_r A}{d} \tag{6}$$

Where d = distance between the two plates in meter (m)

A = plate area or cross section of the plate in meter squared (m^2)

ε_o = permittivity of free space given as 8.854×10^{-12} F/m

ε_r = relative permittivity of the dielectric between the two plates

Note: This equation is based on the assumption that the charge density on the plates is uniformly distributed.

2.3 Wireless Data Communication via Radio Frequency (RF)

Wireless technology has been expanding at a fast pace with many new applications being introduced to the public almost daily [6]. Transmission of data using radio frequency is being used in cordless phones, cellular communication and local area networks due to its better performance compared to infrared [6]. The high efficiency of RFs data transmission and its relatively small size have favoured RFs to be used widely for mobile communication [6]. Transmitting data from field to the main control room for any plant can cut the cost for cabling and maintenance.

According to [7], there are few advantages of wireless data transmission over cable transmission. The most significant advantage is the low price of installation. Installing network cabling through long distance can be costly and a difficult task to be carried out. Through wireless transmission, there is no need to consider pulling long cables from one place to another place. Besides, wireless data communication is more reliable compared to wired network [7]. As the name implies, cabled communication requires cables. These cables are vulnerable to breakdown as the workers might step on it and fails the network connection. Thus, through wireless technology, cable failures can be avoided and overall reliability is improved.

However, radio frequency transmission might face interference due to the present of other signal and also interference from the circuit itself [7]. Different types of signal might disrupt the transmission process and cause errors. Security is also one of the major concerns for RF wireless data communication [7]. Intruders can intercept the signal transmitted via wireless and affects the integrity of data.

The frequency bands used in commercial broadcasting are as follow [6].

Table 1 Frequency and Wavelength Range for AM and FM

Band	Frequency Range	Wavelength Range
AM	535-1605 kHz	186.92-560.75 m
FM	88-108 MHz	2.78-3.41 m

Despite the shortcomings which related to the wireless technology, it is still a practical solution to implement it in this project since pipelines can be hundreds of meter long. It will not be a wise decision to lay cable up to this distance due to its cost and the heavy maintenance work which need to be done.

CHAPTER 3

METHODOLOGY

3.1 Methodologies and Approaches

For this project, the following approaches are adopted in order to accomplish the objectives mentioned earlier.

- Conduct a research and study on the significance of internal pipeline corrosion to the oil companies besides deepen the understanding of corrosion process.
- Construct a capacitive detector using aluminium plates which utilizes the concept of a capacitor.
- Conduct experiments and collect data to analyze the effect in the output voltage when Iron ion (Fe^{2+} and Fe^{3+}) is added into the oil. A stirrer was used to simulate the effect of flow in the beaker. Material Safety Data Sheet (MSDS) for Ferrous(II) Chloride Tetrahydrate and Ferric(III) Chloride Hexahydrate can be found in **Appendix A** and **Appendix B**.
- Analyze the results obtained and determine the relationship between the oil viscosities and the output voltage of the sensor.

3.2 Flow Chart

3.2.1 Project Flow Chart

Figure 2 shows the flow of the project which also covers the construction of the prototype to demonstrate the corrosion process in the oil pipelines. However, due to time constraint and cost limitation, aluminium plates were used to construct the sensor and experiments were done to test the sensor. The prototype of the sensor is not covered in this project and further research can be done on this matter to invent a marketable corrosion capacitive sensor. Software simulation is done to check on the effect of capacitance value to the output voltage and as a reference to the experimental results. The results for simulation and experiments can be found in next chapter.

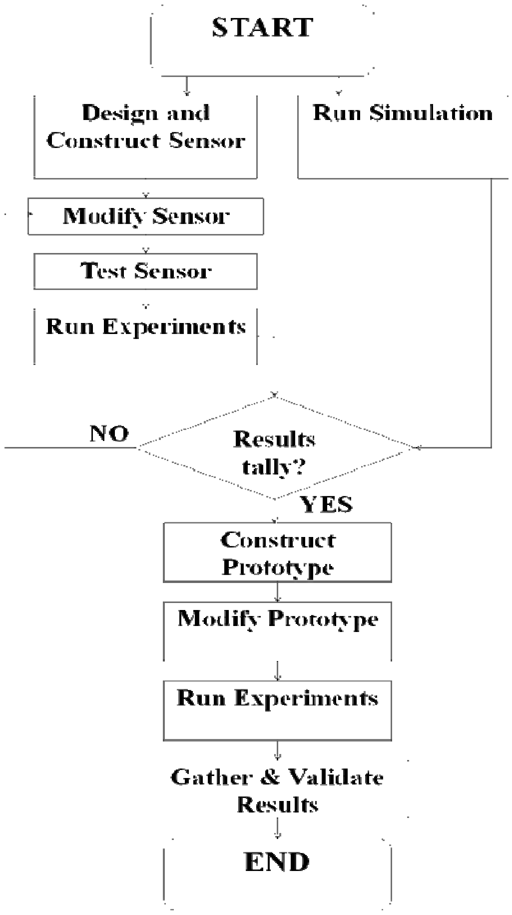


Figure 2 Project Flow Chart

3.2.2 Sensor Algorithm

A corrosion capacitive sensor proposed in this project uses the comparison method to detect the corrosion in the oil pipeline. Two pairs of capacitive plates were placed at the two end of the pipeline i.e. upstream and downstream to have the voltage reading at both sides. In ideal case, when there is no corrosion between the two sensors, the voltage value obtained should be equal. If corrosion happens, the oil permittivity will changed and thus effect the voltage value measured through the capacitive sensor circuit. Further discussion on the effect of capacitance value to the output voltage is discussed in ***Section 4.1.1***.

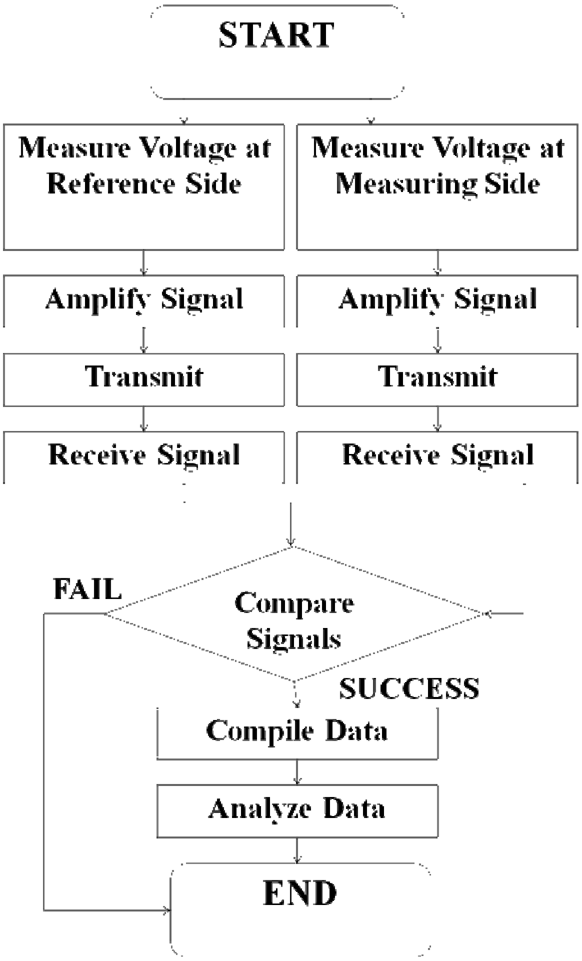


Figure 3 Overall Sensor Algorithm

3.3 Experimental Design and Planning

3.3.1 Equipments and Hardware

Following is the list of equipments and hardware utilized for the experimental works of the capacitive detector:

- Aluminium plates (2 pairs)
- Alternating Current (AC) Source
- Breadboard and resistor 11 kΩ
- Oscilloscope
- Digital Multimeter
- Ionize Compound Ferrous(II) Chloride Tetrahydrate
- Ionize Compound Ferric(III) Chloride Hexahydrate
- Weight Scale
- Beaker

3.3.2 Experimental Design

For this project, the main concern would be the corrosion in the *oil* pipeline. To demonstrate the working principle of the detection circuit, three types of oil with different viscosity are used in the experimental works: engine oil, crude oil (ANGSI Well I63) and cooking oil (Cap Helang).

Experiments are carried out after the detection circuit is completed. Ferrous(II) Chloride Tetrahydrate is used to represent the corroded metal pipe as it releases Iron(II) ion (Fe^{2+}) when it is exposed to air or water. The capacitance value is measured by the detection circuit and output voltage across the capacitor can be seen from the oscilloscope and digital multimeter (DMM). The percentage of Ferrous(II) Chloride Tetrahydrate being mixed with the oil and the output voltage are recorded and analyzed accordingly. Different weight of Ferrous(II) Chloride Tetrahydrate is used to demonstrate the different level of corrosion. For the next stage of corrosion in which rust is being produced, Ferric(III) Chloride Hexahydrate is added into the oil by setting up a new experiment. The output voltages are then being measured and compared with the results obtained from the previous experiment.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Results

4.1.1 Simulation of Circuit using PSIM Demo Version 7.1

PSIM Demo Version 7.1 is one of the software used in this project to simulate the *Resistor-Capacitor* (*RC*) circuit. The *RC* circuit, which is used to simulate the changes in output voltage due to changes in capacitance value, consists of an 110kohm (Ω) resistor, AC input voltage of 10V_{rms} with frequency of 100Hz and a capacitor in which the value is being varied from 20nF to 100nF. The results obtained can be found in Figure 5 – Figure 9. Figure 10 shows the graph of voltage values i.e. $V_{c,rms}$ and $V_{R,rms}$ versus the capacitance value ranging from 20nF – 100nF and is tabulated in Table 2.

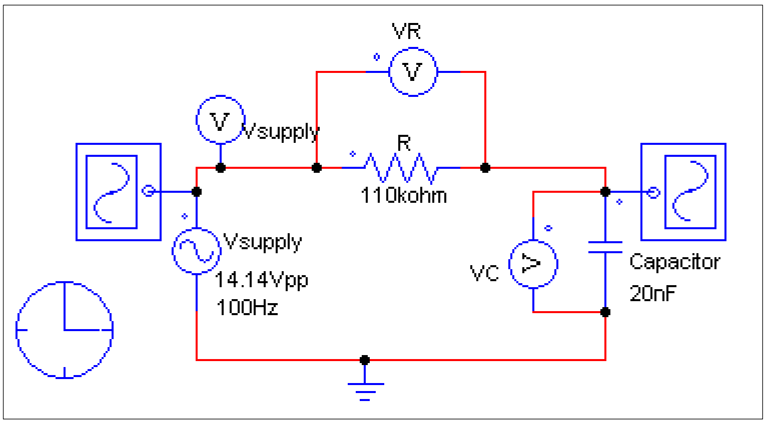


Figure 4 RC Circuit

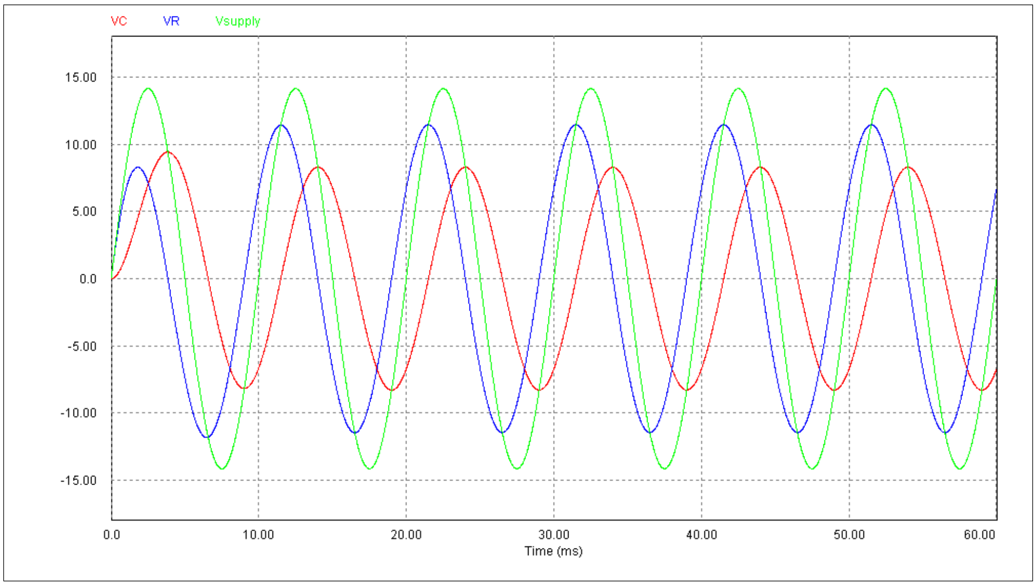


Figure 5 Voltage (volt) versus Time (ms) for C = 20nF

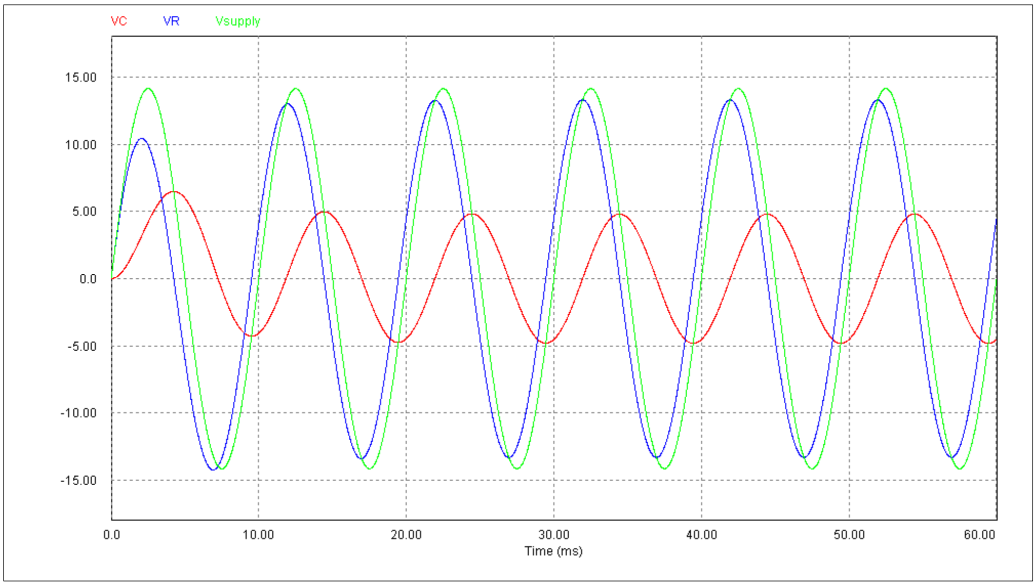


Figure 6 Voltage (volt) versus Time (ms) for C = 40nF

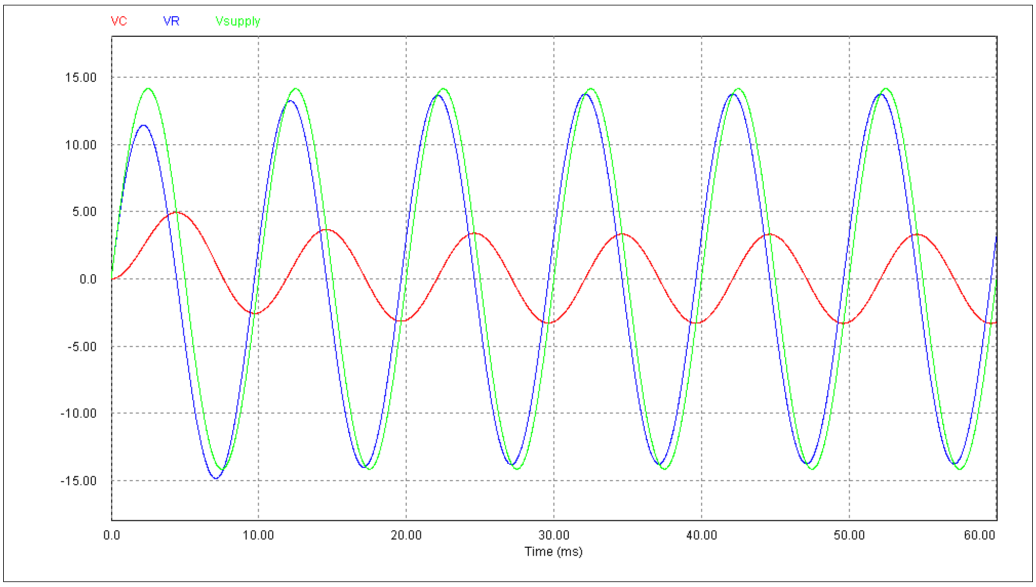


Figure 7 Voltage (volt) versus Time (ms) for C = 60nF

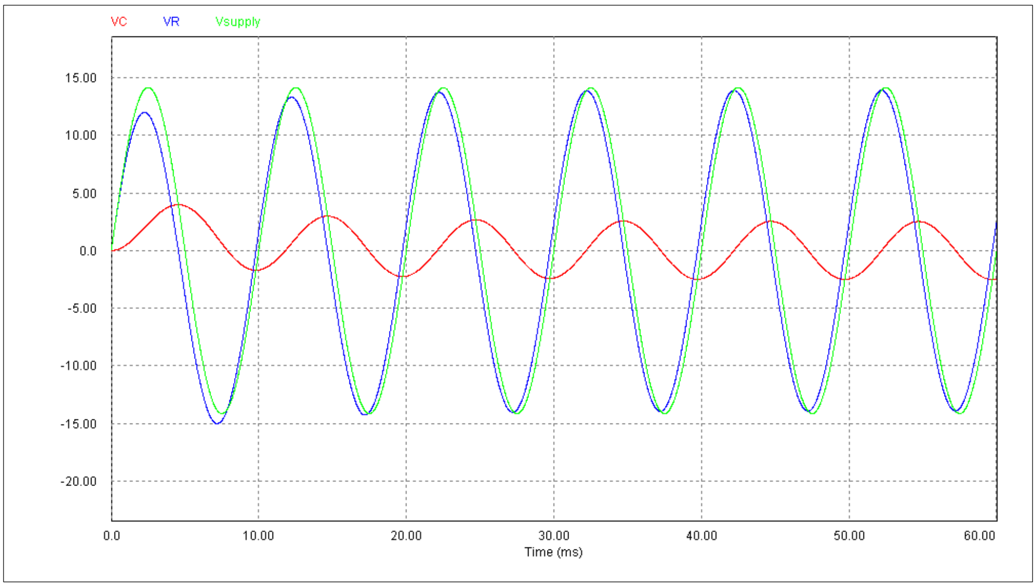


Figure 8 Voltage (volt) versus Time (ms) for C = 80nF

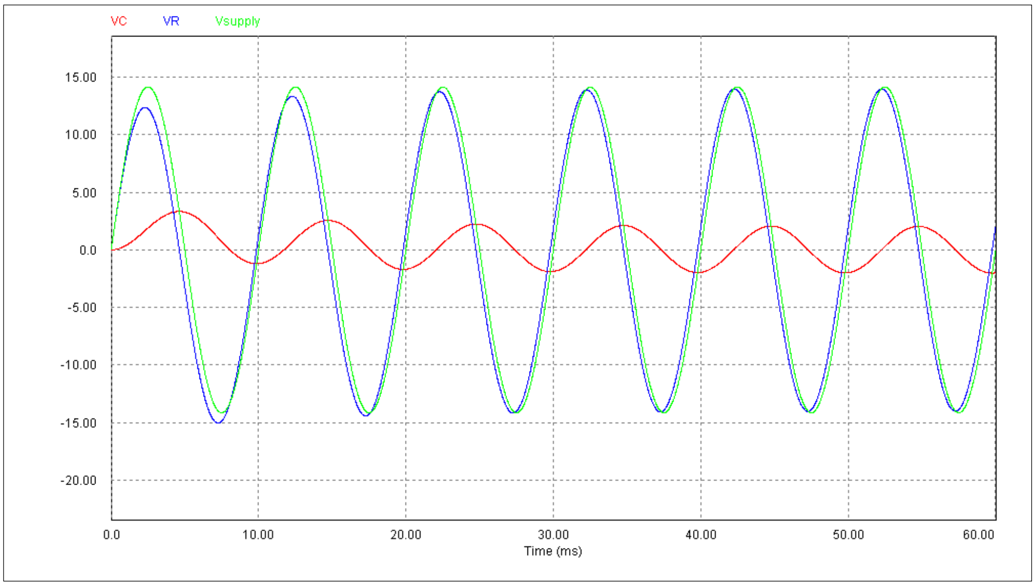


Figure 9 Voltage (volt) versus Time (ms) for C = 100nF

Table 2 Simulation Results for RC Circuit Simulation using PSIM Demo Version 7.1

Capacitance (10^{-9}Farad, nF)	**$V_{c,\ rms}$ (volt, V_{rms})**	**$V_{R\ rms}$ (volt, V_{rms})**
20	5.93087	7.94662
40	3.50974	9.28196
60	2.46288	9.63140
80	1.90173	9.77020
100	1.55508	9.83983

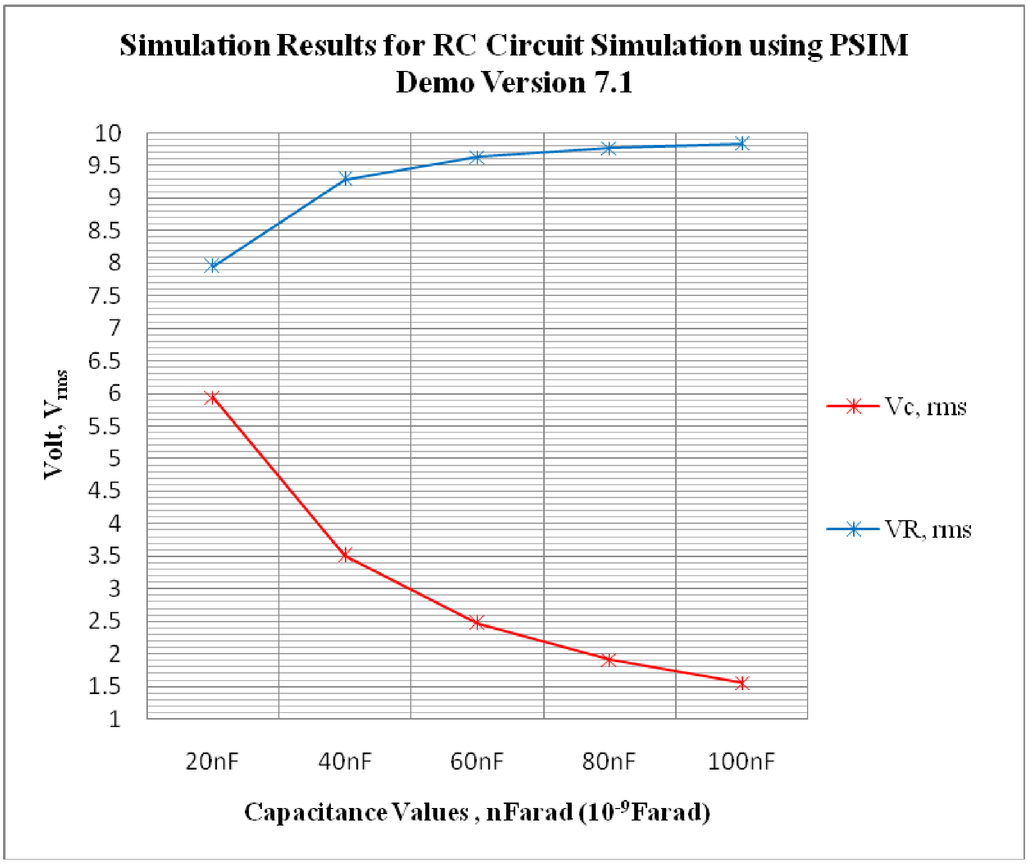


Figure 10 Voltage (volt) for versus Capacitance Value (nF)

From the results obtained in Figure 10, it can be observed that the output voltage in root-mean-square (rms) changes according to the capacitor value. As capacitance value increases, the measured output voltage will decrease. These results verify equation (5) in which output voltage is inversely proportional to the capacitance, C. Since the capacitive detector characteristics such as the area, distance between plates and materials are fixed in this project, the capacitance value will solely change due to the changes in the permittivity of the dielectric materials between the two plates. However, few assumptions need to be done prior conducting the experiment e.g. the level of the oil is constant which will not cause changes in output voltage. The assumptions being made for the experiment is discussed in the next section.

4.1.2 Assumptions

There are few assumptions were made prior conducting the experiments. The list of assumptions is as follow:

i) When there is no corrosion in the pipeline, assumption is to be made that there is only oils present between the capacitive plates and the reading found was totally the capacitance value of the oils without any contamination.

ii) When corrosion starts to happen, the metal pipeline will release and the metal namely Iron(II) ion (Fe^{2+}) and mix with the oils which will then alter the properties (permittivity) of the oils. This situation can be represented by having Ferrous(II) Chloride Tetrahydrate being mix with the oils prior passing them through the sensor plates.

iii) Rust can be represented by adding Ferric(III) Chloride Hexahydrate as it is stated in equation (4) that further oxidation of Iron(II) ion will produce Iron(III) ion (Fe3+) which is the oxidation of the precipitate.

iv) The corrosion level of the pipeline can be categorized into mild, moderate and serious corrosion by varying the percentage of iron powder being mix into the oils.

v) The level of oils in the pipeline stays above the height of the sensor plates to avoid capacitance value being affected by the level.

4.1.3 Capacitance Calculation

The calculation of capacitance using equation (6) will be demonstrated in this section in which different materials have different capacitance values. The values of the dielectric constant for these calculations are taken from [8] and [9]. The area and the distance of the capacitive plates were given in Figure 12. The details of calculation can be found in **Appendix C**.

Table 3 Capacitance Values for Different Materials

Material	**Dielectric Constant (Dimensionless)**	**Capacitance Value (pF, 10^{-12} F)**
Petroleum	2.1	0.1859
Gasoline	2.2	0.1948
Castor Oil	2.6	0.2302
Iron Oxide Powder	14.2	1.2573
Water	80	7.0832

From the tabulation of capacitance values in Table 3, it can be observed that the higher is the dielectric constant, the larger is the capacitance value. Based on the results, prediction can be made: when Ferrous(II) Chloride Tetrahydrate and Ferric(III) Chloride Hexahydrate are being mixed with the oils, the capacitance value would change – increase as the dielectric constant is higher. Thus the output voltage across the capacitor will drop accordingly. Experiments will be carried out to measure the output voltage for different viscosities of oil.

4.1.4 Prototype Designing

The overall design and dimension of the prototype is shown in Figure 11 and Figure 12. However, in this project, the design is roughly made as more concentration was put in the effect of oil viscosities to the output voltage. Further research can be done on how to install the sensor in long distance pipeline with proper design which can withstand the real pressure flow of process operation. One of the propose solution is to come out with the special design pipeline to accommodate the sensor in it. It will not be discussed deeper since it is out of the project scope.

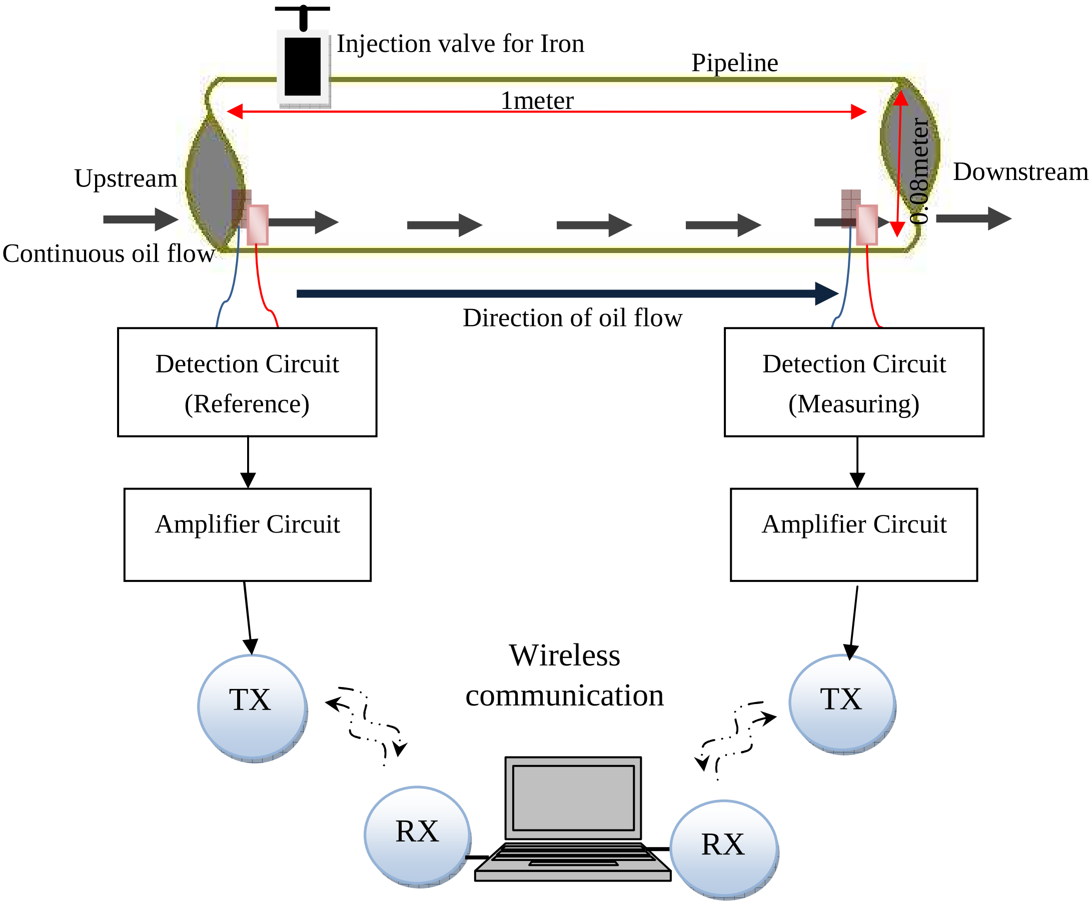


Figure 11 Overall Prototype Design

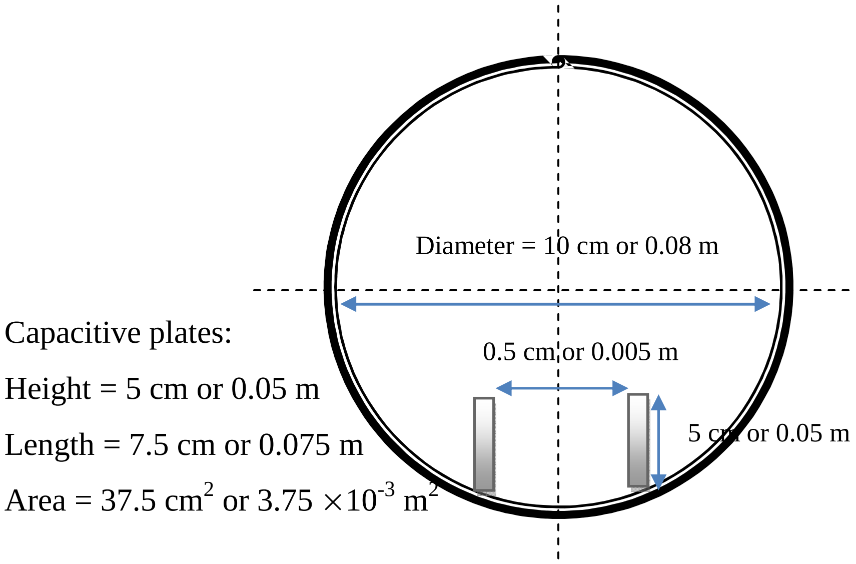


Figure 12 Cross-sectional of Pipeline

4.2 Laboratory Experimental Works

Practical laboratory experiments are seldom perfect. Due to this factor, many assumptions need to be made. In order to get a more accurate and precise results, this experiment were conducted three times under the same atmospheric pressure and room temperature. All readings were recorded and discrepancies were discussed in the next section. For safety purpose in handling chemical in this experiment, Material Safety Data Sheets (MSDS) for $FeCl_2$ and $FeCl_3$ are obtained and understood. Weighing scale was used to weight the ionize compound and were added into the oil and left to react for 10 minutes before the output voltage is taken for measurement. The time to react is being manipulated in order to get consistency in the measuring procedure.

Repeated experiments were conducted throughout the data collection process to ensure the output voltages obtained are reliable and are able to use to predict the dielectric constant of the oils when corrosion starts to happen and when rust begin to develop in the pipelines. Figure 13 shows the viscosity measurement process using Brookfield DV-I+ Digital Viscometer. The capacitive plates were placed in a beaker and DMM is used to measure the output voltage as shown in Figure 14 and Figure 15.

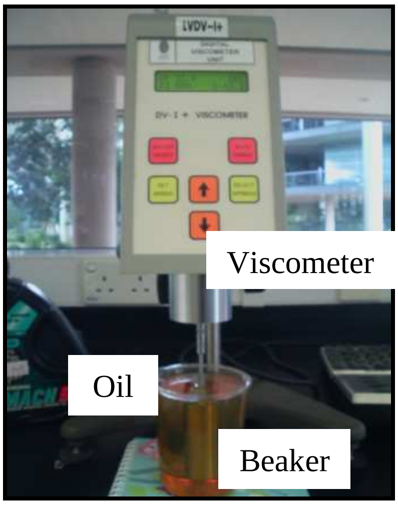


Figure 13 Viscosity Measurement for Oils using Brookfield DV-I+ Digital Viscometer

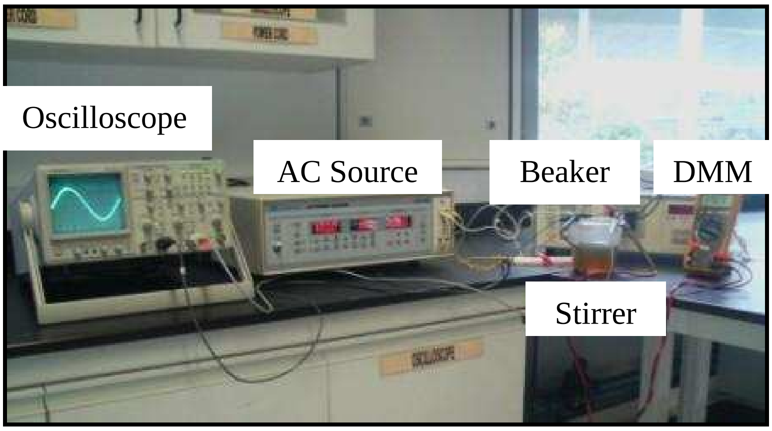


Figure 14 Experimental Setup

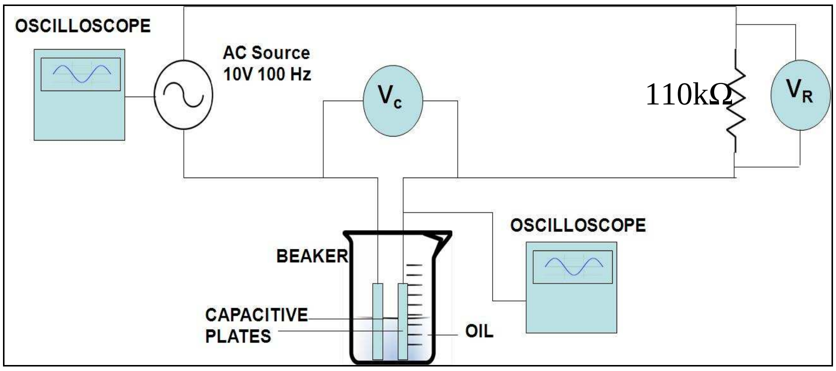


Figure 15 Circuit Diagram

The aluminium plates were placed inside the beaker with 500ml of oil. Oscilloscope with two-channel input was used to monitor the input signal and the output signal. Digital Mulitimeter is also used in data collection to measure the voltage across the resistor. The output voltage is measured between the two aluminium plates and across the resistor. Data obtained is recorded for analysis process.

4.2.1 Early Corrosion Stage - Ferrous(II) Chloride Tetrahydrate

Based on the literature review conducted, the early corrosion process in pipeline started when the metal alloy oxidized to produce metal ion i.e. iron ion Fe^{2+} and also hydroxide ion $4OH^-$ as stated in equation (1) and (2). Three types of oil were used in this experiment and the results were sorted into Part 1 – Crude Oil, Part 2 – Engine Oil, and Part 3 – Cooking Oil Cap Helang.

- Part 1 – Crude Oil (ANGSI Well I63)

Viscosity = 7.5 cp at room temperature (spindle type IV); 2.48 cp at 60°C

Table 4 Voltage Values obtained for Crude Oil (ANGSI Well I63)

Weight of $FeCl_2$ (gram, g)	**$V_{c, rms}$ (Volt, V_{rms})**			**$V_{R, rms}$ (Volt, V_{rms})**		
	Set 1	**Set 2**	**Set 3**	**Set 1**	**Set 2**	**Set 3**
0	8.952	8.982	8.989	1.011	0.997	0.983
10	8.819	8.930	8.933	1.174	1.115	1.109
20	8.550	8.673	8.681	1.323	1.289	1.183
30	8.115	8.208	8.195	1.458	1.447	1.440
40	7.809	7.899	7.913	1.716	1.685	1.672
50	7.206	7.27	7.312	2.007	1.892	1.877

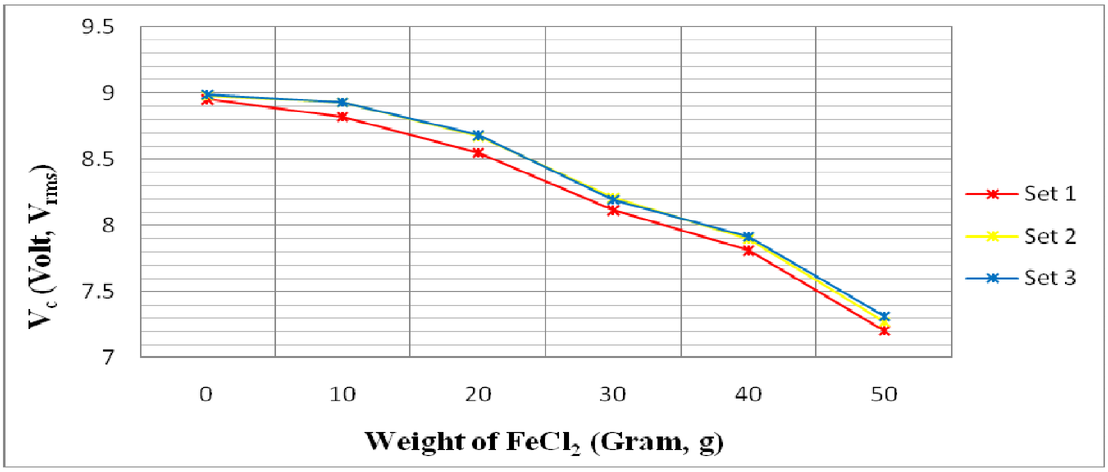


Figure 16 Capacitor Voltage vs. Weight of $FeCl_2$ for Crude Oil

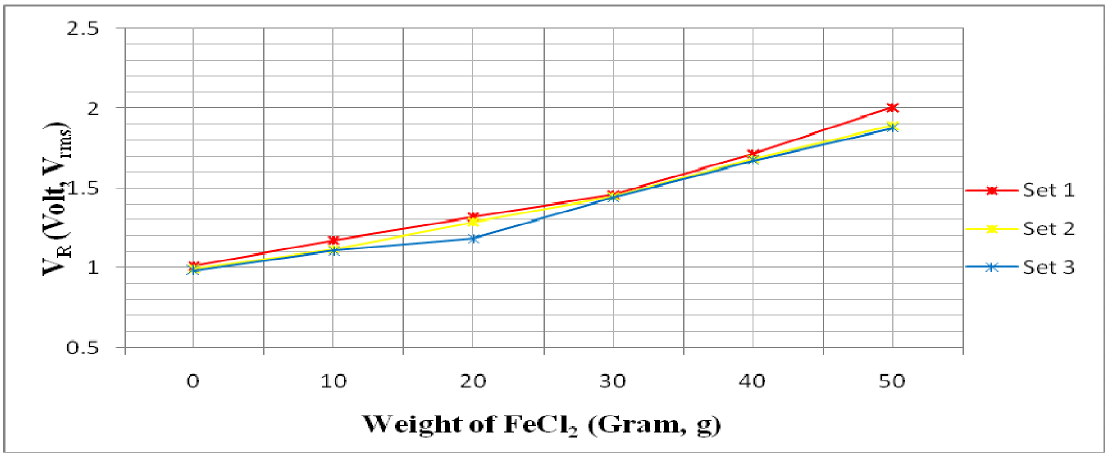


Figure 17 Resistor Voltage vs. Weight of $FeCl_2$ for Crude Oil

From Figure 16 and 17, it can be observed that as the weight of $FeCl_2$ increases, the capacitor voltage decreases almost linearly and the voltage across the resistor increases accordingly. Three sets of experiment were done and the average values were calculated and graph for average output voltages were shown in Figure 28 and Figure 29. The crude oil used for this part of experiment is obtained from Well I63 with viscosity of 7.5 cp at room temperature which is the least ‘thick’ oil used in the experiment.

- <u>Part 2 – Engine Oil (PETRONAS Mach 5 SAE 40)</u>

Viscosity = 33.8 cp at room temperature (spindle type I)

Table 5 Voltage Values obtained for Engine Oil

Weight of $FeCl_2$ (gram, g)	**$V_{c,\ rms}$ (Volt, V_{rms})**			**$V_{R,\ rms}$ (Volt, V_{rms})**		
	Set 1	**Set 2**	**Set 3**	**Set 1**	**Set 2**	**Set 3**
0	8.921	8.917	8.897	1.103	0.977	1.112
10	4.783	4.694	4.618	5.016	5.215	5.278
20	4.110	4.108	4.081	5.651	5.652	5.702
30	3.957	3.830	3.816	6.020	6.109	6.150
40	3.239	3.306	3.325	6.227	6.231	6.316
50	2.968	3.101	3.118	6.873	6.741	6.696

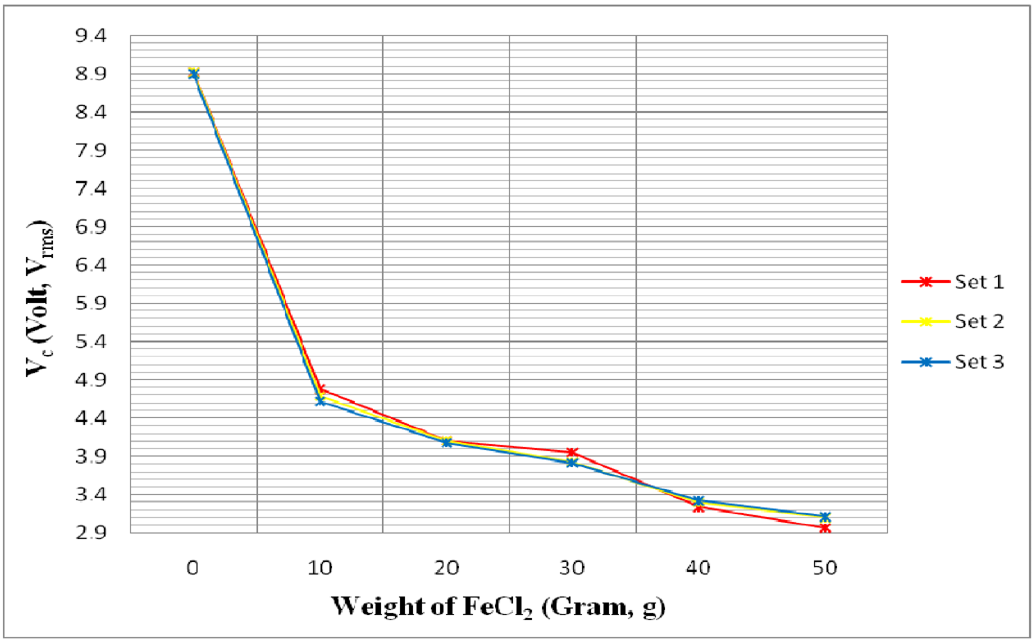


Figure 18 Capacitor Voltage vs. Weight of $FeCl_2$ for Engine Oil

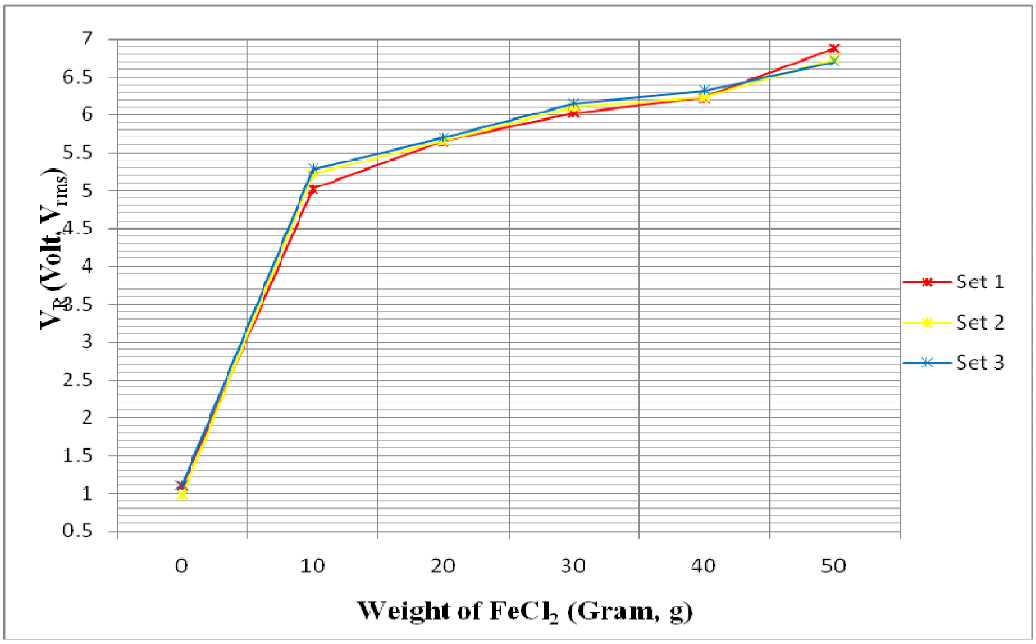


Figure 19 Resistor Voltage vs. Weight of $FeCl_2$ for Engine Oil

For PETRONAS Mach 5 SAE 40 Engine Oil with viscosity of 33.8 cp which is higher than the crude oil, the capacitor voltage measured did decrease as the weight of $FeCl_2$ increased by adding Ferrous(II) Chloride Tetrahydrate into the oil. The capacitor voltage falls between the range of 2.968 V and 4.783 V. Since the output voltage is inversely proportional to the capacitance value as stated in equation (5), it can be concluded that adding $FeCl_2$ into the oil increase the capacitance value of the circuit.

- Part 3 – Cooking Oil Cap Helang

Viscosity = 50.3 cp at room temperature (spindle type I)

Table 6 Voltage Values obtained for Cooking Oil Cap Helang

Weight of $FeCl_2$ (gram, g)	**$V_{c,\ rms}$ (Volt, V_{rms})**			**$V_{R,\ rms}$ (Volt, V_{rms})**		
	Set 1	**Set 2**	**Set 3**	**Set 1**	**Set 2**	**Set 3**
0	8.962	8.961	8.977	1.001	1.001	0.993
10	1.755	1.748	1.780	9.476	9.481	9.372
20	1.542	1.542	1.609	9.835	9.835	9.822
30	1.106	1.112	1.123	9.896	9.901	9.861
40	0.720	0.696	0.810	9.853	9.877	9.871
50	0.697	0.613	0.596	9.871	9.831	9.896

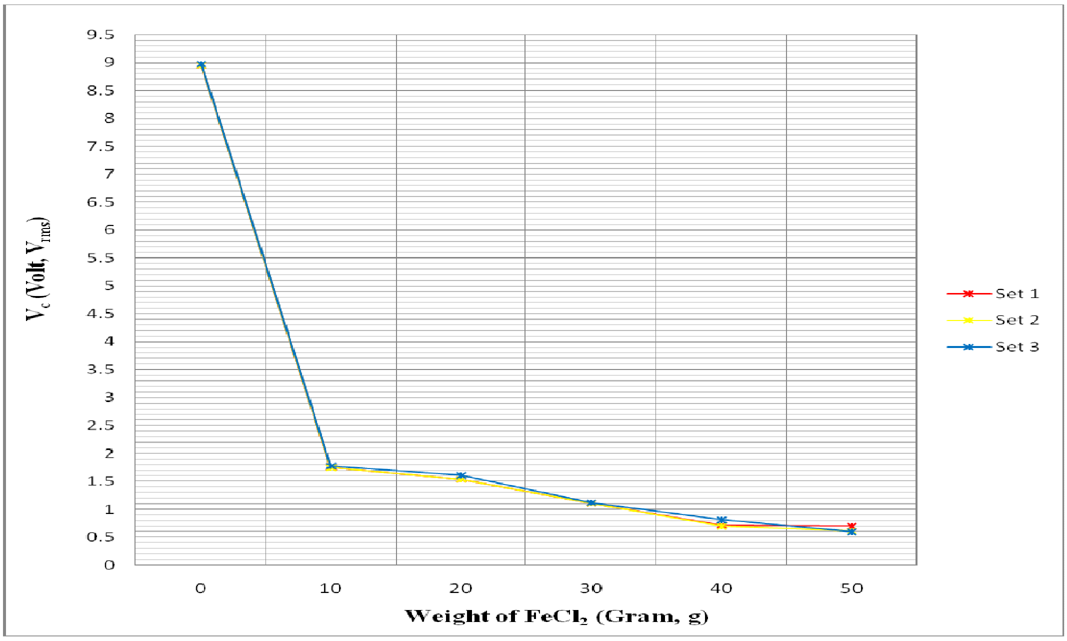


Figure 20 Capacitor Voltage vs. Weight of $FeCl_2$ for Cooking Oil Cap Helang

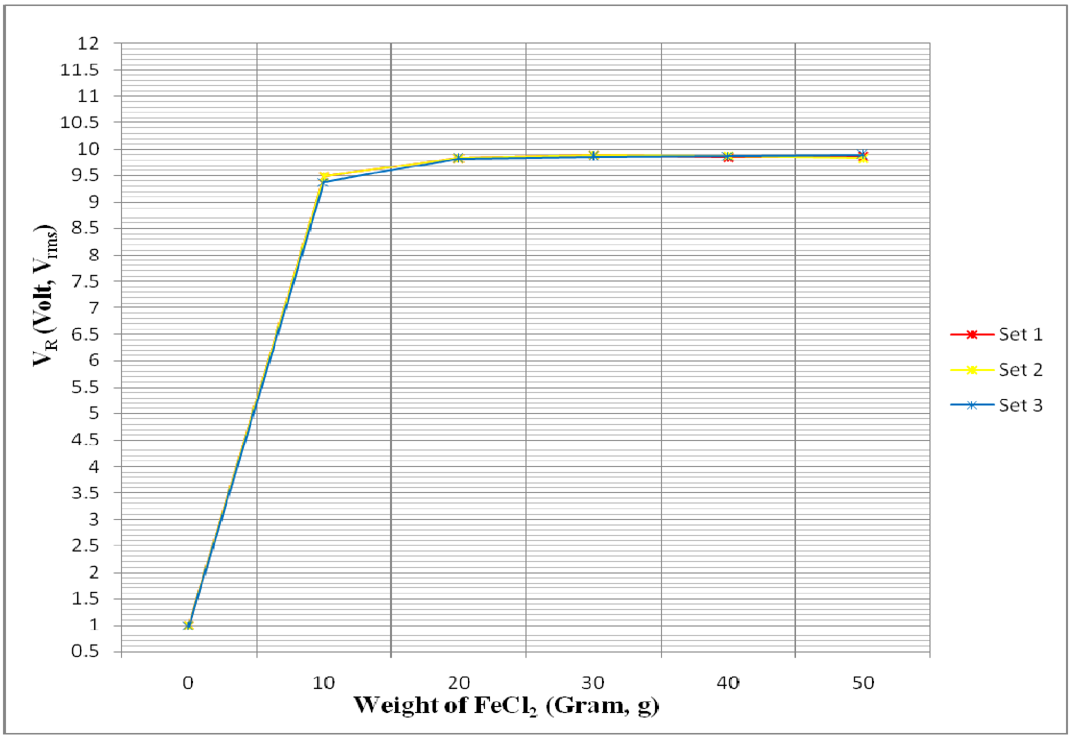


Figure 21 Resistor Voltage vs. Weight of $FeCl_2$ for Cooking Oil Cap Helang

Cooking Oil used in this experiment is Cooking Oil Cap Helang and was chosen randomly due to the fact that it is cheap and easy to obtain from any store. Based on Figure 20 and Figure 21, the capacitor output voltage drops as low as 0.613 V in the Set 2 experiment which shows that cooking oil with the highest viscosity has the highest capacitance value compared to crude oil and engine oil when the same amount of $FeCl_2$ was added. As it was stated in equation (5), the higher the capacitance value, the lower is the output voltage.

Next section covers the results obtained by adding Ferric(III) Chloride Hexahydrate which represents the next stage of corrosion i.e. rusting process.

4.2.2 Rusting Stage – Ferric(III) Chloride Hexahydrate

Rust is produced when solid precipitated produced in the early stage of corrosion is further oxidized as stated in equation (4). The same procedure as previous experiment was implemented in this section and data comparison is done in the discussion section.

- Part 1 – Crude Oil (ANGSI Well I63)

Viscosity = 7.5 cp at room temperature (spindle type IV); 2.48 cp at 60°C

Table 7 Voltage Values obtained for Crude Oil (ANGSI Well I63)

Weight of $FeCl_3$ (gram, g)	**$V_{c, rms}$ (Volt, V_{rms})**			**$V_{R, rms}$ (Volt, V_{rms})**		
	Set 1	**Set 2**	**Set 3**	**Set 1**	**Set 2**	**Set 3**
0	8.964	8.971	8.973	1.002	0.998	0.997
10	7.484	7.878	7.825	1.991	1.299	1.311
20	7.773	7.466	7.459	1.318	1.578	1.572
30	7.462	7.187	7.216	1.721	2.127	2.108
40	6.627	6.785	6.631	3.016	2.992	3.011
50	4.939	5.002	5.112	4.965	4.831	4.826

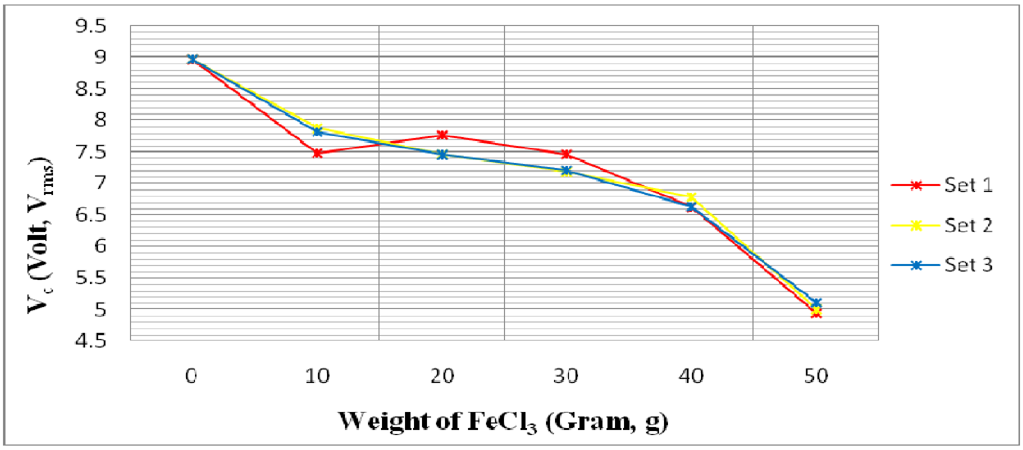


Figure 22 Capacitor Voltage vs. Weight of $FeCl_3$ for Crude Oil

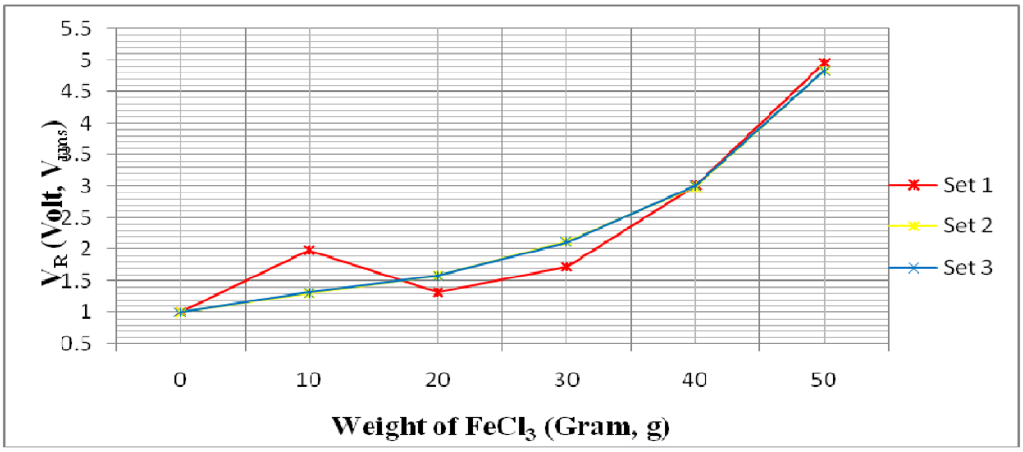


Figure 23 Resistor Voltage vs. Weight of $FeCl_3$ for Crude Oil

The first set of data obtained for this experiment is not constant as error might occur in setting up the experiment i.e. faulty probe. However, the data obtained from Set 2 and Set 3 are reliable as it gives constant changes in the output voltage. The capacitor output voltage drops as increasing amount of $FeCl_3$ were added into the beaker to react with the oil. On the other hand, the resistor output voltage increases as more $FeCl_3$ were added. Further improvement in the data collection can be done by conducting the experiment more frequent and plot the average value for comparison purposes.

- Part 2 – Engine Oil (PETRONAS Mach 5 SAE 40)

Viscosity = 33.8 cp at room temperature (spindle type I)

Table 8 Voltage Values obtained for Engine Oil

Weight of $FeCl_3$ (gram, g)	**$V_{c, rms}$ (Volt, V_{rms})**			**$V_{R, rms}$ (Volt, V_{rms})**		
	Set 1	**Set 2**	**Set 3**	**Set 1**	**Set 2**	**Set 3**
0	8.857	8.953	8.948	1.003	0.989	1.001
10	2.339	2.298	2.333	8.864	8.977	8.894
20	2.278	2.263	2.271	8.987	8.991	8.985
30	2.109	2.157	2.126	9.118	9.026	9.101
40	2.246	2.009	2.101	8.755	9.133	9.128
50	1.989	1.993	1.889	9.217	9.205	9.190

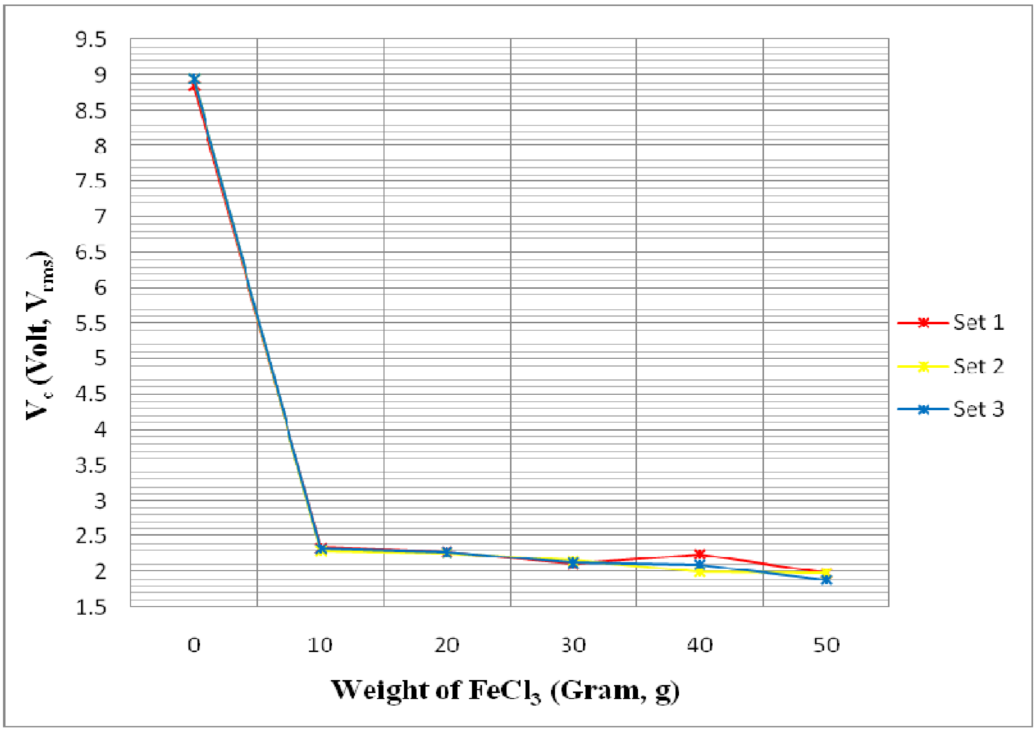


Figure 24 Capacitor Voltage vs. Weight of $FeCl_3$ for Engine Oil

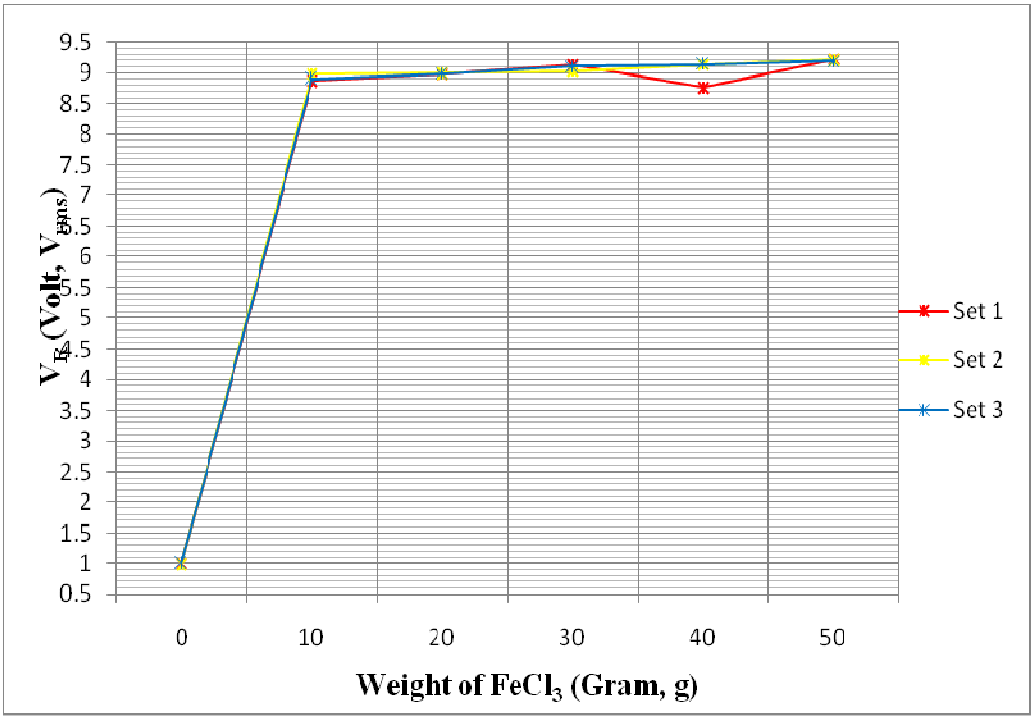


Figure 25 Resistor Voltage vs. Weight of $FeCl_3$ for Engine Oil

Based on Figure 24 and Figure 25, the capacitor output voltage drops as low as 1.889 V in the Set 3 for 50g of $FeCl_3$. As the weight of $FeCl_3$ increased in the oil, the voltage value across the resistor increases almost linearly while the output voltage across the capacitive plates decreases. Engine oil having viscosity of 33.8 cp in room temperature shows small changes in voltage value as $FeCl_3$ was added in increasing amount into the oil.

- Part 3 – Cooking Oil Cap Helang

Viscosity = 50.3 cp at room temperature (spindle type I)

Table 9 Voltage Values obtained for Cooking Oil Cap Helang

Weight of $FeCl_3$ (gram, g)	**$V_{c, rms}$ (Volt, V_{rms})**			**$V_{R, rms}$ (Volt, V_{rms})**		
	Set 1	**Set 2**	**Set 3**	**Set 1**	**Set 2**	**Set 3**
0	8.970	8.967	8.981	0.995	0.997	0.988
10	0.434	0.441	0.442	9.576	9.557	9.557
20	0.117	0.218	0.211	9.935	9.921	9.924
30	0.095	0.156	0.160	9.996	9.973	9.966
40	0.103	0.115	0.117	9.953	9.988	9.985
50	0.093	0.087	0.091	9.971	9.991	9.988

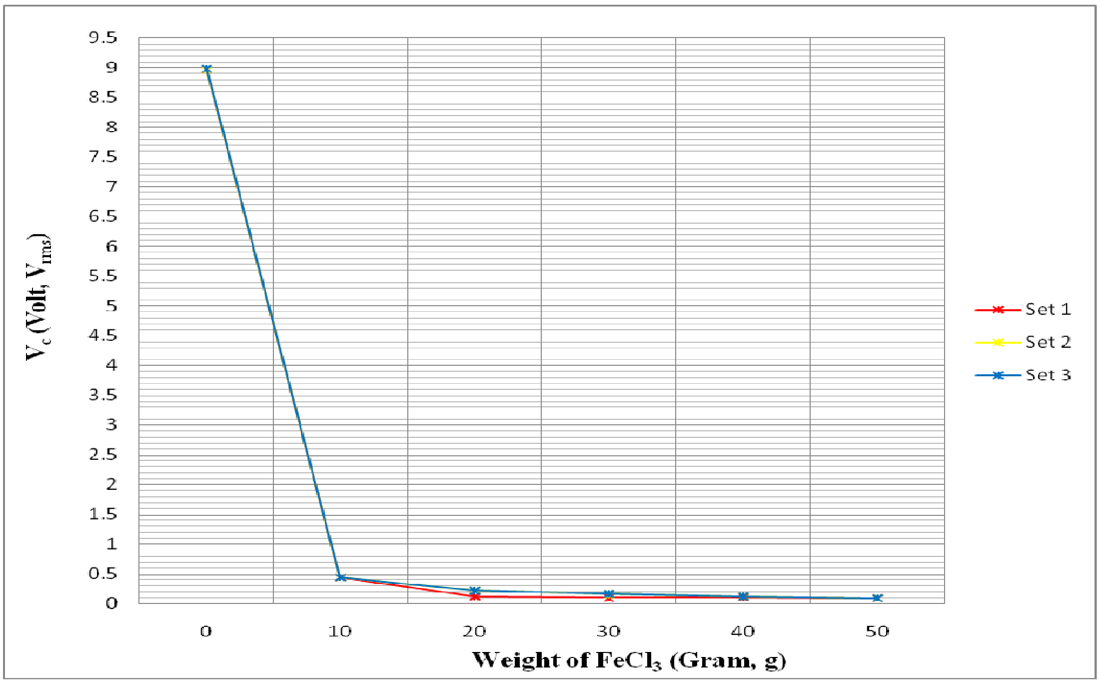


Figure 26 Capacitor Voltage vs. Weight of $FeCl_3$ for Cooking Oil Cap Helang

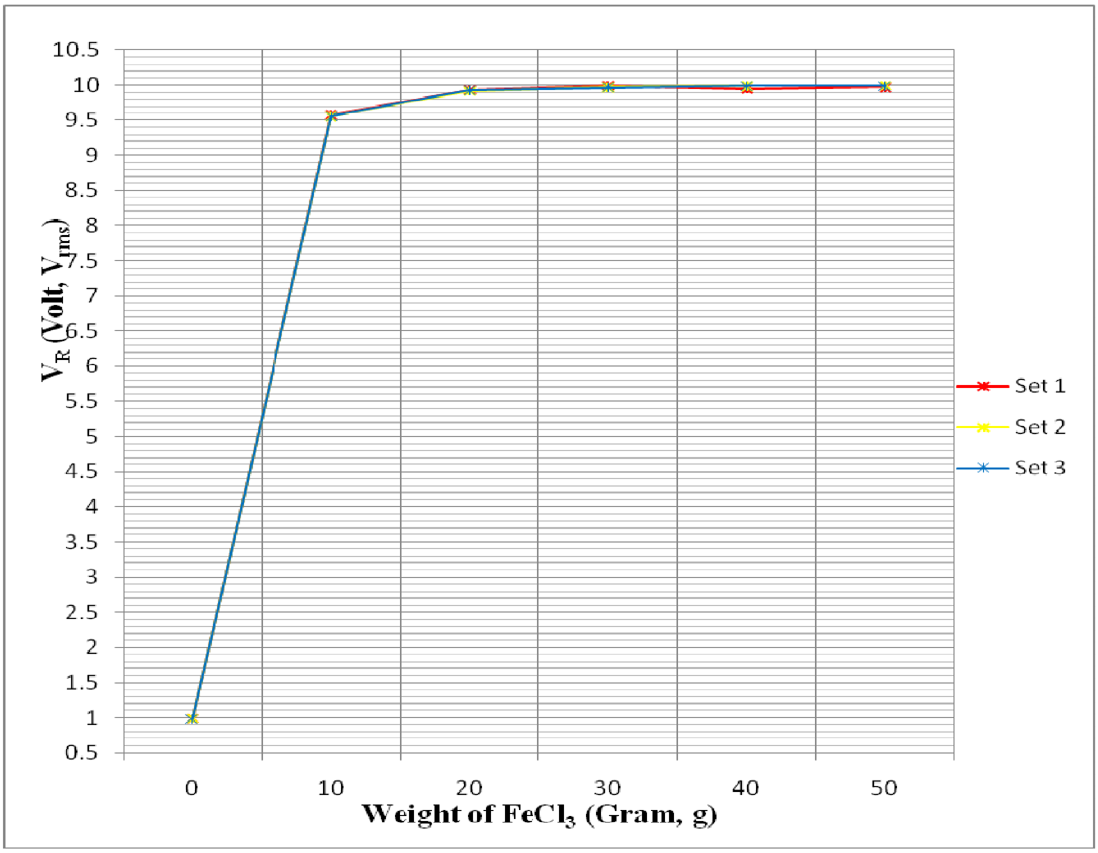


Figure 27 Resistor Voltage vs. Weight of $FeCl_3$ for Cooking Oil Cap Helang

Figure 26 and Figure 27 show the results obtained when $FeCl_3$ were added into cooking oil. The capacitor output voltage is very small - less than 1V and larger voltage drop occurred across the resistor component. The viscosity of the cooking oil was found to be 50.3 cp at room temperature which makes it the ‘thickest’ oil used for the experiment. Further comparison between each part of experiment is discussed in the next section.

4.3 Discussions

4.3.1 Material Selection

For the capacitive plates, aluminium was chosen due to its corrosion resistance and cheaper cost. According to [14], few advantageous properties of aluminium are as follow:

i) Low density (light),
ii) Excellent heat conductor,
iii) Good electrical conductor – around two-thirds of the copper,
iv) Good resistance to atmospheric corrosion.

The principal physical propertied of unalloyed aluminium can be found in Table 10 in **Appendix D**.

Platinum or gold plate can also be used as the capacitive plates as it is well known that the two materials have high resistance to corrosion and tarnishing. They has high boiling point which make them suitable to be installed in the pipeline with high temperature flow. However, please bear in mind that the output voltage does not dependable on the types of material being used as the capacitive plate as stated in equation (6) where the permittivity of the materials between the two plates that determined the value of C.

4.3.2 Results Analysis for Corrosion - Ferrous(II) Chloride Tetrahydrate

The experiments conducted were done in FYP Lab Located at Building 22, Level 1, Academic Complex with room temperature of 25°C and under normal atmospheric pressure. For comparison purpose, the average values of the three set of experiment done for each type of oil were taken and are shown in Figure 28 and Figure 29.

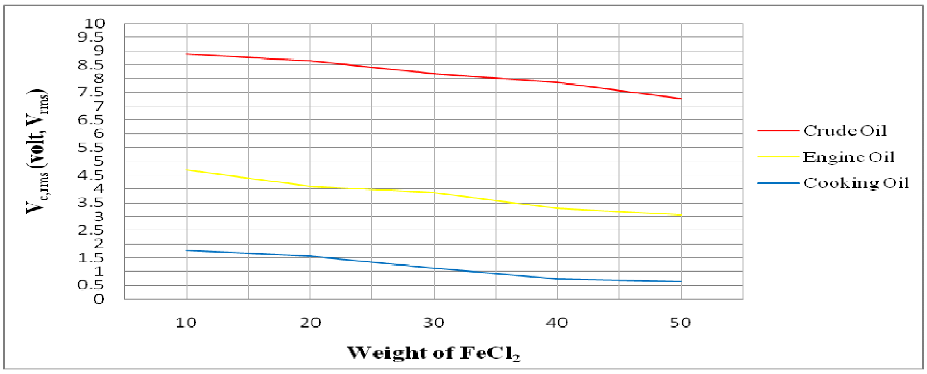


Figure 28 Average Capacitor Voltage vs. Weight of $FeCl_2$ for Crude Oil, Engine Oil and Cooking Oil

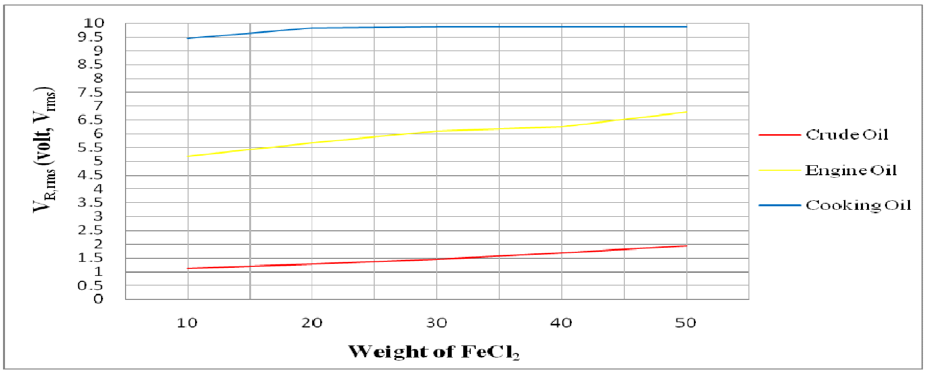


Figure 29 Average Resistor Voltage vs. Weight of $FeCl_2$ for Crude Oil, Engine Oil and Cooking Oil

Based on the graphs above (Figure 28 and Figure 29), the average capacitor voltage, $V_{c,rms}$ decreases as more Ferrous(II) Chloride Tetrahydrate were mix into the oil. Crude oil with the smallest value of viscosity recorded the highest capacitor output voltage – range is between 7V – 9V compared to engine oil and cooking oil. Thus it can be concluded that the lower is the oil viscosity, the higher is the output voltage across the plates.

$$Viscosity \propto \frac{1}{V_{c,rms}} \text{ for the same amount of } FeCl_2$$

By adding FeCl2 in increasing amount, all three types of oil responded in the same manner where the value of capacitor output voltage decreases and the resistor output voltage drops. Thus, it is feasible to apply the capacitor detection principle for detecting corrosion in oil pipelines.

4.3.3 Results Analysis for Rust – Ferric(III) Chloride Hexahydrate

The same procedures of experiment were done in the same location to avoid results being affected by the room temperature and other external factor e.g. amount of moisture in the room. Ferric(III) Chloride Hexahydrate is used to represent the rust component in the oil pipeline which will be produced after certain period of time.

Based on Figure 30 and Figure 31, the voltage across the capacitive plates decreases as more Iron(III) ion was added into the oil. On the other hand, the voltage across the resistor increases with the increasing amount of $FeCl_3$ added into the oil. These show that the output voltage across the capacitor is smaller while the resistor voltage increases when corrosion is more severe – more Iron(III) ion in the oil.

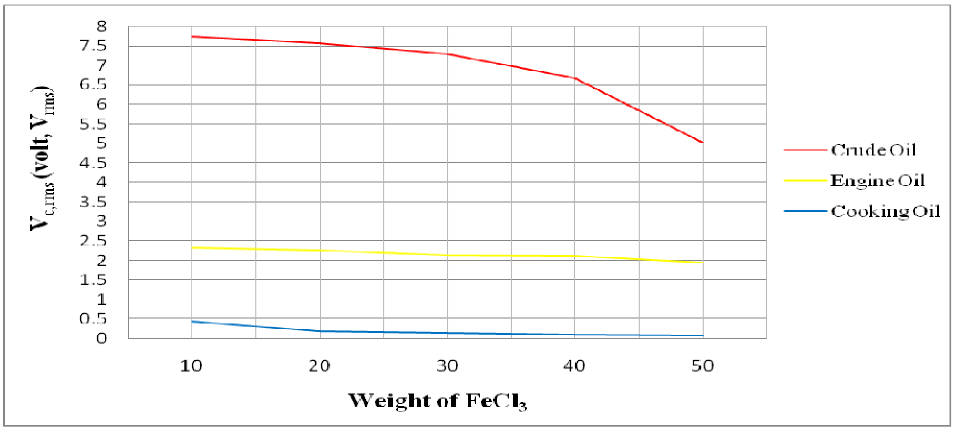


Figure 30 Average Capacitor Voltage vs. Weight of $FeCl_3$ for Crude Oil, Engine Oil and Cooking Oil

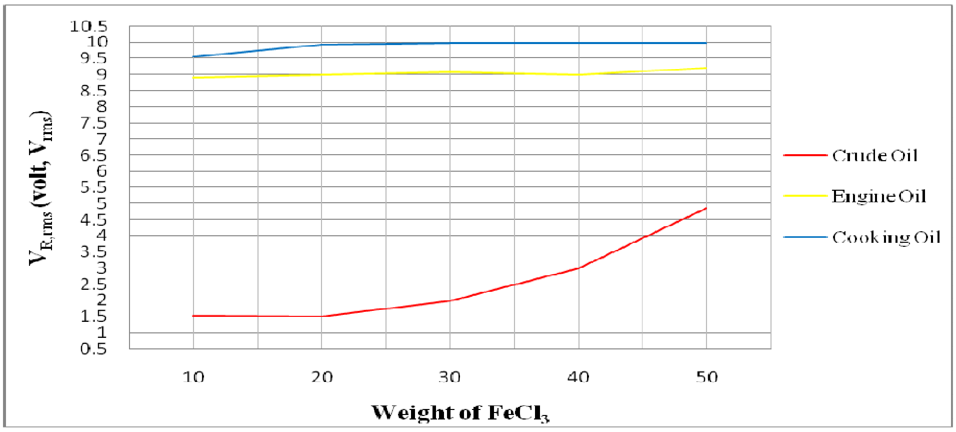


Figure 31 Average Resistor Voltage vs. Weight of $FeCl_3$ for Crude Oil, Engine Oil and Cooking Oil

4.3.4 Comparison between Output Voltages for $FeCl_2$ and $FeCl_3$

In order further understands the effect of different levels of corrosion the output voltages, comparison between the two sections of experiments were done and can be found in the next two figures i.e. Figure 32 and Figure 33.

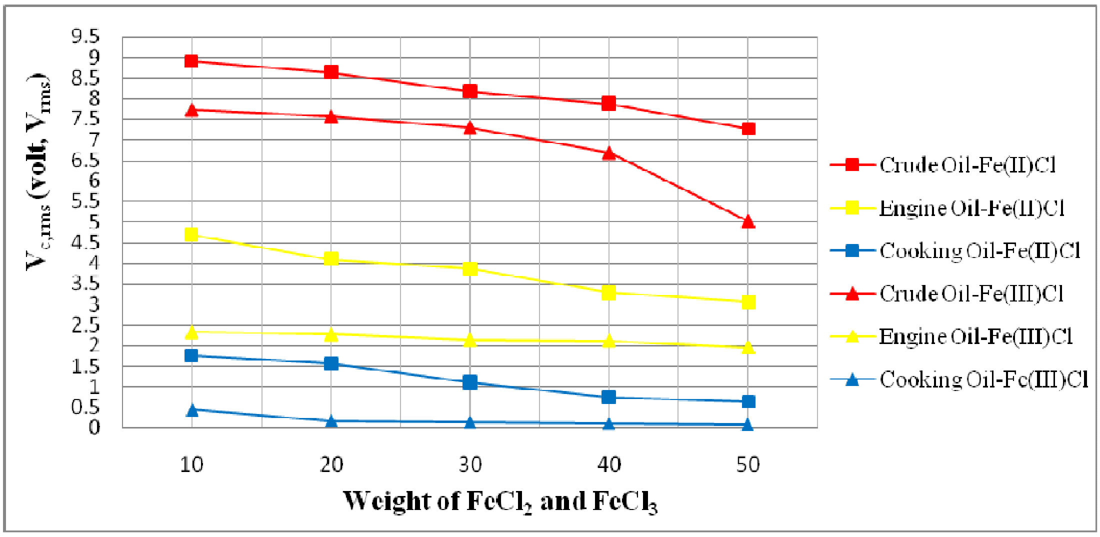


Figure 32 Comparison between Average Capacitor Voltage for Early Corrosion Stage and Rusting Process

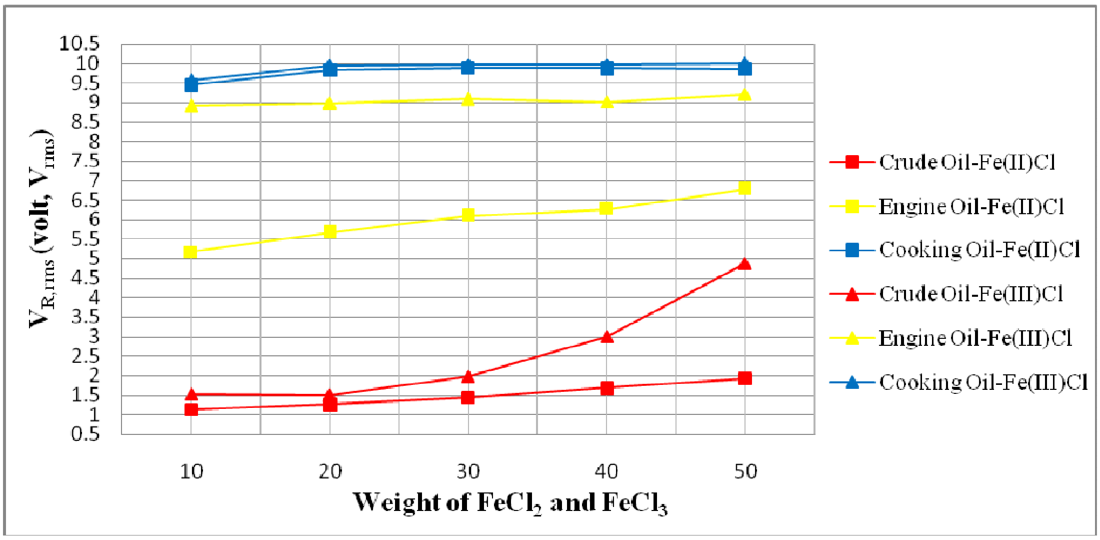


Figure 33 Comparison between Average Resistor Voltage for Early Corrosion Process and Rusting

From Figure 32 and Figure 33, rusting process produce higher voltage drop across the capacitor compared to the early stage of corrosion process which releases Iron(II) ion (Fe^{2+}) into the oil. Based on these findings, it can be concluded that the severe the corrosion process took place in the pipeline, the lower is the voltage reading measured across the plates. For pipelines that carrying crude oil, the voltage drop is more significant as it drops around 0.403V per 10g of $FeCl_2$ compared to 0.2813V for cooking oil. For engine oil and cooking oil which have higher values of viscosity, the difference in voltage drop is smaller and less significant. Sensitivity test can be done for further improvement of the capacitive plates e.g. increasing the frequency of the input voltage.

From the findings and experiment done, capacitive plates can be a corrosion detector since the output voltage across the capacitive plates do correspond to the amount of Iron(II) and Iron(III) ion being released when corrosion process occur. However, it is reminded that these experiments were done under few assumptions in which other particles or impurity present in the oil was neglected. In the real process line, comparison between two pairs of the sensor was made and thus impurity present in the oil does not actually affect the conclusion made based on the voltage readings found. In ideal case, when there is no corrosion between the two pairs of sensor, the voltage readings should be equal despite the impurity of the oil e.g. crude oil might contain different percentage of Sulphur and moisture in it. Thus, it is proven that the permittivity of the oil being measured can be used to determine the condition of the pipeline by making other variables e.g. area of plates and the distance between them as a constant.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The capacitive detector can be an accurate corrosion-measuring as it detects the changes of oil permittivity. Changes in oil permittivity due to present of corroded metal will affect the electric flux being produced between the two capacitive plates which in turn vary the voltage across the circuit. Circuit in Figure 4 is used to simulate this phenomenon for further understanding and clarification. The results clearly show that the output voltage will drop linearly when the capacitance value is increase by the step of 10nF. The frequency is also being varied to show the effects of input voltage to the *RC* circuit.

Real experiments were conducted to test the detection circuit and experiment it with different types of oil with different level of viscosity. From these experiments, relationship between the oils viscosities with the output voltage is determined. From the two sections of experiment done, Figure 32 and Figure 33 conclude it all wherein average values from three sets of experiment were taken for analysis purposes. The viscosity of oils does affect the sensitivity of the sensor i.e. the lower is the viscosity, the more significant is the changes in the output voltage when more iron ion present in it e.g. For crude oil having viscosity of 7.5 cp in room temperature, the difference between the capacitor output voltage for 10g addition of $FeCl_2$ is 0.403V compared to 0.2813V for cooking oil with viscosity of 50.3 cp.

In terms of the level of corrosion, when iron(III) ions present in the oil which refer to the rusting process, the output voltage across the capacitive plates is lower compared to the early stage of corrosion that releases iron(II) ion into the oil. Further experiment and research can to be done so that the operators are able to predict the level of corrosion based on the voltage value found.

5.2 Recommendation

5.2.1 Product Design

Overall product can be improved by using better materials to achieve the objectives of detecting corrosion in oil pipeline. Aluminium plates can be replaced with a better corrosion resistance material such as platinum or gold coated plate to extend the service life of the sensor. A thorough study on the sensor placement and installment need to be done to produce an efficient and reliable corrosion detection sensor and is feasible to be used especially in the oil and gas industries.

As for the data communication, higher radio frequency can be used to achieve longer distance in data transmission. The design of the module must be able to withstand the harsh environment and achieve reliable communication between two points. The small dimension of radio frequency module allows it to be installed anywhere possible and made it easy to be replaced in case of failure.

5.2.2 Experiments and Data Analysis

A series numbers of experiment were done in order to have enough data for analysis purposes and produce a thorough report on the findings. The data collected so far is only sufficient to prove that the capacitive sensor is able to be used as a corrosion detector but the efficiency has yet to be determined. Based on the report, the range of detection and other criteria of the sensor can be made and find ways to improve the overall product and commercialize it. Further research and experimental works can be done to develop an excellent corrosion detection circuit utilizing capacitive plate's principle.

REFERENCES

[1] Mars G. Fontana, *Corrosion Engineering*, Third Ed., McGraw-Hill International Editions.

[2] A.A Gonik, “Local Inner Corrosion of Oil and Gas Pipelines in the West-Siberian Fields and Its Prevention”, *Protection of Metals*, Vol. 41, No. 5, 2005, pp. 487-490.

[3] Richard Pike, “Why Oil Companies Must Grasp the Corrosion Issue”, 25 August 2006, <http://www.rsc.org/images/Corrosion_tcm18-62363.pdf>, Retrieved date: 22nd February 2009.

[4] Peter Elgar, *Sensors for Measurement and Control*, Malaysia: Prentice Hall, 1998.

[5] Charles K. Alexander and Matthew N.O. Sadiku, *Fundamentals of Electric Circuits,* Second Ed., Singapore: McGraw Hill, 2004.

[6] Devendra K. Misra, *Radio-Frequency and Microwave Communication Circuits,* Second Ed., John Wiley and Sons, Inc., 2004.

[7] Mark Ciampa, *Guide to Wireless Communications*, Thomson Course Technology, 2002.

[8] Orion Instruments Tech Tools – Dielectric Constants, <http://www.orioninstruments.com/html/tools/dielectric.aspx>, Retrieved date: 22nd February 2009.

[9] Larry K. Baxter, *Capacitive Sensors Design and Applications*, IEEE Press Series on Electronic Technology, Robert J. Herrick (Series Editor), IEEE Press, New York, 1997.

[10] Alan S. Morris, *Measurement & Instrumentation Principles*, Butterworth Heinemann, 2001.

[11] Bart De Geeter, Olivier Nys and Jean-Paul Bardyn, “A High Temperature Micropower Capacitive Pressure Sensor Interface Circuit”, *Analog Integrated Circuits and Signal Processing*, Kluwer Academic Publisher Boston, 1997, Volume 14, pp 179-191.

[12] William C. Dunn, *Introduction to Instrumentation, Sensors, and Process Control*, Artech House, 2006.

[13] O. P. Thakur and Anjani Kumar Singh, “Modeling of Capacitive Sensor filled with Elastic Dielectrics and its Advantages” in *Third International Conference on Sensing Technology*, 2008, Tainan, Taiwan.

[14] Christian Vargel, *Corrosion of Aluminium*, Elsevier, 2004.

[15] George V. Chilingar, Ryan Mourhatch and Ghazi D. Al-Qahtani, *The Fundamentals of Corrosion and Scaling for Petroleum and Environmental Engineers*, Gulf Publishing Company, 2008.

[16] *Corrosion in the Petrochemical Industry*, ASM International – The Materials Information Society, 1999, edited by Linda Garverick.

[17] Jerome Kruger, April 2001.<http://electrochem.cwru.edu/ed/encycl/art-c02-corrosion.htm>, Retrieved date: 3rd April 2009.

[18] Dr. B. Dunlevy, Material Safety Data Sheet for Ferrous(II) Chloride Tetrahydrate, <http://chemistry.slss.ie/resources/downloads/ph_sd_md_iron2chloride.pdf>, Retrieved date: 16th August 2009.

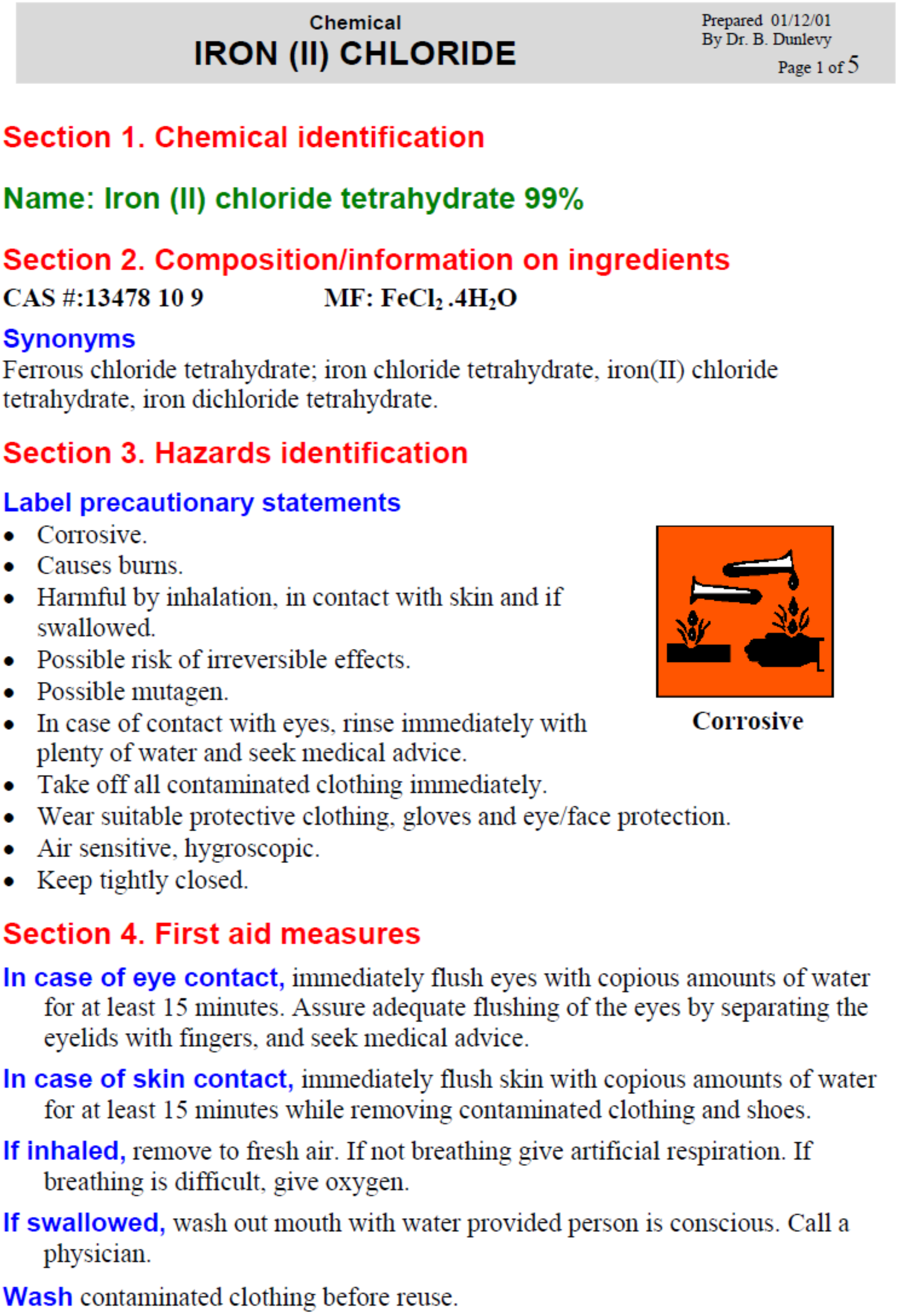
[19] Dr. B. Dunlevy, Material Safety Data Sheet for Ferrous(II) Chloride Tetrahydrate, <http://chemistry.slss.ie/resources/downloads/ph_sd_md_iron3chloride.pdf>, Retrieved date: 16th August 2009.

[20] P. Marcus and J. Oudar, *Corrosion Mechanisms in Theory and Practice*, Maecel Dekker, Inc., 1995.

APPENDICES

APPENDIX A

MATERIAL SAFETY DATA SHEET FOR FERROUS(II) CHLORIDE TETRAHYDRATE



Chemical

IRON (II) CHLORIDE

Prepared 01/12/01
By Dr. B. Dunlevy
Page 1 of 5

Section 1. Chemical identification

Name: Iron (II) chloride tetrahydrate 99%

Section 2. Composition/information on ingredients

CAS #:13478 10 9 **MF: $FeCl_2 .4H_2O$**

Synonyms

Ferrous chloride tetrahydrate; iron chloride tetrahydrate, iron(II) chloride tetrahydrate, iron dichloride tetrahydrate.

Section 3. Hazards identification

Label precautionary statements

- Corrosive.
- Causes burns.
- Harmful by inhalation, in contact with skin and if swallowed.
- Possible risk of irreversible effects.
- Possible mutagen.
- In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
- Take off all contaminated clothing immediately.
- Wear suitable protective clothing, gloves and eye/face protection.
- Air sensitive, hygroscopic.
- Keep tightly closed.

Corrosive

Section 4. First aid measures

In case of eye contact, immediately flush eyes with copious amounts of water for at least 15 minutes. Assure adequate flushing of the eyes by separating the eyelids with fingers, and seek medical advice.

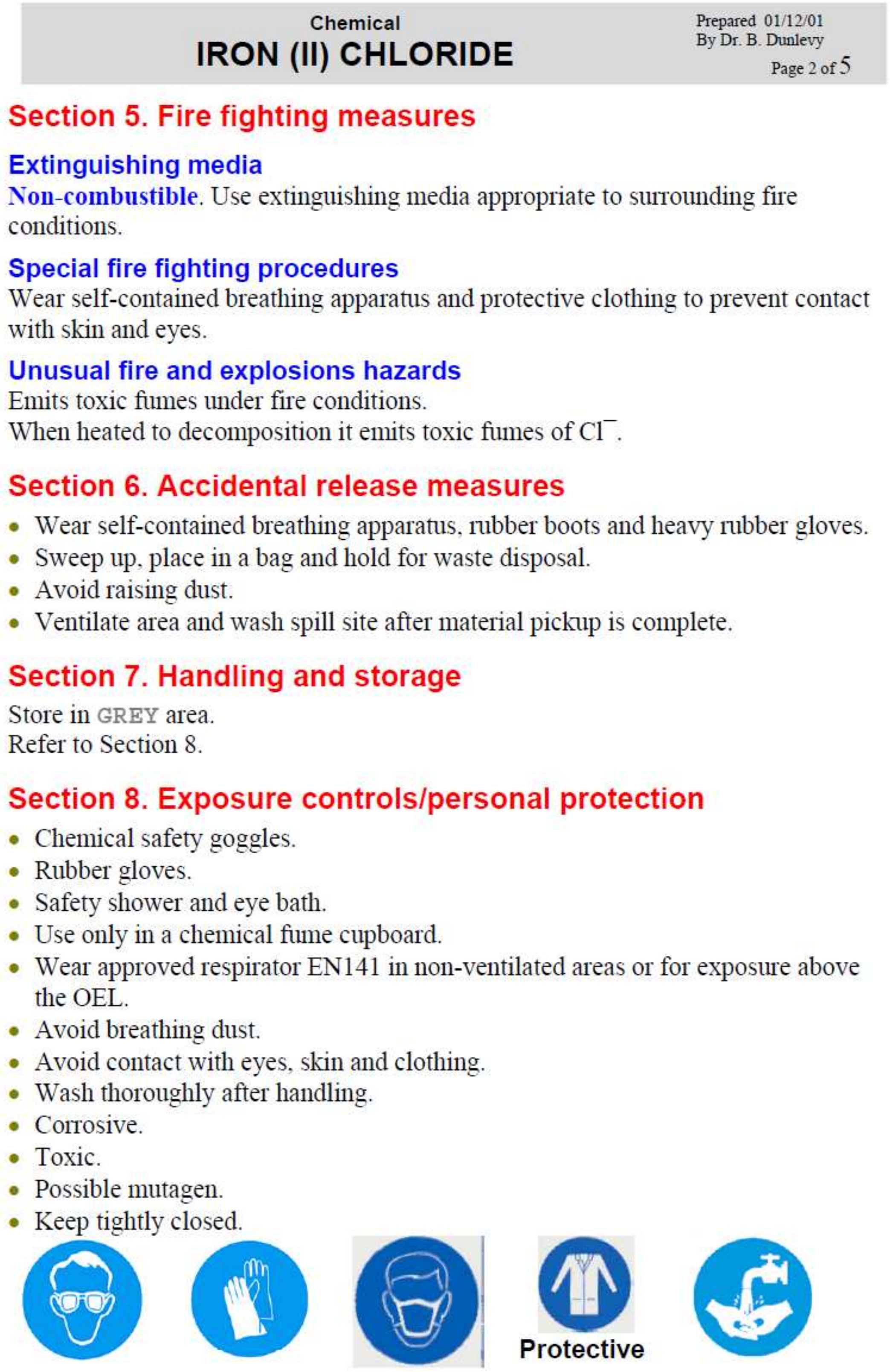
In case of skin contact, immediately flush skin with copious amounts of water for at least 15 minutes while removing contaminated clothing and shoes.

If inhaled, remove to fresh air. If not breathing give artificial respiration. If breathing is difficult, give oxygen.

If swallowed, wash out mouth with water provided person is conscious. Call a physician.

Wash contaminated clothing before reuse.

Source: http://chemistry.slss.ie/resources/downloads/ph_sd_md_iron2chloride.pdf



Chemical

IRON (II) CHLORIDE

Prepared 01/12/01
By Dr. B. Dunlevy
Page 2 of 5

Section 5. Fire fighting measures

Extinguishing media

Non-combustible. Use extinguishing media appropriate to surrounding fire conditions.

Special fire fighting procedures

Wear self-contained breathing apparatus and protective clothing to prevent contact with skin and eyes.

Unusual fire and explosions hazards

Emits toxic fumes under fire conditions.
When heated to decomposition it emits toxic fumes of Cl^{-}.

Section 6. Accidental release measures

- Wear self-contained breathing apparatus, rubber boots and heavy rubber gloves.
- Sweep up, place in a bag and hold for waste disposal.
- Avoid raising dust.
- Ventilate area and wash spill site after material pickup is complete.

Section 7. Handling and storage

Store in **GREY** area.
Refer to Section 8.

Section 8. Exposure controls/personal protection

- Chemical safety goggles.
- Rubber gloves.
- Safety shower and eye bath.
- Use only in a chemical fume cupboard.
- Wear approved respirator EN141 in non-ventilated areas or for exposure above the OEL.
- Avoid breathing dust.
- Avoid contact with eyes, skin and clothing.
- Wash thoroughly after handling.
- Corrosive.
- Toxic.
- Possible mutagen.
- Keep tightly closed.

Source: http://chemistry.slss.ie/resources/downloads/ph_sd_md_iron2chloride.pdf

Chemical

IRON (II) CHLORIDE

Prepared 01/12/01
By Dr. B. Dunlevy
Page 3 of 5

Goggles Gloves Respirator clothing Wash hands

Section 9. Physical and chemical properties

Appearance and odour

Blue green crystals; readily oxidised in solution.

Physical properties

Specific gravity: 1.930 Vapour pressure: 10 mm @ 693 °C

Section 10. Stability and reactivity

Incompatibilities

- Strong oxidizing agents,
- Forms explosive mixtures with: potassium, sodium,
- Protect from moisture.
- Sensitive to air.

Hazardous combustion or decomposition products

Hydrogen chloride gas.

Section 11. Toxicological information

Acute effects

- May be harmful by inhalation, ingestion, or skin absorption.
- Material is extremely destructive to tissue of the mucous membranes and upper respiratory tract, eyes, and skin.
- Inhalation may result in spasm, inflammation, and oedema of the larynx and bronchi, chemical pneumonitis and pulmonary oedema.
- Symptoms of exposure may include burning sensation, coughing, wheezing, laryngitis, shortness of breath, headache, nausea and vomiting.

Chronic effects:

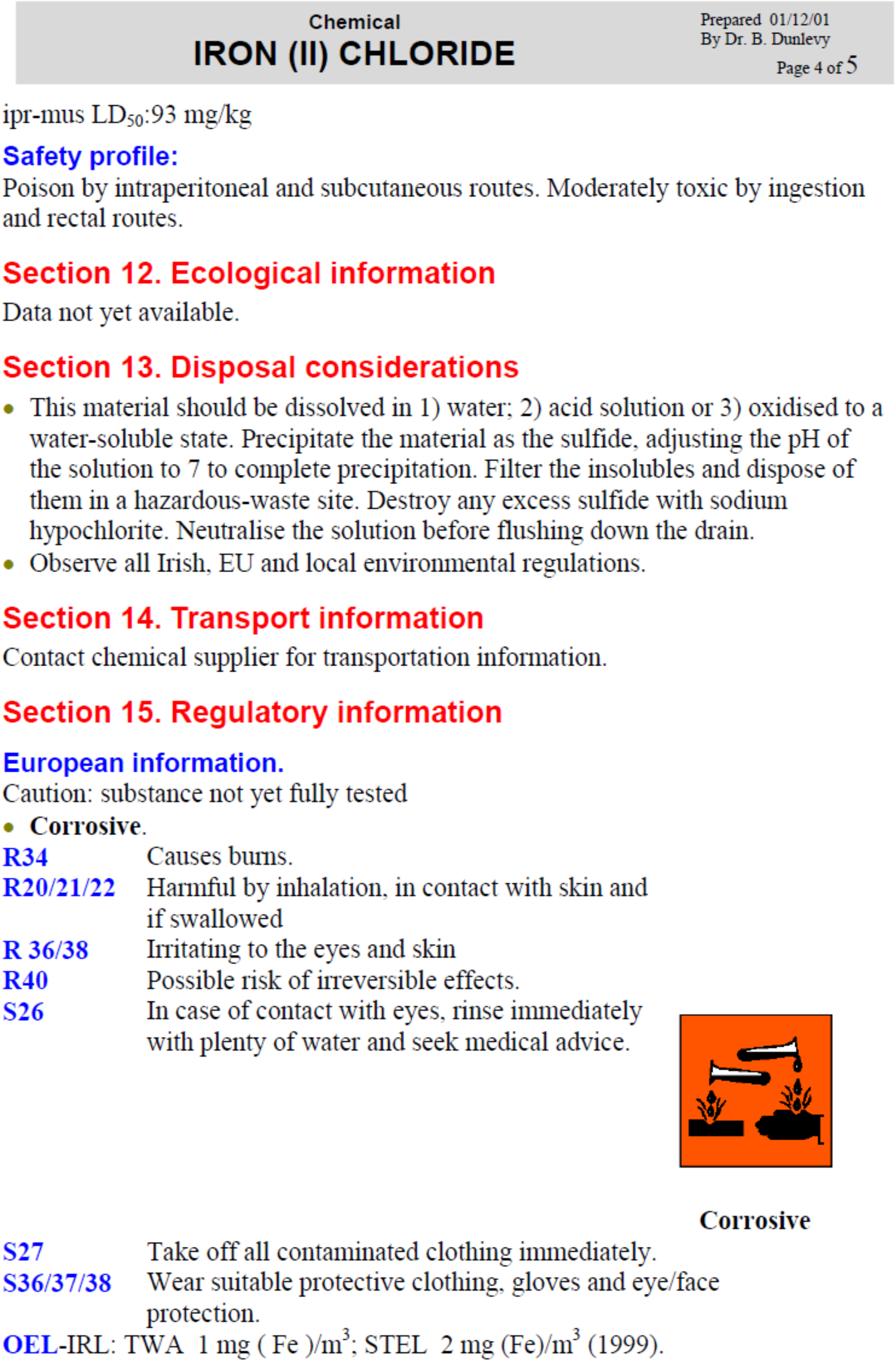
- Laboratory experiments have shown mutagenic effects.

Additional information

Overdose of iron compounds may have a corrosive effect on the gastrointestinal mucosa and be followed by necrosis, perforation and stricture formation. Several hours may elapse before symptoms that can include epigastric pain, diarrhoea, vomiting, nausea and haematemesis occur. After apparent recovery a person may experience metabolic acidosis, convulsions and coma hours or days later. Further complications may develop leading to acute liver necrosis that can result in death due to hepatic coma.

Toxicity data

Source: http://chemistry.slss.ie/resources/downloads/ph_sd_md_iron2chloride.pdf



Chemical
IRON (II) CHLORIDE

Prepared 01/12/01
By Dr. B. Dunlevy
Page 4 of 5

ipr-mus LD_{50}:93 mg/kg

Safety profile:

Poison by intraperitoneal and subcutaneous routes. Moderately toxic by ingestion and rectal routes.

Section 12. Ecological information

Data not yet available.

Section 13. Disposal considerations

- This material should be dissolved in 1) water; 2) acid solution or 3) oxidised to a water-soluble state. Precipitate the material as the sulfide, adjusting the pH of the solution to 7 to complete precipitation. Filter the insolubles and dispose of them in a hazardous-waste site. Destroy any excess sulfide with sodium hypochlorite. Neutralise the solution before flushing down the drain.
- Observe all Irish, EU and local environmental regulations.

Section 14. Transport information

Contact chemical supplier for transportation information.

Section 15. Regulatory information

European information.

Caution: substance not yet fully tested

- **Corrosive**.

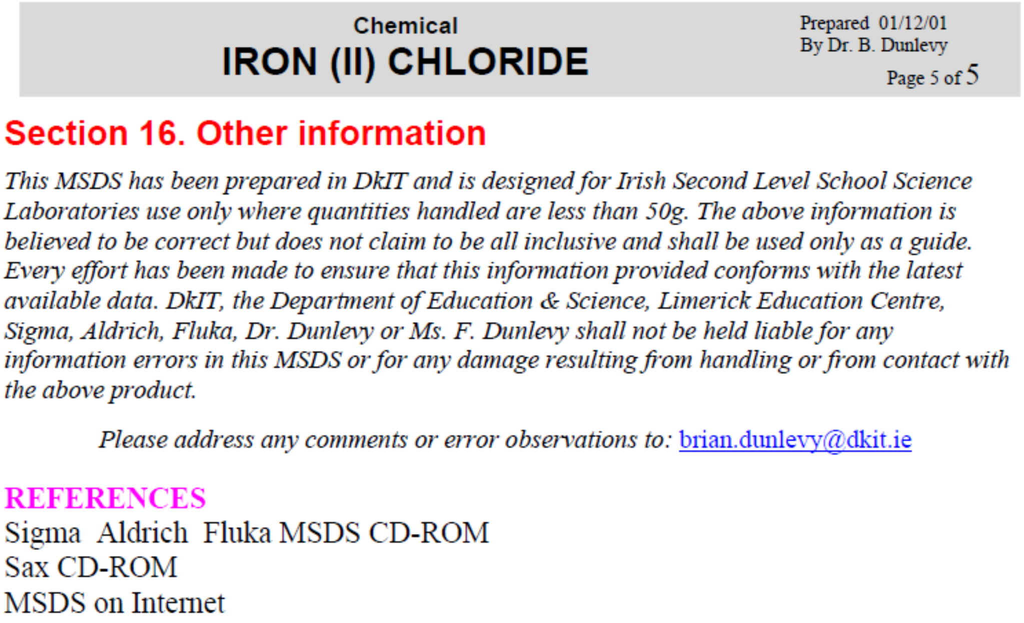
R34	Causes burns.
R20/21/22	Harmful by inhalation, in contact with skin and if swallowed
R 36/38	Irritating to the eyes and skin
R40	Possible risk of irreversible effects.
S26	In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.

Corrosive

S27	Take off all contaminated clothing immediately.
S36/37/38	Wear suitable protective clothing, gloves and eye/face protection.

OEL-IRL: TWA 1 mg (Fe)/m^3; STEL 2 mg (Fe)/m^3 (1999).

Source: http://chemistry.slss.ie/resources/downloads/ph_sd_md_iron2chloride.pdf



Chemical
IRON (II) CHLORIDE

Prepared 01/12/01
By Dr. B. Dunlevy
Page 5 of 5

Section 16. Other information

This MSDS has been prepared in DkIT and is designed for Irish Second Level School Science Laboratories use only where quantities handled are less than 50g. The above information is believed to be correct but does not claim to be all inclusive and shall be used only as a guide. Every effort has been made to ensure that this information provided conforms with the latest available data. DkIT, the Department of Education & Science, Limerick Education Centre, Sigma, Aldrich, Fluka, Dr. Dunlevy or Ms. F. Dunlevy shall not be held liable for any information errors in this MSDS or for any damage resulting from handling or from contact with the above product.

Please address any comments or error observations to: brian.dunlevy@dkit.ie

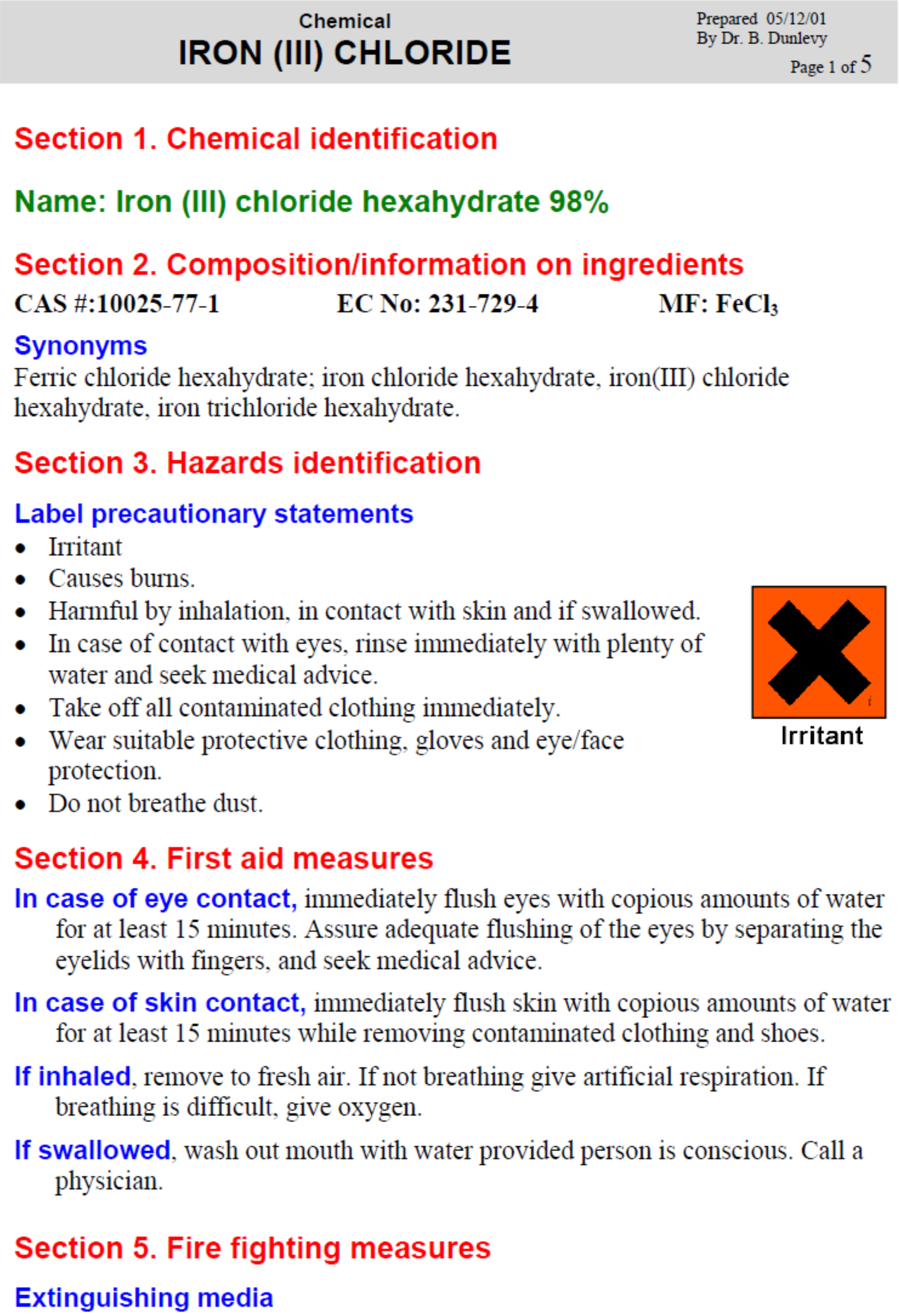
REFERENCES

Sigma Aldrich Fluka MSDS CD-ROM
Sax CD-ROM
MSDS on Internet

Source: http://chemistry.slss.ie/resources/downloads/ph_sd_md_iron2chloride.pdf

APPENDIX B

MATERIAL SAFETY DATA SHEET FOR FERRIC(III) CHLORIDE HEXAHYDRATE



Chemical

IRON (III) CHLORIDE

Prepared 05/12/01
By Dr. B. Dunlevy
Page 1 of 5

Section 1. Chemical identification

Name: Iron (III) chloride hexahydrate 98%

Section 2. Composition/information on ingredients

CAS #:10025-77-1 **EC No: 231-729-4** **MF: $FeCl_3$**

Synonyms

Ferric chloride hexahydrate; iron chloride hexahydrate, iron(III) chloride hexahydrate, iron trichloride hexahydrate.

Section 3. Hazards identification

Label precautionary statements

- Irritant
- Causes burns.
- Harmful by inhalation, in contact with skin and if swallowed.
- In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
- Take off all contaminated clothing immediately.
- Wear suitable protective clothing, gloves and eye/face protection.
- Do not breathe dust.

Section 4. First aid measures

In case of eye contact, immediately flush eyes with copious amounts of water for at least 15 minutes. Assure adequate flushing of the eyes by separating the eyelids with fingers, and seek medical advice.

In case of skin contact, immediately flush skin with copious amounts of water for at least 15 minutes while removing contaminated clothing and shoes.

If inhaled, remove to fresh air. If not breathing give artificial respiration. If breathing is difficult, give oxygen.

If swallowed, wash out mouth with water provided person is conscious. Call a physician.

Section 5. Fire fighting measures

Extinguishing media

Source: http://chemistry.slss.ie/resources/downloads/ph_sd_md_iron3chloride.pdf

Chemical

IRON (III) CHLORIDE

Prepared 05/12/01
By Dr. B. Dunlevy
Page 2 of 5

- Non-combustible.
- Use extinguishing media appropriate to surrounding fire conditions.

Special fire fighting procedures

Wear self-contained breathing apparatus and protective clothing to prevent contact with skin and eyes.

Unusual fire and explosions hazards

Emits toxic fumes under fire conditions.

Section 6. Accidental release measures

- Wear self-contained breathing apparatus, rubber boots and heavy rubber gloves.
- Sweep up, place in a bag and hold for waste disposal.
- Avoid raising dust.
- Ventilate area and wash spill site after material pickup is complete.

Section 7. Handling and storage

Store in GREY area.
Refer to Section 8.

Section 8. Exposure controls/personal protection

- Chemical safety goggles.
- Rubber gloves.
- Safety shower and eye bath.
- Use only in a chemical fume cupboard.
- Wear approved respirator EN141 in non-ventilated areas or for exposure above the OEL.
- Avoid breathing dust.
- Avoid contact with eyes, skin and clothing.
- Wash thoroughly after handling.
- Corrosive.
- Toxic.
- Keep tightly closed.
- Store in a cool dry place.

Goggles

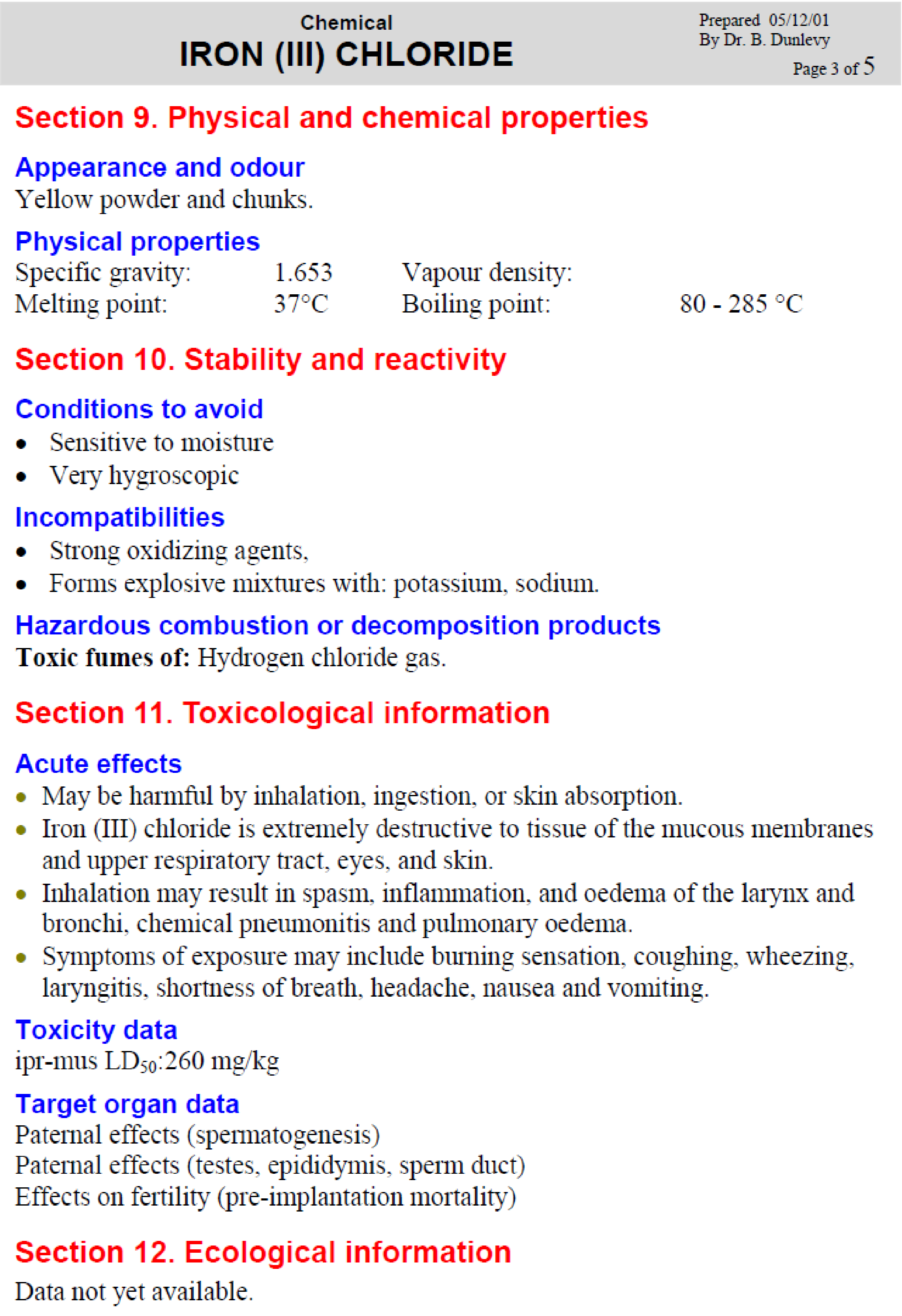
Gloves

Respirator

Protective clothing

Wash hands

Source: http://chemistry.slss.ie/resources/downloads/ph_sd_md_iron3chloride.pdf



Chemical
IRON (III) CHLORIDE

Prepared 05/12/01
By Dr. B. Dunlevy
Page 3 of 5

Section 9. Physical and chemical properties

Appearance and odour

Yellow powder and chunks.

Physical properties

Specific gravity:	1.653	Vapour density:	
Melting point:	37°C	Boiling point:	80 - 285 °C

Section 10. Stability and reactivity

Conditions to avoid

- Sensitive to moisture
- Very hygroscopic

Incompatibilities

- Strong oxidizing agents,
- Forms explosive mixtures with: potassium, sodium.

Hazardous combustion or decomposition products

Toxic fumes of: Hydrogen chloride gas.

Section 11. Toxicological information

Acute effects

- May be harmful by inhalation, ingestion, or skin absorption.
- Iron (III) chloride is extremely destructive to tissue of the mucous membranes and upper respiratory tract, eyes, and skin.
- Inhalation may result in spasm, inflammation, and oedema of the larynx and bronchi, chemical pneumonitis and pulmonary oedema.
- Symptoms of exposure may include burning sensation, coughing, wheezing, laryngitis, shortness of breath, headache, nausea and vomiting.

Toxicity data

ipr-mus LD_{50}:260 mg/kg

Target organ data

Paternal effects (spermatogenesis)
Paternal effects (testes, epididymis, sperm duct)
Effects on fertility (pre-implantation mortality)

Section 12. Ecological information

Data not yet available.

Source: http://chemistry.slss.ie/resources/downloads/ph_sd_md_iron3chloride.pdf

Section 13. Disposal considerations

- Iron (III) chloride should be dissolved in 1) water; 2) acid solution or 3) oxidised to a water-soluble state. Precipitate the material as the sulfide, adjusting the pH of the solution to 7 to complete precipitation. Filter the insolubles and bury them in a hazardous-waste site. Destroy any excess sulfide with sodium hypochlorite. Neutralise the solution before flushing down the drain.
- Observe all Irish, EU and local environmental regulations.

Section 14. Transport information

Contact chemical supplier for transportation information.

Section 15. Regulatory information

European information.

Caution: substance not yet fully tested

EC Index No.

Irritant

- **Irritant**

R 36/38	Irritating to the eyes and skin
S 26	In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
S 27	Take off all contaminated clothing immediately.
S 28	After contact with the skin wash immediately with soap and water.
S 36/37/39	Wear suitable protective clothing, gloves and eye/face protection.

OEL-IRL: TWA 1 mg (Fe)/m^3; STEL 2 mg (Fe)/m^3 (1999).

Section 16. Other information

This MSDS has been prepared in DkIT and is designed for Irish Second Level School Science Laboratories use only where quantities handled are less than 50g. The above information is believed to be correct but does not claim to be all inclusive and shall be used only as a guide. Every effort has been made to ensure that this information provided conforms with the latest available data. DkIT, the Department of Education & Science, Limerick Education Centre, Sigma, Aldrich, Fluka, Dr. Dunlevy or Ms. F. Dunlevy shall not be held liable for any information errors in this MSDS or for any damage resulting from handling or from contact with the above product.

Please address any comments or error observations to: brian.dunlevy@dkit.ie

Source: http://chemistry.slss.ie/resources/downloads/ph_sd_md_iron3chloride.pdf

APPENDIX C
CALCULATION OF CAPACITANCE

1. Petroleum with Dielectric constant = 2.1

$$C = \frac{\varepsilon_o \varepsilon_r A}{d}$$

$$C = \frac{(8.854\times10^{-12})(2.1)(0.4\times10^{-3})}{0.04}$$

$$C = 0.1859\,p\mathrm{F}$$

2. Gasoline with Dielectric constant = 2.2

$$C = \frac{\varepsilon_o \varepsilon_r A}{d}$$

$$C = \frac{(8.854\times10^{-12})(2.2)(0.4\times10^{-3})}{0.04}$$

$$C = 0.1948\,p\mathrm{F}$$

3. Castor oil with Dielectric constant = 2.6

$$C = \frac{\varepsilon_o \varepsilon_r A}{d}$$

$$C = \frac{(8.854\times10^{-12})(2.6)(0.4\times10^{-3})}{0.04}$$

$$C = 0.2302\,p\mathrm{F}$$

4. Iron oxide powder with dielectric constant = 14.2

$$C = \frac{\varepsilon_o \varepsilon_r A}{d}$$

$$C = \frac{(8.854\times10^{-12})(14.2)(0.4\times10^{-3})}{0.04}$$

$$C = 1.2573\,p\mathrm{F}$$

5. Water with dielectric constant = 80

$$C = \frac{\varepsilon_o \varepsilon_r A}{d}$$

$$C = \frac{(8.854\times10^{-12})(80)(0.4\times10^{-3})}{0.04}$$

$$C = 7.0832\,p\mathrm{F}$$

APPENDIX D

PHYSICAL PROPERTIES OF ALUMINIUM

Table 10 Properties of Unalloyed Aluminium [14]

Property	Unit	Value	Note
Atomic number		13	
Density, ρ	$kg \cdot m^{-3}$	$2698^{(1)}$	
Melting point	°C	660.45	$< 1013 \times 10^{-3}$ bar
Boiling point	°C	2056	$< 1013 \times 10^{-3}$ bar
Vapour pressure	Pa	3.7×10^{-3}	at 927 °C
Mass internal energy, u	$J \cdot kg^{-1}$	3.98×10^{5}	
Mass thermal capacity, C_p	$J \cdot kg^{-1} \cdot K^{-1}$	897	at 25 °C
Thermal conductivity, λ	$W \cdot m^{-1} \cdot K^{-1}$	237	at 27 °C
Linear expansion coefficient, α_1	$10^{-6}\ K^{-1}$	23.1	at 25 °C
Electrical resistivity, ρ	$10^{-9} \Omega \cdot m$	26.548	at 25 °C
Magnetic susceptibility, K		0.6×10^{-3}	at 25 °C
Longitudinal elasticity modulus, E	MPa	69000	
Poisson's ratio, v		0.33	

APPENDIX E

KEY MILESTONE FOR FIRST SEMESTER

No.	Detail/ Week	1	2	3	4	5	6	7	8	9		10	11	12	13	14
1	Selection of Project Topic	🟦	🟦								Mid-semester Break					
2	Preliminary Research Work		🟦	🟦	🟦											
3	Submission of Preliminary Report				●											
4	Seminar 1 (optional)					🟦	🟦	🟦	🟦	🟦						
5	Project Work					🟦	🟦	🟦	🟦	🟦						
6	Submission of Progress Report								●							
7	Seminar 2 (compulsory)											🟦	🟦	🟦		
8	Project work continues											🟦	🟦	🟦		
9	Submission of Interim Report Final Draft														●	
10	Oral Presentation															●

● Suggested milestone

🟦 Process

APPENDIX F

KEY MILESTONE FOR SECOND SEMESTER

No.	Detail/ Week	1	2	3	4	5	6	7	8	9		10	11	12	13	14
1	Project Works Continue	🟦	🟦	🟦							Mid-semester Break					
2	Submission of Progress Report				●											
3	Project Work Continue				🟦	🟦	🟦	🟦	🟦	🟦						
4	Submission of Progress Report 2								●							
5	Seminar (compulsory)									🟦		🟦	🟦			
6	Project work continue								🟦	🟦		🟦	🟦			
7	Poster Exhibition											●				
8	Submission of Dissertation (soft bound)													●		
9	Oral Presentation														●	
10	Submission of Project Dissertation (Hard Bound)															●

● Suggested milestone

🟦 Process