## EFFECT OF EARTHING MATERIAL WATER CONTENT ON THE RESISTIVITY AND CORROSION BEHAVIOUR OF EARTHING ELECTRODE

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## EFFECT OF EARTHING MATERIAL WATER CONTENT ON THE RESISTIVITY AND CORROSION BEHAVIOUR OF EARTHING ELECTRODE

## ARINA FATIN BINTI HASAN

Thesis submitted in fulfillment of the requirements for the award of the Bachelor Degree in Civil Engineering

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#### ABSTRAK

Tujuan utama sistem pembumian adalah untuk menyebarkan aliran caj ke muka bumi dalam masa yang paling singkat ketika berlakunya kilat ataupun litar pintas. Kerendahan frekuensi tentangan sistem pembumian menentukan kecekapannya. Oleh itu, sejumlah besar kajian telah dijalankan ke atas pelbagai jenis bahan untuk mencari bahan yang terbaik bagi sistem pembumian. Kajian ini bertujuan untuk menentukan kesan mempelbagaikan kandungan air terhadap daya tahan elektrik bahan pembumian, menentukan kesan sedutan terhadap tingkah laku kakisan elektrod tembaga dan aluminium yang ditanam di bawah bahan pembumian serta mengenal pasti jenis mikrob vang menyebabkan kakisan dan bertanggungjawab terhadap kakisan elektrod bumi dalam bahan pembumian. Dua sampel digunakan dalam kajian ini iaitu bentonite Andrassy dan Marconite. Sifat elektrik sampel telah dikaji dengan menggunakan kaedah kotak tanah dua-elektroda. Lengkungan ciri air-tanah (SWCC) sampel telah dibentuk menggunakan Teknik Keseimbangan Wap (VET). Ciri-ciri biologi sampel ditentukan melalui kaedah penyebaran plat. Hasil kajian menunjukkan bahawa daya tahan elektrik bentonite Andrassy sangat dipengaruhi oleh kehadiran air manakala daya tahan elektrik Marconite tidak terjejas oleh kehadiran air. Selain itu, Tindak balas kakisan elektrod aluminium dan tembaga tidak terjejas semata-mata oleh kandungan air bahan pembumian, sebaliknya ia dikawal oleh beberapa faktor lain seperti keadaan persekitaran, kandungan sulfur, pH, kehadiran mikroorganisma dan sebagainya. Kajian ini juga telah menemui mikrob yang menyebabkan kakisan, yang terdiri daripada satu spesies bakteria iaitu Micrococcus luteus dan empat spesies kulat iaitu Paecilomyces lilacinus, Trichoderma atroviride, Fusarium proliferatum, Rhodotorula mucilaginosa.

#### ABSTRACT

Electrical earthing systems main purposes is to disperse flow of charge to mother earth within the shortest time possible at the event of lightning or fault. Low frequency of earthing resistance of an electrical earthing systems determine its efficiency. Thus, there have been enormous amount of studies conducted on various material in order to find the best performing materials for an earthing systems. This study aims to determine the effect of varying water content on the electrical resistivity of earthing materials, determining the effect of suction on the corrosion behavior of copper and aluminium electrodes buried under earthing materials as well as identifying the type of corrosion induced microbes in earthing materials that is responsible for the corrosion of the earthing electrode. Two sample were used in this study namely Andrassy bentonite and Marconite. The sample electrical properties were studied by Wenner-four point test. The sample soil-water characteristic curve (SWCC) was established by Vapour Equilibrium Technique (VET). The sample biological characteristics was determined by means of spread plate method. The study outcome indicates that Andrassy Bentonite electrical resistivity is highly affected by water presence while Marconite electrical resistivity does not affected by the water presence. Aluminium and copper electrode corrosion behaviour is not affected solely by the water content of the earthing material, instead it is governs by a few other factors such as surrounding environment, sulphur content, pH, the presence of microorganisms and etc. One species of bacteria (i.e. Micrococcus luteus) and four species of fungus (i.e. Paecilomyces lilacinus, Trichoderma atroviride, Fusarium proliferatum, and Rhodotorula mucilaginosa) are the corrosion induced microbes that is responsible for corrosion of earthing electrode, identified in this study.

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## LIST OF SYMBOLS

Ψ	Total suction
$u_v$	Partial pressure of water vapour
$u_{v0}$	Saturation pressure of pure water vapour
$V_{w0}$	Specific volume of water
ω <sub>r</sub>	Molecular mass of water
R	Universal gas constant
Т	Absolute temperature
RH	Relative humidity
$G_s$	Specific gravity
$W_1$	Mass of the density bottle and stopper
W2	Mass of the density bottle, stopper and dry soil
<i>W</i> 3	Mass of density bottle, stopper, soil and water
$W_4$	Mass of density bottle, stopper and water
W	Water content
$M_D$	Mass of the dry soil
$M_S$	Mass of the wet soil
SL	Shrinkage limit
W	Moisture content of the wet soil sample
$V_s$	Volume of the dry soil sample
V	Volume of wet soil sample
$W_s$	Weight of the oven dried sample
Κ	A constant
Т	Time of exposure
Α	Area
W	Mass loss
D	Density
Wi	Hygroscopic water content
$W_L$	Liquid limit
WP	Plastic limit
Ws	Shrinkage limit

## LIST OF ABBREVIATIONS

MIC	Microbiologically induced corrosion
SWCC	Soil water characteristics curve
VET	Vapour equilibrium technique
BET	Brunauer-Emmett-Teller
CEC	Cation exchange capacity
NA	Nutrient agar
PDA	Potato dextrose agar

#### **CHAPTER 1**

#### **INTRODUCTION**

#### 1.1 Introduction

Earthing plays a crucial role as a shield for power systems especially against lightning. The aim of an earthing system is to shorten the time for the dispersion of charge flow to the mother earth at the event of lightning or fault. It is vital to ensure a proper earthing installations, to avoid damage of equipment or improper operation, especially within solid-state equipment (Drive et. al, 2001).

The earthing systems performance is justified by its earthing resistance. In accordance with universally recognized standard, a lightning protection systems should sustain an earth resistance below a restrictive value of 1  $\Omega$ m (Transit et al., 2008; Transit et al., 2005). Hence, there are various method that have been widely used to surpass this obligatory value, including the use of the earth enhancement materials such as bentonite and Marconite conductive concrete as a backfill for earthing (Androvitsaneas, et al., 2016; Aydiner, 2009; Tshubwana, et al., 2017).

Bentonite demonstrates extremely lower resistivity in the wet condition (Gomes, et al., 2017) while Marconite have extremely low resistivity of 0.001  $\Omega$ m at its initial state. Bentonite ability in lowering the earth resistance is contributed by its excellent water absorption and retaining capability. Generally, soil suction refer to the ability of soil to attract and hold water. It has been acknowledged that the soil suction and water content are essential parameters that governs various properties of unsaturated soils (Nam et al., 2010). The wet condition in return depicts high moisture content which is the main factors that contribute to soil corrosion (Lim, et al., 2013).

Soil corrosion is influenced by physicochemical properties such as the type of soil, level of the water table and moisture content, resistivity of soil, soluble ion, pH of the soil, oxidation-reduction potential and the occurrences of microorganisms in soil (Lee, et al., 2017). Microorganisms tend to inhabit the metal surfaces, and further matures into biofilms to enhance the inhabitation process (Percival, 1997; San et al., 2014). The formation of biofilm is well-known phenomenon in the process industry as a mechanisms which possibly triggers microbiologically influenced corrosion (MIC) (San et al., 2014).

#### **1.2 Problem Statements**

There are several factors that governs the performance of earth enhancement material which include having a low resistivity, low permeability and naturally inert (Lim, et al., 2013a). In order to take full advantage of backfilling, the earth enhancement material should acquire preceding properties. The widely practice earth enhancement material worldwide including Malaysia is the Bentonite, which have been proved to exhibits a lower resistivity during wet conditions (Gomes et al., 2017; Lim et al., 2013a).

Permeability of the earth enhancement material relates to its suction, which is its ability to store water (Nam et al., 2010). Bentonite is recognized for its ability to hold water for a significant amount of time, contributing to its application as a backfilling materials (Lim et al., 2013a). However, the preceding properties may results in corrosion of the earthing electrode. Increased in soil moisture will extensively affects the process of corrosion (Abdulloev, et al., 2016).

Among the factor that can induced soil corrosion is the present of microbes which also term as microbiologically influenced corrosion (MIC). The corrosion process is influenced by the microorganisms in the manner of having a number of mechanisms operating instantaneously (Videla, 2001).

#### 1.3 Objective

The objectives of this study are:

- To determine the effect of varying water content on electrical resistivity of Andrassy bentonite and Marconite.
- To determine the effect of suction on the corrosion behaviour of aluminium and copper electrodes buried under Andrassy bentonite and Marconite.
- To identify the type of corrosion induced microbes in Andrassy bentonite and Marconite that is responsible for the corrosion of the earthing electrode.

#### 1.4 Scope of Study

This study highlighted the use Andrassy bentonite and Marconite. The soil - water characteristic curve (SWCC) of Andrassy Bentonite and Marconite is established by vapour equilibrium technique (VET), particularly by applying suction of 3.60, 10.58, 23.58, 39.38, 111.77 and 262.75 MPa. Based on the water content of the SWCC the electrical resistivity of Andrassy bentonite and Marconite was determined by means of Wenner four - point test. The corrosion of the aluminium and copper electrode buried under Andrassy bentonite and Marconite will be determine by using mass - loss method and the type of corrosion induced microbes that is responsible for the corrosion of the earthing electrode will be determined by using spread plate method.

#### **1.5** Significance of Study

It is of high expectation that this study will be a beneficial basis in uncovering the best performing earth enhancing material as a backfill material for earthing. The outcomes of the study may possibly be a resolution for problem encounter when using bentonite and Marconite as a backfill material for earthing. Especially, the one concerning the effect of the material water content on the resistivity and corrosion behaviour of earthing electrode as well as the possibility of corrosion cause by soil microbe which also known as Microbiologically Induced Corrosion (MIC). This in return will results in more effective earthing systems. The findings of the study is also expect to help further discover critical area or helps in generating idea on the part that is that yet to be explore.

#### **CHAPTER 2**

#### LITERATURE REVIEW

#### 2.1 Introduction

This chapter presents concise review on earthing and the earth enhancing material. This chapter also present a review of corrosion and microbiologically induced corrosion (MIC). In addition, a brief review on the soil suction, suction control technique, suction measurement techniques as well as soil - water characteristic curve (SWCC) is represented.

#### 2.2 Earthing

Earthing plays a significant role in ensuring the safety of personnel, equipment and operation, power distribution systems, electronic components, devices, systems and computers as well as lightning protection systems. Hence, it is crucial that the earthing systems is installed properly to avoid any undesirable accidents (Zipse et al., 2003). The earthing systems effectiveness highly dependents on the low frequency of the earthing resistance.

#### **2.2.1** Factor That Governs the Performance of Earthing Systems

One of the ultimate problem encounters in implementing ideal and effective earthing systems is the undesirable soil conditions. When an earthing electrode is driven into the ground there is contact resistance between the electrode and the surrounding soil. This contact resistance plays a significant role in the determination of the value of earthing resistance. There are two factors that affect the earth resistance of an earthing systems, namely the properties of the soil and the components of the earth electrode (Lim et al., 2013a, 2013b; Nor, et al., 2006; Tshubwana et al., 2017). The properties of the soil are highly related to the soil resistivity. Soil resistivity is governed by the soil composition which comprises of moisture, minerals, and the dissolved salt. It is also the main factors that determines the resistance of the charging electrode and it has direct impact on the overall sub-station resistance (Adegboyega et al., 2011). The resistivity of natural soil varies depending on the type of soil encounter, ranging from a several Ohm-meter to several hundred thousand Ohm-meter. Table 2.1 shows approximate resistivity of different type of soil.

Glacial Sediment	Resistivity (Ωm)	Sedimentary Rock	Resistivity (Ωm)
Clays	5 - 100	Shales	6 – 14
Tilts	18 - 2000	Sandstone	18 - 1000
Gravel and sand	800 – 10, 000	Conglomerate	1000 - 10,000

 Table 2.1
 Approximate resistivity of different type of soil

Source: (Lim et al., 2013b).

Arulanandan and Smith (1973) and Mitchell (1993) reported that electricity is conducted through soil systems in a three-phase manner, where the paths through the sample are shown in Figure 2.1. The first path represent electrical path solely through the fluid pore. The second path is the flow of electrons through soil particles and the pore fluid. The last path is through solid particle of soil that is in contact to each other.



(a) At liquid limit

(c) At shrinkage limit

Figure 2.1 Electricity pathways in a porous media

(b) At plastic limit

#### 2.2.2 Standard Application for Improvements of Earthing Systems

There are different approach in reducing the earth resistance of an earthing systems, the conventional method use to attain low earth resistance include enlarging the earthing network dimensions, increasing the earthing depth, connection with an exterior earthing body as well as backfilling with earth enhancing materials (Khan, et al., 2010; Zhang, et al., 2014). However, to date, the used of earth enhancing material as backfill material for earthing is the most preferred method in ensuring that an earthing systems surpass the obligatory value (Gomes et al., 2017). Among the factor that may contributed to this event is the shortcomings or the limitation of the currently available method, for instance, enlarging the earthing network dimensions and connection with an exterior earthing body will results in significant increase of the construction costs and maybe impractical due to space limitations (Aydiner, 2009; Gomes et al., 2017; Zhang et al., 2014).

#### 2.3 Earth Enhancing Materials

There have been enormous amount of studies conducted on various material in order to find the best performing earth enhancing material to be used as backfill for an earthing systems (Ahmad et al., 2010; Anyasi et al., 2007; Gomes et al., 2017; Khan et al., 2010). However, only handful are compatible and have the aptitude to become long-term backfill material. The commonly used earth enhancing materials as backfill includes, the use of bentonite and Marconite conductive concrete.

#### 2.3.1 Characteristics of Good Earth Enhancing Materials

There are several factors that governs the effectiveness of earth enhancing materials as backfills for earthing. A good backfill material should possess the following properties; compactable and soil-compacting, naturally inert, have low and stable resistivity, capable of maintaining low grounding resistance with minimum fluctuation for long period, does not percolates with time, and economically feasible (Lim et al., 2013a; Pius Nyuykonge, 2015).

Earth enhancing material should be compactible and able to compact soil in order to maximize the contact surface between the earthing electrode and the soil surrounding it, which in turn will results in lower resistivity of (Lim et al., 2013a; Smohai et al., 2015). The material must also be naturally inert, in order to protect the earthing electrode against the corrosive environment which may shorten the expected life of the earthing systems (Lim et al., 2013a; Smohai et al., 2015). In order to ensure that the overall effective soil resistivity does not increase, the material must possess low and steady resistivity as the earthing resistance depends on both the resistivity as well as the geometry of the grounding electrode (Lim et al., 2013a).

The material to be used as backfill should also be able to sustain low earthing resistance with minimal fluctuation for prolonged period (Gomes et al., 2017; Lim et al., 2013a). The earth enhancing material must also be able to remain in the earthing electrode surrounding to avoid additional costs incurred cause by rebound of the earth resistance (Lim et al., 2013a; Zhang et al., 2014). Last but not least, the material to be implement should have affordable cost for application (Lim et al., 2013a; Zhang et al., 2014).

#### 2.3.2 Bentonite

In recent years, the used of bentonite as backfill for earthing is increasing rapidly due to its numerous advantage (Rusli et al., 2015). Bentonite also have been recognized as the best earth enhancing material to be used as backfill for earthing (Gomes et al., 2017).

Bentonite is a naturally occurring clay comprises of the mineral montmorillonite, a hydrous aluminium silicate. It is hygroscopic and hydrates, it hold water in its structure and chemically absorbing moisture from the surrounding (Lee et al., 2017). Thus, acting as a drying agent to the surrounding environment. If sufficient amount of water is added, the bentonite capable of absorbing five times its weight in water and swell up to 13 times its dry volume.

At six times of its dry volume, bentonite is very dense, pasty clay that are capable of holding its own shape and will adhere to any surface it touches, increasing the contact surface of the soil and the earthing electrode. Bentonite is non-corrosive, stable, and will not change characteristics as the years past (Lim et al., 2013a) Studies shows that bentonite has a resistivity of 18  $\Omega$ m in its dry state and low resistivity of 3  $\Omega$ m in the presence of water (Gomes et al., 2017).

#### 2.3.3 Marconite

Marconite is a synthetic material designed, developed and manufactured specifically for use in earthing applications. Marconite is a dark grey, granular material that is use as a replacement for traditional aggregate materials used with concretes mixes. Marconite is produced from a unique manufacturing process by using specific raw material feedstocks that is selected with care and mixed in strictly controlled ratio before going through a range manufacturing process and thermal treatments contributing to its distinctive properties.

Marconite are acquainted with exceptional advantages among which having extremely low resistivity of 0.001  $\Omega$ m when compared to of Bentonite. It is also flexible and suitable for most ground conditions, once harden it becomes a permanent, solid structure that is not susceptible to shrinking, drying out or leach. Marconite is economical to be used as it does not required any maintenance to maintain it serviceability. Marconite is chemically inert, it is non-corrosive to steel or copper and does not attack cement structures with a pH that is within the neutral range. Its high strength make it suitable to be used as part of the structure itself.

#### 2.4 Corrosion

The primary objective in designing an electrical earthing systems is to provide a low resistance path for dissipation of electric current at the event of fault and for the protection of personnel by limiting the potential to safe values. The preceding is the normal earthing practice and the underground corrosion has in general been ignored until a considerable amount of damage has occurred to the main structure (Afa, 2011; Company et al., 1955; Huening, 2011).

The corrosion of an earthing electrode could reduce the effectiveness of an earthing systems. The formation of oxide layer that is non-conductive triggers the electrical resistivity of the earthing systems which in turn results in higher resistance (Huening, 2011). It is common phenomenon in an earthing systems where earthing faults problem arise due to corrosion, which might lead to huge economic loss and threat to the safety of an earthing systems (Rong Zheng, et al., 2002).

The fundamental cause of the deterioration of earthing electrode buried underground is soil corrosion. The soil corrosion in turn depends upon the physicochemical properties such as soil type, moisture content and the position of the water table, soil resistivity, soluble ion content, soil pH, oxidation–reduction (redox) potential and the rates of microbes in soil corrosion (Levlin, 1992; Schaschle et al., 1963; Starkey et al., 1983).

#### 2.4.1 Microbiologically Induced Corrosion (MIC)

Microbiologically Influenced Corrosion (MIC) has become a threat to many industrial sectors such as oil and gas, nuclear, chemical, civil engineering and etc. MIC particularly causes the industry to suffer from substantial economic loses (Sette et al., 2010). Microbiologically influenced corrosion (MIC) is a corrosion in which the deterioration of metallic as well as non-metallic materials take place due to the presence and activities of microorganisms (Alasvand et al., 2014).

Microorganisms concerned in bio corrosion of metals and its alloys varied physiologically. They are considered corrosion resistant due to their ability to influence the corrosion of many metals in diverse environment threating the stability of those metals (Beech et al., 1999). Generally, microorganisms influence the process of corrosion via a number of mechanisms operating simultaneously or sequentially. However, the main microbial effects on corrosion is associated to the modification of the interface structure through biofilm accumulation (Videla, 2001). Microorganisms such as bacteria and fungi can influence the corrosion process (Geweely, 2011).

#### 2.4.2 Bacteria

Heavy metal interactions with many different species of microorganisms has been described specifically involving copper (Letnik et al., 2017). A recent studies review have shown that many microorganisms are capable of metal biosorption (Kiran et al., 2011). There are numerous research that provide evidence of the presence of bacteria that promoted corrosion on metal surface such as steel (Romero et al, 2004), and carbon steel (Xu et al., 2013).

#### 2.4.3 Fungi

Metal corrosion and inhibition which may be governed by microscopic fungi spread in the environment has led to passivation in order to prevent the corrosion and inhibition process. Fungi capable of solubilizing minerals and metal compounds through a number of mechanisms, including acidolysis, complexolysis, redoxolyzes and by accumulation of metal in the biomass (Lugauskas et al., 2011). Studies have proved that fungi promoted corrosion on metal surface such as steel, aluminium, zinc, copper as well as carbon steel (Lugauskas, 2010; Lugauskas et al., 2011; Lugauskas et al., 2008).

#### 2.5 Soil Suction

In general, the soil suction can be referred as the soil ability to retain or hold water. Soil suction is defined by Richards (1974) as the water potential in a soil-water system. The suction in soil is often referred to as a total suction and is generally divided into two major components that is matric and osmotic suction (Richards, 1974). Generally, matric suction ascribed mainly to capillary actions in soil structure and the osmotic suction is correlated with physico-chemical interactions between clay minerals and pore water (Wan et al., 1995).

Soil suction is closely related to relative humidity. When a soil relative humidity is 100% the total suction in the soil will be equal to zero (Fredlund and Rahardjo, 1993). The total suction,  $\Psi$ , and relative humidity, *RH*, relationship can be described by Kelvin's equation, Eq. 2.1 (Fredlund and Rahardjo, 1993).

$$\Psi = -\frac{RT}{v_{w0}\omega_r}\ln\frac{u_v}{u_{v0}} = -\frac{RT}{v_{w0}\omega_r}\ln\left(\frac{RH}{100}\right)$$
 2.1

where  $u_v$  and  $u_{vo}$  is the partial pressure of water vapour and the saturation pressure of pure water vapour,  $v_{wo}$  is the specific volume of water (m<sup>3</sup>/kg),  $\omega_r$  is the molecular mass of water vapour (18.016 kg/kmol), *R* is the universal gas constant (8.31432 J mol<sup>-1</sup> K<sup>-1</sup>), *T* is the absolute temperature in Kelvin and RH is the relative humidity.

#### 2.6 Suction Measurement Technique

At hand, there are numerous techniques have been adopted in order to measure the suction of an unsaturated soils, such as filter paper method, null-type axis translation, high suction tensiometer, chilled-mirror dew point technique and suction probe (Agus & Schanz, 2005, ASTM. D 6836-02, 2003; Guan and Fredlund, 1997; Lourenço et al., 2011; Lu and Likos, 2004; Rahardjo and Leong, 2006; Ridley and Burland, 1993).

#### 2.6.1 Chilled – Mirror Dew – Point Technique

In soil science the chilled-mirror dew-point technique has been used to quantify soil water potential. The technique is used for measuring total suction of soils in geotechnical engineering application (Agus & Schanz, 2005; Leong et al., 2003). The chilled-mirror computes the total suction based on equilibration of water in a soil specimen with the water vapour phase in the air space above the sample in a sealed chamber (Bulut et al., 2009; Elgabu, 2013).

The chilled-mirror potentiometer works based on the principle of thermodynamic between relative humidity, temperature and total suction in accordance to Kelvin's equation (Elgabu, 2013). Agus and Schanz (2004) showed that the chilled-mirror provides the most accurate and rapid determination of suction-water content relationship of clay-water mixture.

#### 2.7 Suction Control Technique

Various methods are available currently for the purpose of controlling matric or total suction of soil specimens. Table 2.2 sum-up of some of the common method used in the laboratory for controlling suction in soils.

Technique	Suction component	Measure suction from	Suction range (MPa)	Available suction path
Axis-translation	Matric	Air pressure	0.01 to 1.5	Drying/wetting
Soil column	Matric/Total	Negative water Head	0 to 0.1	Drying
Centrifuge	Matric	Centrifugal force	0.01 to 1.5	Drying
Osmotic	Matric	Osmotic pressure	0 to 1.5	Drying/wetting
Vapour equilibrium	Total	Salt solution	3 to 300	Drying/wetting

Table 2.2Common laboratory method of controlling suction

Source:(Croney, D. and Coleman, 1954).

#### 2.7.1 Vapour Equilibrium Technique (VET)

Vapour equilibrium technique is applied by the control of closed system relative humidity (Delage, Romero, & Tarantino, 2008). There are two types of osmotic solutions that are commonly used to produce uniform suction conditions that is saturated salt solutions and unsaturated acid solutions. In the application of this technique saturated salt solutions are used in general over acid dissolution due to volatilization of acid solutions which may cause safety concern, soil mineralogical composition alteration as well as damage of testing equipment (Delage et al., 2008; Tang and Cui, 2005).

The range of suction in vapour equilibrium technique is from 3 MPa to 1000 MPa (Ng and Menzies, 2007). Generally, the salt solutions generated lower range of suction while the acid solutions are able to generate higher range of suction (Blatz, Cui, & Oldecop, 2009). Figure 2.2 shows the schematic of the experimental setup. The main disadvantage of vapour equilibrium technique is that the time to reach moisture equalisation is extremely long due to the fact that vapour transfer depends on diffusion rate (Delage et al., 2008).



Figure 2.2 Vapour equilibrium technique experimental setup

## 2.8 Soil - Water Characteristic Curve (SWCC)

Relationship between soil suction and water content is referred to as SWCC. However there are few are the terms that has been used which carries the same meaning such as water-suction relationship, retention curves, and moisture retention curves. The relationship between suction and soil water content is provided by the soil-water characteristic curve (Fredlund and Rahardjo 1993; Ng and Menzies, 2007).

#### 2.8.1 Wetting Suction - Water Content (SWCC)

The common method used in the laboratory to establish wetting SWCCs is by decreasing the applied suction (Fredlund and Rahardjo, 1993). Among the factors that influenced the wetting SWCC is the structure of soil, soil type, mineralogy, density, initial water content, stress history, compaction method as well as confining stress (Lu, and Likos, 2004; Tinjum et al., 1997).

#### **CHAPTER 3**

#### METHODOLOGY

#### 3.1 Introduction

This chapter presents the experimental methods implemented in this study. The experiment detail was planned and several laboratory tests were carried out. The determination of physical and chemical properties of the material used is obtained by carrying out a few laboratory test. In addition the biological characteristic of soil was verified by isolation and enumeration of microorganisms in agar medium by means of spread plate method. The wetting suction-water content SWCCs was established by vapour equilibrium technique (VET). The corrosion rates of the earthing electrode was determined by mass-loss method On top of that, the electrical resistivity of soil was determine by Wenner four - point test..

#### 3.2 Sample Selection

#### 3.2.1 Bentonite

The soil sample used in this study was collected in Andrassy, Tawau, Sabah. Auger Borings has been used in order to obtain sample for this study and in accordance to ASTM D 1452 - 80. The auger boring was make by rotating and advancing the auger into the soil to the desired distance. The auger was then withdrawn from the hole, the soil is removed and sealed in airtight container.

#### 3.2.2 Marconite

The Marconite used in this study is procured from Tokai Engineering Malaysia Sdn Bhd.

#### 3.3 Sample Preparation

The specimens used were prepared in various form such as loose powders and saturated slurry conditions. To establish the wetting suction - water content SWCCs, powdered specimens was used. Figure 3.1 shows the prepared specimens for establishing the SWCCs. To determine the corrosion rates of the earthing electrode, the electrode was buried under the specimens of Andrassy bentonite and Marconite. The material for earthing electrode used in this study are aluminium and copper and the diameter of the electrode used are 1.580 cm and 1.407 cm respectively. Figure 3.2 shows the earthing electrode used in this study. The determination of the soil electrical resistivity involve the use of both powdered and saturated slurried specimens.



Figure 3.1 Powdered specimen of Andrassy bentonite and Marconite



Figure 3.2 Aluminium and copper electrode

#### **3.4** Determination of Physical Properties of Soil

#### 3.4.1 Specific Gravity

This test is performed for determination of soil specific gravity by pycnometer method. Specific Gravity is the ratio of the mass unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature. The reference standard for the test method is BS 1377: Part 2:1990:8.3 – Standard Test of Specific Gravity for Fine Grained Soil using Density Bottle. The equation used for the calculation of specific gravity are as follows:

$$G_s = \frac{w_2 - w_1}{(w_4 - w_1)(w_3 - w_2)}$$
3.1

where  $G_s$  is the specific gravity,  $w_1$  is mass of the density bottle and stopper,  $w_2$  is the mass of the density bottle, stopper and dry soil,  $w_3$  is the mass of density bottle, stopper, soil and water,  $w_4$  is the mass of density bottle, stopper and water.

#### 3.4.2 Hygroscopic Water Content

This test is performed for determination the water content of soil. The water content is ratio of the mass of pore or free water in a given mass of soil to the mass of the dry soil solids expressed in percentage. The reference standard for the test method is ASTM D 2216 – Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures. The equation used for the calculation of water content are as follows:

$$w(\%) = \frac{M_D}{M_s} \times 100$$
3.2

where *w* is the water content,  $M_D$  is the mass of the dry soil and  $M_s$  is the mass of the wet soil.

#### 3.4.3 Liquid Limit

The moisture content at the point of transition from plastic to liquid state is the liquid limit (LL), which is measured based on the penetration of a standardized cone of specified mass into the soil. The cone penetration is 20mm at the liquid limit. The reference standard for the test method is BS 1377: Part 2:1990: 43 – Standard Test Method for Liquid Limit.

#### 3.4.4 Plastic Limit

The moisture content at the point of transition from semisolid to plastic state is the plastic limit (PL). The plastic limit (PL) is the water content, at which a soil can no longer be deformed by rolling into 3.2mm (1/8 in.) diameter threats without crumbling and is expressed in percentage. The reference standard for the test method is ASTM D 4318 – Plastic Limit, and Plasticity Index of Soils.

#### 3.4.5 Shrinkage Limit

The shrinkage limit is the moisture content at which the soil volume will not reduce any further with water content reduced. The reference standard for the test method is ASTM D4943-08. The equation used for the calculation of shrinkage limit are as follows:

$$SL(\%) = W - \left(\frac{V - V_s}{W_s}\right) \times 100\%$$
 3.3

where SL is the shrinkage limit, W is the moisture content of the wet soil sample, V is the volume of wet soil sample,  $V_s$  is the volume of the dry soil sample and  $W_s$  is the weight of the oven dried sample.

#### 3.4.6 Specific Surface Area (BET)

Specific surface area is the ratio of soil surface area with its mass or volume. The specific surface area of the soil were determined by means of Brunauer-Emmett-Teller (BET) method (ISO 9277:2010, DIN ISO 9227: 2013).

Prior to the test commencement the BET analyser must be warm up for at least 30 minutes. The nanomaterials is filled in the instrument specific glass holder and weight by using microbalance. 5g of soil sample is placed in the instrument and heat up for minimum of 18 hours at 250 °C. After the sample cooled down, the sample is weight again to determine the possible mass losses.

Thereafter the sample is place in the BET measurement unit for BET analysis. The soil sample will then be cooled down to 77k, the boiling point of liquid nitrogen. Lastly, nitrogen is injected under several pressures to determine the displacement of nitrogen gas for specific surface calculation.

#### 3.5 Determination of Chemical Properties of Soil

#### 3.5.1 Cation-Exchange Capacity (CEC)

Cation exchange capacity (CEC) is the ability of soil to hold certain amount of exchangeable positively charged ions on the negatively charge surface. The exchange capacity denotes the available cations that capable of being replaced by cations of greater reactivity. Ammonium acetate method is use for the CEC determination. The reference standard for the test method is in accordance to ASTM C387-99.

#### 3.6 Determination of Biological Characteristics of Soil

#### 3.6.1 Spread Plate Method

Spread plate technique is the method used for the purpose of isolation and enumeration of microorganisms in agar medium. The results of a perfect spread plate technique is the evenly distributed, visible and isolated colonies of microbes in the plate. Two agar medium will be used in this study, NA as well as PDA.

Approximately 5 ml of clay-saline solution which was taken from its suspension is transferred into prepared NA plate and PDA plate for culturing bacteria and fungi respectively. A sterilised L-shaped glass rod was then used to spread the suspension evenly. The plate were labelled and sealed with parafilm, the NA plate was incubated at 30°C for 2 to 5 days whereas the PDA plate was incubated at 25°C for 7 to 10 days so that the microbe colonies can be observed on the agar medium surface.

#### **3.7** Determination of Suction - Water Content (SWCC)

#### 3.7.1 Chilled-Mirror Dew-Point Technique

The saturated salt solution for the Vapour Equilibrium Technique was prepared by using chilled-mirror dew-point technique. The salts to be used for the test was first weight according to the specific amount needed for 250ml distilled water. Table 3.1 shows the calculation for the amount of salt needed for dilution for each salts. The salt were then mixed and stirred using magnetic stirrer until it reach equilibrium. Afterwards, the suction induced by the saturated salt solution was measured by using WP4C Dew Point Potentiometer.

Table 3.1	Saturated salt solution preparation	
Salt Solution	Mass of Salt for 250ml Water (g)	
$K_2SO_4$	30.00	
KNO <sub>3</sub>	95.75	
KCl	88.75	
NaCl	87.50	
$K_2CO_3$	277.50	
LiCl	211.25	

Prior to the calibration process switch on the WP4C Dew Point Potentiometer to allow for equilibration with the laboratory condition. When the device is ready, the cylindrical specimen holder was filled with the salt solution until it occupied half of the specimen holder and placed into the device chamber. Lock the specimen holder, wait and record the displayed suction value. Figure 3.3 shows the device used for the chilledmirror dew-point technique.



Figure 3.3 WP4C Dew Point Potentiometer

#### **3.7.2** Vapour Equilibrium Technique (VET)

This particular technique controls the total suction. Vapour equilibrium technique controls the relative humidity in an air space above saturated salt solutions in a closed system. The tests were carried out in closed-lid desiccators by using saturated salt solution of Potassium Sulphate (K<sub>2</sub>SO<sub>4</sub>), Potassium Nitrate (KNO<sub>3</sub>), Potassium Chloride (KCl), Sodium Chloride (NaCl), Potassium Carbonate (K<sub>2</sub>CO<sub>3</sub>), and Lithium Chloride (LiCl), each inducing suctions of 3.60, 10.58, 23.58, 39.38, 111.77, and 262.75 MPa respectively.

In order to determine the wetting suction-water (SWCCs) the sample was prepared and placed on the porous disk of each desiccator and weighed every three days until no further change in mass of the sample recorded. Figure 3.4 shows the experimental set up for this study. The tests were carried out near constant temperature of 25°C.



Figure 3.4 Wetting test by using vapour equilibrium technique (a) Desiccator test setup (b) Powdered specimens within tests desiccator

#### **3.8** Determination of Corrosion Rates of the Earthing Electrode

#### 3.8.1 Mass - Loss Method

This test carried out to evaluate the corrosion damage that has occurred. The clean, dry specimens should be measured and weighed prior to the testing and as well as after the testing. The reference standard for the test method is ASTM G1 – 03(2017) e1 – Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens. The equation used for the determination of average corrosion rate are as follows:

Corrosion rates (%) = 
$$\frac{K \times W}{A \times T \times D}$$
 3.4

where *K* is a constant 8.76 x 10<sup>4</sup>, *W* is the mass loss in grams, *A* is the area in cm<sup>2</sup>, *T* is the time of exposure in hours and *D* is the density in g/cm<sup>3</sup>.

#### 3.9 Determination of Soil Electrical Resistivity

#### 3.9.1 Wenner Four - Point Test

This test is performed for the measurement of soil resistivity. Soil resistivity is the property that describes the soil ability to conduct current and whether a given soil type can provide a good or a poor ground in term of its resistivity (high or low). The test method procedures are for the measurement of soil resistivity in the saturated condition and in the as-received condition. The equipment needed for the testing include a resistivity meter (Nilsson Model 400 Soil Resistance Meter), a soil box (M.C.Miller Soil Boxes), and soil box leads in the set of 4 (M. C. Miller Soil Container Test Leads). This resistivity meter is used with the soil box to measure resistivity of the sample and is connected with soil box leads in the set of 4. The resistivity meter gives a measurement in the range of 1.1  $\Omega$ cm to 1, 100, 000  $\Omega$ cm. The experimental set up is as shown in Figure 3.5. The reference standard for the test method is ASTM G187 - 12a – Standard Test Method for Measurement of Soil Resistivity Using the Two-Electrode Soil Box Method.



Figure 3.5 Two-electrode soil box method experimental set up

#### **CHAPTER 4**

#### **RESULTS AND DISCUSSION**

#### 4.1 Introduction

This chapter presents the outcomes of the experiments that have been completed which comprises of the physical, chemical and biological properties of Andrassy bentonite and Marconite. The wetting suction-water content SWCCs was established. The corrosion behaviour of the earthing electrode buried under Andrassy bentonite and Marconite as well as the effect of water content on the electrical resistivity of Andrassy bentonite and Marconite were analysed and discussed. All results were justified in this chapter.

#### 4.2 The Physical Properties of Earthing Materials

#### 4.2.1 Specific Gravity

The specific gravity of Andrassy bentonite and Marconite are 2.78 and 1.69 respectively. Andrassy bentonite has a higher specific gravity value when compared to that of Marconite. Since the soil's specific gravity is governs by the density of the minerals making up the individual soil particles. The value obtained in this study for Andrassy bentonite compliment the results obtained previously (Mohd Tadza et al., 2018). Among the factor that may contribute to this is that both study uses raw Andrassy bentonite for the testing.

#### 4.2.2 Hygroscopic Water Content

Andrassy bentonite and Marconite hygroscopic water content are 6.43% and 0.05% respectively. Bentonite water content is affected by its mineralogical properties. In addition, other factor that affect its water content are, the grain size, specific surface (BET) and cation exchange capacity (CEC). The value obtained in this study is lower than the range of water content that previous study has found (Irawan, 2006). The difference in the value obtained may be due to the condition of the sample used. The sample in the study referred, show improvement in the water content value due to the beneficiation of the original condition of the Andrassy bentonite. Marconite low water content may be contribute by its high porosity and high permeability.

#### 4.2.3 Liquid Limit

The liquid limit of Andrassy bentonite is 129.30%. Bentonite high liquid limit is contributed by its mineralogical properties. In addition, other factor that may contribute to its high liquid limit are the grain size, high specific surface (BET), clay content, and high cation exchange capacity (CEC). The value obtained in this study is within the range of 120.25% - 458.98% as previous study has found (Irawan, 2006). The difference in the value obtained may be due to the condition of the sample used. The sample in the study referred, show improvement in the Atterberg limit value due to the beneficiation of the original condition of the Andrassy bentonite.

#### 4.2.4 Plastic Limit

The plastic limit of Andrassy bentonite is 46.12%. Bentonite high plastic limit is contributed by its mineralogical properties. In addition, other factor that may contribute to its high plastic limit are the grain size, high specific surface (BET), clay content, and high cation exchange capacity (CEC). The value obtained in this study is within the range of 32.25% - 58.65% as previous study has found (Irawan, 2006). The difference in the value obtained may be due to the condition of the sample used. The sample in the study referred, show improvement in the Atterberg limit value due to the beneficiation of the original condition of the Andrassy bentonite.

#### 4.2.5 Shrinkage Limit

Andrassy bentonite shrinkage limit is 13.40%. The shrinkage limit depends upon liquid limit, clay content, and cation exchange capacity (CEC). The value obtained in this study compliment the results obtained previously (Mohd Tadza et al., 2018). Among the factor that may contribute to this is that both study uses raw Andrassy bentonite for the testing.

#### 4.2.6 Specific Surface Area (BET)

The specific surface area of Andrassy bentonite and Marconite are 734.27 m<sup>2</sup>/g and 0.33 m<sup>2</sup>/g respectively. Bentonite high specific surface area (BET) is contributed by its mineralogical properties. In addition, other factor that may contribute to its high specific surface area is the clay content specifically the presence of montmorillonite. The value obtained in this study compliment the results obtained previously (Mohd Tadza et al., 2018). Among the factor that may contribute to this is that both study uses raw Andrassy bentonite for the testing.

#### 4.3 The Chemical Properties of Soil

#### 4.3.1 Cation Exchange Capacity (CEC)

The Cation exchange capacity (CEC) of Andrassy bentonite is 42.15 meq/100g. The exchange reaction depends mainly on the electrovalence of the cations as well as the relative concentration of cations in the water. The value obtained in this study compliment the results obtained previously (Mohd Tadza et al., 2018). Among the factor that may contribute to this is that both study uses raw Andrassy bentonite for the testing.

# 4.4 Summary of the physical and chemical properties Andrassy bentonite and Marconite.

Table 4.1 summarize the physical and chemical properties of Andrassy bentonite and Marconite.

Properties	Andrassy	Marconite
	Bentonite	
Specific Gravity, $G_s$	2.78	1.69
Hygroscopic Water Content, <i>w<sub>i</sub></i> (%)	6.43	0.05
Liquid Limit, $w_L(\%)$	129.30	-
Plastic Limit, $w_P(\%)$	46.12	-
Shrinkage Limit, $w_s$ (%)	13.40	-
Specific Surface Area, $S(m^2/g)$	734.27	0.33
Cation-Exchange Capacity, B (meq/100g)	42.15	-

Table 4.1Physical and chemical properties of Andrassy bentonite and Marconite

#### 4.5 The Biological Characteristics of Soil

The soil microbiological study uncovered the presence of eight microbes in Andrassy bentonite which consists of four species of bacteria (i.e. *Bacillus anthracis, Staphylococcus aureus, Micrococcus luteus, Achromobacter xylosoxidans*) and four species of fungus (i.e. *Paecilomyces lilacinus, Trichoderma atroviride, Fusarium proliferatum, Rhodotorula mucilaginosa*) as tabulated in table 4.2. These microbes present in Andrassy bentonite probably due to the fact that the condition is conducive for their growth. Microbes grows in very diverse condition, thus, some condition is conducive for certain microbes growth while others not.

Phylum	Microbes	Corrosion	References
Bacteria			
Firmicutes	Bacillus anthracis		-
Firmicutes	Staphylococcus aureus	Carbon Steel	(Labjar et al., 2010)
Actinobacteria	Micrococcus luteus	Copper Uptake	(Letnik et al., 2017)
Probacteria	Achromobacter xylosoxidans		-
Fungi			
Sac Fungi	Paecilomyces lilacinus	Aluminium	(Sette et al., 2010)
Ascomycota	Trichoderma atroviride	Copper Uptake	(Anand et al, 2006)
Sac Fungi	Fusarium	Aluminium,	(Lugauskas et
	proliferatum	Ferum, Copper (weak), Zinc (Weak)	al., 2008)
Basidiomycota	Rhodotorula mucilaginosa	Copper	(Colin et al., 2012)

Table 4.2The microbiological analysis of Andrassy bentonite

Studies have shown that, one species of bacteria (i.e. *Micrococcus luteus*) and all four species of fungus (i.e. *Paecilomyces lilacinus, Trichoderma atroviride, Fusarium proliferatum*, and *Rhodotorula mucilaginosa*) may contribute to corrosion of the earthing electrode.

#### 4.6 The Suction Calibrations

Table 4.3 depicts the suction induced by each saturated salt solution based on the Chilled-Mirror Dew-Point Technique. It can be observed that different salt solution induced different suction. There are many published works and chemistry handbook that present range of salt solutions and the relative humidity levels that is generated (Blatz, et al., 2008).

Saturated Salt Solution	Suction (MPa)	
$K_2SO_4$	3.60	
KNO3	10.58	
KCl	23.58	
NaCl	39.38	
$K_2CO_3$	111.77	
LiCl	262.75	

Table 4.3Suction calibration of saturated salt solution

## 4.7 The Soil-Water Characteristic Curve (SWCC)



Figure 4.1 Soil water characteristic curve of Andrassy bentonite and Marconite

It can be observed that based on Figure 4.1 Andrassy Bentonite has a higher water content than Marconite at the end of the experiment. This is due the fact that bentonite has greater ability to retain or hold water. Bentonite is strongly hydrated by water, thus, it is hydrophilic in nature which contribute to the preceding properties (Lim et al., 2013a).

- 4.8 The Effect of Suction on the Corrosion Behaviour of Earthing Electrode
- 4.8.1 The Effect of Suction on the Corrosion Behaviour of Aluminium and Copper Electrode buried under Andrassy Bentonite



Figure 4.2 The corrosion rate of aluminium and copper electrode buried under Andrassy bentonite

It can be observed that based on Figure 4.2 that copper electrode corrosion rates is greater than aluminium electrode. Different suction induced, result in different water content. Water is one of the factor that affect soil corrosion (Levlin, 1992; Schaschle et al., 1963; Starkey et al., 1983). However, from this study it can be seen that high water content does not assure high corrosion rates. Instead, the corrosion most likely occurs because the condition is more conducive for corrosion of copper electrode than aluminium electrode. There are various factor that affect the corrosion process in clay, including the surrounding environment, sulphur content, pH as well as the presence of microorganisms (Yahaya et al., 2011).

## 4.8.2 The Effect of Suction on the Corrosion Behaviour of Aluminium and Copper Electrode buried under Marconite



Figure 4.3 The corrosion rate of aluminium and copper electrode buried under Marconite

It can be observed that based on Figure 4.3 the corrosion rates of aluminium electrode is greater than copper electrode. Different suction induced, result in different water content. Water is one of the factor that affect soil corrosion (Levlin, 1992; Schaschle et al., 1963; Starkey et al., 1983). However, from this study it can be seen that high water content does not assure high corrosion rates. Instead, the corrosion most likely occurs because the condition is more conducive for corrosion of aluminium electrode than copper electrode. In general, aluminium alloys have good corrosion resistance, nonetheless, aluminium does corrode under some conditions (Zhao, 2011).

#### 4.9 The Electrical Resistivity of Earthing Materials



#### 4.9.1 The Electrical Resistivity of Andrassy bentonite

Figure 4.4 Effect of water content on the electrical resistivity of Andrassy bentonite.

It can be observed that based Figure 4.4, Andrassy Bentonite has a high resistivity at its dry state. However, the resistivity decrease abruptly with increasing water content. This phenomenon can be explained by considering the contact surface between the soil particles, at lower water content the contact surface between soil particles is lower as there is presence of voids. Conversely, addition of water that fill in the voids between the soil particles, improve the soil contact surface and facilitate flows of ions, thus, decreasing its electrical resistivity. Study has present that Bentonite demonstrates extremely lower resistivity under wet condition (Gomes et al., 2017).

#### 4.9.2 The Electrical Resistivity of Marconite



Figure 4.5 Effect of water content on the electrical resistivity of Marconite.

It can be observed that based on Figure 4.5, Marconite has a very low resistivity at its initial water content. However, its resistivity shows a small fluctuation with increasing water content. This phenomenon occurs because marconite behaviour is similar to coarse grained soil, it is porous and has high permeability, thus water does not have much effect on its properties. Marconite has a very low resistivity when compared to that of bentonite, even at its initial ("Marconite," 2018).

#### **CHAPTER 5**

#### CONCLUSION

#### 5.1 Conclusion

The objectives of this study were to determine the effect of varying water content on electrical resistivity of Andrassy bentonite and Marconite as well as to determine the effect of suction on the corrosion behaviour of aluminium and copper electrodes buried under Andrassy bentonite and Marconite. In addition, this study aim to identify the type of corrosion induced microbes in Andrassy bentonite and Marconite that is responsible for the corrosion of the earthing electrode.

Based on the findings of this study, the following conclusions were drawn:

- Andrassy Bentonite electrical resistivity is highly affected by the presence of water while Marconite electrical resistivity does not affected by the presence of water.
- The corrosion behaviour of aluminium and copper electrode is not affected solely by the water content of the earthing material instead it is governs by a few other factors such as surrounding environment, sulphur content, pH, the present of microorganisms and etc.
- 3. Corrosion induced microbes that is responsible for corrosion of earthing electrode that is identified in this study consists of one species of bacteria (i.e. *Micrococcus luteus*) and four species of fungus (i.e. *Paecilomyces lilacinus, Trichoderma atroviride, Fusarium proliferatum* and *Rhodotorula mucilaginosa*).

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