UNIVERSITI PUTRA MALAYSIA

ASSESSMENT OF ATMOSPHERIC CORROSIVITY ON METALS AND ITS MITIGATION BY GREEN CORROSION INHIBITORS IN THE KLANG VALLEY, MALAYSIA

FADEL MOHAMED M ALI BINYEHMED

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By

FADEL MOHAMED M ALI BINYEHMED

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

September 2018

DEDICATION

Special dedicated to:

My beloved wife

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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Chairman : Professor Ahmad Makmom Bin Abdullah, PhD
Faculty : Environmental Studies

The severity of atmospheric corrosion has now become a considerable concern worldwide, and poses a serious threat to many building materials. Many works in this field have been conducted, particularly in tropical areas, but Malaysia has not received much attention, only appearing in a few researches. Based on the literature, Malaysia suffers from acid deposition, which is caused by different air pollution sources. Therefore, the corrosion of metals may accelerate in the country. This study was conducted to assess the atmospheric corrosivity in Klang Valley, Malaysia, and to mitigate the corrosion issue by taking the environment into consideration. Physico-chemical characteristics (pH, Electrical Conductivity and Total Dust Fall) were determined, and samples collected at four locations with three sampling sites from August 2014 to July 2015, with one location being chosen as the background location. The samples were collected using a passive sampler consisting of a funnel and polyethylene bottle. The results of acid deposition showed that Klang Valley was slightly acidic with a mean of 4.71 ± 0.48. Shah Alam had the lowest pH values due to development in the area, urbanization, and traffic population. Meanwhile, Puchong—the background station—was less acidic. A mean electrical conductivity (EC) of 52.50 ± 36.03 µS cm^{-1} was observed in this study, with Puchong showing lower EC values indicating improved air quality, and Shah Alam exhibiting higher ones, which may be attributed to the strong contribution of air pollution. Furthermore, the mean of total dust fall concentration exceeded the Malaysian guideline; reaching 199.51 ± 90.31 mg m^{-2} day^{-1}.

An outdoor atmospheric corrosion test of four metals (Carbon steel, Mild steel, Aluminum and Copper) was conducted in five locations, namely Shah Alam, UPM *U2 & U3*, Puchong, and Putrajaya. The corrosion rates were determined using weight loss based on ISO 9226. The results of the corrosion rates reveal that Shah Alam had the highest corrosion rates for all tested metals, while the lowest rates of corrosion were recorded in UPM *U3* and Puchong. The atmospheric corrosivity indicates that the time of wetness was 4600 hour/year (τ_4), with a SO_2 deposition rate of 7.26 µg m^{-3} (P_0), and a chloride deposition rate of 27.44 mg m^{-2} day^{-1} (S_1). The findings of this study reveal that the corrosivity of steel, aluminum, and copper belong to category C_3 (medium) according to ISO 9223, indicating that there is an agreement between environmental parameters and corrosion rate. The results of the correlation coefficient showed that all physico-chemical characterizations of the investigated metals such as time of wetness, and the deposition rate of sulfur dioxide and chloride, strongly affect corrosion rate.

Corrosion mitigation was conducted using four natural products, namely Green Coffee Extract (GCE), Green Tea Extract (GTE), Pomegranate Waste Extract (PWE), and Doum Extract (DE). Corrosion rate and inhibition efficiency were determined using electrochemical methods (Tafel polarization) in artificial acid rain and with different concentrations of extracts and different temperatures. The findings showed that all the green corrosion inhibitors under study acted as good inhibitors for aluminum corrosion, with only PWE and DE showing adverse effects on carbon steel corrosion. The adsorption of these inhibitors onto the tested metals obeyed the Langmuir adsorption isotherm, while the adsorption of molecule inhibitors followed the Temkin isotherm. From the values of the standard free energy of adsorption, ΔG_{ads}, it can be observed that the adsorption process on the tested metal surface was spontaneous adsorption, and the enthalpy of adsorption ΔH_{ads} showed that GCE acted as physical adsorption and the others performed as chemical adsorption, but the relationship between inhibition efficiency and temperatures proved that some extracts could perform chemical and physical adsorption, which was further proven via the Temkin isotherm. The one-way ANOVA analysis revealed that temperature variation did not significantly affect corrosion inhibition, which may be attributed to the chemical components' inhibitor that could have been physically or chemically adsorbed onto the metal surface. In addition, variation in concentration of green inhibitors significantly affected the inhibition efficiency of carbon steel and aluminum. Furthermore, a multifactorial analysis of variance showed that corrosion inhibition was greater for all inhibitors of carbon steel in comparison to that of aluminum.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENILAIAN PENGAKISAN LOGAM DI LEMBAH KLANG DAN PENGURANGANNYA MENGGUNAKAN PERENCAT KAKISAN HIJAU

Oleh

FADEL MOHAMED M ALI BINYEHMED

September 2018

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Keterukan kakisan atmosfera pada masa kini menjadi perhatian utama seluruh dunia, dan boleh menyebabkan ancaman serius kepada bahan-bahan binaan. Terdapat banyak kajian dalam bidang ini yang dilakukan di kawasan tropika, namun Malaysia masih kurang dikaji, dan hanya muncul dalam beberapa kajian sahaja. Berdasarkan literatur, Malaysia mengalami deposisi asid disebabkan oleh pelbagai sumber pencemaran udara. Justeru, kadar kakisan logam dalam negara ini mungkin akan meningkat dengan mendadak. Kajian ini dijalankan untuk menilai pengakisan atmosfera di lembah Klang, Malaysia, dan untuk menyelesaikan masalah kakisan dengan mengambil kira faktor alam sekitar. Ciri-ciri fiziko-kima (pH, kekonduksian elektrik dan jumlah kepekatan debu jatuh) telah ditentukan dan sampel telah dikumpul di empat lokasi dengan tiga tapak pensampelan dari Ogos 2014 hingga Julai 2015, beserta satu lokasi yang dipilih sebagai lokasi latar. Sampel dikumpul menggunakan pensampel pasif yang terdiri daripada sebuah corong dan botol polietilena. Hasil kajian menunjukkan bahawa lembah Klang agak berasid dengan min sebanyak 4.71 ± 0.48. Shah Alam menunjukkan nilai pH paling rendah, disebabkan kepesatan pembangunan, urbanisasi, dan populasi trafik. Sebaliknya, Puchong—stesen latar—kurang berasid. Min kekonduksian elektrik (KE) sebanyak 52.50 ± 36.03 µS cm^{-1} telah direkod dalam kajian ini. Puchong menunjukkan nilai KE yang lebih rendah, menandakan kualiti udara yang lebih baik, manakala Shah Alam menunjukkan nilai KE yang lebih tinggi mungkin kerana pencemaran udara yang banyak di kawasan tersebut. Di samping itu, min jumlah kepekatan debu jatuh iaitu 199.51 ± 90.31 mg m^{-2} day^{-1} di kawasan kajian lebih tinggi daripada yang ditetapkan dalam garis panduan Malaysia.

Ujian kakisan atmosfera luar untuk empat jenis logam (logam keluli, keluli lembut, aluminium, dan kuprum) dijalankan di lima lokasi iaitu Shah Alam, UPM *U2* & *U3*, Puchong, dan Putrajaya. Kadar kakisan ditentukan menggunakan pengurangan berat berdasarkan ISO 9226. Keputusan ujian menunjukkan bahawa Shah Alam mempunyai kadar kakisan tertinggi untuk kesemua jenis logam yang diuji, manakala kadar kakisan terendah telah direkod di UPM *U3* dan Puchong. Pengakisan atmosfera menunjukkan bahawa masa basah adalah 4600 jam/tahun (τ_4), dengan kadar deposisi SO_2 sebanyak 7.26 µg m^{-3} (P_0) dan kadar deposisi klorida sebanyak 27.44 mg m^{-2} $hari^{-1}$ (S_1). Hasil kajian ini menunjukkan bahawa pengakisan keluli, aluminium, dan kuprum adalah tergolong dalam kategori C_3 (sederhana), berdasarkan ISO 9223, yang menandakan persetujuan antara parameter alam sekitar dan kadar kakisan. Keputusan pekali korelasi menunjukkan bahawa semua ciri-ciri fiziko-kimia logam yang telah dikaji seperti masa basah serta kadar deposisi sulfur dioksida dan klorida, mempunyai kesan yang kuat terhadap kadar kakisan.

Pengurangan kakisan telah dijalankan menggunakan empat produk asli iaitu ekstrak biji kopi hijau (EKH), ekstrak teh hijau (ETH), ekstrak sisa delima (ESD), dan ekstrak doum (ED). Kadar kakisan dan kecekapan perencatan ditentukan melalui kaedah elektrokimia (pengutuban Tafel) dalam hujan asid buatan dan dengan pelbagai kepekatan ekstrak dan suhu. Keputusan menunjukkan bahawa kesemua perencat kakisan hijau yang dikaji merupakan perencat kakisan aluminium yang bagus. Hanya ESD dan ED menunjukkan kesan negatif terhadap kakisan keluli karbon. Penjerapan perencat-perencat tersebut ke atas logam mematuhi syarat-syarat penjerapan isoterma Langmuir, manakala penjerapan perencat molekul mematuhi syarat-syarat penjerapan isoterma Temkin. Nilai tenaga bebas standard untuk penjerapan, ΔG_{ads}, dapat dilihat bahawa proses adsorpsi pada permukaan logam yang diuji adalah penjerapan spontan, dan entalpi penjerapan ΔH_{ads} menunjukkan bahawa GCE bertindak sebagai penjerapan fisikal dan yang lain dilakukan sebagai penjerapan kimia , tetapi hubungan antara kecekapan dan suhu pencerobohan membuktikan bahawa beberapa ekstrak boleh melakukan penjerapan kimia dan fizikal, yang dibuktikan melalui isoterm Temkin. Analisis ANOVA satu hala menunjukkan bahawa variasi suhu tidak memberi kesan signifikan ke atas perencatan kakisan. Hal ini mungkin terjadi kerana komponen perencat kimia mungkin telah dijerap secara fizikal atau kimia ke atas permukaan logam. Selain itu, variasi kepekatan perencat hijau memberi kesan signifikan ke atas kecekapan perencatan keluli karbon dan aluminium. Tambahan pula, analisis multi-faktor yang dijalankan menunjukkan bahawa perencatan kakisan lebih berkesan untuk kesemua perencat keluli karbon berbanding perencat aluminium.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy.The members of the Supervisory Committee were as follows:

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K_{ads}	Adsorptive Equilibrium Constant
AOD	Aerosol Optical Depth
ASMA	Alam Sekitar Malaysia Sdn. Bhd.
AIS	Alteration Impedance Spectra
ASTM	American Society for Testing And Materials
ANOVA	Analysis of Variance
β_a	Anodic Tafel Constant
A	Area
AAR	Artificial Acid Rain
bpd	Barrel per Day
BTA	Benzotriazole
BS	British Standard
β_c	Cathodic Tafel Constant
CO_2	Carbon Dioxide
CO	Carbon Monoxide
Cl	Chloride
C	Concentration
R^2	Correlation Coefficient
i_{corr}	Corrosion Current Density
CR	Corrosion Rate
CE	Counter Electrode
θ	Degree of Surface Coverage
D	Density
DOE	Department of Environment
DRC	Deposition Rate of Chloride
DE	Doum Extract

DEIS	Dynamic Electrochemical Impedance Spectroscopy
EC	Electrical Conductivity
EIS	Electrochemical Impedance Spectroscopy
E.C.	Element Carbon
FPAS	Fakulti Pengajian Alam Sekitar (Faculty of Environmental Studies)
GP	Galvanostatic Polarization
GCE	Green Coffee Bean Extract
GTE	Green Tea Extract
GDP	Gross Domestic Product
GNP	Gross National Product
HC	Hydrocarbon
HCl	Hydrochloric Acid
HE	Hydrogen Evolution
ICP	Induced Coupled Plasma
IE	Inhibition Efficiency
ISO	International Organization for Standardization
KL	Kuala Lumpur
LPR	Linear Polarization Resistance
LSV	Linear Sweep Voltammetry
MMS	Malaysian Meteorological Service
MMD	Malaysia Meteorology Department
Mtoe	Million Ton of Oil Equivalent
NO_x	Nitrogen Oxides
OCP	Open Circuit Potential
O.C.	Organic Carbon
PM	Particulate Matter
ppb	Part per Billion

ppm	Part per Million
R_p	Polarization Resistance
PWE	Pomegranate Waste Extract
PP	Potentiodynamic Polarization
RMAQG	Recommended Malaysia Air Quality Guideline
RE	Reference Electrode
RH	Relative Humidity
ΔG_{ads}	Standard Free Energy of Adsorption
SPSS	Statistical Package for Social Sciences
SO_2	Sulfur Dioxide
H_2SO_4	Sulfuric Acid
TEP	Tafel Extrapolriazation
T	Temperature (Centigrade & Absolute)
TOW	Time of Wetness
TDF	Total Dust Fall
UPM	Universiti Putra Malaysia
VPI	Vapor-Phase Inhibitor
VOC	Volatile Organic Compound
VWM	Volume-Weighted Mean
WL	Weight Loss
WD	Wind Direction
WS	Wind Speed
WHO	World Health Organization
WE	Working Electrode

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Air pollution is a serious global concern, and is becoming even more pressing due to rapid urbanization and increased industrial emissions in several cities around the world (Jahn *et al.,* 2013; Sharma *et al.,* 2013; Elansky, 2014; Calderón-garcidueñas *et al.,* 2015). This phenomenon occurs as a consequence of human activity (anthropogenic) as well as natural processes. Generally, anthropogenic air pollution is caused by various sources; mobile sources such as transportation means and stationary sources such as industrial activities (Abdullah *et al.,* 2012). In urban areas, particulate matter (PM) pollutants have been observed as the principal pollutant (Hao & Wang, 2005; Li *et al.,* 2009). Although PM originates from vehicle exhaust, it may also relate to many other sources such as biomass burning (Zhang *et al.,* 2009b) and road traffic (Gurugubelli *et al.,* 2013). In Malaysia, air pollution has become a key environmental problem due to the growing numbers of vehicles, industrial activities, and trans-boundary pollution from neighboring countries, which are the main sources of air pollution in the country (Azid *et al*., 2015). In addition, Afroz *et al.* (2003) stated that mobile sources account for 70–75% of total air pollution, while stationary sources account for 20–25% of the total, with open burning making up 3–5% of total air pollution. In addition, dust fall is a typical primary air pollutant, where the main content of dust fall is particulate matter PM with a diameter equal to or greater than 10 µm that has the capability to deposit on surfaces after temporary suspension in air (Sami *et al.,* 2006). Thus, dust fall is a significant contributor to air pollution in urban areas (Gurugubelli & Pervez, 2009; Harrison *et al.*, 1997; Xia *et al.*, 2007), industrial areas, construction locations (Pandey *et al.,* 2008), and roadways (Arsene *et al.,* 2007). Furthermore, there are also natural contaminants that may affect the quality of air in an urban area such as chloride. The chloride ion is one of the most significant natural contaminants in the marine environment, and plays a vital role in the corrosion process of structural metals (Ma *et al.,* 2009; Corvo *et al.,* 2005). In fact, there are several chemical reactions that occur between pollutants and atmospheric components that lead to deposits on the earth's surface, either by wet deposition (Afroz *et al.,* 2003; Ramírez-lara *et al.,* 2016) or dry deposition (Jaradat *et al.,* 2004; Ramírez-lara *et al.,* 2016).

As is known, air pollution is an important issue that affects population health (Hamatui & Beynon, 2017; Krecl *et al.,* 2017; Lang *et al.,* 2012; Mardani *et al.,* 2015; WHO, 2016). In addition, atmospheric pollution leads to ecological issues (Grantz *et al.,* 2003; Ramírez-lara *et al.,* 2016), acid rain (Chen *et al.*, 2013a), desertification (Molina & Molina, 2004; Zelnik *et al.,* 2017), and global climate change (Zhang *et al.,* 2003; Khan *et al.,* 2015). The impact of air pollution is not only confined to the environment or human health but also to building materials (Slezakova *et al.,* 2011; Corvo *et al.,* 2010; de la Fuente *et al.,* 2013). A considerable amount of literature has been published on the role of pollutants and their effect on the atmospheric corrosion of metals and its alloys (Kamimura *et al.*, 2012; Kosaki, 2008; Samie *et al.*, 2007b; Syed,; 2010; 2013; Qian *et al.,* 2015; Kubzova *et al.,* 2017). According to Syed (2006), "corrosion is defined as the destruction of materials caused by the chemical or electrochemical action of the surrounding environment". Atmospheric corrosion causes a metal surface that is exposed to the atmosphere to erode. Moreover, atmospheric corrosion is the most common form of corrosion, as most materials are exposed to the atmosphere (Morales *et al.,* 2005).

1.2 Atmospheric Corrosion

Atmospheric corrosion is a natural electrochemical reaction (Kamimura *et al.,* 2012; Wint *et al.,* 2016), which takes place in corrosion cells rather than in the form of a direct chemical attack (Tong, 2012). Besides that, atmospheric conditions such as relative humidity, temperature, pollutants, and salinity play a vital role in causing atmospheric corrosion and its behavior (Katayama *et al.*, 2005; Natesan *et al.*, 2006). In particular, the most corrosive conditions that result in serious atmospheric corrosion of metals are found in tropical, subtropical, and marine environments (Li *et al.*, 2010). These conditions are due to the conjoined reactions of base metal, oxygen, and water in which the oxidation of iron and reduction of oxidizing agent occurs simultaneously. Water that condenses on the metal surface acts as an electrolyte for transferring electrons and charges. However, in the absence of the electrolyte, the metal corrodes at a negligible rate. In other cases, the existence of electrolyte could also be associated with atmospheric corrosion. In addition, the existence of dust and contaminants from the atmosphere such as sodium chloride, sulfur dioxide, and carbon dioxide, will speed up corrosion reactions (Tong, 2012).

Importance changes in the atmosphere occur due to certain environmental conditions such as temperature, moisture, and pollutants; hence, atmospheric corrosion rates differ noticeably around the globe. Realization of marked variances in corrosivity has resulted in the grouping of atmospheric corrosivity into several types. The major types are rural, urban, marine, and industrial atmospheres. In addition, there are also subdivisions, such as dry and wet tropical, with great differences in corrosivity (Revie & Uhlig, 2008).

1.2.1 Atmospheric Corrosion Mechanism

Atmospheric corrosion is a complicated electrochemical reaction that is carried out in corrosion cells, comprising of metal, electrolytes, corrosion products, and air (Schweitzer, 2010). Although this process occurs spontaneously, it may be slowed and controlled. Generally, the key reason for corrosion is that the metals used are not in a pure state in the earth, and as a result of metallurgical and manufacturing processes that separate metals from the ore, the energy in the metal will elevate to a higher level. However, most used metals are unstable in the atmosphere, and therefore, when these metals are exposed to the atmosphere, they tend to return to their original state or to similar metallic compounds (Veleva & Kane, 2003).

During the corrosion process, in addition to mass transfer, there is also an interchange of charged particles at the interface of the metal and the electrolyte. Therefore, the transfer of electrons occurs because of the formation of a galvanic corrosion cell on the metal surface. Generally, the corrosion in this cell requires three essential elements to occur; anode and cathode sites, an electrolyte, and an oxidizing agent such as oxygen and hydrogen ions (Veleva & Kane, 2003). Equations 1.1 to 1.6 summarize the anodic and cathodic reactions that occur on the surface interface between metal and atmosphere (see Figure 1.1).

Anodic reaction: $M \rightarrow M^{n+} + ne^{-}$ (1.1)

while, the cathodic reaction can be grouped into one of five different categories of reduction reactions.

Hydrogen evolution: $2H^{+} + 2e^{-} \rightarrow H_2 \uparrow$ (1.2)

Reduction of metal ion: $M^{3+} + e^{-} \rightarrow M^{2+}$ (1.3)

Metal deposition: $M^{2+} + 2e^{-} \rightarrow M$ (1.4)

Reduction of oxygen in acids $O_2 + 4H^{+} + 2e^{-} \rightarrow 2H_2O$ (1.5)

Reduction of oxygen -neutral solutions: $O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-}$ (1.6)

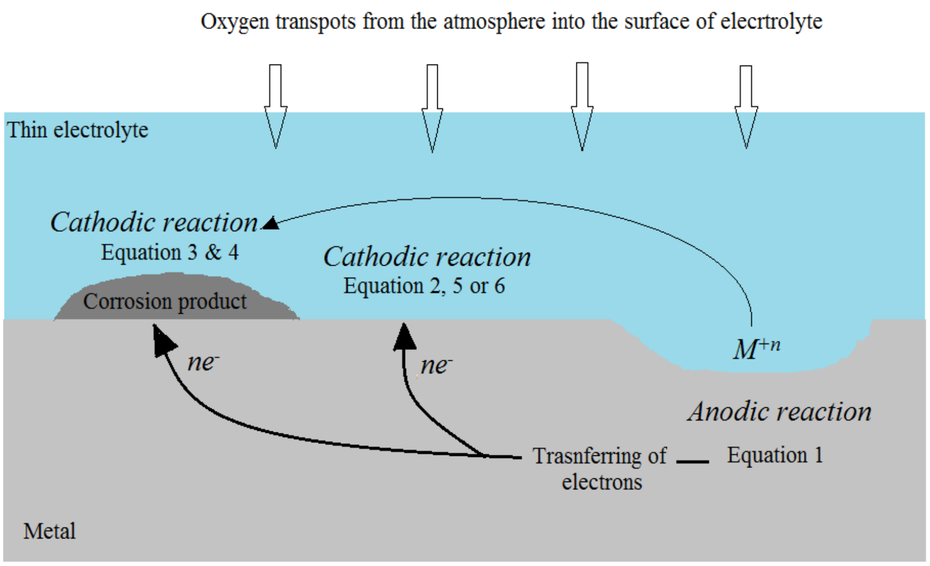

Figure 1.1 : Schematic of atmospheric corrosion mechanism
(Source: Tong, 2012)

In fact, the corrosion reaction cannot be stopped totally, but it can be mitigated using different techniques (Revie, 2011). Unfortunately, most of these techniques are complicated, expensive, non-biodegradable, or toxic. Therefore, the environmental consideration of green methods, which could solve this issue and conserve the environment, is of great concern nowadays.

1.3 Problem Statement

Atmospheric corrosion in tropical areas is a significant problem due to a combination of higher humidity and air pollutants (Beeharry & Surnam, 2018; Juan A. Jaén & Iglesias, 2017). In Malaysia, air pollution is a significant issue that demands the immediate attention of all relevant authorities (Azid *et al.*, 2015; Azmi *et al.*, 2010), as the issue is expected to exacerbate with rapid economic growth, urbanization, and industrial activities particularly in Klang Valley (Abdul Mutalib *et al.*, 2013; Shahid *et al.*, 2014). Consequently, air pollution has become the major issue that influences the choice of buildings and materials (Cai *et al.*, 2018; Díaz *et al.*, 2018). Additionally, natural pollutants such as the deposition rate of chloride has a great impact especially on the degradation of metals (Alcántara *et al.*, 2015; Kubzova *et al.*, 2017). The majority of metallic constructions and equipment are exposed to terrestrial air conditions to some degree and therefore can suffer from atmospheric corrosion (Portella *et al.*, 2012; Veleva & Kane, 2003).

Atmospheric corrosion can be so severe that it can degrade more than 80% of metallic constructions materials (Badea *et al.*, 2011), release hazardous elements into the environment as corrosion products (Goidanich *et al.*, 2011; Hedberg *et al.*, 2015), adversely affect safety (Melchers, 2013), cause a loss in the aesthetic view of metallic structures (Groysman, 2010; Ismail *et al.*, 2012), leads to an accelerated depletion of mineral reserves (Prabhu & Rao, 2017; Vasant & Bansal, 2013), and incur more losses and costs (Ivaskova *et al.*, 2015; Syed, 2013; Vasconcelos *et al.*, 2014). In addition, Okafor *et al.* (2009) stated that the cost of atmospheric corrosion includes damage to structures such as historical monuments, buildings, bridges, transport vehicles, power grids, communications hardware, and household equipment. It is found that roughly 20% of the failures of aircraft electronics are due to atmospheric corrosion.

A report on the economic impact of corrosion published in the USA from 1999 to 2001 showed that the total cost of corrosion was USD 276 billion annually, equivalent to 3.1% of the country's Gross Domestic Product (GDP) (Hansson, 2011; Koch *et al.*, 2002). In 2016, NACE International estimated that the global cost of corrosion was approximately US$ 2.5 trillion, equivalent to 3.4% of the global GDP (Koch, 2017). In addition, Dai *et al.* (2016) stated that the annual costs of corrosion reached USD trillions and accounted for about 6% of GDP in that year.

A number of researches have studied atmospheric corrosion and classified atmospheric corrosivity in tropical areas worldwide. However, there are only a few studies that have studied Malaysia, which is a tropical country. One study conducted an international project involving Malaysia (Tidblad, 2012), while another developed a corrosion risk map (Fathoni *et al.*, 2013). In addition, studies were also conducted to compare the indoor and outdoor corrosion of some metals (Ismail, 2009; Tong, 2012), and the effect of temperature on the corrosion behavior of stainless steel (Ishak *et al*., 2008). In fact, the study of this issue will enrich the literature and knowledge, assist to avoid the great costs and protect the environment.

Considering the above, mitigating this problem should be made a priority, and using a suitable corrosion control method could prevent about 20–25% of the corrosion cost (Badea *et al.*, 2011), and result in global savings of between 15% and 35% of the cost of damage, or between US$ 375 and US$ 875 billion (Koch, 2017). In fact, most mitigation techniques e.g., coating (Graziani *et al.*, 2017), electrochemical methods (Revie & Uhlig, 2008), and environmental alteration (El Ouadi *et al.*, 2015) are complicated. One of the most widespread methods of environmental alteration is the use of corrosion inhibitors (Akpan & Offiong, 2014; El Ouadi *et al.*, 2015). Unfortunately, most corrosion inhibitors are toxic, expensive, and non-biodegradable. Therefore promising materials, which are friendly towards the environment (e.g., non-toxic, cheap, available, and bio-degradable) should be used instead. These are called green or eco-friendly corrosion inhibitors. Many researchers have started to see the promise of using green corrosion inhibitors to prevent the corrosion process in different media, but this study is the first of its kind to investigate this issue in artificial acid rain conditions.

1.4 Objectives of the Study

1.4.1 General Objective

The general objective of this study is to assess the atmospheric corrosivity and its effect on metals in the Klang Valley, and its mitigation.

1.4.2 Specific Objective

The specific objectives of the study are:

1. To characterize atmospheric corrosion by determining the physicochemical characteristics of dust fall in terms of acid deposition, electrical conductivity (EC), and total dust fall (TDF) concentration in urban areas in Klang Valley.
2. To classify atmospheric corrosivity using time of wetness and deposition rate of chloride and sulfur dioxide in Klang Valley.
3. To determine the atmospheric corrosion rate by conducting weight loss method in the Klang Valley.
4. To assess the effectiveness of corrosion control using green corrosion inhibitors via potentiodynamic polarization (Tafel polarization), and to study the corresponding adsorption isotherms.

1.5 Scope and Limitation

The investigation was conducted to assess the atmospheric corrosivity on metals in Klang Valley, Malaysia. This includes the assessment of physicochemical characteristics of dust fall in five locations in Klang Valley, namely Shah Alam, Cheras, Kajang, UPM, and Puchong, from August 2014 to July 2015. In addition, this study pinpoints the issue of atmospheric corrosion, due to many metallic structures being exposed outdoors and part of them being left without any protection. Thus, these findings will provide information on areas exposed to atmospheric corrosion that require more attention to prevent and to avoid huge costs and negative impacts on the environment. The atmospheric corrosion assessment was conducted outdoors using four types of metals i.e. carbon steel, mild steel, aluminum, and copper, with Shah Alam, UPM, Putrajaya and Puchong as the exposure sites.

Many attempts have been conducted to mitigate the negative impact of corrosion attack. Anodic and cathodic protection, using a selected noble material, overdesign of the metallic structure, painting, coating and using chemical inhibitors are conventional techniques, but using inhibitors are more significant methods to prevent corrosion, which has not been fully explored. In fact, most chemical inhibitors— besides being expensive—have some drawbacks in terms of their impact on the environment. This study attempts to use eco-friendly materials found in common plants and waste agriculture as the green corrosion inhibitors for the tested metals. In the future, the findings of this work will help to improve the mitigation of atmospheric corrosion using materials obtained from plants.

However, the present study is subjected to several limitations. The first limitation is that the author was unable to perform Ion Chromatography to determine the chemical composition of deposition due to limited budget. Furthermore, the study of corrosion products requires specific techniques. Thirdly, the plant extracts need to be identified to determine the main chemical components in the plants that are responsible for the inhibitory action.

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