



Faculty of Engineering

**CONVERSION OF PLASTIC WASTE INTO FUEL USING
MICROWAVE-PYROLYZER WITH THE ADDITION OF
ALUMINIUM DROSS AS A CATALYST**

Hazeliana binti Henry Litong

Bachelor of Engineering with Honours

(Chemical Engineering)

2015

UNIVERSITI MALAYSIA SARAWAK

Grade: _____

Please tick (√)

Final Year Project Report

Masters

PhD

| |
|-------------------------------------|
| <input checked="" type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |

DECLARATION OF ORIGINAL WORK

This declaration is made on the 23 day of June 2015.

Student's Declaration:

I, HAZELIANA BINTI HENRY LITONG (30340), DEPT. OF CHEMICAL ENGINEERING AND ENERGY SUSTAINABILITY, FACULTY OF ENGINEERING hereby declare that the work entitled, CONVERSION OF PLASTIC WASTE INTO FUEL USING MICROWAVE-PYROLYZER WITH THE ADDITION OF ALUMINIUM DROSS AS A CATALYST is my original work. I have not copied from any other students' work or from any other sources except where due reference or acknowledgement is made explicitly in the text, nor has any part been written for me by another person.

23 JUNE 2015

HAZELIANA BINTI HENRY LITONG (30340)

Date submitted

Name of the student (Matric No.)

Final Year Project Coordinator's Declaration:

I, NUR SYUHADA BINTI AHMAD ZAUZI hereby certifies that the work entitled, CONVERSION OF PLASTIC WASTE INTO FUEL USING MICROWAVE-PYROLYZER WITH THE ADDITION OF ALUMINIUM DROSS AS A CATALYST was prepared by the above named student, and was submitted to the "FACULTY OF ENGINEERING" as a fulfilment for the conferment of BACHELOR OF ENGINEERING WITH HONOURS (CHEMICAL ENGINEERING), and the aforementioned work, to the best of my knowledge, is the said student's work

Received for examination by: NUR SYUHADA AHMAD ZAUZI Date: 23 JUNE 2015
(Name of the coordinator)

I declare this Report is classified as (Please tick (√)):

CONFIDENTIAL (Contains confidential information under the Official Secret Act 1972)*

RESTRICTED (Contains restricted information as specified by the organisation where research was done)*

OPEN ACCESS

Validation of Report

I therefore duly affirmed with free consent and willingness declared that this said Report shall be placed officially in Department of Chemical Engineering and Energy Sustainability with the abide interest and rights as follows:

- This Report is the sole legal property of Department of Chemical Engineering and Energy Sustainability, Universiti Malaysia Sarawak (UNIMAS).
- The Department of Chemical Engineering and Energy Sustainability has the lawful right to make copies for the purpose of academic and research only and not for other purpose.
- The Department of Chemical Engineering and Energy Sustainability has the lawful right to digitise the content to for the Local Content Database.
- The Department of Chemical Engineering and Energy Sustainability has the lawful right to make copies of the Report for academic exchange between Higher Learning Institute.
- No dispute or any claim shall arise from the student itself neither third party on this Report once it becomes sole property of Department of Chemical Engineering and Energy Sustainability, Universiti Malaysia Sarawak (UNIMAS).
- This Report or any material, data and information related to it shall not be distributed, published or disclosed to any party by the student except with Department of Chemical Engineering and Energy Sustainability, Universiti Malaysia Sarawak (UNIMAS) permission.

Student's signature _____
(23 JUNE 2015)

Supervisor's signature: _____
(23 JUNE 2015)

Current Address:

NO,158, TABUAN HEIGHTS PHASE 1, JALAN SONG, 93350, KUCHING, SARAWAK

Notes: * If the Report is **CONFIDENTIAL** or **RESTRICTED**, please attach together as annexure a letter from the organisation with the period and reasons of confidentiality and restriction.

CONVERSION OF PLASTIC WASTE INTO FUEL USING MICROWAVE-
PYROLYZER WITH THE ADDITION OF ALUMINIUM DROSS AS A
CATALYST

HAZELIANA BINTI HENRY LITONG

A dissertation submitted in partial fulfilment
of the requirement for the degree of
Bachelor of Engineering with Honours
(Chemical Engineering and Energy Sustainability)

Faculty of Engineering
Universiti Malaysia Sarawak

2015

I would like to dedicate my thesis to my beloved family and friends.

ACKNOWLEDGEMENT

I would like to express my deepest appreciation to my final year project supervisor, Madam Nur Syuhada Ahmad Zauzi whose contribution in stimulating suggestions, encouraged and helped me to coordinate my project throughout the course. Furthermore I would also like to acknowledge with much appreciation my course coordinator, Mrs. Noraziah Abdul Wahab. Special thanks to the crucial role of the staff and technicians, Department of Chemical Engineering, University Malaysia Sarawak (UNIMAS) who gave the permission to use all required equipment and the necessary materials to complete this project. Last but not least, many thanks go to my beloved family and friends for their support and motivations in completing this report.

ABSTRACT

Aluminium dross is a by-products produced from the smelting process of aluminium. It has the potential of risking the environment as it will release hazardous gaseous when it is in contact with moisture such as ammonia, methane and hydrogen. In order to reduce the harmful effect of aluminium dross to the environment, it can be treated to become catalyst by undergoing physical as well as chemical processes by recovering aluminium hydroxide ($\text{Al}(\text{OH})_3$). Aluminium dross undergoes leaching process in 500 ml of sodium hydroxide (NaOH) at 10% concentration. The second stage was precipitation using hydrogen peroxide (H_2O_2) followed by calcination in a furnace at $600\text{ }^\circ\text{C}$ for 3 hours. The characteristics of the untreated aluminium dross and treated aluminium dross have been studied using Brunauer-Emmett-Teller (BET) analysis. BET result showed an increase on the surface area of aluminium dross from $10.06\text{ m}^2/\text{g}$ to $74.21\text{ m}^2/\text{g}$ after treatment. The treated aluminium dross was used as a catalyst in converting plastic into liquid hydrocarbon in a modified microwave pyrolyzer with the condition of 1000W and 800W at 18 minutes and 15 minutes. The result is 1% of liquid obtained from the pyrolysis of plastic waste at the condition of 1000W for 15 minutes and 3% liquid at the condition 800W for 18 minutes. Microwave pyrolysis was also conducted without the presence of catalyst. The result is 1% liquid at the condition 1000W for 20 minutes and 3% liquid at the condition of 800W for 20 minutes.

ABSTRAK

Keladak aluminium adalah hasil sampingan yang terhasil daripada proses peleburan aluminium. Ia mempunyai potensi merisikokan alam sekitar kerana ia akan membebaskan gas berbahaya apabila ia bersentuhan dengan lembapan seperti ammonia, metana dan hidrogen. Bagi mengurangkan kesan bahaya keladak aluminium terhadap alam sekitar, ia boleh dirawat untuk menjadi pemangkin dengan menjalani proses kimia serta fizikal bagi memperolehi aluminium hidroksida ($\text{Al}(\text{OH})_3$). Proses kimia tersebut bermula melarutkan keladak aluminium dengan 500 ml natrium hidroksida (NaOH) pada kepekatan 10%. Peringkat kedua adalah pengurusan menggunakan hidrogen peroksida (H_2O_2) diikuti oleh pengkalsinan dalam relau pada 600°C selama 3 jam. Pencirian keladak aluminium sebelum dan selepas dirawat telah dikaji menggunakan Brunauer-Emmett-Teller (BET) analisis. Keputusan BET menunjukkan peningkatan kawasan permukaan daripada $10.06 \text{ m}^2/\text{g}$ ke $74.21 \text{ m}^2/\text{g}$ selepas rawatan. Keladak aluminium terawat telah digunakan sebagai pemangkin dalam menukarkan bahan plastik kepada cecair hidrokarbon dalam pyrolyzer gelombang-mikro yang diubahsuai dengan keadaan 1000W dan 800W selama 18 minit dan 15 minit. Keputusan yang didapati ialah 1% cecair dalam keadaan 1000W selama 15 minit dan 3% cecair dalam keadaan 800W selama 18 minit. Pirolisis gelombang-mikro telah dijalankan tanpa kehadiran pemangkin. Keputusan yang didapati ialah 1% cecair dalam keadaan 1000W selama 20 minit dan 3% cecair dalam keadaan 800W selama 20 minit.

TABLE OF CONTENTS

| | Page | |
|----------------------|---|----|
| Acknowledgement | i | |
| Abstract | ii | |
| Abstrak | iii | |
| Table of Contents | v | |
| List of Tables | vi | |
| List of Figures | vii | |
| List of Abbreviation | viii | |
| | | |
| Chapter 1 | BACKGROUND OF STUDY | |
| 1.1 | Overview | 1 |
| 1.2 | Problem Statement | 2 |
| 1.3 | Research Objectives | 3 |
| 1.4 | Research Scope | 4 |
| | | |
| CHAPTER 2 | LITERATURE REVIEW | |
| 2.1 | Aluminium Dross | 5 |
| 2.1.1 | Chemical Composition | 7 |
| 2.1.2 | Physical Characterisation | 8 |
| 2.2 | Plastic Waste | 9 |
| 2.2.1 | Polyethylene | 12 |
| 2.2.2 | High Density Polyethylene | 13 |
| 2.3 | Aluminium Dross Treatment | 14 |
| 2.3.1 | Acid and Alkali Treatment | 15 |
| 2.4 | Properties of Characterisation of Treated Aluminium Dross | 16 |
| 2.5 | Characterisation of Untreated Aluminium Dross and Treated Aluminium Dross | 17 |
| 2.5.1 | Brunauer-Emmett-Teller (BET) Method | 17 |
| 2.5.2 | Scanning Electron Microscopy | 20 |
| 2.6 | Microwave Pyrolysis | 22 |
| 2.6.1 | Effect of Time and Power | 23 |

| | | |
|----------------------|--|----|
| CHAPTER 3 | METHODOLOGY | |
| 3.1 | Raw Material | 24 |
| | 3.1.1 Aluminium Dross | 24 |
| | 3.1.2 Plastic Waste | 24 |
| 3.2 | Flow Chart of Experimental Work | 24 |
| 3.3 | Aluminium Dross Treatment | 26 |
| 3.4 | Characterisation of Untreated Aluminium Dross and Treated Aluminium Dross | 27 |
| | 3.4.1 Brunauer-Emmett-Teller (BET) Surface Area Analysis | 27 |
| | 3.4.2 Scanning Electron Microscopy (SEM) | 28 |
| 3.5 | Microwave Pyrolysis | 29 |
| 3.6 | Designation of Sample | 30 |
| CHAPTER 4 | RESULT AND DISCUSSION | |
| 4.1 | Characterisation of Untreated Aluminium Dross and Treated Aluminium Dross | 31 |
| | 4.1.1 Brunauer-Emmett-Teller (BET) Analysis | 31 |
| | 4.1.2 Scanning Electron Microscopy (SEM) | 34 |
| 4.2 | Microwave Pyrolysis | 35 |
| CHAPTER 5 | CONCLUSION | |
| 5.1 | Conclusion | 37 |
| 5.2 | Further Work and Recommendation | 38 |
| REFERENCES | | 39 |
| RISK ASSESSMENT FORM | | 43 |

LIST OF TABLES

| Table | | Page |
|--------------|---|-------------|
| 2.1 | Chemical Composition of Aluminium Dross | 7 |
| 2.2 | Composition Comparisons of Raw Dross and Calcined Dross | 8 |
| 2.3 | Plastic Waste Generation in Kuching | 9 |
| 2.4 | Solid Waste Statistics in Malaysia | 10 |
| 2.5 | Product Type of Some Plastic Pyrolysis | 11 |
| 2.6 | Classification of Polyethylene by Density | 13 |
| 2.7 | HDPE Generation in the USA Per Year | 14 |
| 2.8 | Results of Precipitation Experiments | 16 |
| 2.9 | Pore Classification | 17 |
| 2.10 | Comparison between Microwave Pyrolysis and Conventional Pyrolysis of Plastic Waste | 23 |
| 2.11 | Microwave Pyrolysis: Correlation among Power, Time and Yield | 23 |
| 3.1 | The Condition for BET Surface Area Analysis | 28 |
| 3.2 | Sample Designation | 30 |
| 4.1 | BET Analysis Result | 32 |
| 4.2 | Microwave Pyrolysis | 36 |

LIST OF FIGURES

| Figure | | Page |
|--------|--|------|
| 2.1 | The Different Route of Plastic Waste | 12 |
| 2.2 | Chemical Structure of HDPE | 13 |
| 2.3 | Categories of Adsorption Isotherms | 19 |
| 2.4 | Hysteresis Loop | 19 |
| 2.5 | Diagram of SEM column and Specimen Chamber | 21 |
| 2.6 | SEM Photograph of Reaction Product Synthesized from $\text{Al}(\text{OH})_3$ | 21 |
| 3.1 | Experimental Work Flow | 25 |
| 3.2 | Nabertherm Furnace | 26 |
| 3.3 | Treated Aluminium Dross | 27 |
| 3.4 | Quantachrome Instruments Surface Area Analyzer | 28 |
| 3.5 | Hitachi TM3000 Tabletop Microscope | 29 |
| 4.1 | N_2 Adsorption-Desorption Isotherms Determined at 77.35 K on the Untreated Aluminium Dross | 33 |
| 4.2 | N_2 Adsorption-Desorption Isotherms Determined at 77.35 K on the Treated Aluminium Dross | 34 |
| 4.3 | (a) Untreated Aluminium Dross of 2000X magnification (b) Treated Aluminium Dross of 2000X magnification | 35 |

LIST OF ABBREVIATIONS

| | | |
|---|---|---------------------------------------|
| AD | - | Aluminium Dross |
| AlO(OH) | - | Aluminium Oxyhydroxide |
| Al(OH) ₃ | - | Aluminium Hydroxide |
| Al ₂ O ₃ | - | Aluminium Oxide |
| Al ₂ O ₃ ·3H ₂ O | - | Trihydrate Aluminium Hydroxide |
| Au | - | Gold |
| BET | - | Brunauer-Emmett-Teller |
| CAD | - | Calcined Aluminium Dross |
| DBKU | - | Dewan Bandaraya Kuching Utara |
| Fe ₂ O ₃ | - | Iron Oxide |
| FTIR | - | Fourier Transform Infrared |
| GCMS | - | Gas Chromatography-Mass Spectrometry |
| HDHPE | - | High Density Homopolymer Polyethylene |
| HDPE | - | High Density Polyethylene |
| H ₂ O ₂ | - | Hydrogen Peroxide |
| LDPE | - | Low Density Polyethylene |
| LLDPE | - | Linear Low Density Polyethylene |
| MBKS | - | Majlis Bandaraya Kuching Selatan |
| MDPE | - | Medium Density Polyethylene |
| MgO | - | Magnesium Oxide |

| | | |
|----------------------------------|---|----------------------------------|
| Na ₃ AlF ₆ | - | Sodium Aluminium Fluoride |
| NaOH | - | Sodium Hydroxide |
| PAHs | - | Polycyclic Aromatic Hydrocarbons |
| PE | - | Polyethylene |
| PP | - | Polypropylene |
| RAD | - | Raw Aluminium Dross |
| SUD | - | Sustainable Urban Development |
| SEM | - | Scanning Electron Microscopy |
| SiO ₂ | - | Silicon Dioxide |
| TAD | - | Treated Aluminium Dross |
| TGA | - | Thermogravimetric Analyser |
| UAD | - | Untreated Aluminium Dross |
| XRD | - | X-Ray Fluorescence |

CHAPTER 1

BACKGROUND OF STUDY

1.1 Overview

Aluminium dross is a by-products produced from the smelting process of aluminium (Hwang, Huang, & Xu, 2006). It is a major by-product of all processes which comprises molten aluminium (Drouet, Leroy, & Tsantrizos, 2000). The chemical compositions of dross are aluminium oxides, metallic aluminium, nitride, salts and several alloy (Dai, 2012). It can be divided into white dross and black dross in which black dross contain salt whereas white dross does not contain any salt (Dai, 2012). Aluminium dross has the potential of risking the environment as it will release hazardous gases when it is in contact with moisture such as ammonia, methane and hydrogen (Miskufova, Petranikova, & Kovacs, 2009). One of the alternatives in reducing this waste is by processing it in a rotary kiln to retrieve aluminium which result in salt cake that will be sent for landfilling (Dai, 2012). This in turn, could harm the environment due to the potential leaching of the salt cake (Dai, 2012).

Aluminium dross can be used as a filler in concrete and asphalt products to enhance stiffness abrasion resistance as well as controlling micro-cracking (Wastes & Study, 2007). Another use of dross is it can be a substitute of sand or cement to produce concrete blocks (Ozerkan et al., 2014). Manufacturing of aluminate cement is also an application of dross as it contain salt cake which is a source of calcium oxide (CaO) and aluminium oxide (Al_2O_3) (Ozerkan et al., 2014).

Aluminium dross has the potential in becoming catalyst. It can undergo physical as well as chemical processes to be used in catalysis and filtration process (Yusoff,

Muslim, & Paulus, n.d.). The dross catalyst can assist in microwave pyrolysis process of oil from plastic wastes (Lam & Chase, 2012). Meanwhile, plastic is a cheap and lightweight item which does not rot or rust with a reusable application (Panda, Singh, & Mishra, 2010). Thus, it is used widely nowadays. Panda et al., (2010) stated that plastic will be used continuously in the future. As the use of plastic increase, the amount of plastic as a waste will also increase which demands solution to decrease the waste. Therefore, plastic waste has been used in the plastic cracking process to be recycled into petrochemical materials (Buekens & Huang, 1998).

Accordingly, aluminium dross will be used in the catalyst cracking of plastic waste using microwave pyrolyzer to obtain the product of liquid hydrocarbons which is known as biodiesel.

1.2 Problem Statement

The by-product aluminium dross generation amount in Malaysia is within the range of 5000 to 10000 tonnes per month which is a huge amount. Problems arise as 95% of the waste by-product is land filled (Hong et al., 2010). Without proper treatment, the land filling activity of aluminium dross affects surface and groundwater (Hong et al., 2010). However, the recycling process through refining of the waste consumes a large amount of electricity which also require large amount of money (Hiraki et al., 2005).

Another recycling process of aluminium dross would be the resmelting. The by-product of smelting is white dross meanwhile resmelting produce a by-product of black dross along with salt cake (Gómez, Lima, & Tenório, 2008). Malaysia oblige disposal activities, storage and transportation of aluminium dross is carried out by contractors with license (Yusoff et al., n.d.). Yet, the disposal cost RM2000 per tonne as per licensed company (Yusoff et al., n.d.). This causes certain company to take cheaper route which is to landfill the waste. Hence, the need to treat or finding an alternative in managing the by-product is high. Furthermore, the recycling of dross is attractive from the energy and economic perspective because aluminium production uses large amount of energy to transform the material (Drouet et al., 2000).

Another issue related to waste disposal is plastic waste which is a problem faced by consumers globally. The increase of plastic usage is caused by the fact that it is much cheaper and have good physical properties as compared to other material such as glass and metal (Sarker et al., 2012). It is a waste which cannot biodegrade naturally (Buekens & Huang, 1998). Consequently, alternatives in managing plastic waste need to be done instead of land filled. Another problem faced with plastic waste is littering because plastic is available everywhere from being used in food packaging, to being used around the house. Littering then will cause drain clogging and also health problem towards animals (Sarker et al., 2012). Plastic waste management come with a cost and it demands an efficient way to make full use of the waste (Sarker et al., 2012).

In order to minimize the amount of plastic waste, solutions are required. A number of studies on the degradation of different type of plastic waste into liquid fuel using different catalysts have been carried out. However, many of them are impracticable due to cost of manufacturing (Panda & Singh, 2013). Thus, the potential of aluminium dross as a catalyst will be studied. The aluminium dross as a catalyst will be used in converting plastic waste into fuel. The main purpose of this study is to monitor the effect of time and power of microwave pyrolyzer in converting plastics into hydrocarbon oil.

1.3 Research Objectives

The main objectives of this study are as shown below:

- i. To treat aluminium dross by undergoing the process of leaching, precipitation and calcination to be used as catalyst in converting plastic waste into liquid hydrocarbons
- ii. To evaluate the properties of treated aluminium dross using Brunauer-Emmett-Teller (BET) and Scanning Electron Microscopy (SEM) analysis
- iii. To assess the performance of treated aluminium dross as a catalyst in the conversion of plastic waste into fuel using microwave pyrolyzer

1.4 Research Scope

In this study, aluminium dross will be treated as a catalyst. The main component from dross to be used as a catalyst is aluminium hydroxide ($\text{Al}(\text{OH})_3$). The step of treating aluminium dross into catalyst can be divided into three stages. The first stage is a leaching process of the dross in 500 ml of sodium hydroxide (NaOH) at 10% concentration. The second stage is precipitation using hydrogen peroxide (H_2O_2) followed by calcination in a furnace at $600\text{ }^\circ\text{C}$ for 3 hours. The characteristics of the untreated aluminium dross and treated aluminium dross will be studied. Treated aluminium dross will be used as a catalyst in converting plastic waste high density polyethylene (HDPE) into hydrocarbon oil in a modified microwave pyrolyzer. The presence of catalyst in the pyrolysis process will increase the rate of chemical reaction without undergoing any changes on the catalyst itself. Thus, the yield of liquid hydrocarbons will increase.

CHAPTER 2

LITERATURE REVIEW

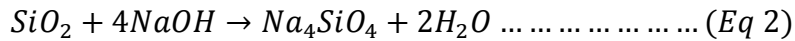
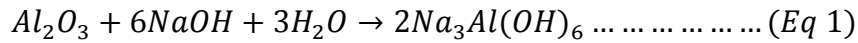
2.1 Aluminium Dross

Aluminium dross is categorised as schedule waste in Malaysia (Yusoff et al., n.d.). It is a by-product of the production of aluminium in which the formation is inevitable (Ünlü & Drouet, 2002). The melting of metal in a conservative purification or recycling method creates aluminium dross (AD) (Li, Zhang, & Yang, 2014). Electrolysis of alumina into aluminium is known as primary smelters and result in the formation of dross (Drouet et al., 2000). Meanwhile, the recycling method that produce aluminium dross occur at remelt plants which recycle aluminium scrap and beverage cans (Drouet et al., 2000).

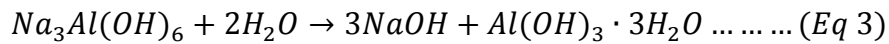
The dross by-product can be obtained from primary aluminium production which will undergo three steps. The first step is bauxite mining, followed by aluminium production and finally the electrolysis (Tsakiridis, 2012). This first step is known as Bayer Process in which the standard process is to extract alumina from bauxite using caustic soda within elevated pressures and temperatures (Berdowski et al., 2009). The normal yield of aluminium oxide (Al_2O_3) is 35% to 55% from a tropical monohydrate bauxite grades (Baux & America, n.d.). Aluminium oxyhydroxide ($\text{AlO}(\text{OH})$) can be found in caustic bauxite whereas aluminium hydroxide ($\text{Al}(\text{OH})_3$) is a component in lateric bauxite (Baux & America, n.d.). Mining includes washing of the raw material bauxite to remove any solid impurities (Fitzgerald & French, 1971).

Next step is the aluminium production. This is where the process of aluminium oxide (Al_2O_3) extraction from the bauxite occur (Pahladsingh, 2004). Bauxite is a

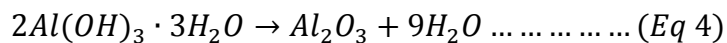
mixture of trihydrate aluminium hydroxide ($Al_2O_3 \cdot 3H_2O$), iron oxide (Fe_2O_3) and silicon dioxide (SiO_2) (Fitzgerald & French, 1971). Reactions which involves in the extraction of Al_2O_3 is shown in Eq 1, Eq 2, Eq 3 and Eq 4 (Fitzgerald & French, 1971).



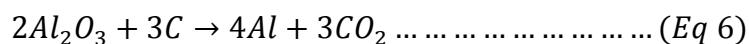
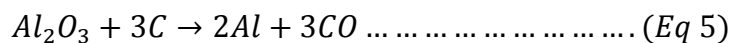
While Al_2O_3 and SiO_2 are soluble, Fe_2O_3 is insoluble in the solution due to its basic oxide and can be filtered out (Fitzgerald & French, 1971). The product from Eq 1 will then decomposed as shown in Eq 3.



Heating of $Al_2O_3 \cdot 3H_2O$ up to temperature above $1000^\circ C$ will extract Al_2O_3 as shown in Eq 4 (Fitzgerald & French, 1971).



The third step in primary aluminium production is electrolysis process, the electrolytic reduction of Al_2O_3 . This process is also known as the Hall Heroult process (Pahladsingh, 2004). At the temperature of around $960^\circ C$, electrolytic reduction of Al_2O_3 dissolved in molten cryolite, sodium aluminium fluoride (Na_3AlF_6) (Berdowski et al., 2009). This form an electrically conductive solution which result in Eq 5 and Eq 6 when undergoes reaction using consumable carbon anode with two concurrent reactions (Fitzgerald & French, 1971). This finally results in the formation of aluminium along with aluminium dross.



Aluminium dross has the potential in affecting health. The dust, fumes and powder of aluminium dross can causes irritation towards the eyes, nose, throat and respiratory tract (“Material Safety Data Sheet,” 2008). Wet aluminium dross releases ammonia and cause moderate to severe eye irritation. The released ammonia can also cause moderate irritation towards the respiratory tract when inhaled (“Material Safety Data Sheet,” 2008). The presence of nickel in aluminium dross can cause respiratory

tract and skin sensitization (“Material Safety Data Sheet,” 2008). Chromium is also present in aluminium dross. It can cause skin ulcers, dermatitis, perforation of the nasal septum, lung cancers, nasal cavity and as well as paranasal sinuses (“Material Safety Data Sheet,” 2008).

2.1.1 Chemical Composition

The chemical composition of aluminium dross (AD) can be obtained using the X-Ray Fluorescence (XRF) analysis. The main composition of the dross is shown in **Table 2.1**. The highest component in AD is aluminium oxide with the mass fraction of 64.40% followed by silicon dioxide with the mass fraction of 7.40% which is comparable with mass fraction of other component such as magnesium oxide and sodium oxide.

Table 2.1 Chemical Composition of Aluminium Dross (Hong et al., 2010)

| Component | Mass fraction (%) |
|------------------------------------|--------------------------|
| Al₂O₃ | 64.40 |
| SiO₂ | 7.40 |
| MgO | 6.40 |
| Na₂O | 6.20 |
| Cl | 5.80 |
| CaO | 2.70 |
| Fe₂O₃ | 2.50 |
| TiO₂ | 1.50 |
| Others | 3.10 |

Dai (2012) carried out calcination of dross at 1450°C for an hour in air in his study to evaluate the equivalent oxide content of metallic elements. The result of the comparison is shown in **Table 2.2**. The major difference between raw aluminium dross (RAD) and calcined aluminium dross (CAD) is the composition. The major constituent of the CAD is aluminium oxide of 84% whereas the second major constituent is magnesium oxide (MgO).

Table 2.2 Composition Comparisons of Raw Dross and Calcined Dross (Lorber, 2012)

| Raw Aluminium Dross | | Calcined Aluminium | |
|--|----|------------------------------------|-----|
| (wt%) | | Dross (wt%) | |
| MgAl₂O₄ | 48 | Al₂O₃ | 84 |
| AlN | 28 | MgO | 11 |
| a- Al₂O₃ | 7 | SiO₂ | 2 |
| (NO)₂Al₂₂O₃₄ | 6 | CaO | 1 |
| NaAl₁₁O₁₇ | 6 | Na₂O | 0.7 |
| CaF₂ | 3 | K₂O | 0.4 |
| Al | 2 | Fe₂O₃ | 0.3 |
| | | TiO₂ | 0.3 |

2.1.2 Physical Characterisation

The physical characteristic of aluminium dross can be classified into four classes which are the volume shrinkage, apparent porosity, cold crush strength and also permeability. It can be investigated by identifying the percentage of absorbent aluminium phyllosilicate, bentonite in the dross (Adeosun et al., 2014).

Aluminium dross which contain higher percentage of bentonite have a lower volume shrinkage while dross which contain more aluminium have a higher volume shrinkage (Adeosun et al., 2014). This behaviour can be explained by structural changes that occur due to thermal treatment (Adeosun et al., 2014). Bentonite is hydrophilic and the percentage of bentonite is directly proportional to water content of the dross (Adeosun et al., 2014). High water content means less air-pores space in aluminium dross which will be eliminated during firing and causes shrinkage (Adeosun et al., 2014). This also depicts the level of apparent porosity of the dross. Higher water content which caused by higher percentage of bentonite means lower porosity (Adeosun et al., 2014).

The cold crush strength of aluminium dross depends on the size of the particles. The larger the particle size, the lower the cold crush strength due to low binder content (Adeosun et al., 2014). Moreover, physical characteristic of aluminium dross can be measured by the permeability. Fine particles of dross promote de-agglomeration while

large particles form gaseous pores (Adeosun et al., 2014). For both of the cases, the permeability increases.

2.2 Plastic Waste

Plastic wastes are categorized into two categories which are municipal and industrial plastic waste, depending on the origin of the waste, which indicates the difference in properties and qualities (Panda et al., 2010). As plastics are used in our daily lives with various of uses, the generation of this wastes increases significantly (Al-Salem, Lettieri, & Baeyens, 2009). Therefore, finding an alternative or a path in managing the waste is important.

Around 55 million tons of plastic waste generated by the USA, Europe and Japan (Brems et al., 2013). Narrower statistics which is in Kuching region located in Sarawak, Malaysia is obtained from Majlis Bandaraya Kuching Selatan (MBKS), Dewan Bandaraya Kuching Utara (DBKU) and Sustainable Urban Development (SUD). The increase of plastic waste generation is shown in **Table 2.3**. Comparing the data of plastic waste, it is noticed that the amount of plastic waste increased more than double amount within the range of 1 year and 15 years.

Table 2.3 Plastic Waste Generation in Kuching (Huong, Yang, & Larsen, 2003)

| Type of waste | Waste source and amount | | | |
|------------------------------|--|---------------------------------------|--|-------------------------------------|
| | MBKS ('86) Kuching, landfill waste | DBKU ('96) Kuching, residential | Trienekens ('97) Kuching, landfill waste | SUD ('01) Kuching residential |
| Organic waste | 48% | 40% | 50% | 50% |
| Paper & cardboard | 24% | 21% | 15% | 14% |
| Plastics | 9% | 21% | 16% | 20% |
| Metals | 6% | 6% | 4% | 3% |

Johari et al. (2014) studied on the management of solid waste including plastic waste in Malaysia. The 7 years statistics are shown in **Table 2.4** which shows that plastic waste increased throughout the years up to 25.2% in 2010.

Table 2.4 Solid Waste Statistics in Malaysia (Johari et al., 2014)

| Components | 2001 | 2002 | 2003 | 2004 | 2005 | 2007 | 2010 |
|----------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Food waste & organics | 68.40% | 56.30% | 37.40% | 49.30% | 45.00% | 42.00% | 43.50% |
| Mix plastic | 11.80% | 13.10% | 18.90% | 9.70% | 24.00% | 24.70% | 25.20% |
| Mix paper | 6.30% | 8.20% | 16.40% | 17.10% | 7.00% | 12.90% | 22.70% |
| Textiles | 1.50% | 1.30% | 3.40% | NA | NA | 2.50% | 0.90% |

Note: NA – Not available

There are issues regarding the disposal of the municipal solid waste. Improper disposal of plastic waste causes in increasing of undesirable species such as soot and polycyclic aromatic hydrocarbons (PAHs) (Lam & Chase, 2012). Sewage effluents and urban runoff contain high concentrations of PAHs due to the contamination of the waste (Lam & Chase, 2012). Another problem caused by plastic waste is that the disposal of it on land makes the land barren (Bhawan & Nagar, 2012).

Toxic emission is also a problem caused by the disposal of plastic waste primarily on burning of the municipal plastic waste (Bhawan & Nagar, 2012). The toxic released are carbon monoxide, chlorine, hydrochloric acid, dioxin, furans, amines, nitrides, styrene, benzene and acetaldehyde (Bhawan & Nagar, 2012). Additives in low density polyethylene (LDPE), high density polyethylene (HDPE) and polypropylene (PP) such as lead and cadmium pigments are toxic and leach out due to plastic waste disposal (Bhawan & Nagar, 2012). Littered plastic waste will also block drains (Bhawan & Nagar, 2012).

The potential of plastic waste to be converted into hydrocarbon oil have been studied. The product of pyrolysis towards different type of plastic waste is shown in **Table 2.5**. Only certain plastics are allowed to be used as a feedstock of liquid fuels such as polyethylene, polypropylene, polystyrene and polymethyl metacrylate (Into,