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EXPERIMENTAL STUDY ON THE EFFECT OF SOIL RESISTIVITY WHEN TREATED WITH WATER, SALT AND CARBON

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JUNE 2015

"I hereby declare that I have read through this report entitle "Experimental Study On The Effect Of Soil Resistivity When Treated With Water, Salt And Carbon" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

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A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Electrical Engineering (Industrial Power)

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2015

“I declare this report entitle “Experimental Study On The Effect Of Soil Resistivity When Treated With Water, Salt And Carbon” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree”

Signature :...

Name : YONG SING XING

Date :...

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First of all I would like to thank God as finally I would manage to finish this final year project although before doing this final year project I have been gone through many obstacles. Besides that, I would like to express my deepest appreciation to all those who provided me the possibility to complete this report. A special gratitude I give to my final year project supervisor, Miss Arfah Binti Ahmad, whose contribution in stimulating suggestions and encouragement, helped me to coordinate my project especially in writing this report.

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ABSTRACT

Grounding is a very important aspect in any modern electrical protection system design. Improper grounding may expose the personnel as well as the equipments to unsafe condition. Generally, there are two ways can be used to reduce the earth resistance of a system. The first method is adding more ground rod and the second method is doping on the soil medium. However, the first method is not economically viable when compared to second method which is more effective and cheaper way in reducing the grounding resistance and thereby improve the system performance. Before implementing the grounding system in certain location, the soil characteristic and resistivity in the proposed location must be determined first. This laboratory research aims to test on five different types of soil which includes clay, loam, sandy soil, laterite and top soil at uniform room temperature in order to determine which type of soil will exhibit the lowest resistivity and suitable to be used in grounding system. All five types of soil with the mass of 1 kilogram are treated by water content, salt solution, charcoal and salted charcoal with percentage variation from 2.5% to 30% and 200V DC voltage being applied to BS 1377-3 cylindrical soil resistivity tester. The recorded current is used to obtain resistivity values by applying resistivity equation. Then, the resistivity data is analyzed by using statistical methods which include scatter plot, correlation coefficient analysis and regression analysis. From the scatter plot, the relationships appear to be curvilinear trend and the clay soil is the best soil to be used for grounding installation as it has strongest correlation coefficient. The observations have shown that the resistivity values for all soils will decrease as the water, salt and salted charcoal treatment are increased. However, the relationship between charcoal content and soil resistivity do not show any decrease in resistivity but it appears to increase the resistivity value.

ABSTRAK

Pembumian adalah aspek terpenting dalam mana-mana reka bentuk sistem perlindungan elektrik moden. Asas yang tidak sempurna boleh mendatangkan risiko kepada pekerja serta peralatan. Secara umumnya, terdapat dua cara boleh diguna bagi mengurangkan rintangan bumi dalam sesuatu sistem. Kaedah pertama adalah dengan menambah lebih banyak rod bumi dan kaedah kedua pula dengan menambahkan bahan asing dalam tanah. Walau bagaimanapun, kaedah yang pertama adalah tidak ekonomi manakala kaedah kedua adalah lebih berkesan di mana ia ialah satu cara yang murah untuk mengurangkan rintangan pembumian serta akan meningkatkan prestasi sesuatu sistem. Kerintangan dan ciri-ciri tanah harus ditentukan sebelum melakukan sistem pembumian di sesuatu lokasi. Kajian makmal telah dilaksanakan untuk menguji lima jenis tanah iaitu tanah liat, tanah gembur, tanah berpasir, tanah laterit dan tanah hitam pada suhu bilik yang seragam bagi menentukan jenis tanah yang tersesuai digunakan dalam sistem pembumian. Lima jenis tanah dengan jisim 1 kilogram telah ditambah dengan kandungan air, larutan garam, arang dan campuran larutan arang dengan garam dengan peratusan yang berbeza yang bermula daripada 2.5% sehingga 30% dengan penggunaan 200V DC pada BS 1377-3 penguji kerintangan tanah jenis silinder. Nilai arus yang dicatat telah diguna untuk mengira kerintangan dengan menggunakan persamaan kerintangan. Kemudian, data kerintangan dianalisis dengan menggunakan kaedah statistik iaitu gambar rajah berselerak, analisis korelasi dan analisis regresi. Trend berbentuk garis lengkung telah dilihat pada gambar rajah berselerak dan juga didapati bahawa tanah liat adalah tanah tersesuai digunakan untuk pemasangan sistem pembumian kerana ia mempunyai korelasi yang kuat. Pemerhatian menunjukkan bahawa nilai kerintangan bagi semua tanah akan berkurangan apabila kandungan air, garam dan campuran larutan arang dengan garam meningkat. Namun, penambahan kandungan arang dalam tanah tidak menunjukkan pengurangan kerintangan disebaliknya ia telah meningkatkan kerintangan tanah.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	-	Alternating Current
DC	-	Direct Current
OSHA	-	Occupational Safety and Health Administration
NIOSH	-	National Institute Occupational Safety and Health
BS	-	British Standard
EMI	-	Electromagnetic Interference
RFI	-	Radio Frequency Interference
IEEE	-	Institute Of Electrical And Electronics Engineers
Z	-	Impedance
Ø	-	Phase Angle
PSD	-	Particle Size Distribution
K	-	Conductivity
FYP	-	Final Year Project
UTeM	-	University Technical Malaysia Malacca
R	-	Resistance
ρ	-	Soil Resistivity

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Project Background

The earth's interior is composed of four layers, namely crust, mantle, liquid outer core and solid inner core. The crust is the outermost layer. It is made up of loose material, like rocks, soil and seabed. Soil has covered out much of the land on earth's surface. The soil is an important resource that is used in people's daily lives and other living things. There are different types of soil on the earth and each type of the soil has its own unique characteristics [1]. These unique characteristics must be determined in order to decide what the soil will be used for as there are many different materials composition exists in the soil. In electrical engineering field, precise determination of engineering properties of soil is essential for proper design and successful construction of any electrical system [2].

In conjunction with the characteristics of the soil, one term in electrical field has been automatically connected with different kinds of soil in this world is the resistivity. Resistivity is the measure of how much a material resists flowing of an electrical current. Soil resistivity is directly affected the design of a grounding (earthing) electrode system. It is the vital factor that determines the resistance to earth of a grounding electrode system. Therefore, prior to the design and installation of a new grounding electrode system, the proposed location should be tested to determine the soil resistivity.

Soil electrical resistivity depends on the physical and chemical properties of the soil, water content, fluid composition, seasonal variation and current magnitude [3]. Since the soils all around the world have different characteristics, the difference values of soil resistivity will be observed under the application of electric field.Seasonal variations will also affect soil resistivity, primarily due to change in soil moisture content. These dynamic variations may impact significantly on earthing measurement, depending on both the nature of the soil and underlying rock and the type of earthing system [4].

It is a statutory obligation in most countries, as well as a technical requirement, that all parts of an electric power system should have an effective connection to earth. This implies that each electrically separate part of a system which is magnetically coupled to other parts at the transformation points must be separately earthed. In the words of the definition contained in the 1937 Electricity Supply Regulations which still remain relevant today, "A connection to earth means connected with the general mass of earth in such a manner as to ensure at all times an immediate and safe discharge of energy"[5].

The earthing of electrical installation is primarily concerned with safety; in particular, the prevention of electrical shock risks to life. Others are to help in providing protection of the plants and equipment from unintentional contact with the live conductor besides providing a safe path to efficiently dissipate lightning energy, static discharge, EMI (electromagnetic interference) and RFI signals and interference into the ground. As such, an earthing system must be designed, tested and maintained to satisfy this primary aim [4]. A ground system that provides adequate current-carrying capacity and a low resistance path to an earthing connection will dissipate, isolate or disconnect overpotential areas resulting from overcurrent or surge overvoltage. Equipment grounding conductors under normal conditions carry no current. The only time they carry current is under abnormal conditions when an electrical appliance or piece of electrical equipment is faulty and has become a potential shock or fire hazard. Under fault conditions, the grounding conductor that is connected to the outer shell of the equipment must be able to provide a very low resistance path back to the source of the power so that sufficient current will flow, causing a breaker or fuse to open the circuit and automatically disconnect the hazard from the system[5].

1.2 Research Motivation

Soil resistivity is an important parameter in power system; it plays a key role in designing an effective grounding system. At the present day, the electric power is becoming an important part of human life. Constant supply of electricity is essential for mankind because it may affect human activities or cause life-threatening. However, the electrical power system from all over the world is subjected to disturbances such as faults and lightning strikes. The component in power system that will protect the human being from electrical shock or deaths is the grounding system. A system without a proper grounding may cause harming to the surrounding living things or damage to the equipments. There are many accidents due to electric shock can be seen at the newspaper or via Occupational Safety and Health Administration (OSHA) website throughout the years. On the other hand, based on the statistical data from National Institute Occupational Safety and Health (NIOSH) there are 5348 deaths caused by electrocutions accounted for 7% of all fatalities and an average of 411 deaths per year [6]. Hence, the study of soil resistivity should be continued as it has a clear correlation of having a well calculated and planned for grounding system. Although there is impossible of having a grounding resistance equal to zero, as an electrical power engineer must continuously improve the earthing system in order to achieve a more reliable, secure, efficient and effective system besides meeting the electrical system requirements.

1.3 Problem Statement

In this new era, the technologies have grown rapidly which is then caused the demand of the electricity for the loads to increase. Most of the technologies are required the supply of electricity to function. As the demand of the electricity is increasing, the mankind needs to construct more low, medium and high voltage systems in order to fulfill the demand for the loads besides ensuring the continuity supply of electric. When constructing an electrical power system, the grounding system is the main concerned. This is because when lightning or ground fault has occurred, the high intensity of current will tend to flow through the path which has the lowest resistance. Normally, the fault current flows to the earth which is then caused the ground surface potential to increase to a high level. If a system without a proper grounding, it may cause harming to the surrounding living things.

As grounding is an integral part of any modern electrical protection system design, the understanding on what factors will affect the earthing system is crucial. Normally, the ground resistance is dependent on the electrode arrangement and the soil resistivity. Thus, there are two ways can be used to reduce the earth resistance of a system. The first method is adding more ground rod and the second method is doping on the soil medium. However, the first method is not economically in which it will be needed to expense a lot of money on doing the grounding system. The second method is more effective and it is an inexpensive way to reduce the grounding resistance which will then improve the system performance.

Soil resistivity is one of the vital factors that must be taken into account when designing a grounding system in order to avoid constructing less effective earthing system. An accurate assessment of the soil condition is required as each type of soil has different characteristics and properties which will affect the soil resistivity. Basically, the soil at different location will exhibit different characteristics because there are many different materials composition exists in the soil. The soil resistivity is varied according to the soil types. The soil with high resistivity will resist the flow of electricity and vice versa. If based on the ideal condition the ground resistance should be zero ohm. However, in the real situation it is impossible to achieve the zero ohm earth resistance. Practically the ground resistance should be 5 ohms or less [7]. Therefore, when planning for installation of grounding system it is recommended to locate to a place where the soil resistivity is low. Otherwise, it will be very costly and need a lot of effort in maintenance if it locates at the place where the soil resistivity is high.

This research experiment is conducted to evaluate the variation of soil resistivity with several parameters such as moisture content and chemical content. Other than that, this research experiment will identify a soil with the lowest soil resistivity among five different types of soil to be used in grounding installation system. Generally, soil with lowest resistivity or high conductivity value is chosen. This is because when lightning or power system fault has occurred, the huge intensity of current will tend to flow through the path which has the lowest resistance.

It is therefore, the knowledge of factors affecting the soil resistivity is essential in designing for the grounding purpose. A system with excellent grounding should be able to provide personnel safety as well as reliable protection for equipments and to minimize the interruptions of service which will result in costly downtime. The outcomes from this research experiment will definitely provide some guidelines for those who in charge in implementing grounding installation system and consequently will help lessen future issues with grounding.

1.4 Objectives

The aims of this research project are:

i. To determine the best type of soil between clay, loam, sandy soil, laterite and top soil that give the lowest resistivity for grounding installation.
ii. To investigate the effect of moisture content on soil resistivity.
iii. To investigate the effect of chemical content, which are sodium chloride, charcoal and salted charcoal on soil resistivity.
iv. To analyze the effect of soil resistivity when treated with water, salt, charcoal and salted charcoal by using statistical analysis techniques.

1.5 Scope of Project

This research is focused primarily on examining the effect of soil resistivity when treated with water, salt, charcoal and salted charcoal. A vivid scopes is required in order to ensure that the development of this research project in the right path so that all the objectives are achieved at the end of the research. The scopes of this project are:

(a) Focus on five types of soil only which are:

i. Clay
ii. Loam
iii. Sandy soil
iv. Laterite

v. Top soil

(b) Types of statistical analysis technique will be used are:

i. Scatter plot diagram
ii. Regression Analysis
iii. Correlation Coefficient

(c) Locations of the experiment will be carried out are:

i. The experiment will be conducted at power system protection laboratory, UTeM, Melaka

(d) Apparatus will be used are:

i. Electric Oven
ii. Cylindrical type soil container
iii. BS 1377-3 soil resistivity tester based on disc electrode method
iv. ECS820C Digital multimeter
v. 200Volt DC power supply
vi. Two disc electrodes
vii. Weighing machine

(e) Additives materials will be applied on the soil are:

i. Distilled water
ii. Common salt solution
iii. Carbon (charcoal)
iv. Salted charcoal

(f) This experiment is to study on the two factors affecting the soil resistivity which are moisture content and chemical content.

(g) The resistivity of each type of soil will be calculated based on the derivation of formula from the Ohm's Law.

(h) The experiment will be carried out at constant room temperature due to soil resistivity varies with temperature.

1.6 Report Outline

The report is organized into five chapters as follows:

Chapter 1 introduces the background of electrical resistivity measurement in soil and the importance of grounding connection, research motivation, the statement of problem, specific objectives, scopes of the research and report organization. Basically this chapter is used to give an overview of what have been motivated to carry out this project and the significance of this project to the society. The project limitation and boundary is described in the objectives and scope section.

Chapter 2 presents literature review about the soil profile on the earth and the basic terms that are related to the soil resistivity of the grounding system. Then, the previous related works are being discussed and summarized. The comparison of this research with others related research is done in table form.

Following that, the chapter 3 will provide the different methodologies that will be used to complete this research. The flowchart diagram is used to describe the research methodology and experiment procedure. Various techniques that will be used to analyze the data are also presented in this chapter.

In chapter 4 of this report will present the result of this project. The scatter plot diagram, correlation coefficient and regression analysis is used to show the relation between soil resistivity and the parameters that affect the soil resistivity such as water content, sodium chloride solution and charcoal content. After that the detailed explanation on the results that have obtained is directed.

At the end, the chapter 5 is for doing a conclusion and recommendation for this research. The outcome from this project will be compared with the early specified objectives or hypotheses to see whether the objectives are achieved or not. Then, the suggestion for improving of the future project is included in this section.

CHAPTER 2

LITERATURE REVIEW

2.1 Theory and Basic Principles

2.1.1 Soil on the Earth

Most soils have a distinct profile or sequence of horizontal layers. Generally, these horizons result from the processes of chemical weathering, eluviation, illuviation, and organic decomposition. Up to five layers can be present in a typical soil which are O, A, B, C, and R horizons as shown in Figure 2.1[8].

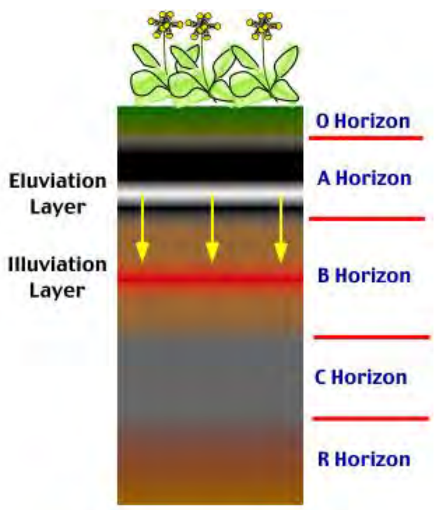


Figure 2.1: Five layers in a soil profile [8].

The O horizon is the topmost layer of most soils. It is composed mainly of plant litter at various levels of decomposition and humus.

Below the O layer is the A horizon. This layer is composed primarily of mineral particles and has two characteristics namely, it is the layer in which humus and other organic materials are mixed with mineral particles and it is a zone of translocation from which eluviation has removed finer particles and soluble substances, both of which may be deposited at a lower layer. Thus, the A horizon is dark in color and usually light in texture and porous. The A horizon is commonly differentiated into a darker upper horizon or organic accumulation, and a lower horizon showing loss of material by eluviation.

The B horizon is a mineral soil layer which is strongly influenced by illuviation. Consequently, this layer receives material eluviated from the A horizon. The B horizon also has a higher bulk density than the A horizon due to its enrichment of clay particles. The B horizon may be colored by oxides of iron and aluminum or by calcium carbonate illuviated from the A horizon.

The C horizon is composed of weathered parent material. The texture of this material can be quite variable with particles ranging in size from clay to boulders. The C horizon has also not been significantly influenced by the pedogenic processes, translocation or organic modification.

The final layer in a typical soil profile is called the R horizon. This soil layer simply consists of unweathered bedrock [8].

2.1.2 Basic Term and Theory

There are four basic formula being employed when discussing soil resistivity and these are current, current density, Ohm's law and resistivity [9].

Current is determined by charge in columbs over a given period of time in seconds. The current formula is shown as below:

$$I = \frac{q}{t} \tag{2.1}$$

where:

I=Current (A)

q= Charge (C)
t=Time(s)

Current density is the amount of current flowing through a particular area. The current density formula is shown as below:

$$j=\frac{I}{A} \tag{2.2}$$

where:

j= Current density (A/m^2)
I=Current (A)
A= Area (m^2)

Ohm's law is the relation of voltage, resistance, and current. This is first presented by the German physicist Georg S. Ohm. The Ohm's Law is shown as below:

$$I=\frac{V}{R} \tag{2.3}$$

where:

I=Current (A)
V= Voltage (V)
R=Resistance(Ω)

Resistivity is the relation of resistance, area, and current and is written as [9]:

$$\rho=R\frac{A}{L} \tag{2.4}$$

where:

ρ = Soil resistivity (Ω-m)
R = Resistance to earth (Ω)
L =Length of conducting path (m)
A = Cross-sectional area of path (m^2)

Soil resistivity is a measure of how far a volume of soil will resist an electric current. It is usually being measure in unit of ohm-meter. In designing a grounding system, soil resistivity is one of the most important parts as the ground resistance is very much depended on the soil resistivity. Several factors may influence the soil resistivity such as type of soil, temperature, moisture, mineral content and compactness [10]. The Figure 2.2 will show the soil resistivity variations with salt, moisture and temperature.

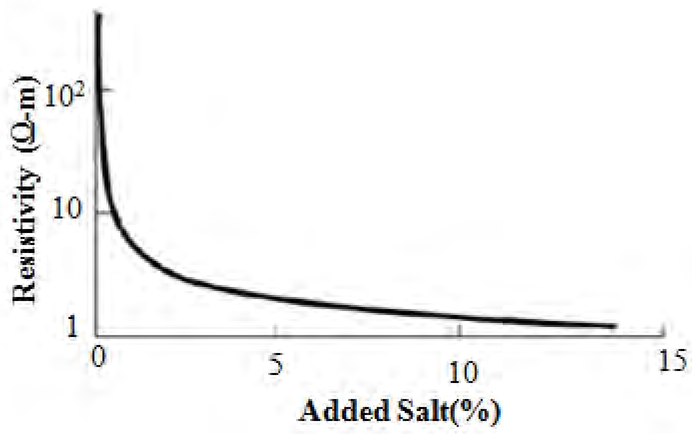


Figure 2.2: Soil resistivity variations with salt [5].

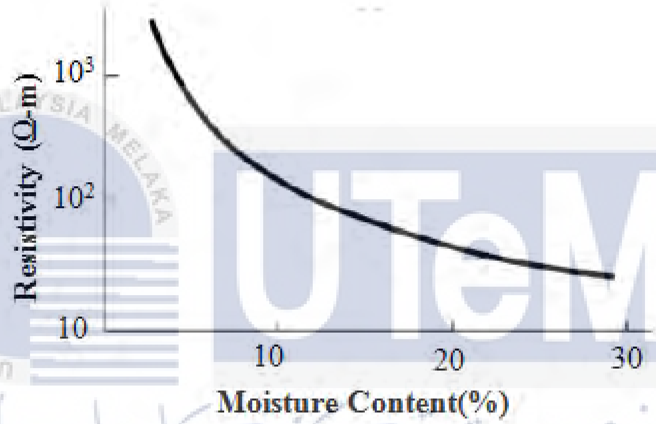


Figure 2.3: Soil resistivity variations with moisture [5].

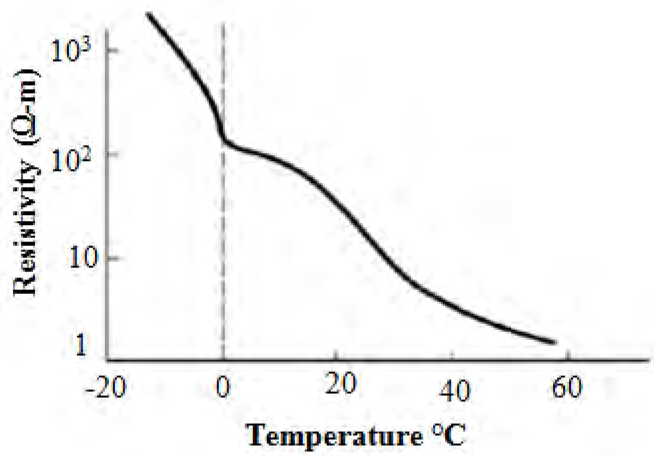


Figure 2.4: Soil resistivity variations with temperature [5].

Soil resistivity varies not only with the type of soil but also with temperature, moisture and salt content. It can be seen from the Figure 2.2, Figure 2.3 and Figure 2.4 that the soil resistivity is decreased with the increasing of the temperature, moisture and salt content .The resistivity of the soil increases slowly with decreasing temperature from 20°C to 0°C. Below 0°C, the resistivity increases rapidly [5]. On the other hand, the different types of soil will have different resistivity values. Soil resistivity values typically range from about 2 to 100000Ωm, yet more extreme values are not unusual. Table 2.1 shows the different types of soil and their typical soil resistivity. From the table, it can be seen that different types of soil will have different resistivity value. In practical cases, soil can be represented by two layers; it is rare to find a single layer structure [12]. Other than treatment of moisture content and salt content to the soil, the earth pit actually can be filled with alternate layers of sand soil, common salt and charcoal powder to reduce the resistivity further [11].

Table 2.1: Typical soil resistivity of various types of soil [12].

Type of Soil or water	Typical Resistivity,(Ωm)
Sea Water	2
Clay	40
Ground well and spring water	50
Top soil	60
Clay and sand mix	100
Shale, slates, sandstone	120
Peat, loam and mud	150
Lake and brook water	250
Sand	2000
Morane gravel	3000
Ridge gravel	15000
Solid granite	25000
Ice	100000

2.1.3 Soil Resistivity Measurement

Surface electrical resistivity surveying is based on the principle that the distribution of electrical potential in the ground around a current carrying electrode depends on the electrical resistivity distribution of the surrounding soils and rock. The usual practice in the field is to apply an electric direct current (DC) between two electrodes implanted in the ground and to measure the potential difference between two additional electrodes. Electrodes used are generally stainless steel stakes and must be driven into the ground far enough to make good electrical contact. If the contact is bad and the injected current is too small, quality of measurement will be degraded (sensitive to noise). The current used is DC, commutated DC (i.e., a square –wave alternating current) or AC of low frequency typically around 20Hz.All analysis and interpretation are done on the basis of direct currents. The current is measured by ammeter. One common difficulty encounter is that the high contact resistance between current electrodes and soil. It can be sometimes alleviated by pouring salt water around the current electrodes or adding electrodes in parallel. However, if the problem is due to combination of the high earth resistivity and large electrode spacing, the remedy is to increase the input voltage across the electrodes. Power is usually supplied by dry cell batteries in series in the smaller instruments and motor generators in the large instruments. From the 90V up to several hundred volts may be used across the current electrodes in surveys for engineering purposes. On the current electrodes, the actual value of contact resistance does not affect the measurement [13].

The typical measurement of soil resistivity values with the variation of the moisture content is recoded in Table 2.2. When the top soil and sandy loam is thoroughly dried may become good insulators of having a resistivity in excess of 10^6 Ωm whereas the silica based sand resistivity in dry condition is not shown in the table. The resistivity of the soil sample is seen change quite rapidly until approximately 20% or greater moisture content is reached [14].

Table 2.2: Effect of moisture content on soil resistivity values[14].

Moisture content by weight, (%)	Resistivity,(Ωm)		
	Top soil	Sandy loam	Silica based sand
0	$>10^6$	$>10^6$	-
2.5	2500	1500	3000000
5	1650	430	50000
10	530	185	2100
15	210	105	630
20	120	63	290
30	100	42	-

2.2 Review of the Previous Related Works.

2.2.1 Resistivity and Dielectric Constant Characteristics of Soil If are Treated by Water, Salt and Carbon

This research is done by Bambang Anggoro Ngapuli I. Sinisuka, Parouli M.Pakpahan from school of Electrical Engineering and Informatics Institut Teknologi Bandung. This IEEE paper has stated that the impedance of grounding system depends on the configuration of grounding electrodes and the condition of the soil. The electrical properties of soil are resistivity and permittivity which will cause the change in the resistance and capacitance of the soil. The resistivity and permittivity also depends on the chemical or other solution treatment besides the mineral composition inside the soils. This study is focusing on lowering the impedance of the grounding system by treating the soil with the water, salt and carbon as the solution with percentage variation from 2.5% until 15%.The soil is taken from 1m depth underground surface at Gede Bage village near from Bandung Indonesia and has been tested in the mineralogy laboratory. The mineral content of this soil is montmoullonite-14A, methane, iron oxide and silicone oxide with percentage of gravel=1%, sand=7%, silt=47% and clay=45% respectively. The soil is filled in the fibre glass box with dimension of 10x10x10 cm^3 and is being injected by 50 Hz alternating current from the two parallel metal plates. The impedance (Z) and phase angle(∅)of the soil is then measured by oscilloscope. The resistivity and permittivity is then calculated by using the equivalent circuit of the soil.

The results that have been obtained from the experiment indicate that the resistivity of the soil tested will be reduced until below than 30% of resistivity at dry soil if the percentage of water content more than 7.5%.This is because the conductivity of water higher than the conductivity of these soil. Carbon treatment is not enough to reduce the resistivity of the soil if the percentage of carbon is less than 15% because of the carbon is particle not solution. May be more than 15% of carbon will make resistivity drop. Salt solution is more effective to reduce the resistivity of the soil. This can be seen from the table that with the addition of 2.5% salt solution to the soil, the resistivity of soil will be reduced until less than 10% of the resistivity dry soil. Resistivity of soil can be reduced by water, salt and carbon treatment as shown in Figure 2.5. On the other hand, the permittivity of the soil at all conditions is not depending on the water, salt and carbon treatment as shown in Figure 2.6. From the graph, it can be observed that the resistivity starting to drop after 2.5% added water and salt while carbon treatment do not help much in reducing the resistivity value of the soil. Salt solution is more effective to reduce resistivity than water treatment while permittivity does not affected by water, salt and carbon treatment [15].

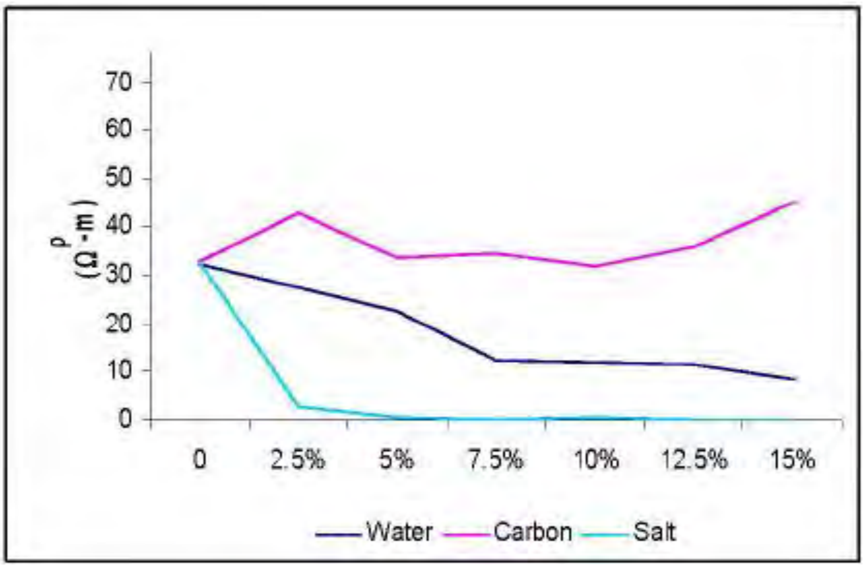


Figure 2.5: Resistivity fluctuation caused by water, salt, and carbon treatment [15].

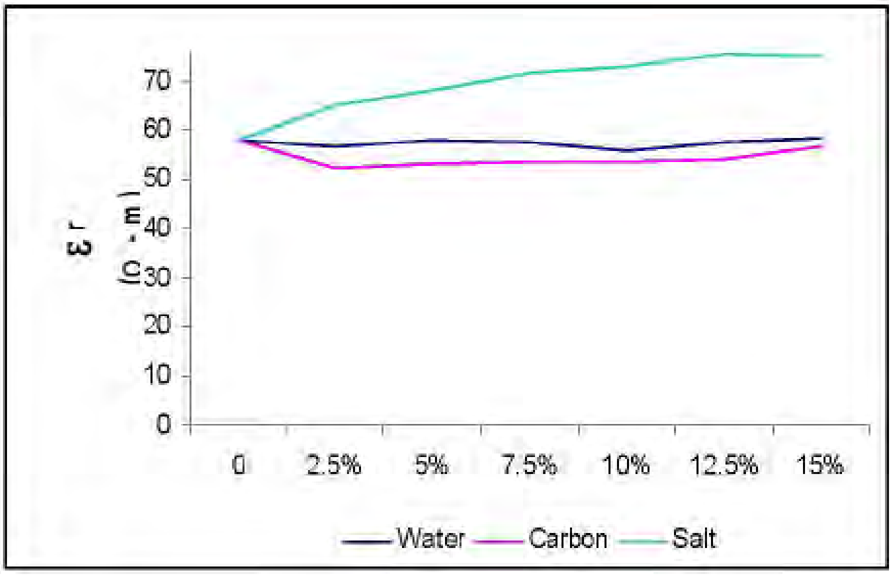


Figure 2.6: Permittivity fluctuation caused by water, salt, and carbon treatment[15].

2.2.2 The Characteristics of Soil which is Treated by Salt Solution and Water as the Basic of Grounding Diagnostics

This research is done by Anggoro B and Irman D.B from school of Electrical Engineering and Informatics Institut Teknologi Bandung.The authors have stated that the soil resistivity, permittivity and permeability varies depends on the soil composition, temperature, water content and its chemical content. All these characteristics will be tested by variable frequency from low until high frequency.

In this research, the researchers analyze the soil characteristics of the samples which are taken from the Yogyakarta region that located in Central Java Province, Indonesia to conduct some physical treatments such as water, salt solution. The soil sample is taken in the minimum of 1m depth from Yogyakarta region. The soil sample is being tested at first time must be dried and small grained homogenously and it is as a control sample condition. The soil is then put into a box with the dimension of 10x10x10 cm^3 and the soil is pressed until it makes certain volume. At the bottom and top of the soil experiment is laid the metal plate for measuring the voltage and current. For 1kg dry soil that has been pressed in a box will occupy 0.001m^3volume. After that, every sample of the dry soil will be treated by adding certain percentage of water or salt or carbon content. The soil will become wet when it is added by water about 2.5% of the 1kg soil weight which is equivalent to 25 gram of water. The addition of water is done step by step from 2.5% until 15% and mixed homogenously. The same step is applied for adding the salt solution from 2.5% until 15% of the weight of dry soil. The frequency generator is being used as a power supply to inject the alternating current to the soil sample with variable frequency from 0 until 15MHz. The voltage drop is measured by using oscilloscope. From the measured current and voltage the impedance, power factor, resistivity, permeability and permittivity for the soil has been calculated.

The resistivity that has been calculated is tabulated in the table form as shown in Table 2.3. From Table 2.3, it can be seen that the resistivity of dry soil is 980Ω-cm. The resistivity value will become smaller when the soil is treated by salt and water solution. It is more effective to reduce the soil resistivity when it is treated with 5% of water and 15% of salt solution in which it will reduce to 2.4Ω-cm compare with the 15% of water which will decease until 188Ω-cm only. The impedance and phase angle that has been calculated based on data measurement. It can be observed that the trend of treatment with 15% of water will decrease the impedance to 50Ω whereas with 5% of water and 15% of salt solution will reduce to 40Ω. The decreasing impedance will be very obvious if it is injected with frequency more than 1MHz for water solution but for salt solution treatment if the frequency is injected 1MHz until 10MHz the impedance will be increased [16].

Table 2.3: Resistivity of experiment soil Jogyakarta with several treatments[16].

Soil Treatments	Resistivity (Ohm Cm)
Dry Soil	980
Dry Soil+ 2.5% Water	704
Dry soil + 5.0% Water	440
Dry soil + 7.5% Water	424
Dry soil + 10% Water	328
Dry soil + 12.5% Water	264
Dry soil + 15% Water	188
Dry soil + 5% Water + 2.5% Salt Solution	118
Dry soil + 5% Water + 5% Salt Solution	16.4
Dry soil + 5% Water + 7.5% Salt Solution	5.2
Dry soil + 5% Water + 10% Salt Solution	2.4
Dry soil + 5% Water + 12.5% Salt Solution	6.4
Dry soil + 5% Water + 15% Salt Solution	2.4

2.2.3 Non-Quantitative Correlation of Soil Resistivity with Some Soil Parameters

This research is done by Mohammad Nabil Fikri Bin Razali with the guidance of Dr. Syed Baharom Azahar Bin Syed Osman from Civil Engineering Department, Universiti Teknologi Petronas Tronoh, Perak. This research is aimed at determining the correlation between soil resistivity and soil parameters in order to find the slope factor of safety (FOS). The researcher is focusing on finding possible preliminary crude correlation between resistivity and some soil parameters with various soil conditions. The field investigation work is involved in finding the electrical resistivity and charges of shear strength with variations of soil types, pH, organic content, temperature, moisture content, and particle size distribution(PSD) of the soil.

The researcher has purchased the three different types of soil from soil processing factory according to their grades namely, KM80, K200 and L2B20.The author has designated predominant particle size for KM80, K200 and L2B20 as clay, silt and sand respectively in accordance to their respective predominant particle sizes. The soil samples are being compacted using standard protor test (2.5kg free drop).The cubic metal mould with a size dimension of 100 mm x 100 mm x 100mm is used to conduct the experiment. The mould modified to put an electrical insulator before electrical resistivity test is conducted. A DC supply is used as power supply. A multimeter is used to read the current through the specimen. The value of currents between 30V to 200V supply is recorded for determining the electrical resistance R by using Ohm's law formula V=IR. It can be seen that for the relation of resistivity and moisture content, soil resistivity is decreased when the water content has increased as shown in Figure 2.7. For the comparison purpose, the author has summarized that the trend of resistivity result from different soil parameters as shown in Table 2.4. It can be seen that the resistivity will increase when the moisture content is decreased. On the other hand, when the compaction energy is increased will result the resistivity to be decreased. The resistivity will increase when the parameters such as bulk density, dry density, friction angle and cohesion is increasing [17].

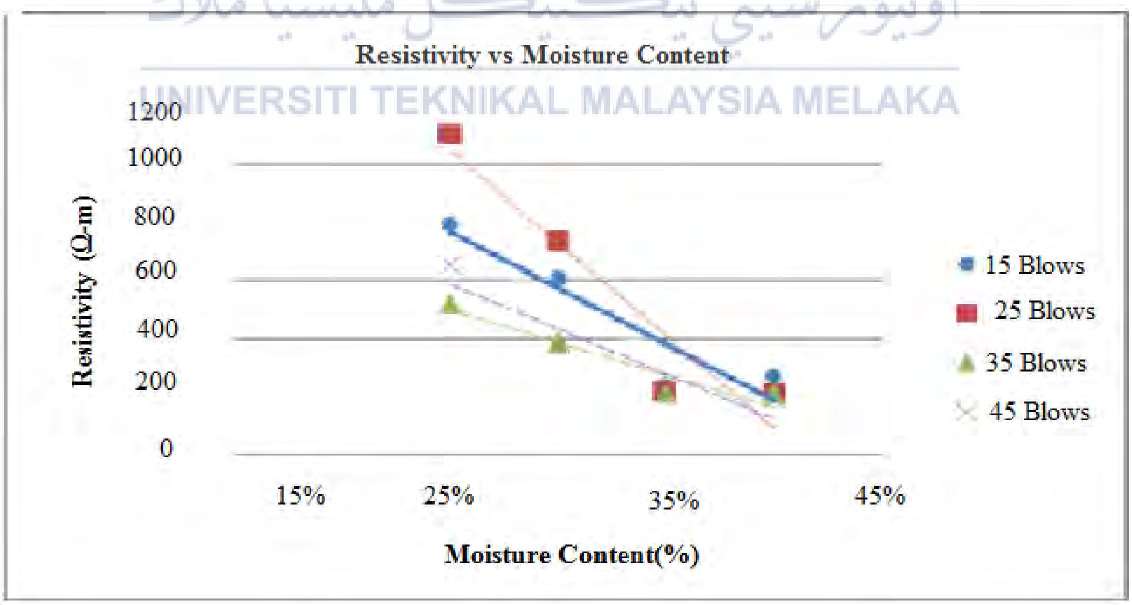


Figure 2.7: Electrical resistivity result from moisture content [17].

Table 2.4: Trend of resistivity result from different soil parameters[17].

Parameters	Electrical Resistivity, ρ
Moisture Content, ↓	ρ, ↑
Compaction Energy, ↑	ρ, ↓
Bulk Density, ↑	ρ, ↑
Dry Density, ↑	ρ, ↑
Friction Angle, ↑	ρ, ↑
Cohesion, ↑	ρ, ↑

2.2.4 Study on Impact of Precipitation pH and Conductivity on Soil Resistivity

This research is done by Li Liang Fu, Qin Bin Quan, Xiang Bo and Yang Lei from Chongqing Meteorological Bureau Chongqing, China. In this IEEE paper, the impact of pH and conductivity on soil resistivity are studied by analyzing observation data of precipitation pH value and conductivity (K-value) and simultaneous observation data of resistivity at different depths of soil in Chongqing Meteorological Bureau with the standard of Operational Norms of Acid Rain Observation in the duration of one year. The researchers have chosen the observation field at Chongqing Meteorological Bureau Chongqing which is a dry land with purple soil with 0-35cm as surface soil profile and 35-320cm as subsoil layer profile. Stainless steel bars with diameter of 20cm are being fixed in the soil depth of 320cm, 160cm, 80cm, 30cm and 15cm in observation field. These stainless steel bars are used as soil resistivity test from surface to different soil depths. The three pole method is being applied to automatically monitor the grounding resistance of each soil resistivity test electrode on the hour every day, and the grounding resistance measurement time of 5 test electrodes is controlled within 20 seconds to obtain the true and accurate data. At the same time, the precipitation sampling framework and buckets which are installed strictly according to relevant provisions specified in the Operational Norms of Acid Rain Observation issued by China Meteorological Bureau, simultaneously observe daily precipitation, pH value of precipitation, conductivity (K) and temperature of precipitation sample.

The authors have presented that at a fixed location of the same area, the smaller the daily precipitation, the higher the concentration of pollutants in precipitation, the higher the concentration of charged ions in precipitation and the stronger the conductivity of precipitation, the higher the K value, the lower the pH value and the more charged ions the precipitation transported to soil to enhance soil conductivity and reduce soil resistivity. However, as the precipitation becomes smaller, the soil moisture at the surface, affected by other meteorological factors, the soil moisture is easy to evaporate, and as the content of soil moisture in deep layer is large and is hard to obtain moisture provided by precipitation to increase soil moisture, the electrolyte in soil decreases, which is not good for enhancing the activity of electrolyte, thereby reducing the soil conductivity and increasing soil resistivity. The researchers have concluded that the impact of pH value and its conductivity on soil resistivity can be neglected compared with the impact of daily precipitation on soil resistivity provides a scientific basis for research and design of resistance reducing agent product [18].

2.3 Summary and Discussion of the Review

It can be observed from the previous study that the soil resistivity is affected by the several factors namely, moisture content, salt, carbon, compaction energy, bulk density, dry density and cohesion. The soil from different places will have different value of resistivity due to the presence of difference composition in the soil. To carry out an experiment, the researcher can either inject the alternating current and direct current to the soil and the results that have obtained is the same that the presence of moisture content and salt will reduce the soil resistivity. There is not much different for the results that have obtained in the real field compared with the experiment that has conducted in the laboratory. Normally, the researcher is using cubic soil container to conduct the experiment with the application of alternating current or direct current with varying voltage from 30V to 200V. However, for this research experiment the BS1377-3 cylindrical container will be used as the soil resistivity tester with the application of 200V direct current. On the other hand, from the research carbon is said will not have much effect on soil resistivity is less than 15 percent. So, in this research more than 15 percent of charcoal powder will be tested. Other than that, the charcoal powder will mixed with salt solution first before being used to test the rate of decreasing the soil resistivity value and also to observe the rate of adsorption of charcoal by comparing the results have been gained with the salt treatment. Moreover, the comparison in term of methods of this experiment study with others related research works have shown in the Table 2.5.

Table 2.5: Comparison with others related research.

No. of Journal	Title and Author	Method	Results/Outcomes	Comparison with the research
Journal 1 (2.2.1)	Resistivity and Dielectric Constant Characteristics of Soil If Are Treated by Water, Salt and Carbon by Bambang AnggoroNgapuli I. Sinisuka, Parouli M.Pakpahan.	Soil is taken from 1m depth underground surface at Gede Bage village with mineral content of montmoullonite-14A, methane, iron oxide and silicone oxide with percentage of gravel=1%, sand=7%, silt=47% and clay=45% respectively. The soil type is silty clay. The soil is filled in the fibre glass box with dimension of 10x10x10 cm^3 and injected by 50 Hz alternating current from the two parallel metal plates.The water, salt and carbon is varied from 2.5% to 15%.	Resistivity of the soil can be reduced by using salt and water treatment. The 15% of carbon do not reduce much of resistivity. Salt solution treatment is more effective to reduce resistivity than the water treatment while permittivity does not affected by water, carbon and salt treatment.	This research is using silty clay soil type. The alternating current (AC) is applied to the soil instead of direct current (DC). Other than that, the cube soil container is being used instead of cylindrical soil container.
Journal 2 (2.2.2)	The Characteristics of Soil which is Treated by Salt Solution and Water as the Basic of Grounding Diagnostics by Anggoro B and Irman D.B	Soil is taken in the minimum of 1m depth from Yogyakarta region is dried and small grained homogenously. The soil is put into a box with the dimension of 10x10x10 cm^3 and the soil is pressed until it makes certain volume. The dry soil is added with salt and water from 2.5% of 1kg soil weight (2.5 gram of water) until 15%. The frequency generator is used as a power supply to inject the alternating current (AC) to the soil sample with the variation of frequency from 0 until 15MHz. The voltage drop is measured by using oscilloscope.	The resistivity value will be decreased with the treatment of salt and water solution. The resistivity and impedance are decreased significantly when treated by salt solution compared with water.	This research is using soil from Yogyakarta region. The soil is injected with alternating current from frequency generator. The soil is put in the cube box instead of cylindrical container. This study also has covered on resonance frequency, impedance and phase angle.

Journal 3 (2.2.3)	Non-Quantitative Correlation of Soil Resistivity with Some Soil Parameters by Mohammad Nabil Fikri Bin Razali and Dr. Syed Baharom Azahar Bin Syed Osman.	Three soil samples have been purchased which are KM80 (clay), K200 (silt) and L2B20 (sand).The soil specimens are compacted using standard protor test (2.5kg free drop).The cubic metal mould with a size dimension of 100 mm x 100 mm x 100mm is used for the experiment. 200 V DC power supply is used to inject current. Multimeter is used to measure the current through the samples.	The resistivity value will increase with the decreasing of moisture content. The compaction energy is increasing will result the resistivity to drop. The resistivity value is increased when the bulk density dry density, friction angle and cohesion is increased.	This study is using cubic metal mould container instead of cylindrical soil container. Besides that, it also cover on various soil parameters namely, compaction energy, bulk density dry density, friction angle and cohesion that will affect the soil resistivity.
Journal 4 (2.2.4)	Study on Impact of Precipitation pH and Conductivity on Soil Resistivity by Li Liang Fu, Qin Bin Quan, Xiang Bo and Yang Lei	The observation field is in a dry land with purple soil with 0-35cm as surface soil profile and 35-320cm as subsoil layer profile at Chongqing Meteorological Bureau. Stainless steel bars are used as soil resistivity test. Three pole method is applied to monitor the grounding resistance.	The higher the concentration of charged ions in precipitation and the stronger the conductivity of precipitation, the higher the K value, the lower the pH value and the more charged ions the precipitation transported to soil to enhance soil conductivity and reduce soil resistivity. Thus, the impact of pH value and its conductivity on soil resistivity is neglected compared with the impact of daily precipitation on soil resistivity.	This research is carried out on field and using stainless steel bars. Three pole method is applied.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter will introduce the research methodology used for this experiment and how it has guided development of theory or hypothesis, analysis and data collection. In order to complete the objectives of this research, the following methods are used to ensure the outcome of the project is near to what have expected. The flowchart that will clarify the flow of this research project is shown in Figure 3.1:

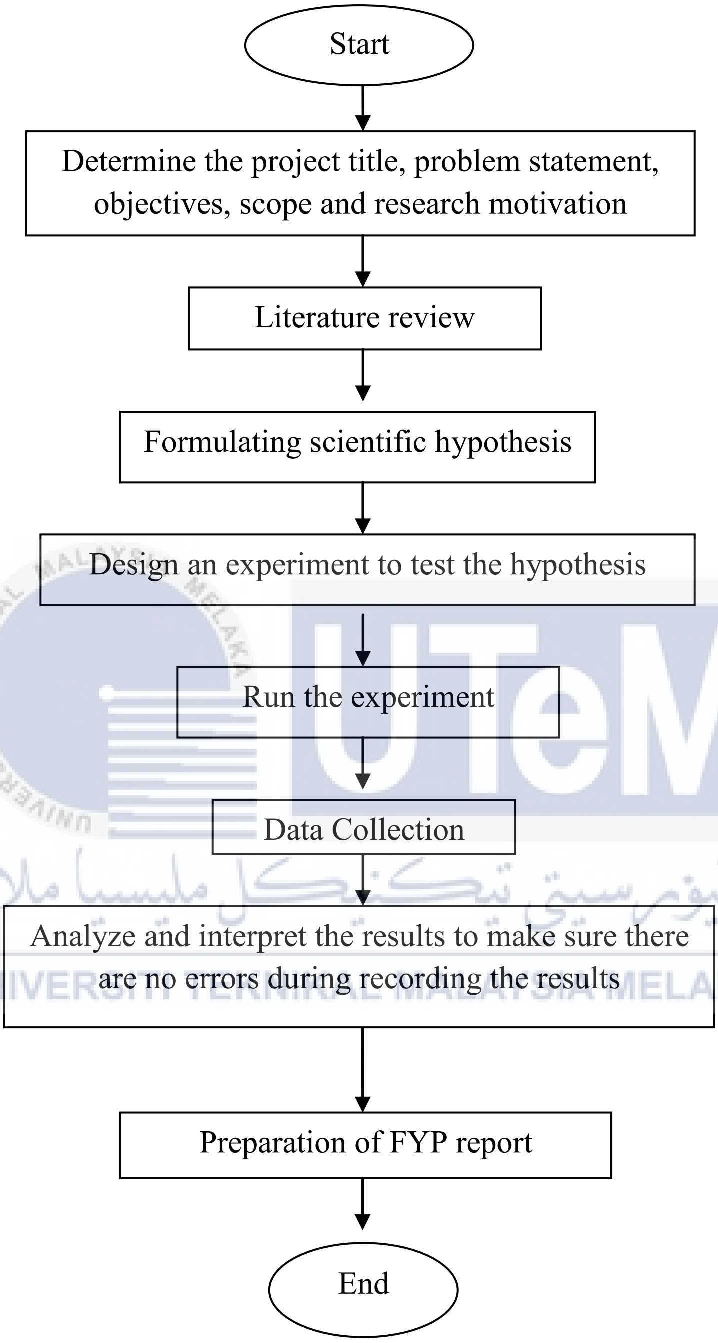


Figure 3.1: Flowchart of research methodology.

3.2 Literature Review

Various types of resources are being explored and referred, including journal, books, standard, and previous related projects that have done by people and information from world wide website. This is to do survey and find out the fundamental theory of the research project.

3.3 Formulating Scientific Hypothesis

In order to achieve the objectives of the project, the hypothesis is needed to formulate first before proceeding to test the hypothesis with an experiment.

The Ohm's law formula (*V=IR)* as shown in equation 2.3 can be used to obtain the resistance of the soil sample being tested. In the Ohm's law formula the term V represents voltage (V), I represents current (A) and R represents resistance (Ω).Basically, when carry out an experiment the 200 V of DC voltage will be applied through the specific weight of a soil sample. The current is then will be measured by using specific instrument. Then, by referring to ohm law formula there is just one unknown left which is resistance, R and this R can be determined via calculation. Theoretically, the soil electrical resistivity can be calculated by using the general resistivity formula:

$$\rho = R\frac{A}{L} \tag{3.2}$$

$$\rho = \frac{V}{I}\frac{\pi r^2}{L} \tag{3.3}$$

where:

ρ = Soil resistivity (Ω-m)
R = Resistance of soil sample (Ω)
L = Distance between the electrodes (m)
$A = \pi r^2$ = Cross-sectional area of sample/ electrode (m^2)

Therefore, the hypotheses for this research experiment are:

(a) If the higher concentration of moisture, salt and salted charcoal content are being applied to the dry soil, then will result a decrease in soil resistivity value.

(b) The clay soil under treatment of water and salt solution will give the lowest resistivity value if comparing with other types of soil under the same percentage of treatment.

(c) The sodium chloride solution will reduce soil resistivity value for all types of soil more rapidly compared with charcoal, distilled water and salted charcoal.

(d) If the 30% of water content or salt content is added to all types of soil, then will result almost constant rate of decreasing of soil resistivity or current values.

3.4 Experimental Design and Measurement

3.4.1 List of Equipment and Materials

The equipments and materials used to conduct this experiment at laboratory were shown in the Table 3.1 below:

Table 3.1: Experimental equipments and materials.

 BS 1377-3 Soil resistivity tester	 Weighing machine

 Electrical oven	 DC power supply station
 Digital multimeter	 Beaker
 Soil sample	 Table Salt
 Charcoal powder	 Distilled water

3.4.2 Orthographic Drawing for the BS 1377-3 Cylinder Container

The orthographic projection was used to show the three dimensional (3D) of BS1377-3 cylindrical container from different directions. The length, width and diameter of the cylindrical container were measured. Then, the top, front and side views were drawn and labeled in centimeter (cm) as in Figure 3.2. From here, it could be known that the maximum height of soil could be filled in cylindrical container is up to 41.7cm or equivalent to 0.417m. The inner diameter of the cylinder was 10cm or equivalent to 0.1m. This inner diameter was divided by two to get the inner radius of the cylinder which will then substitute into equation 3.3 for calculation of soil resistivity values.

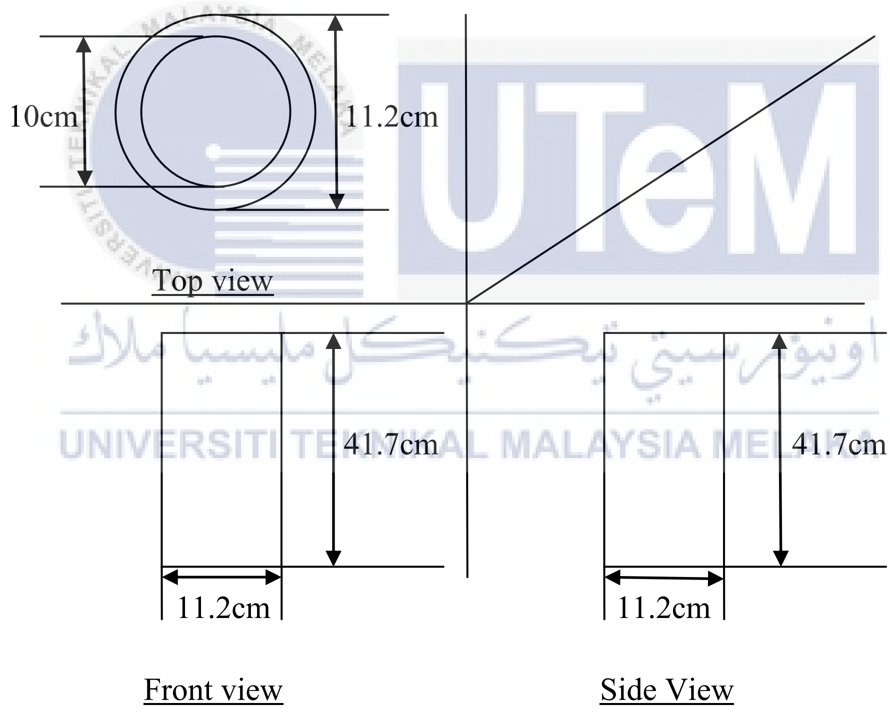


Figure 3.2: BS1377-3 cylindrical soil resistivity tester for resistivity determination.

3.4.3 Schematic Circuit Diagram for Experimental Set Up

The schematic circuit diagram for soil resistivity determination was constructed as shown in Figure 3.3. All the equipments in the circuit were connected by series connection. There were two points of electrical contacts with the soil which were upper and lower electrode discs. When 200 V of DC supply was injected, the current would be driven through the upper and lower electrode discs. The current was then measured by the multimeter in ammeter mode.

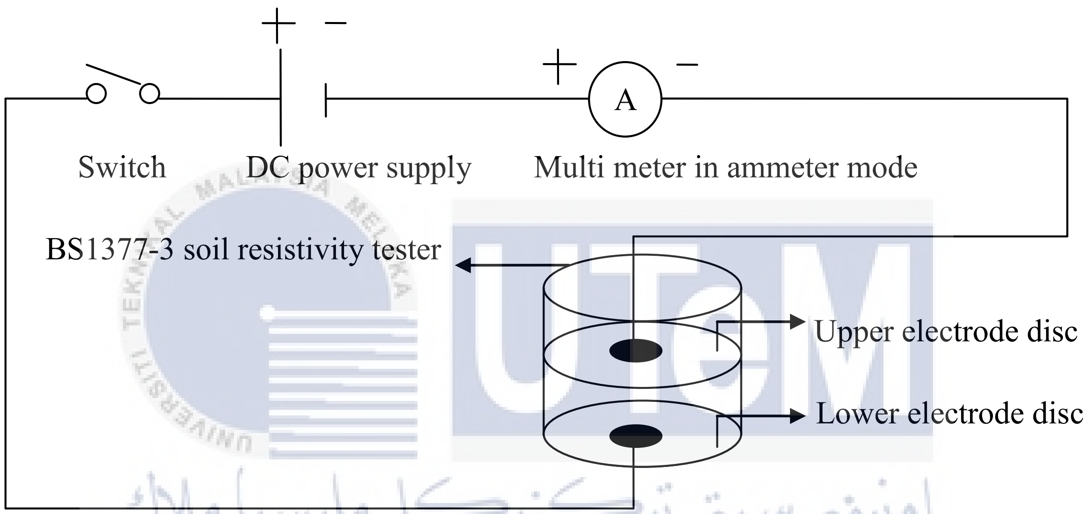


Figure 3.3: Schematic circuit diagram for resistivity determination.

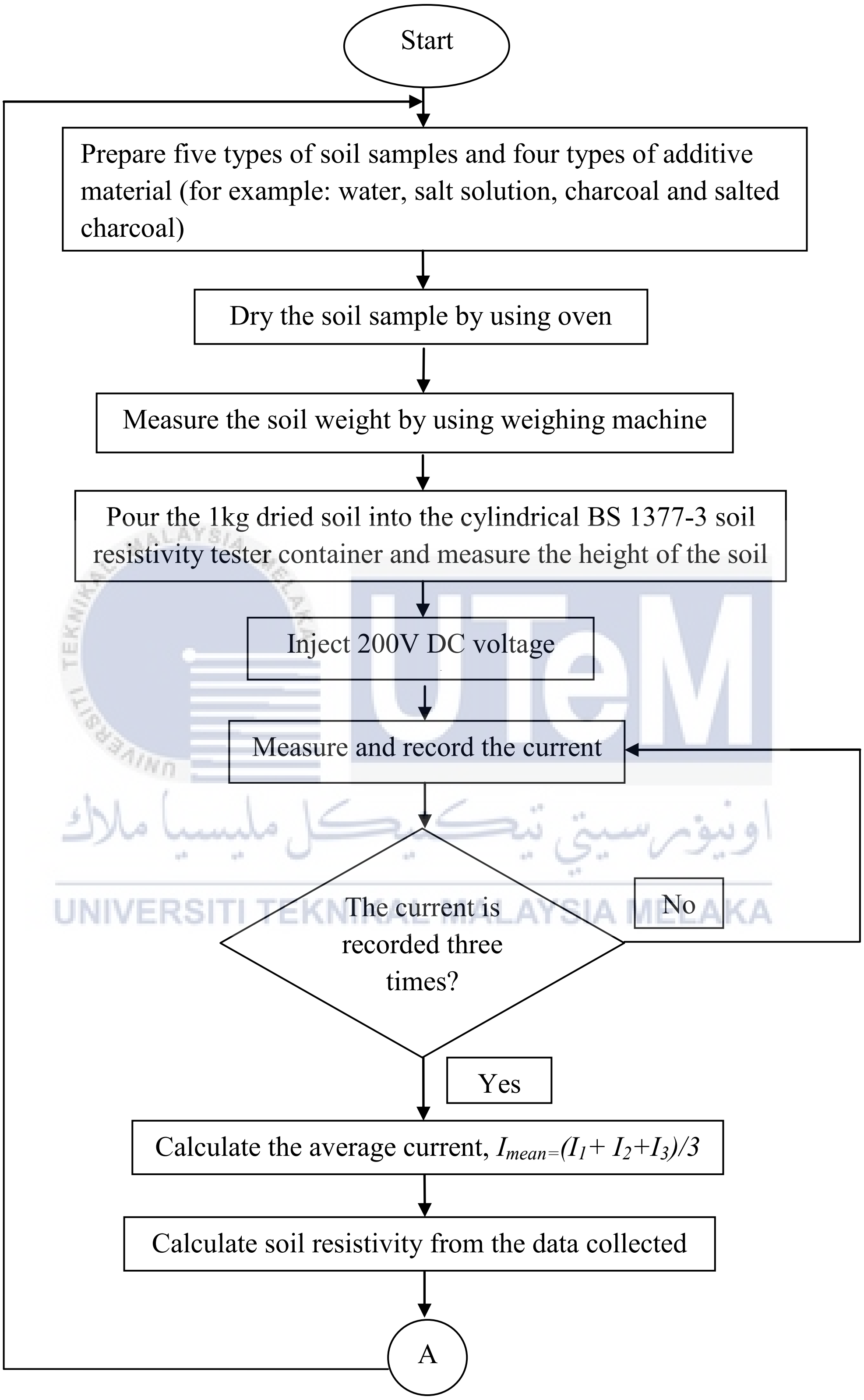
3.4.4 Soil Resistivity Testing Procedure

This research was aimed to carry out an experiment to determine the best type of soil between clay, loam, sandy soil, laterite and top soil that would give the lowest resistivity which was suitable to be used for grounding installation. The factors that would affect the resistivity value of the soil were determine and would be tested in this experiment. There were five parameters would affect the soil resistivity values which were soil types, water content, salt content, charcoal and salted charcoal. Since soil resistivity varies with temperature; therefore, it was important that the soil resistivity testing was carried out at uniform room temperature. Before conducting an experiment the five types of soil as mentioned above would be prepared. The dry soil with the mass of one kilogram was used to conduct the experiment.

In the beginning, one out of five sample soils was dried out by using electrical oven at 100°C until there was no moisture content. The soil was allowed to cool down at room temperature. The weight was measured by using weighing machine. The dry soil with mass 1 kilogram was poured into the BS 1377-3 soil resistivity tester. The BS 1377-3 was a cylindrical container with two electrodes that was fitted at upper and lower part of the cylindrical as shown in Table 3.1. The soil was pressed by using the handle that connected with the upper electrode disc. This was to ensure that there was a maximum contact between the soil and the electrode discs. The height of the soil specimen was measured by using ruler.

Then, the BS 1377-3 soil resistivity tester would be connected to the DC power supply and also measuring probe from the multimeter in series as shown in Figure 3.3. Next, DC voltage of 200V was injected to the BS 1377-3 soil resistivity tester. This step was repeated three times in order to get consistent and accurate reading of the current values. The mean current would be calculated by using the equation, $I_{mean}=(I_1+ I_2+I_3)/3$ and at the same time the resistivity value would be calculated also. After that, the soil was treated with 2.5% of distilled water which was equivalent 25 grams until 30%. The incremental of percentage of distilled water was 2.5% for each test and which was expected to give the almost constant rate of decreasing of soil resistivity or current values after reaching 30% of water content. The BS 1377-3 soil resistivity tester container was washed by using tap water. The same steps were repeated for the rest of the four types of soil.

Subsequently, the new sample of five different types of soil would be used to conduct the new test by repeating the same procedures as mentioned above except that the water content was changed with either one of the additive materials such as sodium chloride solution, charcoal or salted charcoal. The Figure 3.4 and Figure 3.5 show how the project was implemented. From the figures would give a full picture on how the work was run.


Start
Prepare five types of soil samples and four types of additive material (for example: water, salt solution, charcoal and salted charcoal)
Dry the soil sample by using oven
Measure the soil weight by using weighing machine
Pour the 1kg dried soil into the cylindrical BS 1377-3 soil resistivity tester container and measure the height of the soil
Inject 200V DC voltage
Measure and record the current
The current is recorded three times?
No
Yes
Calculate the average current, $I_{mean}=(I_1+I_2+I_3)/3$
Calculate soil resistivity from the data collected
A

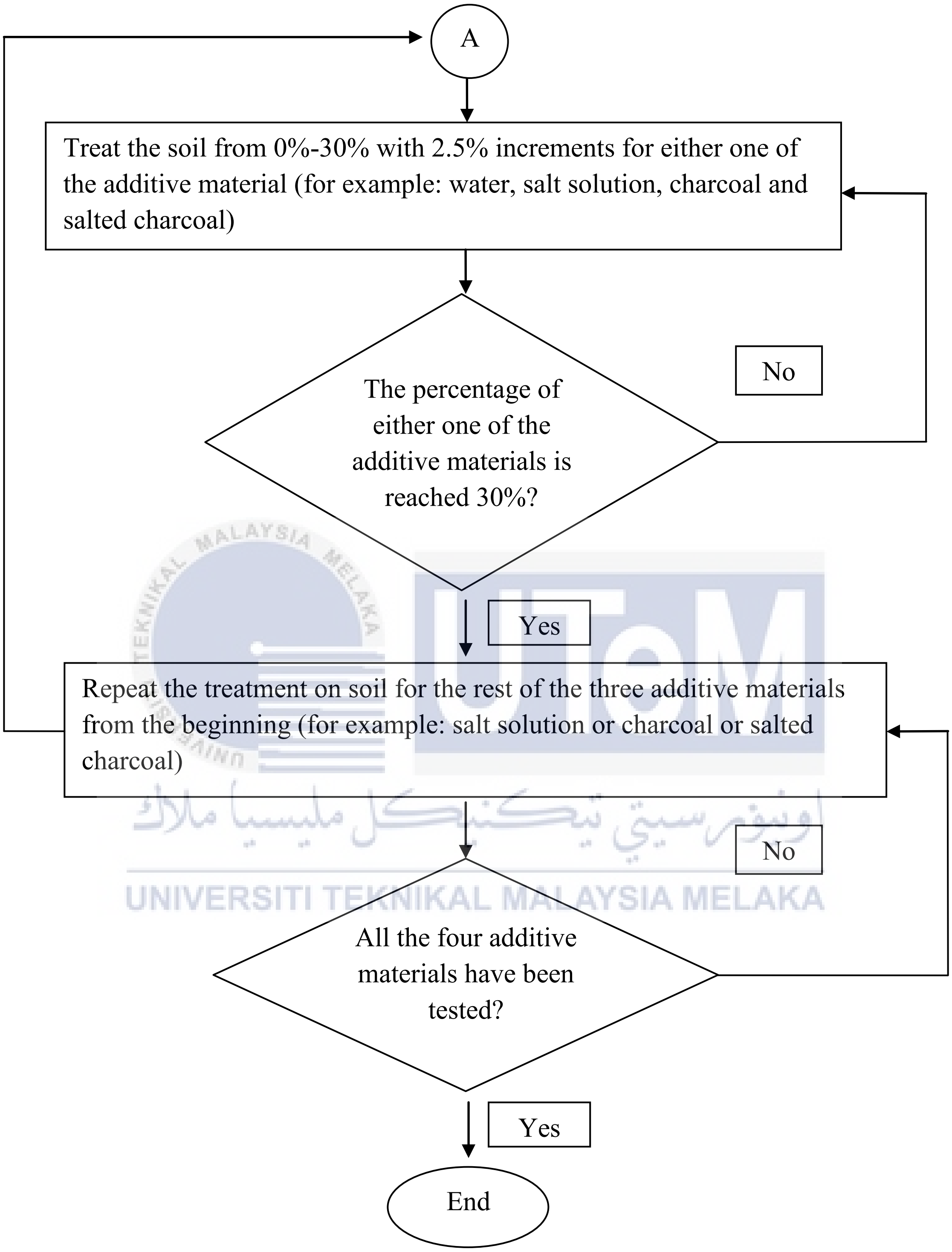


Figure 3.4: Flowchart of experiment procedure.

3.4.5 Project Implementation for Resistivity Measurement

The whole steps for conducting the experiment with one type of soil were presented in the Figure 3.5. This would give a better understanding on the each stages of the experiment. The same process was repeated with the rest of the four types of soils.

Figure 3.5: Process of conducting experiment for one type of soil.

3.5 Analysis and Interpretation of Results

The purpose of data analysis and interpretation stage is to obtain reliable and useful information from the data that have been gathered from the research experiment. The data collected will then transform to be used for statistical analysis. There are three types of statistical analysis methods are used to analyze the data which includes scatter plot diagram, correlation coefficient analysis and regression analysis. All the data collected will be compared with the expected results. The discussion of the reason for the deviation of expected result with the experimental result will be further discussed before conclusion and recommendation are being made.

3.5.1 Scatter Plot Diagram

Before fitting the regression model, scatter plot diagram are used to investigate the possible relationship between two variables that relate to the same event. In this experiment, the scatter plot will provide a visual evaluation of the relationship between the soil resistivity (response variable) and the percentage of water content, salt content, charcoal and salted charcoal content (independent variable).

3.5.2 Correlation Coefficient Analysis

A correlation coefficient indicates the strength and direction of the linear relationship between two variables. Correlation coefficient can range from -1 to +1. A value of +1 is used to indicate a perfect positive correlation whereas value of -1 is used to indicate a perfect negative correlation. However, a value of 0 will show no relationship between the variables. The value ranges from 0 to +0.29 or 0 to -0.29 indicates a weak positive or negative correlation coefficient. Moreover, the range of value from 0.30 to +0.69 or -0.30 to -0.69 indicates a moderate positive or negative correlation coefficient. For value ranges from 0.70 to +1.00 or -0.70 to -1.00 indicates a strong positive or negative correlation coefficient. A negative coefficient means that one variable tend to increase and the other is decreasing. On the other hand, the positive coefficient means that both variables tend to increase or decrease together [19].

3.5.3 Regression Analysis

After plotting the scatter plot, the regression analysis is performed. Regression analysis is a statistical tool that used to investigate the relationship between the variables. The reason that the regression analysis is used in this experiment is to help in understanding when there is a variation of the independent variable (water, salt, charcoal and salted charcoal content) how the dependent variable (soil resistivity) will change whilst all the independent variables are kept constant. By using this regression analysis, it is expected to obtain a correct model to define the relationship between the soil resistivity with the parameters that affect the soil resistivity such as water, salt, charcoal and salted charcoal content. The graph from the scatter plot analysis is expected to result a curvilinear trend rather than linear trend. As what have been hypothesized earlier, the dependent variable is expected to decrease exponentially as the independent variable is increased. The scatter plot will be best fitted with exponential function. Hence, the relationship between independent variable and dependent variable should be linearized by using the logarithms to base e ($\log_e$) to transform the data on the dependent variable (y-axis). This will result linear equation as follows:

$$\ln Y = \alpha + \beta X \tag{3.4}$$

Where: Y= Average predicted soil resistivity (Ω-m) value for any of X

α = Coefficient of the soil resistivity/Y-intercept

β= Coefficient of the independent variable percentage/Slope of the line

X= Independent variable (water, salt, charcoal and salted charcoal content)

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The purpose of this chapter is to present the data results and analyses of the experiment that have been conducted. Statistical analysis techniques will be used to analyze the data acquired through the laboratory tests. There are three types of statistical analysis techniques will be used in this research which are scatter plot diagram, correlation coefficient and regression analysis to get full understanding on the interrelation between soil resistivity with moisture content, salt solution, charcoal and salted charcoal content.

The experiment was conducted on the collected soil samples from various locations in order to determine the relationship between the soil resistivity and the parameters that were affecting the soil resistivity such as water content, sodium chloride solution, charcoal content and salted charcoal content. The test results and variation of soil resistivity with all those parameters will be further discussed in the following subsections.

Figure 4.1 shows apparatus that have been used to set up the experiment. From Figure 4.1, it can be seen that the main equipments that have been used in this experiment are BS1377-3 soil resistivity tester, DC power supply and digital multimeter.

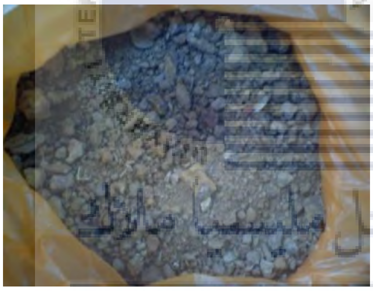
Figure 4.1: Materials and experimental set up.

4.2 Location of Soil Samples

The five types of soil specimen that have been collected from various locations are presented in the Table 4.1.

Table 4.1: Five types of soil sample collection locations.

Soil sample	Location
 Clay	Teluk Intan, Perak

 Loam	Sitiawan, Perak
 Sandy soil	Sitiawan, Perak
 Laterite	Bukit Beruang, Malacca
 Top soil	Sitiawan, Perak

4.3 Experimental Data Collection

The experiment was established at power system protection laboratory. At first the five types of the soil would be heated up by using the electric oven. However, the clay soil that had been dug from the Teluk Intan, Perak could not be directly heated up by using the electric oven due to the reason that the lump clay soil was wet and sticky and if was heated with electric oven would take longer time to dry up. Hence, the clay soils were molded into smaller pieces and then being exposed to sunlight so that it would take less time to get dried when heated up by using electric oven. The molded clay soils are as shown in Appendix C, Figure C1 and Figure C2. The molded clay soils would then crush into smaller soil particles as shown in Figure C3 in Appendix C.

Once the experiment was set up and launched, the data from the multimeter was collected and recorded in a paper. As mentioned previously in chapter 3 section 3.4, the data for the current would be taken thrice in order to get the average value for the current of each testing that had been done on the five types of soil sample. The Ohm's Law formula ($V=IR$) as shown in section 2.1.2 equation 2.3 was used to get the resistance value. However, the distance between the height and the radius of the electrode had to determine first before calculating the resistivity value by using the equation as stated in section 3.3. For this research there were 20 experiments were needed to be conducted. There were 39 data of current would be collected for each experiment. Totally, there would be 780 data obtained throughout the experiment. All the data that had been obtained and calculated would be tabulated in the table form in the following subsections and Appendix B. Moreover, there were some important things need to be aware in this experiment was that the rust from the screw and nut had to be removed first in order for the current to pass through it. This was because the equipment had been used for so long times. The rusting part on the screw would not permit the electron move through the electrode disc efficiently. After that, the continuity test was done to make sure that there was a continuous conductive path for the equipment.

4.3.1 Water Test Data

This subsection provides the results of the recorded data for five types of soil at different moisture content. Table 4.2 shows the data that have been calculated from the collected data. For detailed information on the collected data and calculation can refer to Appendix B from Table B1 until Table B5.

Table 4.2: Five different types soil resistivity values at varied moisture content.

Water Percentage (%)	Resistivity,(Ωm)				
	Clay Soil	Loam Soil	Sandy Soil	Laterite Soil	Top Soil
0.00	1402496.72	1231997.12	7699981.99	1476312.34	1422822.76
2.50	17753.12	12833.30	3542.94	15086.40	23072.80
5.00	6493.04	6201.33	974.68	7488.54	2022.97
7.50	2310.54	2409.38	416.97	2520.53	826.02
10.00	1108.69	1138.63	287.67	1356.19	439.26
12.50	489.87	539.88	201.98	631.48	272.88
15.00	299.68	317.69	167.07	343.73	185.65
17.50	193.18	185.36	164.50	187.60	135.75
20.00	125.03	108.85	164.26	168.58	94.77
22.50	81.02	77.00	163.63	79.49	71.14
25.00	63.75	63.72	165.47	82.67	48.78
27.50	33.39	63.00	166.34	78.49	48.32
30.00	31.40	60.92	165.39	74.70	49.73

4.3.2 Sodium Chloride Solution Test Data

The results of experiment for five different types of soil resistivity values at different percentage of sodium chloride solution are presented in Table 4.3. For detailed information on the collected data and calculation for sodium chloride solution test can refer to Appendix B from Table B6 until Table B10.

Table 4.3: Five different types soil resistivity values at varied sodium chloride content.

Sodium Chloride Percentage (%)	Resistivity,(Ωm)				
	Clay Soil	Loam Soil	Sandy Soil	Laterite Soil	Top Soil
0.00	1985836.06	1319996.91	11382582.08	1396263.40	1232964.15
2.50	7020.63	1464.34	794.04	1933.88	870.91
5.00	2348.12	513.33	430.34	701.17	457.86
7.50	511.06	344.13	188.56	414.73	247.55
10.00	327.31	266.94	119.71	297.63	192.37
12.50	207.88	218.44	77.61	236.04	172.05
15.00	138.14	169.59	65.67	195.14	124.51
17.50	87.39	102.80	69.69	124.13	90.51
20.00	53.46	50.40	70.41	70.28	44.64
22.50	23.30	23.39	68.99	31.73	24.31
25.00	13.95	22.09	65.67	29.09	18.90
27.50	11.58	22.45	71.89	28.82	18.76
30.00	10.97	22.26	68.99	28.56	18.76

4.3.3 Charcoal Test Data

The results in Table 4.4 represent the variation of soil resistivity with different charcoal content for the investigated soils. The dash line in the table indicates no data available due to the current is zero. For detailed information on collected data for sodium chloride solution test can refer to Appendix B, Table B11 until Table B15.

Table 4.4: Five different types soil resistivity values at varied charcoal content.

Charcoal Percentage (%)	Resistivity,(Ωm)				
	Clay Soil	Loam Soil	Sandy Soil	Laterite Soil	Top Soil
0.00	1753120.90	1319996.91	7699981.99	1476312.34	1552170.28
2.50	1707387.31	1274997.02	7479982.51	1529499.83	1503154.38
5.00	1885709.88	1422822.76	21226977.39	1720477.90	1762958.84
7.50	2533542.46	1487496.52	-	2006125.58	2199994.86
10.00	4090615.43	1728048.76	-	3414774.62	3670084.88
12.50	5995405.83	2493327.50	-	4133674.54	4759988.87
15.00	11635528.35	2908882.09	-	7933314.78	13900852.45
17.50	-	6889457.57	-	-	-
20.00	-	13541347.64	-	-	-
22.50	-	-	-	-	-
25.00	-	-	-	-	-
27.50	-	-	-	-	-
30.00	-	-	-	-	-

4.3.4 Salted Charcoal Test Data

The results in Table 4.5 provide the information on the variation of soil resistivity with different salted charcoal content for the investigated soils. For detailed information on the collected data and calculation for salted charcoal test can refer to Appendix B from Table B16 until Table B20.

Table 4.5: Five different types soil resistivity values at varied salted charcoal content.

Salted Charcoal Percentage (%)	Resistivity,(Ωm)				
	Clay Soil	Loam Soil	Sandy Soil	Laterite Soil	Top Soil
0.00	1544539.16	1421535.14	7699981.99	1291773.30	1569227.10
2.50	161206.52	50153.14	24128.98	76474.99	31868.46
5.00	68325.20	15176.78	4066.47	19278.31	10314.51
7.50	12955.02	10711.92	2410.12	9701.06	4060.69
10.00	5716.77	5849.83	1297.14	7173.90	2190.33
12.50	3499.99	4525.36	689.99	3497.58	1469.13
15.00	2323.94	2562.01	408.07	2700.08	962.21
17.50	1824.39	1960.02	296.48	1903.30	609.14
20.00	1542.90	1604.43	249.87	1595.90	429.99
22.50	1273.22	1270.87	198.57	1285.35	344.04
25.00	1062.09	1052.46	171.70	1173.88	271.07
27.50	923.83	961.26	148.68	1035.83	211.65
30.00	851.35	796.41	125.78	926.04	159.67

4.4 Scatter Plot for Soil Resistivity with Additive Materials

The scatter plot diagrams will be used to visualize correlation between dependent variable (soil resistivity values) and independent variables (salt, water, charcoal and salted charcoal percentage) for each type of soil. The dependent variable is plotted on the vertical y-axis whereas the independent variable is plotted on the horizontal x-axis. The vertical y-axis that contains the dependent variable (soil resistivity values) is plotted in logarithmic scale because the values are covered in very large range. However, the independent variables (salt, water, charcoal and salted charcoal percentage) are plotted on x-axis with the incremental of 2.5 percent for the consecutive percentage until reaches 30 percent. There is exceptional case in which the adding of charcoal percentage does not show much variation in soil resistivity so the graph is plotted without using logarithmic scale.

4.4.1 Variation of Soil Resistivity with Moisture Content

The scatter plot diagram in Figure 4.2 below shows the variation for five types of soil sample resistivity with moisture content. From Figure 4.2, it can clearly be seen that under zero percentage of water content the sandy soil exhibit the highest soil resistivity value with 7699981.99Ωm then followed by laterite, top soil, clay and loam with soil resistivity values of 1476312.34Ωm, 1422822.76Ωm, 1402496.72Ωm and 1231997.12Ωm respectively. Under 2.50 percent of water treatment, the resistivity values decline rapidly for all types of soil. From 2.50 percent until 15 percent of water treatments, the resistivity value for all types of soil are continued to decrease but the rate of dropping is lower than rate of decrease from 0 percent until 2.50 percent of water. The sandy soil resistivity values from 15 percent of water treatment onwards are remained in almost constant. From 2.50 percent until 17.50 percent, the sandy soil exhibits the lowest soil resistivity values then followed by top soil, loam, laterite and clay. On the other hand, the clay, loam, laterite and top soil are stayed almost constant at 27.50, 22.50, 22.50 and 25.00 of water percentage treatment respectively. The lowest resistivity value after 30 percent water treatment is achieved by clay soil which is 31.40 Ωm. Overall the graph shows a curvilinear trend of decreasing in soil resistivity values as the moisture content is increased.

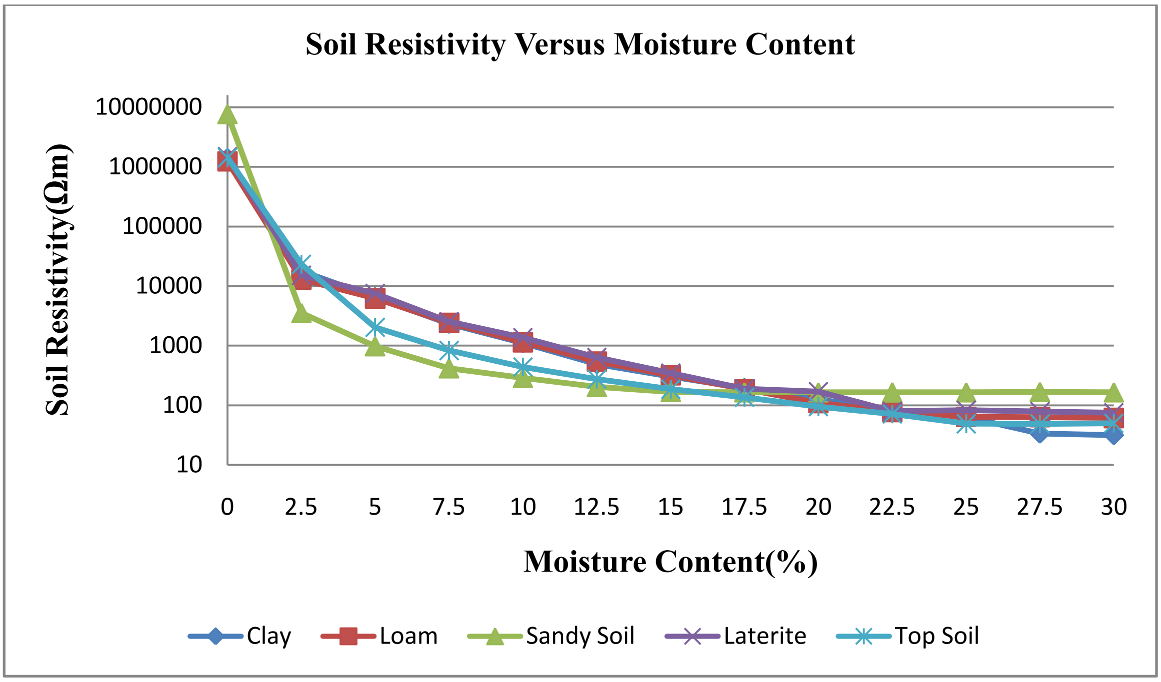


Figure 4.2: Variation of five types of soil sample resistivity with moisture content.

4.4.2 Variation of Soil Resistivity with Salt Solution

The variation of five types of soil sample resistivity with different salt solution content is as illustrated in Figure 4.3. Under 2.50 percent of salt treatment, it can be observed that the resistivity values from for clay, loam sandy, laterite and top soil is dipped sharply from 1985836.06Ωm, 1319996.91Ωm, 11382582.08Ωm, 1396263.40Ωm, 1232964.15Ωm to 7020.63Ωm, 1464.34Ωm, 794.04Ωm, 1933.88Ωm, 870.91Ωm respectively. Then, all soil resistivity values are dropped steadily until it reaches almost constant value. From the graph loam, topsoil and laterite are stayed at almost constant values when it reaches 22.50 percent of water treatment. However, clay and sandy soil remain almost stable at 15.00 percent and 27.50 percent of salt treatment. After 30 percent of salt treatment, the highest resistivity is achieved by sandy soil 65.67Ωm while the lowest resistivity is achieved by clay soil which is 10.97Ωm. Overall the resistivity values are decreased in curvilinear manner with increasing of salt solution content.

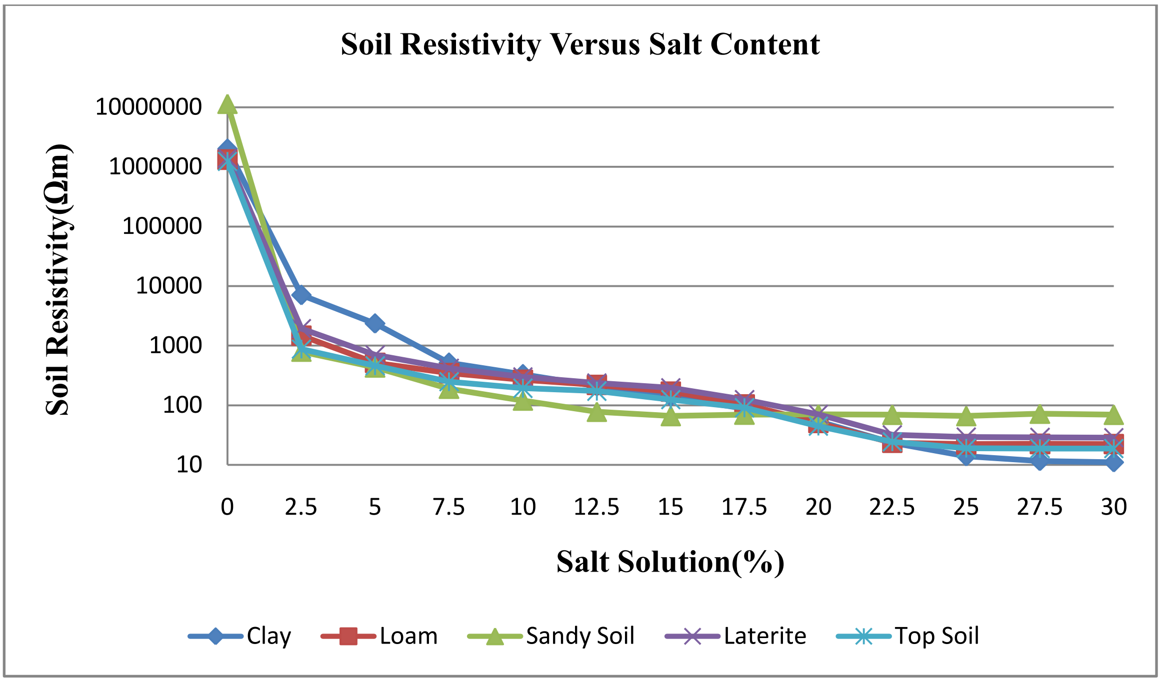


Figure 4.3: Variation of five types of soil sample resistivity with salt solution.

4.4.3 Variation of Soil Resistivity with Charcoal Content

The scatter plot in Figure 4.4 below indicates the variation for five types of soil sample resistivity with different charcoal content. As can be seen from the graph sandy soil resistivity is fallen from 7699981.99Ωm to 7479982.51Ωm at 2.50 percent of charcoal treatment. The sandy soil resistivity value shows a sharply increase to 21226977.39Ωm at 5 percent of charcoal treatment compared with other types of soil. After 2.50 percent charcoal treatment the clay and loam show a reduction in soil resistivity about 45733.59Ωm and 44999.89Ωm respectively before it keep on increasing in resistivity value to certain percentage. On the other hand, laterite and top soil show upward trend to a very high resistivity value of 7933314.78Ωm and 13900852.45Ωm respectively. No data available for clay, loam, sandy, laterite and top soil after treatment of charcoal at 17.50%, 22.50%, 7.50%, 17.50% and 17.50% respectively. This is because there are zero current value is shown in the multimeter. Overall the graph reveals an increasing trend of soil resistivity. This is not met the objective of reducing the soil resistivity values. Hence, the charcoal treatment will not further be analysed in the following subsections.

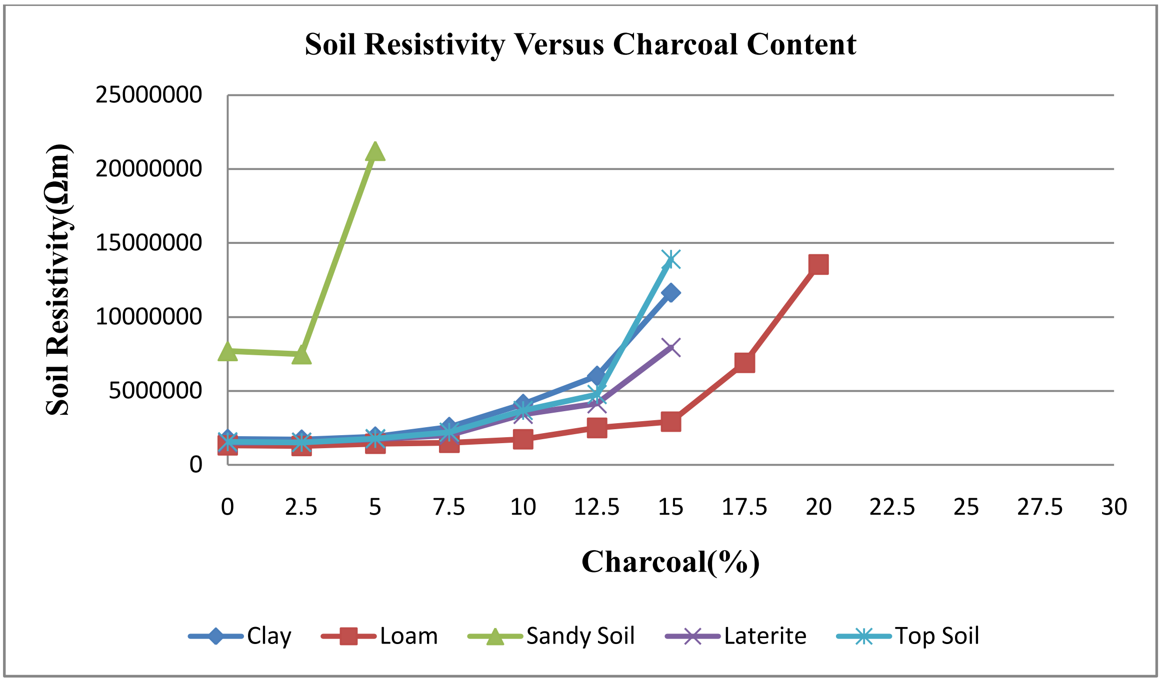


Figure 4.4: Variation of five types of soil sample resistivity with charcoal content.

4.4.4 Variation of Soil Resistivity with Salted Charcoal Content

The scatter plot in Figure 4.5 depicts the variation for five types of soil specimen's resistivity with different percentage salted charcoal content. Under 2.50 percent of salted charcoal treatment, the resistivity values drop rapidly for all types of soil. Then, from 2.50 percent until 15 percent of salted charcoal treatment, the resistivity value for all types of soil are continued to decrease steadily. In this salted charcoal test, the sandy soil has shown the lowest soil resistivity value then followed by topsoil, loam, clay, laterite. The trend of dropping is curvilinear.

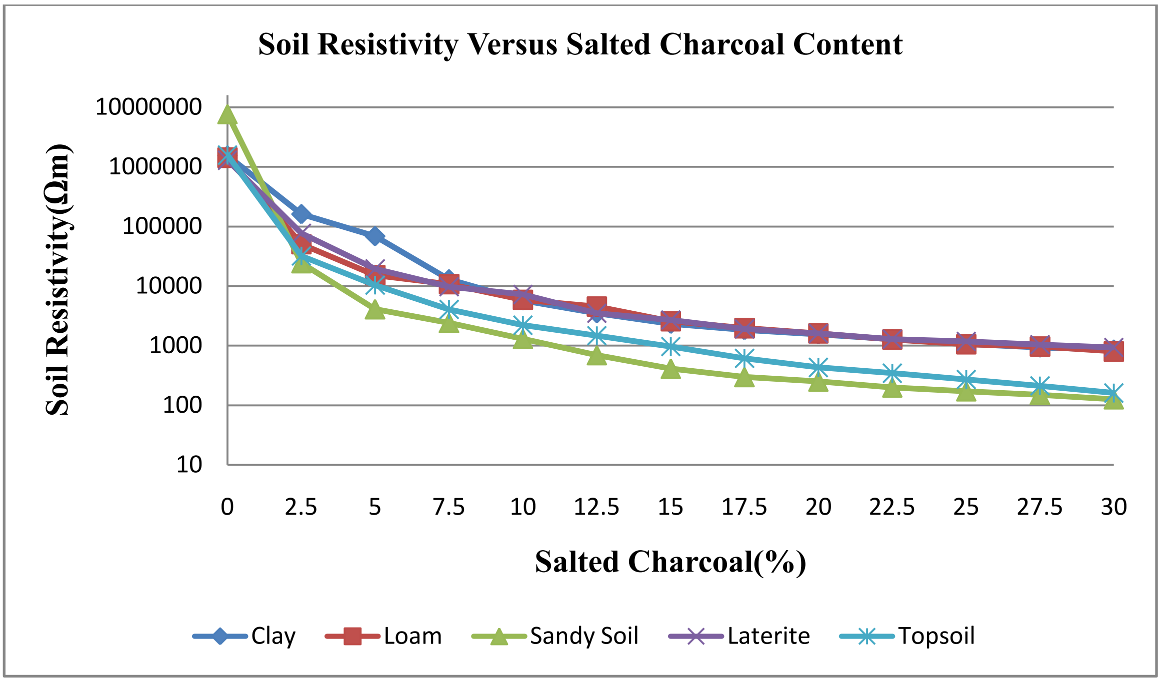


Figure 4.5: Variation of five types of soil sample resistivity with salted charcoal.

4.4.5 Variation of Each Type of Soil Resistivity with Additive Materials

4.4.5.1 Clay Soil

The scatter plot in Figure 4.6 outlines the variation of clay resistivity with water, salt and salted charcoal content. The dry clay soils before the water, salt and salted charcoal treatment are 1402496.72Ωm, 1985836Ωm and 1544539.16Ωm respectively. The clay soils give a sharp reduction in resistivity value than water and salted charcoal treatment at 2.50 percent of salt treatment. The clay soil resistivity values at 2.50 percent of water, salt and salted charcoal treatment are 17753.12Ωm, 7020.63Ωm and 161206.52Ωm. This numbers continue dropping steadily for every 2.50 percent increment in water, salt and salted charcoal application. After it reaches 27.50 percent of water and salt application onwards, the soil resistivity values remained almost constant. However, the clay soil resistivity after 27.50 percent salted charcoal treatment continues decreasing. The lowest clay soil resistivity value is 10.97Ωm which is obtained after 30 percent of salt application.

As an overall trend, it is clear that the soil resistivity is decreasing exponentially under the influence of additive materials.

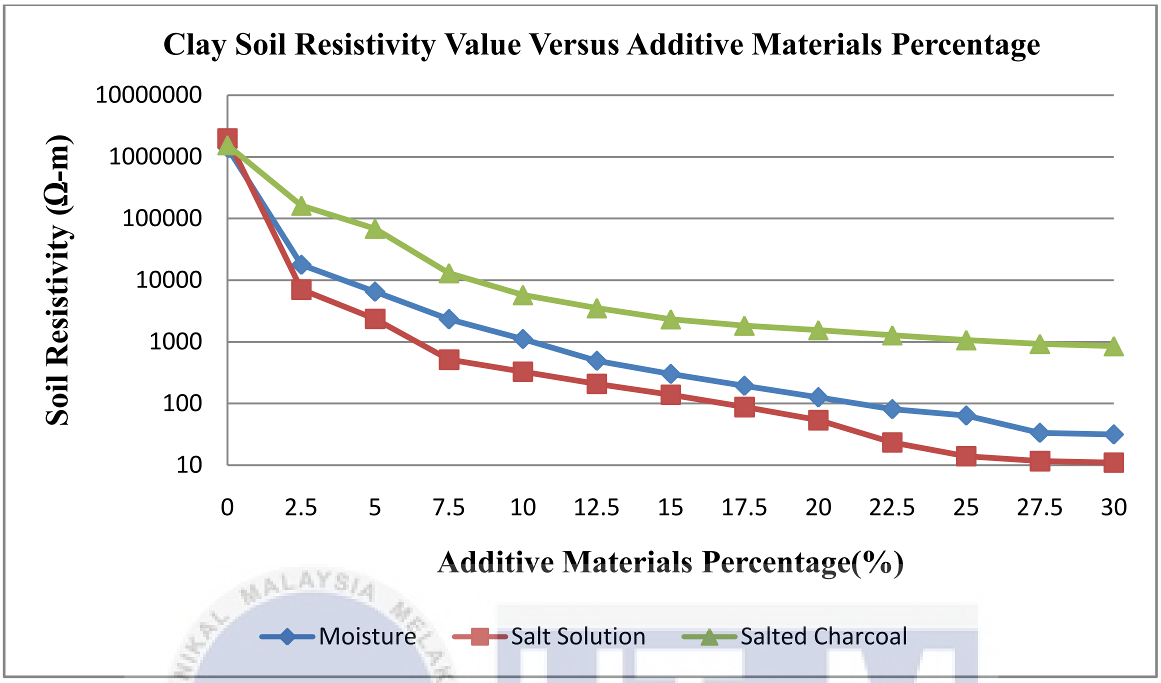


Figure 4.6: Variation of clay resistivity with water, salt and salted charcoal content.

4.4.5.2 Loam Soil

The scatter plot in Figure 4.7 represents the variation of loam resistivity with water, salt and salted charcoal content. The dry loam soils before the water, salt and salted charcoal treatment are 1231997.12Ωm, 1231997.12Ωm and 1421535.14Ωm respectively. The loam soils give a huge decline in resistivity value than water and salted charcoal treatment at 2.50 percent of salt treatment. The loam soil resistivity values at 2.50 percent of water, salt and salted charcoal treatment are decreased to 12833.3Ωm, 1464.34Ωm and 50153.14Ωm respectively. This numbers continue decreasing steadily for every 2.50 percent increment in water, salt and salted charcoal application. After it reaches 22.50 percent of water and salt application onwards, the soil resistivity values hold almost constant. However, the loam soil resistivity after 30.00 percent salted charcoal treatments is still continued decreasing and expected will continue decreasing if more salted charcoal being applied. The lowest loam soil resistivity value is 22.09Ωm which is obtained after 30 percent of salt application. The application of water and salted charcoal give the lowest soil resistivity of 60.92Ωm and 796.41Ω only. Hence, it is clear that the soil resistivity is decreasing exponentially under the influence of additive materials.

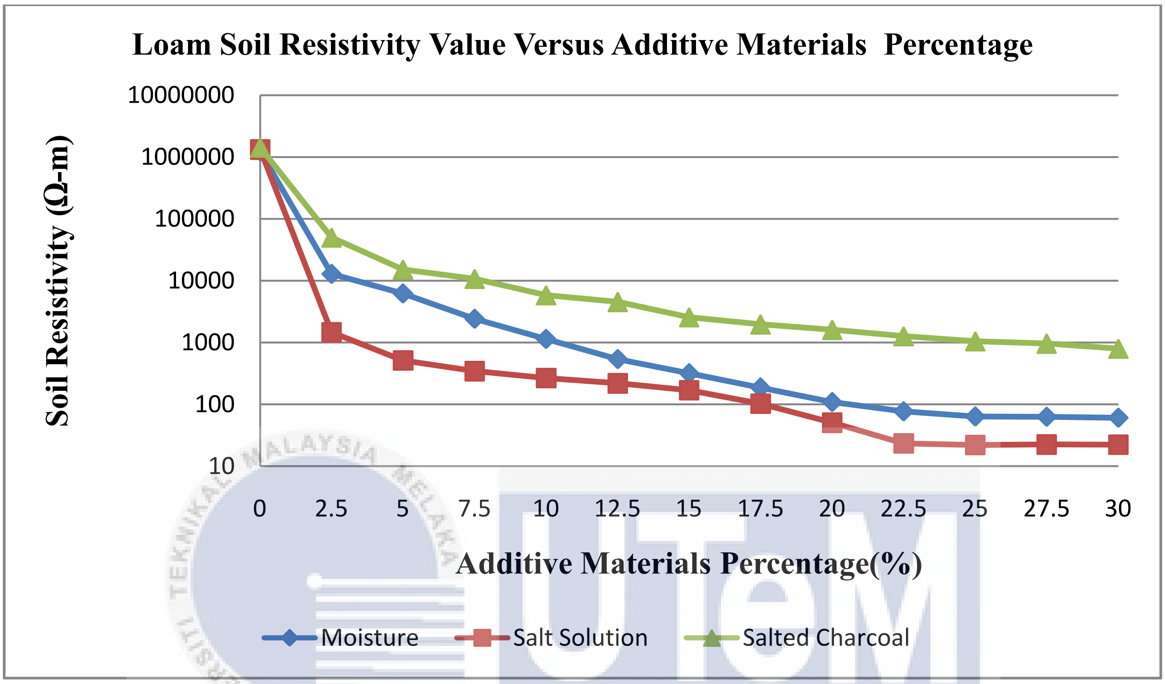


Figure 4.7: Variation of loam soil resistivity with water, salt and salted charcoal content.

4.4.5.3 Sandy Soil

The graph in Figure 4.8 represents the variation of loam resistivity with water, salt and salted charcoal content. Initially, the dry sandy resistivity values before water salt and salted charcoal application are 7699981.99Ωm, 11382582.08Ωm and 7699981.99Ωm respectively. This numbers drop drastically to 3542.94Ωm, 794.04Ωm and 24128.98Ωm respectively by 2.50 percent of water, salt and salted charcoal content. The moisture is decreased steadily in between the salted charcoal and salt. The sandy soil resistivity values are seen to be kept almost stable at around 143.99Ωm and 65.67Ωm after 15 percent water and salt treatment onwards. However, the sandy soil after 15 percent of salted charcoal treatment is still kept on decreasing and it is expected will continue decreasing if more than 30 percent of treatment. Overall the graph is decreasing exponentially.

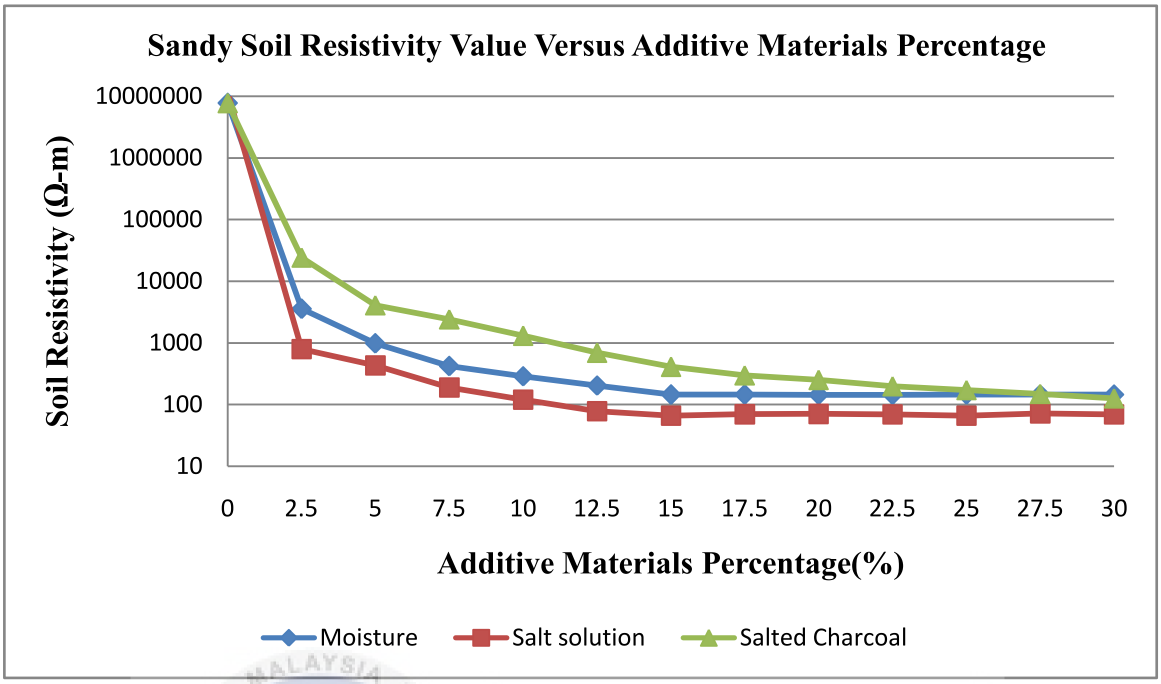


Figure 4.8: Variation of sandy soil resistivity with water, salt and salted charcoal content.

4.4.5.4 Laterite Soil

Figure 4.9 depicts the variation of laterite soil resistivity with water, salt and salted charcoal content. The dry laterite soils before the water, salt and salted charcoal treatment are 1476312.34Ωm, 1396263.4Ωm and 1291773.3Ωm respectively. The laterite soils give a rapid drop in resistivity value than water and salted charcoal treatment at 2.50 percent of salt treatment. The laterite soil resistivity values at 2.50 percent of water, salt and salted charcoal treatment are decreased to 15086.4Ωm, 1933.88Ωm and 1933.88Ωm. This numbers continue decreasing steadily for every 2.50 percent increment in water, salt and salted charcoal application. After it reaches 22.50 percent of water and salt application onwards, the variation soil resistivity values stay almost constant. However, the laterite soil resistivity after 30 percent salted charcoal treatments is still continued decreasing and expected will continue decreasing if more salted charcoal being applied. The lowest laterite soil resistivity value is 28.56Ωm which is obtained after 30 percent of salt application. The application of water and salted charcoal give the lowest soil resistivity of 74.70Ωm and

926.04Ω only. Hence, it is clear shown that the soil resistivity is decreasing exponentially under the influence of additive materials.

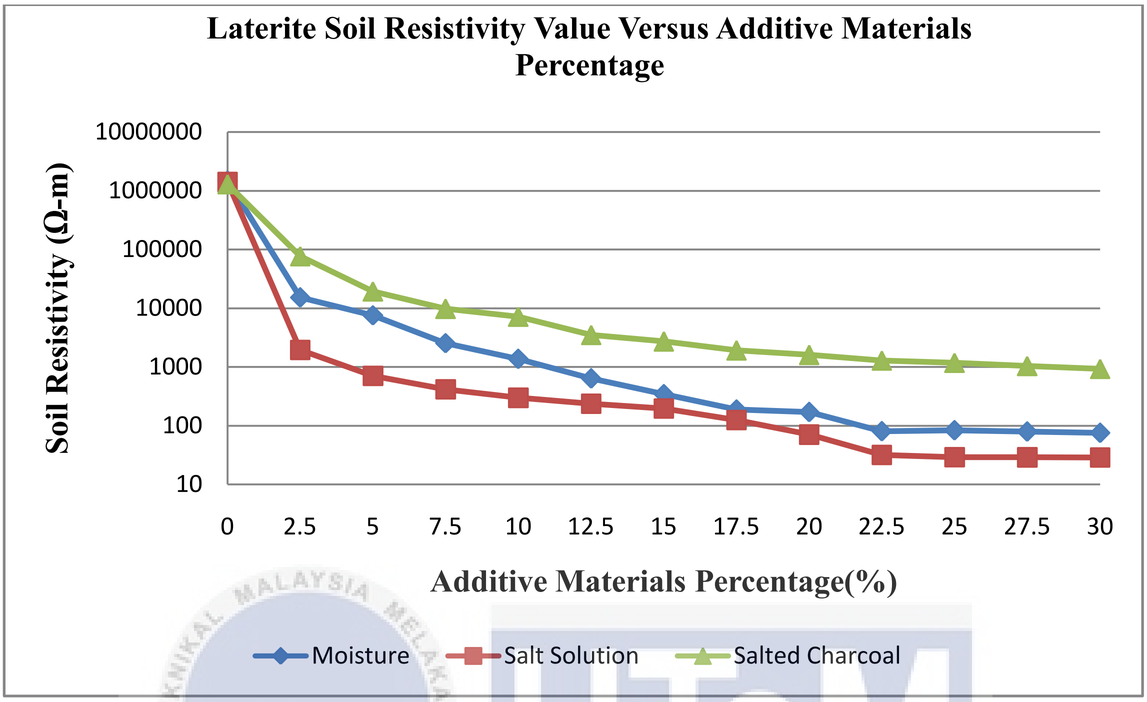


Figure 4.9: Variation of laterite soil resistivity with water,salt and salted charcoal content.

4.4.5.5 Top Soil

The graph in Figure 4.10 shows the variation of top soil resistivity with water, salt and salted charcoal content. The top soil resistivity values from 0 percent until 5 percent of water, salt and salted charcoal content treatment are seen to decrease drastically and nonlinearly to 2022.97Ωm, 457.86Ωm and 10314.51Ωm respectively. After 5 percent until 25 percent, the soil resistivity is seen to be decline steadily. Then, 25 percent onwards, the top soil resistivity is kept almost uniform for each type of treatment.

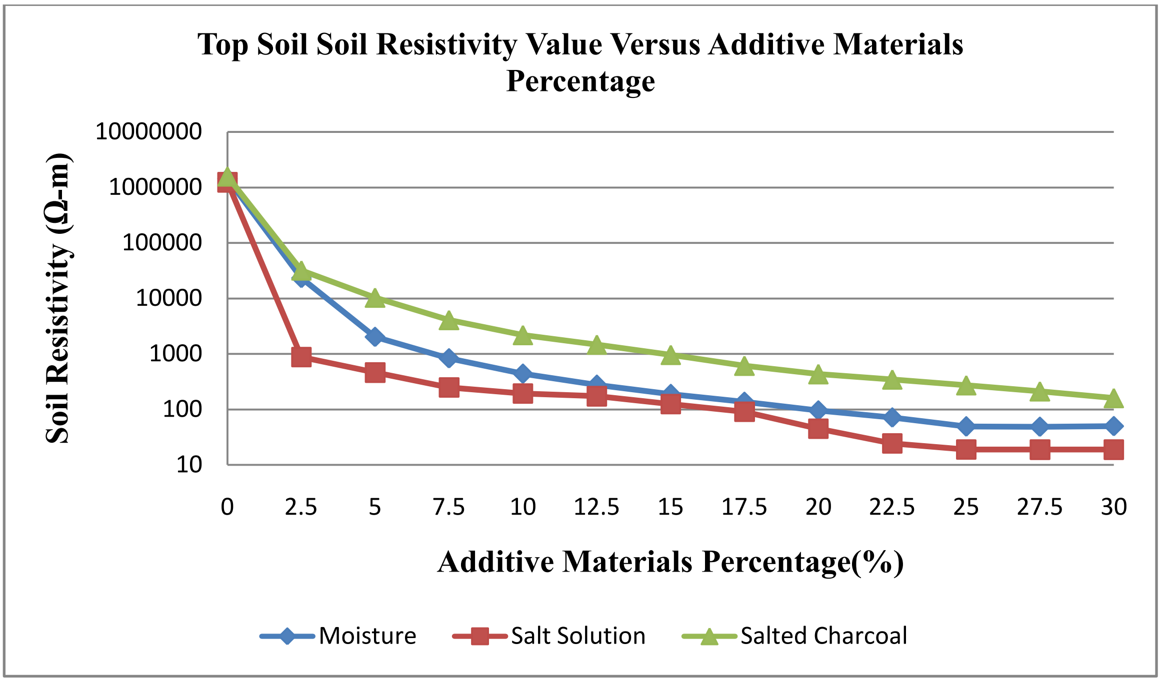


Figure 4.10: Variation of top soil resistivity with water, salt and salted charcoal content.

4.5 Correlation Coefficient Analysis

From the scatter plot in Figure 4.2 until Figure 4.10, it can be seen clearly that the relationships appear to be curvilinear trend rather than linear trend. It is also noted that as independent variable (moisture, salt solution and salted charcoal) content are increased, resistivity seems to decrease exponentially, as what have been hypothesized. The exponential regression model is chosen to represent the data since it makes sense that this model will be best represented the data. Hence, the non-linear data is transformed into a linear data by using logarithm to base e ($\log_e$) to obtain the correlation coefficient and linear regression equation. Although the soil resistivity under charcoal treatment show a curvilinear relationship but it is in increasing trend instead of decreasing trend. So, the soil resistivity under charcoal treatment will not be further analysed in this subsections as this does not met the objective of reducing the soil resistivity values.

The correlation coefficient, *r* values for five types of soil resistivity values with water, salt and salted charcoal will only be computed from the Microsoft Excel. The computed *r* values are then round off to two decimal places and recorded in the Table 4.6.

From the Table 4.6, it can be observed that the strongest negative correlation coefficient are obtained by clay soil with *r* equal -0.92, -0.89 and -0.90 under the treatment of water, sodium chloride and salted charcoal respectively. All soils under treatment of water and sodium chloride have exhibited a strong negative correlation coefficient except the sandy soils which have moderate negative correlation of *r* equal -0.65 and -0.62. Nevertheless, the sandy soil on the salted charcoal treatment has shown a strong negative correlation coefficient. This is due to the reason that 30 percent of salted charcoal is not adequate to moisten up the sandy soil. The sandy soil is still dependent on the salt solution attach at the surfaces of salted charcoal to reduce the soil resistivity. Moreover, from the graph in Figure 4.6 until Figure 4.10, it is found that salt solution will decrease the soil resistivity values rapidly than the moisture and salted charcoal content. By looking at Table 4.6 it can be clearly be seen that the correlation coefficient, *r* values for salt solution are lowest than the correlation coefficient, *r* values water content and salted charcoal. This means that the smaller absolute values give the rapid decreasing in soil resistivity values.

Table 4.6: Correlation coefficient, *r* values.

Soil type	Correlation coefficient, *r*		
	Water	Sodium chloride solution	Salted charcoal
Clay	-0.92	-0.89	-0.90
Loam	-0.90	-0.81	-0.88
Sandy soil	-0.65	-0.62	-0.82
Laterite	-0.89	-0.81	-0.88
Top soil	-0.85	-0.80	-0.89

The exponential regression model equation and coefficient of determination, r^2 for the variation of five types of soil resistivity values with independent variables (salt, water and salted charcoal percentage) are found by using scatter plot diagram analysis will be tabulated in the Table 4.7. For the details of scatter plot with exponential regression equation and coefficient of determination, r^2 can refer to Appendix B from Figure B1 until Figure B15.

Table 4.7: Exponential regression equation and coefficient of determination, r^2.

Soil type	Exponential regression equation and coefficient of determination, r^2		
	Water	Sodium chloride solution	Salted charcoal
Clay	$y = 49212e^{-0.28x}$ $r^2 = 0.840$	$y = 25754e^{-0.30x}$ $r^2 = 0.789$	$y = 16059e^{-0.21x}$ $r^2 = 0.803$
Loam	$y = 38889e^{-0.26x}$ $r^2 = 0.804$	$y = 9024e^{-0.24x}$ $r^2 = 0.658$	$y = 87705e^{-0.18x}$ $r^2 = 0.765$
Sandy	$y = 12534e^{-0.20x}$ $r^2 = 0.427$	$y = 6449.e^{-0.21x}$ $r^2 = 0.387$	$y = 59439e^{-0.25x}$ $r^2 = 0.669$
Laterite	$y = 44320e^{-0.26x}$ $r^2 = 0.795$	$y = 10522e^{-0.24x}$ $r^2 = 0.660$	$y = 95076e^{-0.18x}$ $r^2 = 0.770$
Topsoil	$y = 24945e^{-0.26x}$ $r^2 = 0.727$	$y = 6782e^{-0.24x}$ $r^2 = 0.632$	$y = 64439e^{-0.23x}$ $r^2 = 0.794$

4.6 Regression Analysis

From the correlation coefficients that have computed via Microsoft Excel, it is shown that the clay soil resistivity values have the strongest negative correlation coefficient with r equal -0.92, -0.89 and -0.90 under the treatment of water, sodium chloride and salted charcoal respectively. Therefore, the analysis will continue on clay soil to build a linear regression model in order to obtain the linear regression equation for the soil resistivity. For obtaining the linear regression equation by using the Minitab software, the non-linear data is required to transform into a linear data by using logarithm to base e ($\log_e$). This will result of $\log_e$ of soil resistivity on the y-axis versus water percentage on the x-axis as shown in Appendix B, Figure B16.

The linear regression analysis results that have acquired via Minitab software are shown Figure 4.11, Figure 4.12 and Figure 4.13.

Regression Analysis: ln (Soil Resistivity) versus Water Percentage

```
The regression equation is
ln(Soil Resistivity) = 10.8 - 0.285 Water Percentage


Predictor               Coef  SE Coef      T      P
Constant             10.8039   0.6614  16.33  0.000
Water Percentage    -0.28453  0.03742  -7.60  0.000


S = 1.26193   R-Sq = 84.0%   R-Sq(adj) = 82.6%


Analysis of Variance

Source          DF       SS      MS      F      P
Regression       1   92.092  92.092  57.83  0.000
Residual Error  11   17.517   1.592
Total           12  109.609
```

Figure 4.11: Regression analysis of $\log_e$ (soil resistivity) versus water content.

Regression Analysis: ln(Soil Resistivity) versus Salt Percentage

```
The regression equation is
ln(Soil Resistivity) = 10.2 - 0.305 Salt Percentage


Predictor               Coef  SE Coef      T      P
Constant             10.1564   0.8409  12.08  0.000
Salt Percentage     -0.30535  0.04757  -6.42  0.000


S = 1.60432   R-Sq = 78.9%   R-Sq(adj) = 77.0%


Analysis of Variance

Source          DF      SS      MS      F      P
Regression       1  106.06  106.06  41.21  0.000
Residual Error  11   28.31    2.57
Total           12  134.37
```

Figure 4.12: Regression analysis of $\log_e$ (soil resistivity) versus salt solution.

Regression Analysis: ln(Soil Resistivity) versus Salted Charcoal(%)

```
The regression equation is
ln(Soil Resistivity) = 12.0 - 0.215 Salted Charcoal(%)


Predictor                 Coef   SE Coef       T       P
Constant               11.9866    0.5654   21.20   0.000
Salted Charcoal(%)-0.21476   0.03198   -6.72   0.000


S = 1.07866   R-Sq = 80.4%   R-Sq(adj) = 78.6%


Analysis of Variance

Source           DF       SS       MS       F       P
Regression        1   52.465   52.465   45.09   0.000
Residual Error   11   12.798    1.163
Total            12   65.263
```

Figure 4.13: Regression analysis of $\log_e$ (soil resistivity) versus salted charcoal content.

The regression analysis that has been done on clay soil will be further explained in here. From Figure 4.11, it can be seen that the relationship of transformed clay soil resistivity with water percentage equation has been produced from Minitab software is quoted as below:

ln(Soil Resistivity) = 10.8 - 0.285 Water Percentage

If referring back to equation (3.4), it can be noticed that α and β values from this equation are actually equal to 10.8 and - 0.285 respectively. When there is zero water percentage will just left α=10.8Ωm only. From this log-linear model, the interpretation of the coefficient β is that one percent increase in water percentage will produce an expected decrease in *ln(Soil Resistivity)* of 0.285Ωm for clay soil. The 82.6% of R^2*(adj)* or known as correlation determination adjusted indicates that whenever there is a variation in the value of *ln(Soil Resistivity)*, 82.6% of it is due to the change in independent variable of water and only 17.4% are unexplained variation or due to error.

This linear regression equation can be converted to reflect soil resistivity instead of ln(Soil Resistivity) by letting both sides be exponent of base e. The regression can also directly take from Table 4.7. The regression equation is $\textit{Soil Resistivity } (\Omega m) = 49212e^{-0.28 \textit{ Water Percentage}}$ which will be used to predict the *soil resistivity (Ωm)* when there is zero percentage of water. When water percentage is zero the soil resistivity is equal to 490212Ωm. From this new equation it can be known that the graph will decrease exponentially as water percentage is increased.

The relationship of the transformed clay soil resistivity with sodium chloride solution percentage equation has been displayed on Minitab output as shown in Figure 4.12 is as follows:

ln(Soil Resistivity) = 10.2 - 0.305 Salt Percentage

From the above log- linear equation it is clearly known that α=10.2 whereas β=-0.305. This means that under zero percentage of salt will result α=10.2Ωm only. For β=-0.305 is meant that the resistivity of the transformed clay soil resistivity will expected to decrease in *ln(Soil Resistivity)* of 0.305Ωm for every one percent increase in salt percentage. The 77% of $R^2(adj)$ or known as correlation determination adjusted indicates that whenever there is a variation in the value of *ln(Soil Resistivity)*, 77% of it is due to the change in independent variable of salt and only 23% are unexplained variation or due to error.

The regression equation takes from Table 4.7 is $\textit{Soil Resistivity } (\Omega m) = 25754e^{-0.30 \textit{ Salt Percentage}}$ which will be used to predict the *soil resistivity (Ωm)* when there is zero percentage of salt. When salt percentage is zero the soil resistivity is equal to 25754Ωm. From this new equation it can be known that the graph will decrease exponentially as salt percentage is increased.

The relationship of the transformed clay soil resistivity with salted charcoal mixture percentage equation has been displayed on Minitab output as shown in Figure 4.13 is represented as below:

ln(Soil Resistivity) = 12.0 - 0.215 Salted Charcoal(%)

From the above log- linear equation it is clearly known that α=12.0 whereas β=-0.215. This means that under zero percentage of salted charcoal will result α=12Ωm only.

For β=- 0.215 is meant that the resistivity of the transformed clay soil resistivity will expected to decrease in *ln(Soil Resistivity)* of 0.215Ωm for every one percent increase in salted charcoal percentage. The 78.6% of $R^2(adj)$ or known as correlation determination adjusted indicates that whenever there is a variation in the value of *ln(Soil Resistivity),* 78.6% of it is due to the change in independent variable of salted charcoal and only 21.4% are unexplained variation or due to error.

The regression equation takes from Table 4.7 is $Soil\ Resistivity\ (\Omega m) = 16059e^{-0.21\ Salted\ Charcoal\ Percentage}$ which will be used to predict the *soil resistivity (Ωm)* when there is zero percentage of salted charcoal. When salted charcoal percentage is zero the soil resistivity is equal to 16059Ωm. From this new equation it can be known that the graph will decrease exponentially as salted charcoal percentage is increased.

From the linear regression model analysis on the transformed data as shown in Figure 4.11 until Figure 4.13, it can be known that the *p* values for water, salt and salted charcoal treatment are 0.00. This is meant that the three β coefficients of water, salt and salted charcoal are significant role in the model as the p-values are less than the significant level of p=0.05.

4.7 Discussion on the Parameters that Affect the Soil Resistivity.

The soil specimens had been tested with several factors that had identified would affect the soil resistivity value. The parameters that would affect the soil resistivity were soil types, water content, sodium chloride solution, charcoal and salted charcoal were determined and being verified through this research project.

There were five types of soil specimens with different height were tested for determining electrical resistance and soil resistivity. Five types of soil with different physical structure and composition were being tested in this study are clay, loam, sandy soil, laterite and top soil. During treatment with the distilled water content, salt, charcoal and salted charcoal on the soil it was essential to ensure that the content was distributed evenly with the soil to avoid getting inaccurate reading of current. Besides, the soil was compacted as compact as possible in order to get a maximum contact with electrode discs.

The other parameter that was said will affect the soil resistivity value was the variation of temperature. This was because when the temperature had changed the humidity of the surroundings environment would be affected. It would indirectly affect the soil resistivity value since the moisture content in the surroundings was varied. So, it was essential for this experiment to be implemented at the uniform room temperature during preparation and measurement. Since this experiment was carried out in Malaysia, the affect of the temperature would not be investigated through this experiment. This was due the reason that Malaysia was in tropical region that had two climate conditions only. The two seasons would be experienced in Malaysia were dry and monsoon. Thus, in dry weather it could be seen that the resistivity would be very high whereas in monsoon months the resistivity would be very low. However, for the countries which will experience four seasons, the experiment is essential to be conducted to see the trend of varying of soil resistivity with certain parameters.

The test results that have been presented on previous subsection will be discussed thoroughly in the following subsections.

4.7.1 Discussion on Soil Resistivity with Water Content

Soil resistivity test was conducted for each type of the soil specimen that had mentioned earlier with different moisture condition. For this test to be carried out successfully all the soil specimens would be dried to a constant mass at 100 degree Celsius by using electrical oven. After that, the soil sample would be compacted in the cylindrical BS1377-3 soil resistivity tester. The soil resistivity value would be calculated for each type of soil that has been tested. Moisture content was then varied from 2.50 percent until 30 percent .The incremental of each test of moisture content was 2.50 percent or equivalent to 25 grams.

In this test, the distilled water had been used as the moisture agent to promote the flow of the current to the soil. Even though it has been known that distilled water does not conduct electricity because it does not contain any ionic compound like salts, acid or bases, it will be able to exhibit good electrical conductivity with the presence of the containminants and electrical energy input [20]. This is because when the distilled water has been added to the soil, it will start to mix with the foreign ions that presence in the soil. It is known that inside the soils will have cations and anions nutrient element. The commonly presence of cations and anions are calcium ($Ca^{2}+$), magnesium ($Mg^{2}+$), potassium(K+) , hydrogen (H+), chlorine (Cl^{-}), nitrate (NO_3^{-}), sulfate ($S0_4^{2-}$) phosphate (PO_4^{3-}) and so on [21]. Under the injection of DC voltage, the water will undergo electrolysis process and mix with others ionic compound. So, when there is an increase in the amount of concentration of the distilled water in the soil it will give a better conduction in electricity as the mobility of the electrical charges and the mobility of hydroxyl (OH^{-}) and hydrogen (H^{+}) ions are increased. As the electrical conductivity is increased, the resistance and resistivity of the soil will be decreased. This can be seen the results in Appendix B, Table B1 until Table B5.

As can be seen from the scatter plot in Figure 4.2, the soils at below the optimum water content which is about in 2.50 percent until 5 percent, the resistivity of soils is reduced nonlinearly and the variation rate decreased dramatically. Besides that, from Figure 4.2 it can be clearly seen that the clay, loam, sandy, laterite and top soil are stayed almost constant at 27.50, 22.50, 15.00 22.50 and 25.00 percentage of water treatment respectively. This implies that soils have reached the saturation point and that is maximum water percentage can be absorbed by the soil. There may be observed a little decrease in soil resistivity values after the saturation point. At this point, the soils are said to be oversaturated and will observe the water is raised to the surface during compaction of the soil samples. Hence, the soil resistivity values are significantly influenced by water content, but minor influence is observed after saturation has reached.

At the end of this moisture content test, it is found that all results are in line with the initial assumptions that have been made except there should be around 15 percent until 30 percent of water treatment is required in order to get the almost constant rate of decreasing soil resistivity values. Previously has formulated a scientific hypothesis about after the 15 percent of water treatment will be expected to get the result of almost constant rate of decreasing soil resistivity values were true for the sandy soil only. The reason is that different types of soil with the mass of 1 kilogram will have different levels of porosity and height in the cylindrical container. These physical properties are the main factor that will determine how fast the soils will reach saturation level. Thus, the hypothesis that has formulated previously will be modified.

4.7.2 Discussion on Soil Resistivity with Sodium Chloride (NaCl) Content

The common salt was used in this test. The common salt is an ionic compound with the chemical formula NaCl which known as sodium chloride. Before conducting the experiment, the 50 gram of sodium chloride was being dissolved in the 1 kilogram hot water. This implies that the ratio between water and sodium chloride is 10:0.5. It is essential to identify the chemical salt percentage to be used in the test. This is because it is a significant factor affecting the value of soil resistivity. A high concentration of salt will result in low resistivity whereas the low salt percentage will result in high resistivity.

The aqueous solution of sodium chloride was poured into the soil. The soil was stirred in order to ensure the soil was mixed well with sodium chloride solution. It can be observed in Figure 4.3 that the higher the percentage of salt is being treated to the soil will result in very low resistivity. This is because the salt in aqueous state is an electrolyte due to the dissociation of the sodium chloride (NaCl) compound into positively charged Na^+ ions and negatively charged Cl^- ions when dissolved in water. These freely moving ions will then align on anode (positive polarity) and cathode (negative polarity) of the disc electrode under the application of DC voltage. The positively charged Na^+ ions will migrate to the cathode electrode whereas the negatively charged Cl^- ions will move to the anode electrode. Generally the positively charged ions such as Na^+ ions will move to the cathode and gain electron to become sodium metal while the negatively charged ions such as Cl^- ions will lose and electron when move to anode to become chlorine [22]. However, the reactions that take place in here cannot be said that is the overall reactions for the process due to presence of differences nutrient element in the soil and the element will react with salt solution or migrate towards the two electrode discs.

From scatter plot in Figure 4.3, it can be seen that all types of soil resistivity will decrease rapidly at the beginning under the influence of the salt electrolyte. Moreover, the graph from Figure 4.6 until Figure 4.10 have revealed that all soils under the treatment of salt solution will decline drastically when compared with others additive materials such as distilled water, charcoal and salted charcoal. The magnitude of resistivity values variation are hold almost constant at 27.50, 22.50, 15.00 22.50 and 25.00 percentage of salt solution treatment for clay, loam, sandy, laterite and top soil respectively.

Other than that, the temperature was observed to increase drastically in all types of soils after the application of aqueous salt solution. Especially the sandy soil would exhibit a highest temperature under the application of aqueous salt solution during the experiment. If comparing with water treatment, it was found that the soil will heat up faster under salt treatment. This is due to the present of freely moving sodium chloride ions that will make the temperature increases. When the temperature increases the viscosity of the liquid is decreased due to dissociation of ions from molecules. Thus, soil resistivity will decrease when temperature is increased.

In short, all types of soil are seen to decrease more rapidly under salt solution treatment than other additive materials. The soil resistivity is decreased nonlinearly or exponentially under salt solution treatment. Thus, the hypothesis about the salt treatment is supported by the results. The salt solution is said to be the one of the controlling factor of soil resistivity.

4.7.3 Discussion on Soil Resistivity with Charcoal

For this charcoal test, the charcoal was used. The charcoal was smashed into the powder or pieces form with a hammer as shown in Figure C4 and Figure C5 in Appendix C. The experiment had been done by putting 2.50 percent until 30 percent of charcoal powder into soil.

By referring to Figure 4.4, it can be observed that the soil resistivity appears to be increased as the charcoal powder treatment is increased from 2.50 percent onwards. This is because the non-conductor of electricity charcoal powder is being added and mixed well with soil will cause increase in height of the soil sample and then will make it difficult for current polarization through the two electrode discs. However, the scatter plot illustrates that at 2.50 percent of charcoal powder treatment on the clay, loam, sandy and top soil shows a fall in resistivity value about 45733.59 Ωm, 44999.89Ωm, 219999.48Ωm and 49015.90Ωm respectively. This is due to the 2.50 percent of charcoal powder has filled up the voids in the soil and will not increase much height of the soil samples which still can allow the current same as under zero percent of charcoal treatment passing through the soil samples as shown in Appendix B Table B11 until Table B15.

If comparing with the results from the journal in chapter 2, section 2.2.1 which is written by Bambang Anggoro Ngapuli I. Sinisuka, Parouli M.Pakpahan, it can be found that the results of charcoal test are almost same with the results obtained by the authors. The results obtained in this journal are as shown in Chapter 2, Figure 2.5. From the Figure 2.5, it can be seen that there is a trend of increasing after 2.50 percent of carbon treatment and then there is a decrease trend in soil resistivity after 5 percent carbon treatment. Nevertheless, the results have obtained from this experiment showed a decreasing trend after 2.50 percent of charcoal treatment and then the trend appears to be increased until no more data available. Besides that, the authors have made suggestion in that paper that more than 15 percent of carbon is used will reduce the soil resistivity. This seems untrue because four types of soils after 15 percent of charcoal treatment will not allow current to pass through. So, the resistivity values will not able to be calculated as current is zero.

Since with 30 percent of charcoal powder do not show any reducing in soil resistivity values, further statistical analysis will not be done on charcoal powder as it does not meet the objective that have been set. The hypothesis that has been formulated previously will be rejected and rewritten. At the end of charcoal test, it is also proven that the theory sated about the charcoal is not conductor of electricity due to the arrangement of amorphous carbon atoms in non-crystalline, irregular state that there is not free movement of electrons available is true [23].

4.7.4 Discussion on Soil Resistivity with Salted Charcoal

As the charcoal test did not cause the soil resistivity value to be fallen, the experiment was then conducted by using salted charcoal mixture. At first 50 gram of sodium chloride was being dissolved in the 1 kilogram hot water and then the charcoals were immersed into the aqueous sodium chloride solution. The salt solution was then poured away which would leave only the wet charcoals. These wet charcoal pieces were used to conduct the experiment. The salted charcoal test was conducted by varying the wet salted charcoal content from 2.50 percent until 30 percent. It can be seen from Figure 4.5 that the soil resistivity will decrease under the application of salted charcoal. From Figure 4.6 until Figure 4.10, it can be observed also that the soil resistivity is not decreased as fast as the moisture content or salt solution but is decreased in a more steady way. This is because this test is conducted to investigate how much sodium chloride ions will be chemically bound to the active sites of the charcoal through the adsorption process. This adsorption process is not same as absorption process because adsorption is a phenomenon of attracting and retaining the ions of sodium chloride on the surface of charcoal. After 300 grams of wet salted charcoal treatment, it is found that the charcoal will be able to adsorb about 5.00 percent to 7.50 percent of salt solution at their surface. This is found by comparing the soil resistivity under salt solution treatment in Table 4.3 with salted charcoal treatment in Table 4.5.

At the end of this experiment, it can be said the used of charcoal in the earth pit is not because it is a conductor. The reason behind of using charcoal pieces to mix with sand and salt in the earth pit in equal part is that the charcoal will adsorb the moisture and salt solution at their surfaces and maintain moist condition around the earth pit. Besides, the earth pit is needed to be watering regularly. When watering the earth pit, the salt will percolate through the porous material such as sand and charcoal. This charcoal and sand will adsorb the salt solution and with the presence of this freely moving ions on the charcoal and sand surfaces will make it to conduct electricity better. Besides, it is also known that the good insulator such as charcoal and sandy soil will decrease the resistivity values only with the temperature is increased. The sandy soils have a low specific heat capacity which means it will heat up faster which had observed during water and salt test. During the fault occur, the temperature of sandy soil surrounding will increase faster due to the presence of freely moving sodium chloride ions and the charcoal will function as an absorbent to absorb the heat from the sandy soil surrounding. If the fault is continuously occurring, the charcoal will burn up and turn into ash. At this time, the soil resistivity will be lowered due to temperature has risen.

4.7.5 Discussion on Soil Resistivity with Soil Types

Every time conducting the experiment it is necessary to press the soil until as compact as possible in order to displace the air from soil pores. This is due to compactness of the soil particles have been identified as the factor will affect the soil resistivity values. When the air has been displaced from soil pores, the soil particles will move closer to each others. It will make electrical conduction better as air which is very poor conductor of electricity has been removed. Other than that, it will make the soils to have proper contact with electrode disc also. A proper contact between the electrode discs soil is important for obtaining correct data.

From all the scatter plot graphs and table at Appendix B, it can be observed that before the treatment of additive materials the soil resistivity value is very high for all types of soil. This is due to the 100 percent dry soil condition will make difficulty of current propagation in the soil specimens. Besides, the dry soil is known as poor or fair conductor of electricity due to the air filled inside the soil is also the bad conductor of electricity. Among the five types of soil, it can be found that sandy soils have the highest soil resistivity values at dry state. The reason is that the sandy soils have the largest pores size to be filled up with air which is then cause it to have highest resistivity value compared with other types of soil.

Based on scatter plot in Figure 4.2 until 4.5, it can be found that different types of soil will give the different level of soil resistivity values under the treatment of the same additive materials. This because when the different type of soil specimens with the mass of 1 kilogram are being poured into the cylindrical soil resistivity tester container will result in different volume due to different heights. The heights and volume of the different type soil specimens occupy in cylindrical soil container are actually affected by the physical properties of soil such as soil texture, structure and particle size. These physical properties will then give impact on the soil resistivity values when the soils are threaten with the soil enhancement materials such as salt, water and salted charcoal.

After the 30 percent of water and salt solution treatment the lowest soil resistivity values are observed in the clay soils. The clay soil give the lowest soil resistivity values among the five types of soils have been tested is due to the reason that that clay soil have the finer soil particles and a lot of tiny spaces which make it has a high surface area per volume for it to absorb and retain huge amounts of water. These finer soil particles have made the clay soils have the highest height when putting into the cylindrical container. This property has made the clay soil reaches to the saturation level slower than the other types of soil. The saturation level for the clay soil is achieved at 27.50 percent of water and salt treatment. After 27.50 percent of salt and water treatment, the variation in soil resistivity values will be not much.

From Figure 4.2 and Figure 4.3, the sandy soil is observed to reach it saturation point after 15 percent of water and salt solution treatment. This is the reason that the sandy soils have larger solid soil particles and low surface area to absorb the water than other types of soil in this experiment. The water will seep to the porous sandy soil easily. Moreover, it is observed that the sandy soil resistivity values decrease so fast than other types of soil at 2.50 percent until 17.50 under both water and salt solution treatment. This may be due to the sandy soil contain a little soluble salt at it surfaces and after the treatment of water or salt will make this resistivity to decrease rapidly. As sandy soil is a great insulator and has a low specific heat capacity which will make it to heat up faster with the presence of water or salt solution under the injection of DC voltage. When the sandy soil is heated up, the temperature of the sandy soil will increase. The increase in temperature will make sandy soil resistivity value become lower. Furthermore, the sandy soil is found to achieve the lowest soil resistivity value than the clay soil under the treatment of salted charcoal. This is because the 300 grams wet salted charcoal is not enough for the clay soil to reach saturation. Nevertheless, the salted charcoal test is used to determine how much the salt solution will adsorb at the surface of charcoal. From the salted charcoal test cannot be used to conclude that the sandy soil is the best soil for grounding purpose as it has the poor water holding capacity.

If observed properly from Figure 4.2 and Figure 4.3, it will be noticed that the top soil resistivity values are in between the clay and loam under both water and salt treatment. This is due to the fact that the top soil is on the surface of the soil where most nutrients and organism are found. It also composed of a lot of organic decay matter which left by the plants and organisms such as earthworm. Besides, the top soil is collected from the garden area is fertile and may be acidic due to it has mixed with waste excreted by chickens. The presence of the organic matter and waste are the factors that contribute the top soils to have the resistivity in between the loam and clay soil. The loam soil has the resistivity in between the clay and sandy because it has the mixed soil particles size in between the clay and sandy soil. This property has made the loam soils have height of 8.5cm which is less than clay with the height of 11.2cm but more than sandy soil which has the height of 6.8cm under cylindrical container. However, for the rusty reddish laterite soil which has the soil composition approximately same as loam has exhibited the soil resistivity values higher than loam is due to it have less height and density than the loam soil under the cylindrical container. Hence, this makes the laterite soil hold water less than loam.

In the soil drying-rewetting cycle, the soils will undergo five stages which are from dry, moist, wet, saturated and oversaturated. The soil is said to reach saturation if the space between the soil particles is fully filled up with water or salt content which will cause the closer contact between the soil particles and forming a conductive path among the soil particles. At this point, the water or salt solution will allow the soils to conduct the electricity easily and the lowest resistivity is obtained. The excessive water around the soil but not inside the void will be evaporated first due to the heat generated during the conduction of electricity. After this saturated state the resistivity value will not further increase much.

In brief, all types of soil are decreased more rapidly under salt treatment than moisture and salted charcoal treatment. The clay soil is the best soil to be used in the grounding system as it will give the lowest soil resistivity values under water and salt treatment. Besides, it also has good water holding capacity property. Hence, the hypothesis about the clay soil will give the lowest resistivity is supported by the test results from experiment.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This experimental study is focused on accessing five key parameters that have been identified that will influence the soil resistivity value. The five key parameters are soil types, moisture content, sodium chloride content, charcoal and also the salted charcoal content. All the parameters have been successfully studied through the experiment investigation that has been carried out by using all the materials and apparatus that have been mentioned in this report. The results obtained from the experiment have been well analyzed and discussed by using the illustrative scatter plot diagram, correlation coefficient and regression model analysis. Hence, the project has achieved all of the four objectives that have been set earlier.

If reviewing back to the hypotheses that have been developed, it can be noticed that the results from this research bear out only three out of five hypotheses. This means that the two hypotheses that do not supported by the results from the experiments are rejected or modified throughout these studies.

Besides, the trend and reliability relationships between moisture content, sodium chloride content, charcoal content and salted charcoal content with transformed soil resistivity are established from the research. Relationship between transformed of soil resistivity and independent variables such as moisture, salt solution and salted charcoal content reveals that higher content of moisture, salt solution and salted charcoal content will cause the soil resistivity values to be lowered with the strongest negative correlation coefficient of regression of r=-0.92, r=-0.89 and r= -0.90 respectively are gained from the clay soil specimen. The clay is found to give the lowest soil resistivity values among the five types of soils have been tested as the clay soil have finer particles size, high degree of saturation and high water holding capacity. Hence, the clay is the best soil to be used in grounding installation.

From the scatter plot, it is also noted that as independent variables such as moisture, salt solution and salted charcoal content are increased; resistivity seems to decrease exponentially, as what have been hypothesized. However, the relationship between charcoal content and soil resistivity do not show any decrease in soil resistivity but it appears to increase the soil resistivity value.

Other than that, soil resistivity values for all soil types will decrease as the water, salt and salted charcoal treatment are increased. In comparison to the moisture content and salted charcoal content treatment, the salt solution treatment is more effective on reducing the soil resistivity values for all types of soil. The salted charcoal is not effective to reduce the soil resistivity values because only the wet charcoal pieces are mixed in the soil in order to test the rate of adsorption of salt solution at charcoal surfaces.

Finally, all the variation of the resistivity values is greatly depended on the presence of the volatile water content. This implies that without the moisture the soil will not able to conduct electricity as there will not have any freely moving ions in the soil. The same goes for the salt in solid state will not able to conduct electricity if without water. Ultimately these conclusions are only based on laboratory soil resistivity test by using cylindrical type soil container. It cannot be concluded that all types of soil will exhibit the same values of soil resistivity under the influence of the parameters that affecting the soil. This is due to the reasons that every soil has different characteristics which include composition, chemical properties, structure, permeability, water holding capacity and pH value. These properties must be determined first before designing a reliable grounding grid system for specific area. So, when designing grounding system, the experiments and the field observations must be carry out. The experiment in the laboratory is done to prepare a comprehensive database for reflecting the value of soil resistivity in that particular area whereas the field observation is done for verifying the conclusions that have been made through the laboratory experiment.

5.2 Recommendation

In today's rapidly changing world of technological advances, grounding system is playing a significant part of any designation in electrical protection system. There should be a continuous research on the soil resistivity in order to get as low as possible grounding resistance. The research should be included all common types of soil that present in the housing area as well as the mixture of different composition of the soil types which is based on the real environment and situation that will be used for building up a good grounding system. Further investigation on the wide variety of soil is necessary for verifying the correlation of the parameters that affecting the soil resistivity. Other factors that will affect the soil resistivity must be further verified through future studies. Proper understanding of those parameters which cause the variation of soil resistivity can be helpful in development of correlations.

Nowadays, the soil with a very low level of soil resistivity is generally indicated that the soil is highly corrosive. For reducing the corrosiveness of the soil the further research effort can be done in which it will be focused on creating chemical substances that are able to be incorporated into the various types of soil which will give the lowest possible soil resistivity for grounding system. The chemical substances that have been created must be hydrophilic or adhesive to the soil. This property is important because it will enable the soil to absorb and hold the moisture or water content in the soil and not easily get washed by rain during rainy season. Other than that, the chemical substances that have been created must not cause corrosion to the equipments which will then reduce the effort and the cost for the maintenance. It is imperative to ensure that the chemical substances will not pollute the environment which have been emphasized on the code of ethics that an engineer should at all times hold paramount the safety, health and welfare of the public.

Other than that, ones can make amendment for the soils. For instance, adding suitable proportion of clay with sandy soil to observe the variation of soil resistivity. By adding these suitable proportion of clay is expected to get a lower soil resistivity values. The reason for this is that the clay will help in absorption of water while sandy soil with larger surface area will heat up faster. The sandy soils have low specific heat capacity and high thermal conductivity which will cause the surrounding temperature of the soil to increase with the condition that there must be present of adequate percentage of water. As the temperature has risen, the charge carrier will move very fast and the conduction of electricity will become better which is then caused the soil resistivity value decreased. However, the sandy itself is not suitable to be used in grounding system because it has larger soil particles which will make it heat up easily and increase the rate of water evaporation due to heat generated by the current.

In brief summary, it is imperative that to put some effort on doing research to reduce the earthing resistance or soil resistivity by using the natural resources that are available with some modification on the chemical properties of the material in order to be able to mix well with the soil. The field experiment must be done on the artificial chemical substances that have been produced in order to test the absorption rate, moisture retention property, rate of causing water in the soil to be evaporated and to test whether it will cause corrosion of the equipments as well as the impact of these chemical substances to the environment. These steps are necessarily to be carried out so that the equipments that are used for grounding will be last longer.

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APPENDICES

APPENDIX A

Project Milestone and Project Gantt Chart

Project Milestone

No.	Activity	Starting Date	Achieved (Yes/No)	Actual Completion Date
1	Project briefing	17 September 2014	Yes	17 September 2014
2	Finding supervisor and title selection	12 September 2014	Yes	19 September 2014
3	Study and research about the project	12 September 2014	Yes	22 May 2015
4	Discussion with supervisor	12 September 2014	Yes	12 June 2015
5	Writing introduction	September2014- October 2014	Yes	29 September 2014
6	Writing literature review	September 2014 -October 2014	Yes	26 October 2014
7	Writing methodology	October 2014 -November 2014	Yes	06 November 2014
8	Writing expected result	October 2014 - November 2014	Yes	10 November 2014
9	Report writing FYP 1	September 2014-November 2014	Yes	12 November 2013
10	Presentation of FYP 1	01 December 2014	Yes	19 November 2014
11	FYP 2 briefing	04 March 2015	Yes	04 March 2015
12	Conducting experiment	February 2015-May 2015	Yes	07 May 2015
13	Data analysis	February 2015- May 2015	Yes	21 May 2015
14	Seminar report refinement and submission	Mac 2015 –Jun 2015	Yes	1 Jun 2015

Project Gantt Chart

Gantt Chart	FINAL YEAR PROJECT 1 (2014)				FINAL YEAR PROJECT 2 (2015)					
Month / Activities	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
Project briefing										
Finding supervisor &title selection										
Study and research about the project										
Discussion with supervisor										
Writing introduction										
Writing literature review										
Writing methodology										
Writing expected result										
Report writing FYP1										
Presentation of FYP 1										
FYP 2 briefing										
Conducting experiment										
Data analysis										
Seminar report refinement and submission										
Preparation for presentation FYP 2										

APPENDIX B

Laboratory Test Results

Water Test Data

Table B1: Calculation of clay soil resistivity values at varied moisture condition.

Water Percentage (%)	Clay(Length=11.2cm)					
	I_1(mA)	I_2(mA)	I_3(mA)	$I_{average}$(mA)	Resistance(Ω)	Resistivity(Ωm)
0.00	0.010	0.010	0.010	0.010	20000000.00	1402496.72
2.50	0.80	0.79	0.78	0.79	253164.56	17753.12
5.00	2.17	2.16	2.16	2.16	92592.59	6493.04
7.50	6.08	6.07	6.07	6.07	32948.93	2310.54
10.00	12.65	12.65	12.64	12.65	15810.28	1108.69
12.50	28.60	28.70	28.60	28.63	6985.68	489.87
15.00	46.90	46.80	46.70	46.80	4273.50	299.68
17.50	72.70	72.60	72.50	72.60	2754.82	193.18
20.00	112.20	112.10	112.20	112.17	1783.01	125.03
22.50	173.10	173.20	173.00	173.10	1155.40	81.02
25.00	220.00	220.00	220.00	220.00	909.09	63.75
27.50	420.00	420.00	420.00	420.00	476.19	33.39
30.00	450.00	450.00	440.00	446.67	447.76	31.40

Table B2: Calculation of loam soil resistivity values at varied moisture condition.

Water Percentage (%)	Loam (Length=8.5cm)					
	I_1(mA)	I_2(mA)	I_3(mA)	$I_{average}$(mA)	Resistance(Ω)	Resistivity(Ωm)
0.00	0.015	0.015	0.015	0.015	13333333.33	1231997.12
2.50	1.45	1.43	1.43	1.44	138888.89	12833.30
5.00	2.98	2.97	2.97	2.98	67114.09	6201.33
7.50	7.68	7.66	7.67	7.67	26075.62	2409.38
10.00	16.20	16.20	16.30	16.23	12322.86	1138.63
12.50	34.30	34.20	34.20	34.23	5842.83	539.88
15.00	58.20	58.10	58.20	58.17	3438.20	317.69
17.50	99.70	99.80	99.60	99.70	2006.02	185.36
20.00	169.80	169.80	169.70	169.77	1178.06	108.85
22.50	240.00	240.00	240.00	240.00	833.33	77.00
25.00	290.00	290.00	290.00	290.00	689.66	63.72
27.50	300.00	290.00	290.00	293.33	681.83	63.00
30.00	310.00	300.00	300.00	303.33	659.35	60.92

Table B3: Calculation of sandy soil resistivity values at varied moisture condition.

Water Percentage (%)	Sandy soil (Length= 6.8cm)					
	I_1(mA)	I_2(mA)	I_3(mA)	$I_{average}$(mA)	Resistance(Ω)	Resistivity(Ωm)
0.00	0.003	0.003	0.003	0.003	66666666.67	7699981.99
2.50	6.54	6.52	6.51	6.52	30674.85	3542.94
5.00	23.80	23.70	23.60	23.70	8438.82	974.68
7.50	55.50	55.40	55.30	55.40	3610.11	416.97
10.00	86.20	86.20	86.10	86.17	2320.99	287.67
12.50	114.30	114.40	114.40	114.37	1748.71	201.98
15.00	138.20	138.30	138.30	138.27	1446.46	167.07
17.50	140.40	140.50	140.40	140.43	1424.20	164.50
20.00	140.70	140.70	140.50	140.63	1422.17	164.26
22.50	141.20	141.20	141.10	141.17	1416.73	163.63
25.00	139.70	139.6	139.50	139.60	1432.66	165.47
27.50	138.90	138.90	138.80	138.87	1440.20	166.34
30.00	139.70	139.60	139.70	139.67	1431.95	165.39

Table B4: Calculation of laterite soil resistivity values at varied moisture condition.

Water Percentage (%)	Laterite (Length= 7.6cm)					
	I_1(mA)	I_2(mA)	I_3(mA)	$I_{average}$(mA)	Resistance(Ω)	Resistivity(Ωm)
0.00	0.014	0.014	0.014	0.014	14285714.29	1476312.34
2.50	1.37	1.36	1.37	1.37	145985.40	15086.40
5.00	2.77	2.76	2.75	2.76	72463.77	7488.54
7.50	8.21	8.20	8.20	8.20	24390.24	2520.53
10.00	15.25	15.24	15.23	15.24	13123.36	1356.19
12.50	32.70	32.80	32.70	32.73	6110.60	631.48
15.00	60.20	60.10	60.10	60.13	3326.13	343.73
17.50	110.20	110.10	110.20	110.17	1815.38	187.60
20.00	170.20	170.10	170.20	170.17	1631.32	168.58
22.50	260.00	260.00	260.00	260.00	769.23	79.49
25.00	250.00	250.00	250.00	250.00	800.00	82.67
27.50	270.00	260.00	260.00	263.33	759.50	78.49
30.00	280.00	270.00	280.00	276.67	722.88	74.70

Table B5: Calculation of top soil resistivity values at varied moisture condition.

Water Percentage (%)	Top soil (Length=9.2cm)					
	I_1(mA)	I_2(mA)	I_3(mA)	$I_{average}$(mA)	Resistance(Ω)	Resistivity(Ωm)
0.00	0.012	0.012	0.012	0.012	16666666.67	1422822.76
2.50	0.75	0.74	0.74	0.74	270270.27	23072.80
5.00	8.43	8.45	8.44	8.44	23696.68	2022.97
7.50	20.70	20.70	20.60	20.67	9675.86	826.02
10.00	38.90	38.90	38.80	38.87	5145.36	439.26
12.50	62.50	62.60	62.60	62.57	3196.42	272.88
15.00	92.00	92.00	91.90	91.97	2174.62	185.65
17.50	125.90	125.80	125.60	125.77	1590.20	135.75
20.00	180.20	180.10	180.20	180.17	1110.06	94.77
22.50	240.00	240.00	240.00	240.00	833.33	71.14
25.00	350.00	350.00	350.00	350.00	571.43	48.78
27.50	360.00	350.00	350.00	353.33	566.04	48.32
30.00	350.00	340.00	340.00	343.33	582.53	49.73

Sodium Chloride (NaCl) Solution Test Data

Table B6: Calculation of clay soil resistivity values at varied NaCl solution condition.

Sodium Chloride Percentage (%)	Clay (Length= 11.3cm)					
	I_1(mA)	I_2(mA)	I_3(mA)	$I_{average}$(mA)	Resistance(Ω)	Resistivity(Ωm)
0.00	0.007	0.007	0.007	0.007	28571428.57	1985836.06
2.50	1.97	1.99	1.97	1.98	101010.10	7020.63
5.00	5.93	5.91	5.91	5.92	33783.78	2348.12
7.50	27.20	27.30	27.10	27.20	7352.94	511.06
10.00	42.50	42.40	42.50	42.47	4709.21	327.31
12.50	67.00	66.90	66.70	66.87	2990.88	207.88
15.00	100.80	100.60	100.50	100.63	1987.48	138.14
17.50	159.20	158.90	159.10	159.07	1257.31	87.39
20.00	260.00	260.00	260.00	260.00	769.23	53.46
22.50	590.00	600.00	600.00	596.67	335.19	23.30
25.00	990.00	1000.00	1000.00	996.67	200.67	13.95
27.50	1200.00	1200.00	1200.00	1200.00	166.67	11.58
30.00	1300.00	1300.00	1200.33	1266.67	157.89	10.97

Table B7: Calculation of loam soil resistivity values at varied NaCl solution condition.

Sodium Chloride Percentage (%)	Loam(Length=8.5 cm)					
	I_1(mA)	I_2(mA)	I_3(mA)	$I_{average}$(mA)	Resistance(Ω)	Resistivity(Ωm)
0.00	0.014	0.014	0.014	0.014	14285714.29	1319996.91
2.50	12.60	12.62	12.64	12.62	15847.86	1464.34
5.00	36.10	36.00	35.90	36.00	5555.56	513.33
7.50	53.70	53.80	53.60	53.70	3724.39	344.13
10.00	69.50	69.20	69.00	69.23	2888.92	266.94
12.50	84.50	84.60	84.70	84.60	2364.07	218.44
15.00	109.20	108.90	108.80	108.97	1835.37	169.59
17.50	179.80	179.70	179.80	179.77	1112.53	102.80
20.00	370.00	360.00	370.00	366.67	545.45	50.40
22.50	790.00	790.00	790.00	790.00	253.16	23.39
25.00	840.00	840.00	830.00	836.67	239.04	22.09
27.50	830.00	820.00	820.00	823.33	242.92	22.45
30.00	830.00	830.00	830.00	830.00	240.96	22.26

Table B8: Calculation of sandy soil resistivity values at varied NaCl solution condition.

Sodium Chloride Percentage (%)	Sandy soil (Length= 6.9cm)					
	I_1(mA)	I_2(mA)	I_3(mA)	$I_{average}$(mA)	Resistance(Ω)	Resistivity(Ωm)
0.00	0.002	0.002	0.002	0.002	100000000.00	11382582.08
2.50	28.70	28.80	28.50	28.67	6975.93	794.04
5.00	53.20	52.80	52.70	52.90	3780.72	430.34
7.50	120.70	120.80	120.70	120.73	1656.59	188.56
10.00	190.20	190.20	190.10	190.17	1051.69	119.71
12.50	290.00	290.00	300.00	293.33	681.83	77.61
15.00	340.00	340.00	360.00	346.67	576.92	65.67
17.50	330.00	320.00	330.00	326.67	612.24	69.69
20.00	330.00	320.00	320.00	323.33	618.56	70.41
22.50	340.00	330.00	320.00	330.00	606.06	68.99
25.00	330.00	330.00	320.00	326.67	612.24	65.67
27.50	320.00	320.00	310.00	316.67	631.57	71.89
30.00	340.00	330.00	320.00	330.00	606.06	68.99

Table B9: Calculation of laterite soil resistivity values at varied NaCl solution condition.

Sodium Chloride Percentage (%)	Laterite (Length= 7.5cm)					
	I_1(mA)	I_2(mA)	I_3(mA)	$I_{average}$(mA)	Resistance(Ω)	Resistivity(Ωm)
0.00	0.015	0.015	0.015	0.015	13333333.33	1396263.40
2.50	10.82	10.84	10.83	10.83	18467.22	1933.88
5.00	29.90	29.70	30.00	29.87	6695.68	701.17
7.50	50.60	50.50	50.40	50.50	3960.40	414.73
10.00	70.40	70.30	70.40	70.37	2842.12	297.63
12.50	88.70	88.90	88.60	88.73	2254.03	236.04
15.00	107.50	107.30	107.20	107.33	1863.41	195.14
17.50	168.90	168.70	168.60	168.73	1185.33	124.13
20.00	290.00	300.00	300.0	296.67	674.15	70.28
22.50	660.00	660.00	660.00	660.00	303.03	31.73
25.00	720.00	720.00	720.00	720.00	277.78	29.09
27.50	730.00	730.00	720.00	726.67	275.23	28.82
30.00	740.00	730.00	730.00	733.33	272.73	28.56

Table B10: Calculation of top soil resistivity values at varied NaCl solution condition.

Sodium Chloride Percentage (%)	Top soil(Length=9.1cm)					
	I_1(mA)	I_2(mA)	I_3(mA)	$I_{average}$(mA)	Resistance(Ω)	Resistivity(Ωm)
0.00	0.014	0.014	0.014	0.014	14285714.29	1232964.15
2.50	19.81	19.82	19.83	19.82	10090.82	870.91
5.00	37.60	37.80	37.70	37.70	5305.04	457.86
7.50	69.70	69.80	69.70	69.73	2868.21	247.55
10.00	89.90	89.80	89.50	89.73	2228.91	192.37
12.50	100.50	100.30	100.20	100.33	1993.42	172.05
15.00	138.70	138.60	138.60	138.63	1442.69	124.51
17.50	190.80	190.70	190.60	190.70	1048.77	90.51
20.00	390.00	380.00	390.00	386.67	517.24	44.64
22.50	710.00	710.00	710.00	710.00	281.69	24.31
25.00	920.00	910.00	910.00	913.33	218.98	18.90
27.50	920.00	920.00	920.00	920.00	217.39	18.76
30.00	920.00	920.00	920.00	920.00	217.39	18.76

Charcoal Powder Test Data

Table B11: Calculation of clay soil resistivity values at varied charcoal condition.

Charcoal Percentage (%)	Clay						
	I_1 (mA)	I_2 (mA)	I_3 (mA)	$I_{average}$ (mA)	Resistance (Ω)	Length (cm)	Resistivity (Ωm)
0.00	0.008	0.008	0.008	0.008	25000000.00	11.20	1753120.90
2.50	0.008	0.008	0.008	0.008	25000000.00	11.50	1707387.31
5.00	0.007	0.007	0.007	0.007	28571428.57	11.90	1885709.88
7.50	0.005	0.005	0.005	0.005	40000000.00	12.40	2533542.46
10.00	0.003	0.003	0.003	0.003	66666666.67	12.80	4090615.43
12.50	0.002	0.002	0.002	0.002	100000000.00	13.10	5995405.83
15.00	0.001	0.001	0.001	0.001	200000000.00	13.40	11635528.35
17.50	0.000	0.000	0.000	0.000	0.00	13.90	-
20.00	0.000	0.000	0.000	0.000	0.00	14.40	-
22.50	0.000	0.000	0.000	0.000	0.00	14.80	-
25.00	0.000	0.000	0.000	0.000	0.00	15.10	-
27.50	0.000	0.000	0.000	0.000	0.00	15.40	-
30.00	0.000	0.000	0.000	0.000	0.00	15.80	-

Table B12: Calculation of loam soil resistivity values at varied charcoal condition.

Charcoal Percentage (%)	Loam						
	I_1 (mA)	I_2 (mA)	I_3 (mA)	$I_{average}$ (mA)	Resistance (Ω)	Length (cm)	Resistivity (Ωm)
0.00	0.015	0.015	0.014	0.014	14285714.29	8.50	1319996.91
2.50	0.014	0.014	0.014	0.014	14285714.29	8.80	1274997.02
5.00	0.012	0.012	0.012	0.012	16666666.67	9.20	1422822.76
7.50	0.011	0.011	0.011	0.011	18181818.18	9.60	1487496.52
10.00	0.010	0.009	0.009	0.009	22222222.22	10.10	1728048.76
12.50	0.006	0.006	0.006	0.006	33333333.33	10.50	2493327.50
15.00	0.005	0.005	0.005	0.005	40000000.00	10.80	2908882.09
17.50	0.002	0.002	0.002	0.002	100000000.00	11.40	6889457.57
20.00	0.001	0.001	0.001	0.001	200000000.00	11.60	13541347.64
22.50	0.000	0.000	0.000	0.000	0.00	11.90	-
25.00	0.000	0.000	0.000	0.000	0.00	12.30	-
27.50	0.000	0.000	0.000	0.000	0.00	12.60	-
30.00	0.000	0.000	0.000	0.000	0.00	12.90	-

Table B13: Calculation of sandy soil resistivity values at varied charcoal condition.

Charcoal Percentage (%)	Sandy soil						
	I_1 (mA)	I_2 (mA)	I_3 (mA)	$I_{average}$ (mA)	Resistance (Ω)	Length (cm)	Resistivity (Ωm)
0.00	0.003	0.003	0.003	0.003	66666666.67	6.80	7699981.99
2.50	0.003	0.003	0.003	0.003	66666666.67	7.00	7479982.51
5.00	0.001	0.001	0.001	0.001	200000000.00	7.40	21226977.39
7.50	0.000	0.000	0.000	0.000	0.00	7.80	-
10.00	0.000	0.000	0.000	0.000	0.00	8.10	-
12.50	0.000	0.000	0.000	0.000	0.00	8.60	-
15.00	0.000	0.000	0.000	0.000	0.00	9.00	-
17.50	0.000	0.000	0.000	0.000	0.00	9.40	-
20.00	0.000	0.000	0.000	0.000	0.00	9.90	-
22.50	0.000	0.000	0.000	0.000	0.00	10.20	-
25.00	0.000	0.000	0.000	0.000	0.00	10.60	-
27.50	0.000	0.000	0.000	0.000	0.00	10.90	-
30.00	0.000	0.000	0.000	0.000	0.00	11.30	-

Table B14: Calculation of laterite soil resistivity values at varied charcoal condition.

Charcoal Percentage (%)	Laterite						
	I_1 (mA)	I_2 (mA)	I_3 (mA)	$I_{average}$ (mA)	Resistance (Ω)	Length (cm)	Resistivity (Ωm)
0.00	0.014	0.014	0.014	0.014	14285714.29	7.60	1476312.34
2.50	0.013	0.013	0.013	0.013	15384615.38	7.90	1529499.83
5.00	0.012	0.011	0.011	0.011	18181818.18	8.30	1720477.90
7.50	0.009	0.009	0.009	0.009	22222222.22	8.70	2006125.58
10.00	0.005	0.006	0.005	0.005	40000000.00	9.20	3414774.62
12.50	0.004	0.004	0.003	0.004	50000000.00	9.50	4133674.54
15.00	0.002	0.002	0.002	0.002	100000000.00	9.90	7933314.78
17.50	0.000	0.000	0.000	0.000	0.00	10.40	-
20.00	0.000	0.000	0.000	0.000	0.00	10.80	-
22.50	0.000	0.000	0.000	0.000	0.00	11.00	-
25.00	0.000	0.000	0.000	0.000	0.00	11.30	-
27.50	0.000	0.000	0.000	0.000	0.00	11.60	-
30.00	0.000	0.000	0.000	0.000	0.00	12.00	-

Table B15: Calculation of top soil resistivity values at varied charcoal condition.

Charcoal Percentage (%)	Top soil						
	I_1 (mA)	I_2 (mA)	I_3 (mA)	$I_{average}$ (mA)	Resistance (Ω)	Length (cm)	Resistivity (Ωm)
0.00	0.012	0.011	0.011	0.011	18181818.18	9.20	1552170.28
2.50	0.011	0.011	0.011	0.011	18181818.18	9.50	1503154.38
5.00	0.009	0.009	0.009	0.009	22222222.22	9.90	1762958.84
7.50	0.008	0.007	0.007	0.007	28571428.57	10.20	2199994.86
10.00	0.004	0.004	0.004	0.004	50000000.00	10.70	3670084.88
12.50	0.003	0.003	0.003	0.003	66666666.67	11.00	4759988.87
15.00	0.001	0.001	0.001	0.001	200000000.00	11.30	13900852.45
17.50	0.000	0.000	0.000	0.000	0.00	11.70	-
20.00	0.000	0.000	0.000	0.000	0.00	12.00	-
22.50	0.000	0.000	0.000	0.000	0.00	12.40	-
25.00	0.000	0.000	0.000	0.000	0.00	12.90	-
27.50	0.000	0.000	0.000	0.000	0.00	13.30	-
30.00	0.000	0.000	0.000	0.000	0.00	13.70	-

Salted Charcoal Powder Test Data

Table B16: Calculation of clay soil resistivity values at varied salted charcoal condition.

Salted Charcoal Percentage (%)	Clay						
	I_1 (mA)	I_2 (mA)	I_3 (mA)	$I_{average}$ (mA)	Resistance (Ω)	Length (cm)	Resistivity (Ωm)
0.00	0.009	0.009	0.009	0.009	22222222.22	11.30	1544539.16
2.50	0.085	0.083	0.083	0.084	2380952.38	11.60	161206.52
5.00	0.19	0.19	0.18	0.19	1052631.58	12.10	68325.20
7.50	0.97	0.98	0.97	0.97	206185.57	12.50	12955.02
10.00	2.15	2.12	2.13	2.13	93896.71	12.90	5716.77
12.50	3.40	3.41	3.40	3.40	58823.53	13.20	3499.99
15.00	4.98	4.97	4.97	4.97	40241.45	13.60	2323.94
17.50	6.17	6.15	6.14	6.15	32520.33	14.00	1824.39
20.00	7.08	7.07	7.07	7.07	28288.54	14.40	1542.90
22.50	8.27	8.30	8.28	8.28	24154.59	14.90	1273.22
25.00	9.73	9.75	9.72	9.73	20554.98	15.20	1062.09
27.50	10.83	10.82	10.84	10.83	18467.22	15.70	923.83
30.00	11.45	11.47	11.46	11.46	17452.01	16.10	851.35

Table B17: Calculation of loam soil resistivity values at varied salted charcoal condition.

Salted Charcoal Percentage (%)	Loam						
	I_1 (mA)	I_2 (mA)	I_3 (mA)	$I_{average}$ (mA)	Resistance (Ω)	Length (cm)	Resistivity (Ωm)
0.00	0.013	0.013	0.013	0.013	15384615.38	8.50	1421535.14
2.50	0.38	0.36	0.35	0.36	555555.56	8.70	50153.14
5.00	1.15	1.16	1.14	1.15	173913.04	9.00	15176.78
7.50	1.57	1.56	1.55	1.56	128205.13	9.40	10711.92
10.00	2.74	2.75	2.72	2.74	72992.70	9.80	5849.83
12.50	3.40	3.37	3.35	3.37	59347.18	10.30	4525.36
15.00	5.73	5.73	5.72	5.73	34904.01	10.70	2562.01
17.50	7.23	7.22	7.22	7.22	27700.83	11.10	1960.02
20.00	8.45	8.43	8.44	8.44	23696.68	11.60	1604.43
22.50	10.30	10.28	10.32	10.30	19417.48	12.00	1270.87
25.00	11.96	11.94	11.93	11.94	16750.42	12.50	1052.46
27.50	12.60	12.60	12.50	12.57	15910.90	13.00	961.26
30.00	14.63	14.60	14.59	14.61	13689.25	13.50	796.41

Table B18: Calculation of sandy soil resistivity values at varied salted charcoal condition.

Salted Charcoal Percentage (%)	Sandy soil						
	I_1 (mA)	I_2 (mA)	I_3 (mA)	$I_{average}$ (mA)	Resistance (Ω)	Length (cm)	Resistivity (Ωm)
0.00	0.003	0.003	0.003	0.003	66666666.67	6.80	7699981.99
2.50	0.94	0.93	0.93	0.93	215053.76	7.00	24128.98
5.00	5.22	5.23	5.21	5.22	38314.18	7.40	4066.47
7.50	8.24	8.23	8.27	8.25	24242.42	7.90	2410.12
10.00	14.58	14.60	14.58	14.59	13708.02	8.30	1297.14
12.50	25.70	26.00	25.90	25.87	7730.96	8.80	689.99
15.00	42.40	42.30	42.20	42.30	4728.13	9.10	408.07
17.50	55.90	55.80	55.60	55.77	3586.16	9.50	296.48
20.00	63.50	63.50	63.50	63.50	3149.61	9.90	249.87
22.50	76.80	76.90	76.70	76.80	2604.17	10.30	198.57
25.00	85.50	85.50	85.50	85.50	2339.18	10.70	171.70
27.50	94.50	94.30	94.20	94.33	2120.22	11.20	148.68
30.00	105.90	105.80	105.80	105.83	1889.82	11.80	125.78

Table B19: Calculation of laterite soil resistivity values at varied salted charcoal condition.

Salted Charcoal Percentage (%)	Laterite						
	I_1 (mA)	I_2 (mA)	I_3 (mA)	$I_{average}$ (mA)	Resistance (Ω)	Length (cm)	Resistivity (Ωm)
0.00	0.016	0.016	0.016	0.016	12500000.00	7.60	1291773.30
2.50	0.25	0.26	0.27	0.26	769230.77	7.90	76474.99
5.00	0.97	0.97	0.98	0.97	206185.57	8.40	19278.31
7.50	1.85	1.83	1.84	1.84	108695.65	8.80	9701.06
10.00	2.37	2.39	2.37	2.38	84033.61	9.20	7173.90
12.50	4.65	4.62	4.63	4.63	43196.54	9.70	3497.58
15.00	5.76	5.75	5.77	5.76	34722.22	10.10	2700.08
17.50	7.85	7.86	7.88	7.86	25445.29	10.50	1903.30
20.00	9.04	9.03	9.03	9.03	22148.39	10.90	1595.90
22.50	10.72	10.73	10.72	10.72	18656.72	11.40	1285.35
25.00	11.34	11.35	11.32	11.34	17636.68	11.80	1173.88
27.50	12.44	12.43	12.43	12.43	16090.10	12.20	1035.83
30.00	13.57	13.58	13.56	13.57	14738.39	12.50	926.04

Table B20: Calculation of top soil resistivity values at varied salted charcoal condition.

Salted Charcoal Percentage (%)	Top soil						
	I_1 (mA)	I_2 (mA)	I_3 (mA)	$I_{average}$ (mA)	Resistance (Ω)	Length (cm)	Resistivity (Ωm)
0.00	0.011	0.011	0.011	0.011	18181818.18	9.10	1569227.10
2.50	0.54	0.52	0.52	0.53	377358.49	9.30	31868.46
5.00	1.57	1.57	1.58	1.57	127388.54	9.70	10314.51
7.50	3.84	3.83	3.82	3.83	52219.32	10.10	4060.69
10.00	6.84	6.83	6.82	6.83	29282.58	10.50	2190.33
12.50	9.70	9.72	9.73	9.72	20576.13	11.00	1469.13
15.00	14.33	14.32	14.32	14.32	13966.48	11.40	962.21
17.50	21.70	21.80	21.50	21.67	9229.35	11.90	609.14
20.00	29.80	29.70	29.60	29.70	6734.01	12.30	429.99
22.50	35.70	35.60	35.70	35.67	5606.95	12.80	344.04
25.00	43.50	43.60	43.60	43.57	4590.31	13.30	271.07
27.50	54.70	54.60	54.40	54.57	3665.02	13.60	211.65
30.00	70.30	70.30	70.20	70.27	2846.16	14.00	159.67

Variation of Soil Resistivity versus Moisture Content with Trend Line

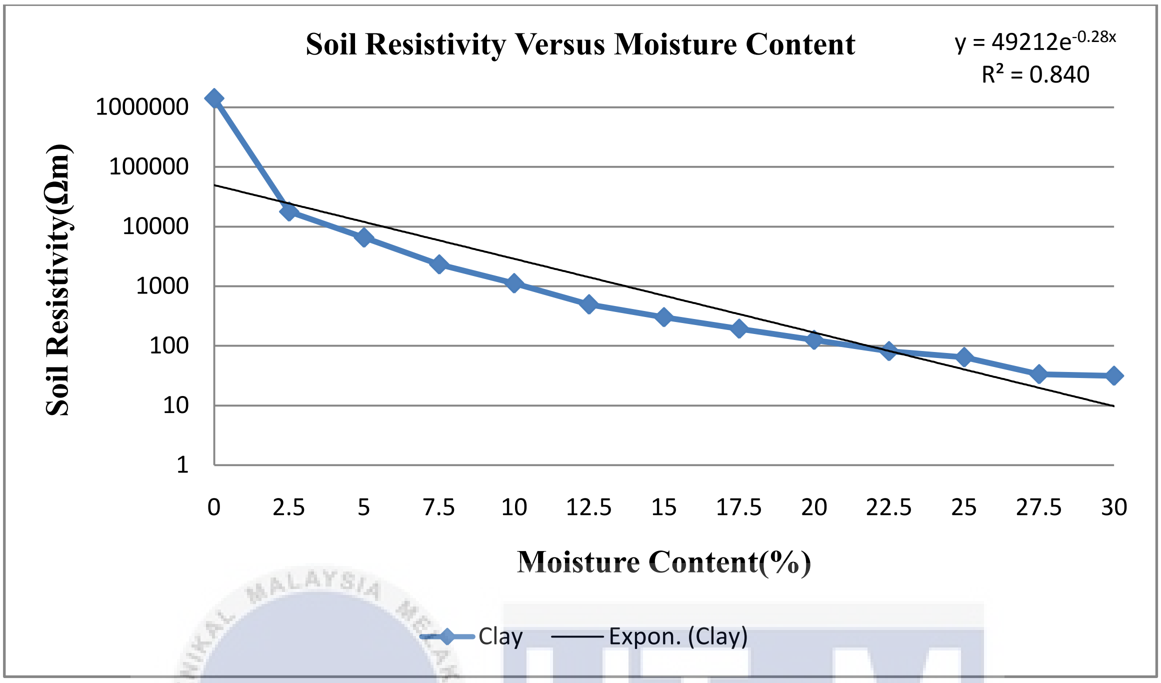

Figure B1: Variation of clay soil resistivity with water content.

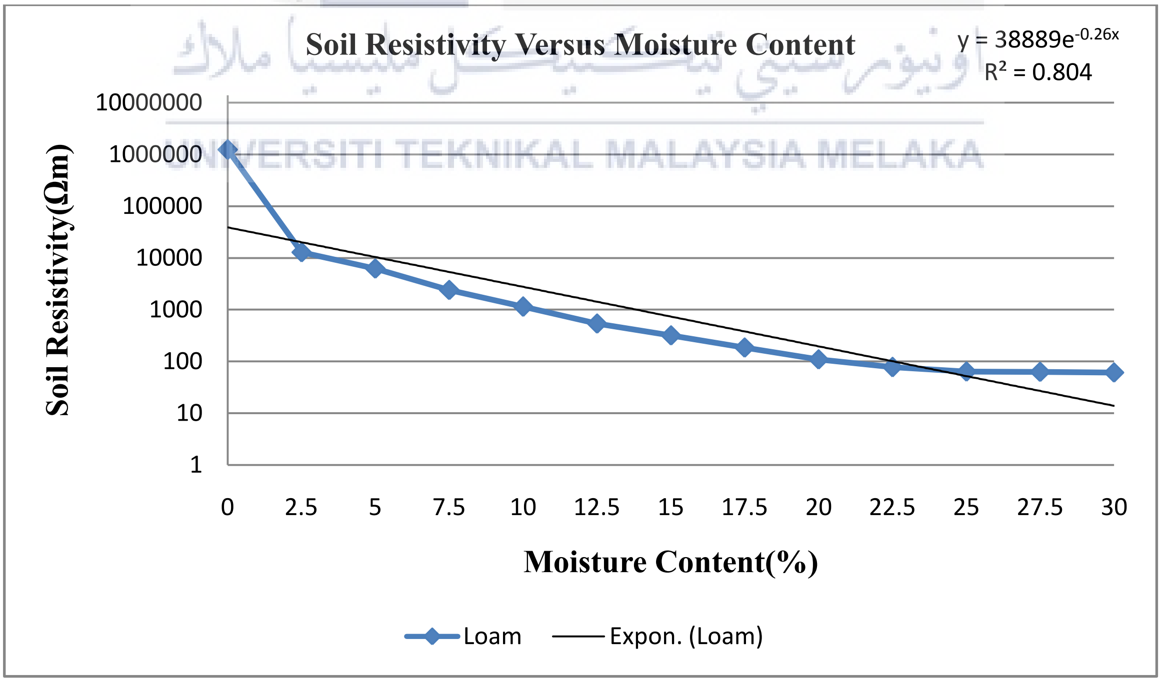

Figure B2: Variation of loam soil resistivity with water content.

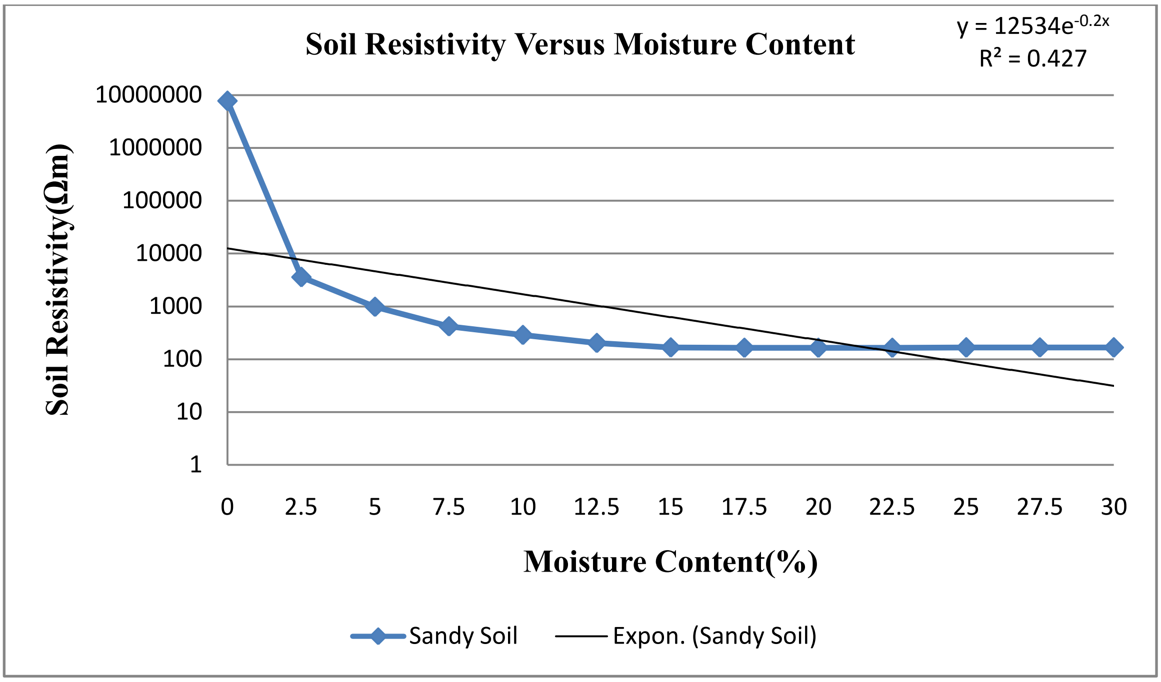

Figure B3: Variation of sandy soil resistivity with water content.

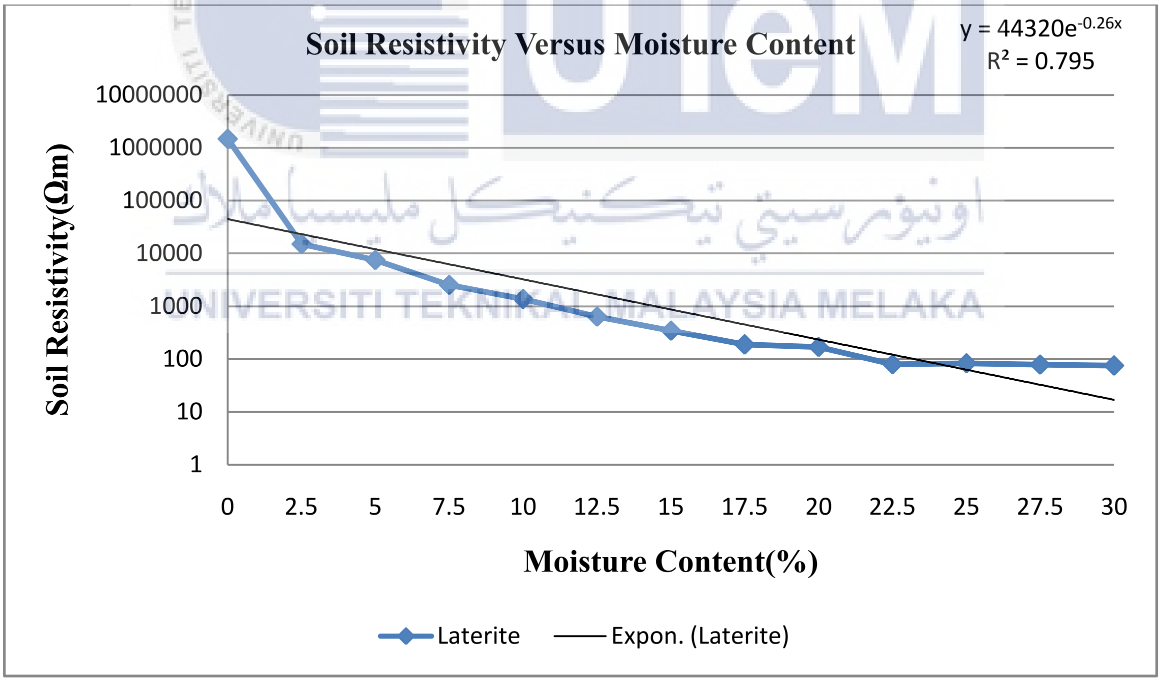

Figure B4: Variation of laterite soil resistivity with water content.

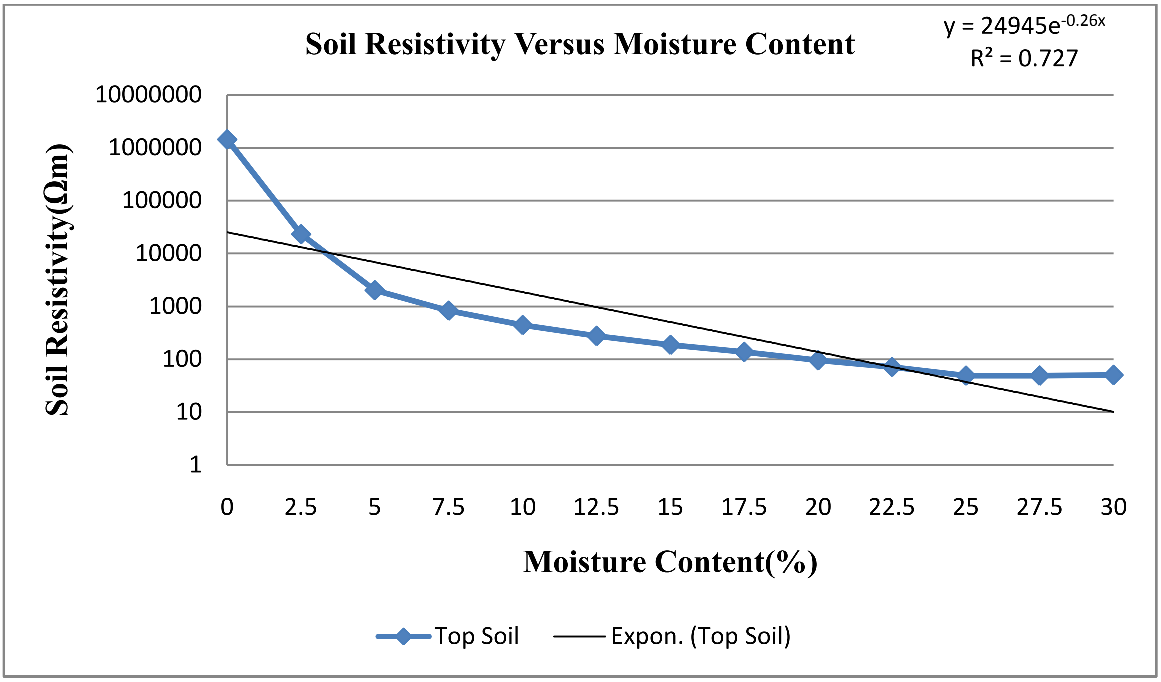

Figure B5: Variation of top soil resistivity with water content.

Variation of Soil Resistivity versus Sodium Chloride Content with Trend Line

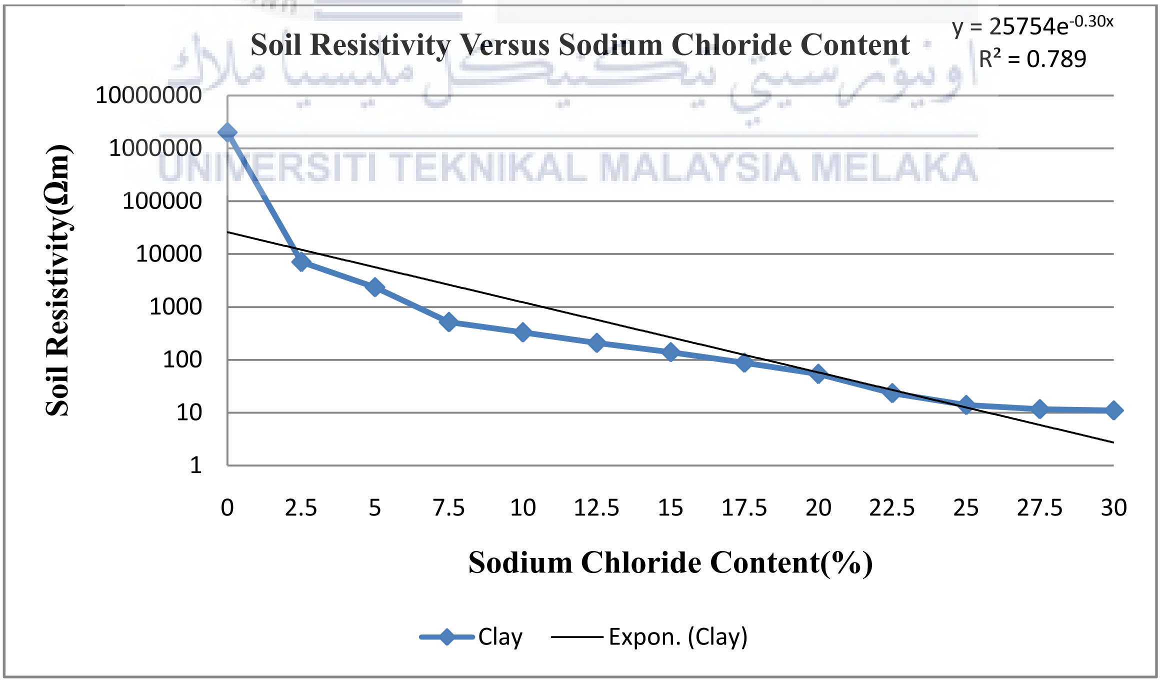

Figure B6: Variation of clay soil resistivity with sodium chloride content.

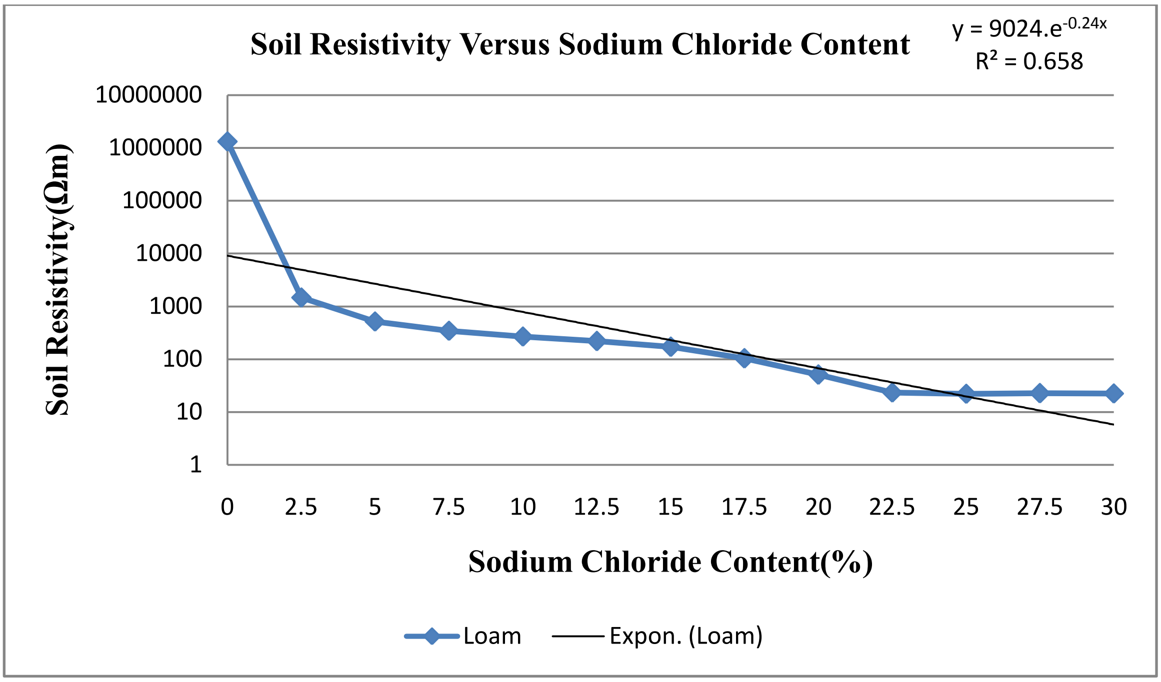

Figure B7: Variation of loam soil resistivity with sodium chloride content.

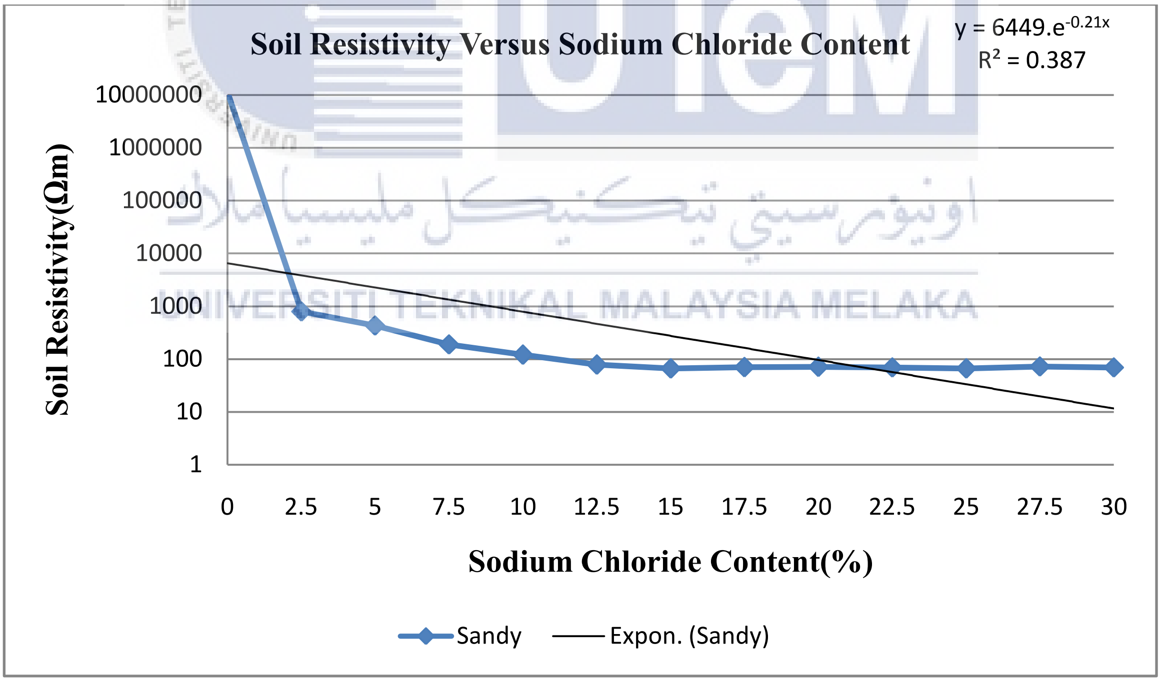

Figure B8: Variation of sandy soil resistivity with sodium chloride content.

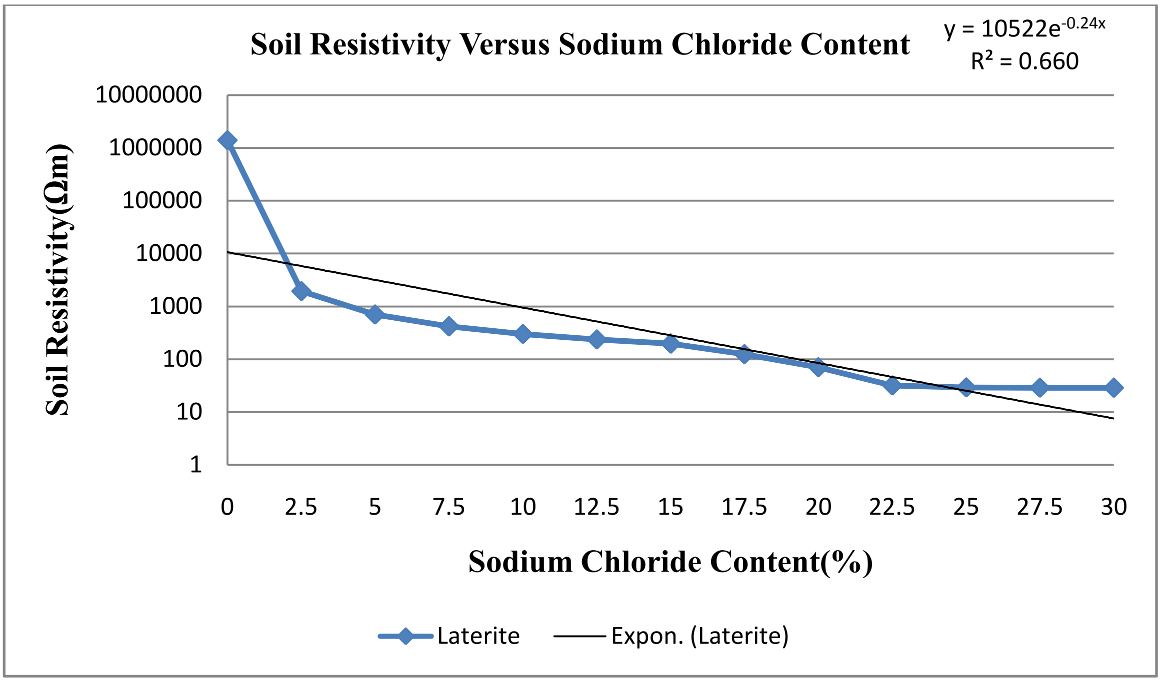

Figure B9: Variation of laterite soil resistivity with sodium chloride content.

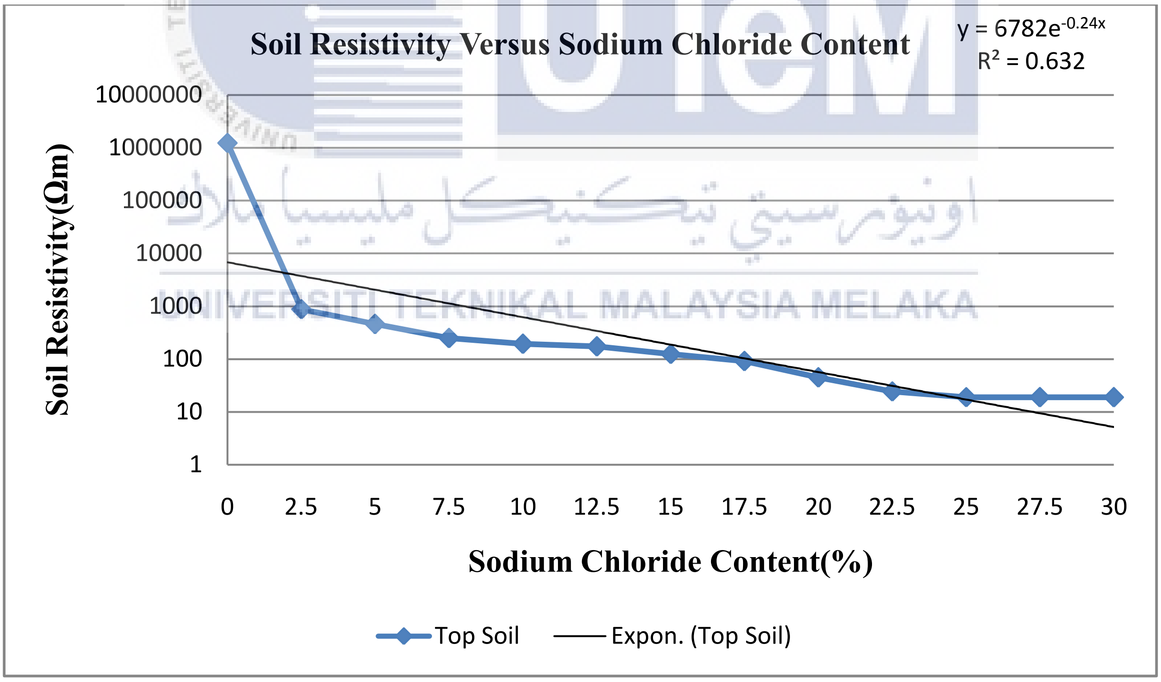

Figure B10: Variation of top soil resistivity with sodium chloride content.

Variation of Soil Resistivity versus Salted Charcoal Content with Trend Line

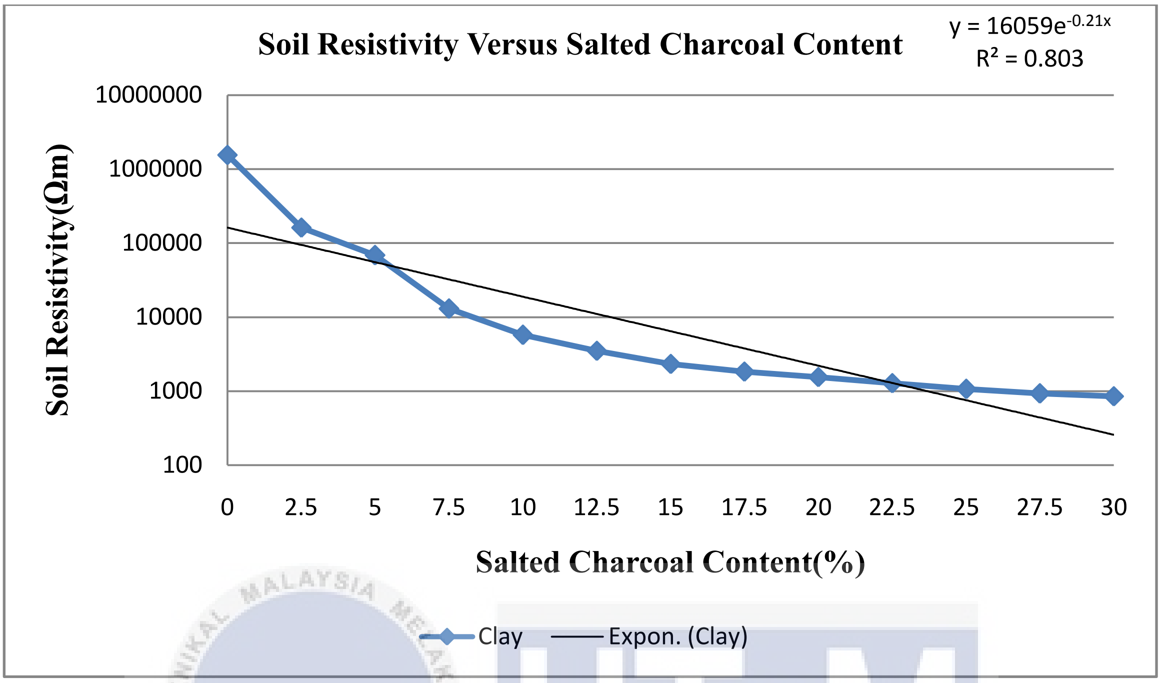

Figure B11: Variation of clay resistivity with salted charcoal content.

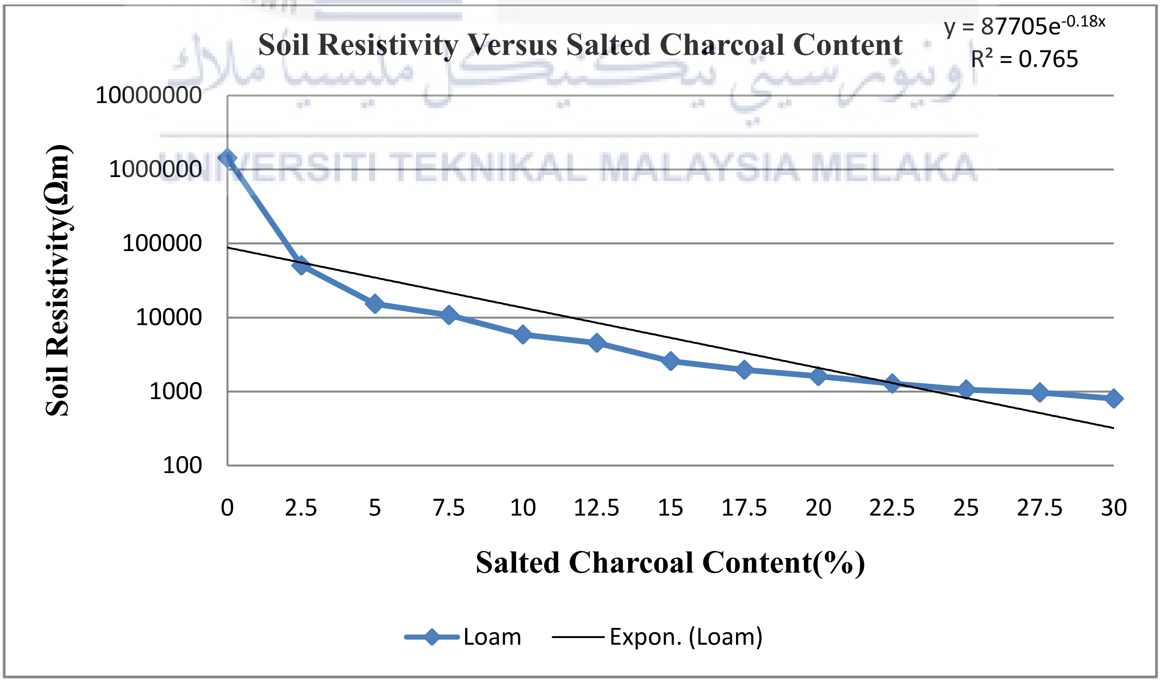

Figure B12: Variation of loam resistivity with salted charcoal content.

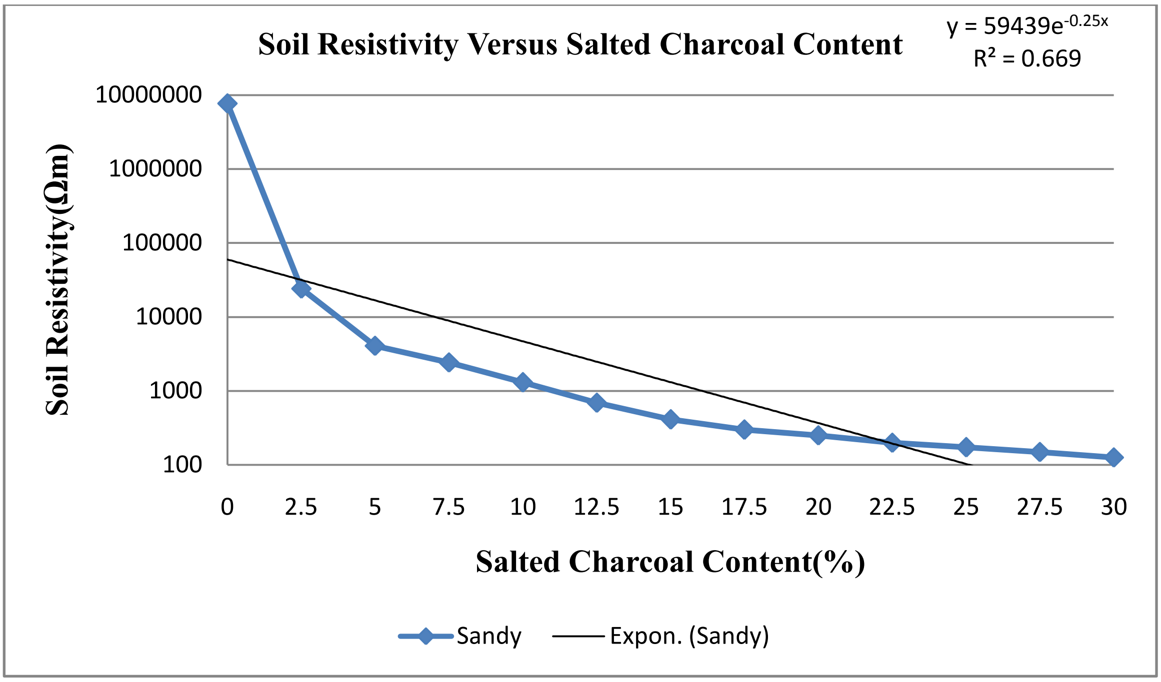

Figure B13: Variation of sandy resistivity with salted charcoal content.

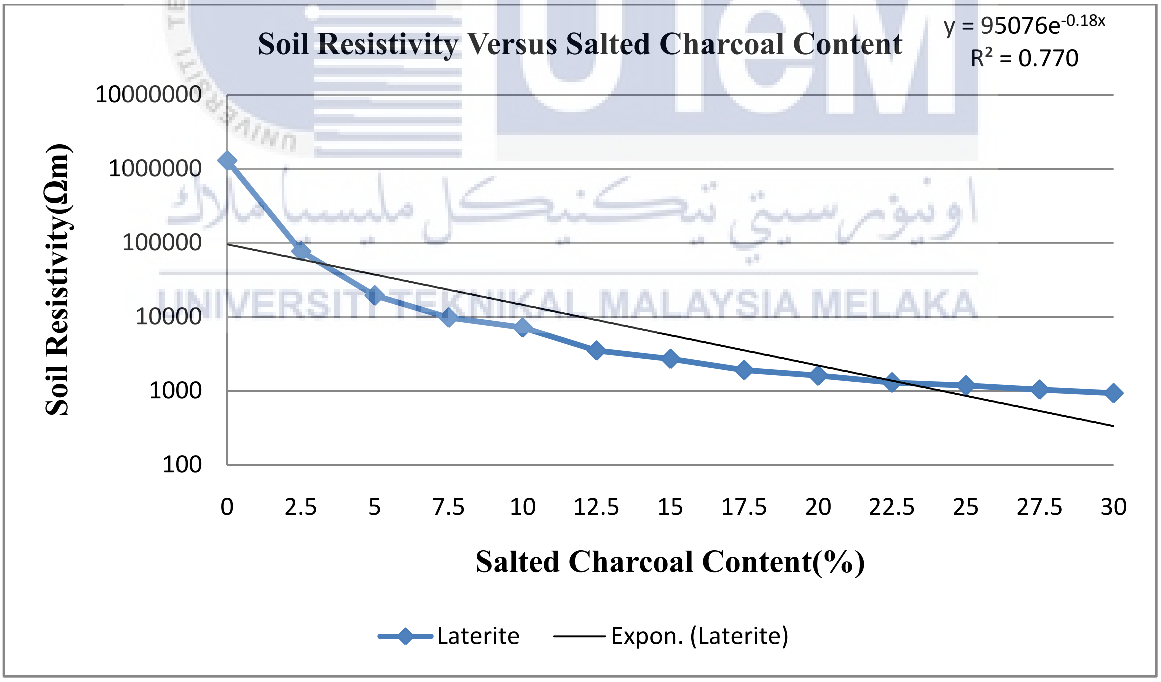

Figure B14: Variation of laterite resistivity with salted charcoal content.

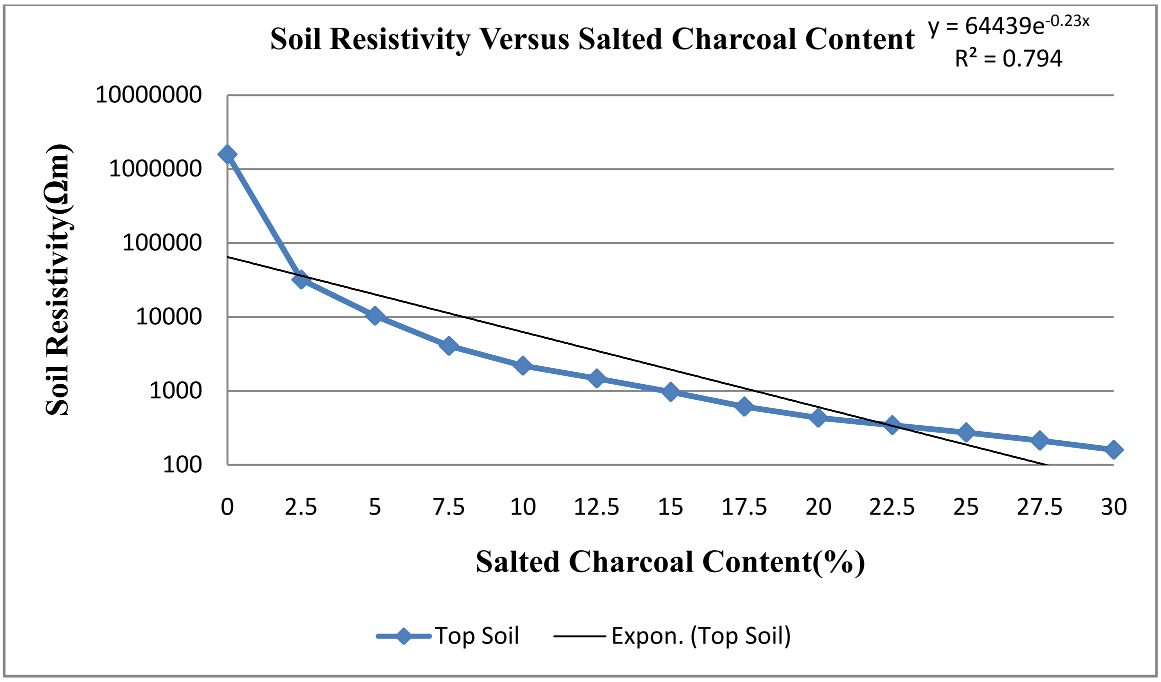

Figure B15: Variation of Topsoil resistivity with salted charcoal content.

Fitted Line Plot

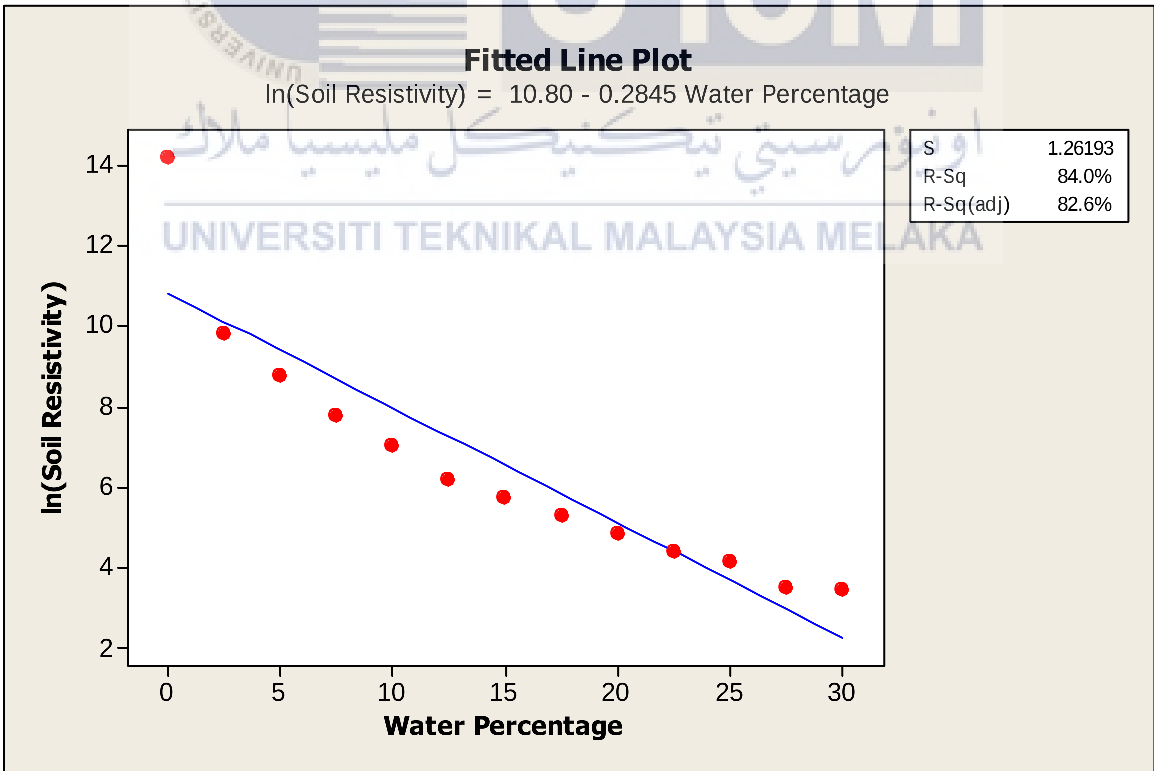

Figure B16: Fitted line plot of clay $\log_e$ (soil resistivity) versus water content.

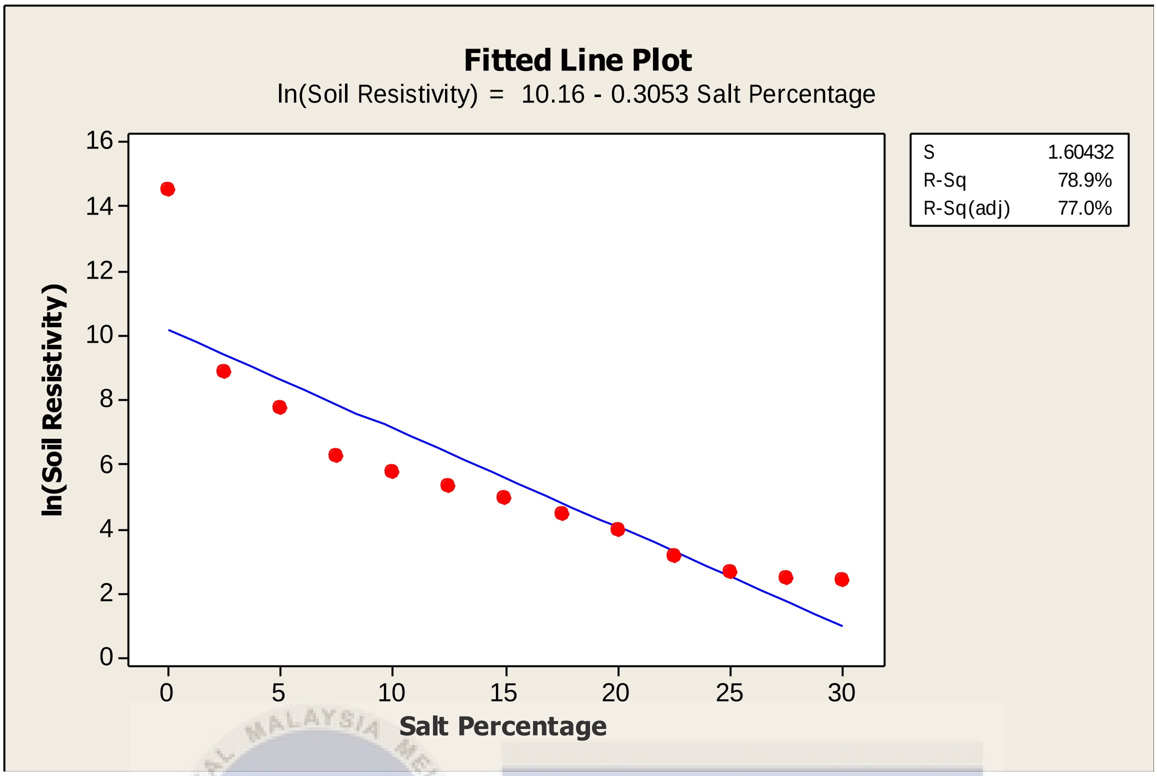

Figure B17: Fitted line plot of clay $\log_e$ (soil resistivity) versus salt content.

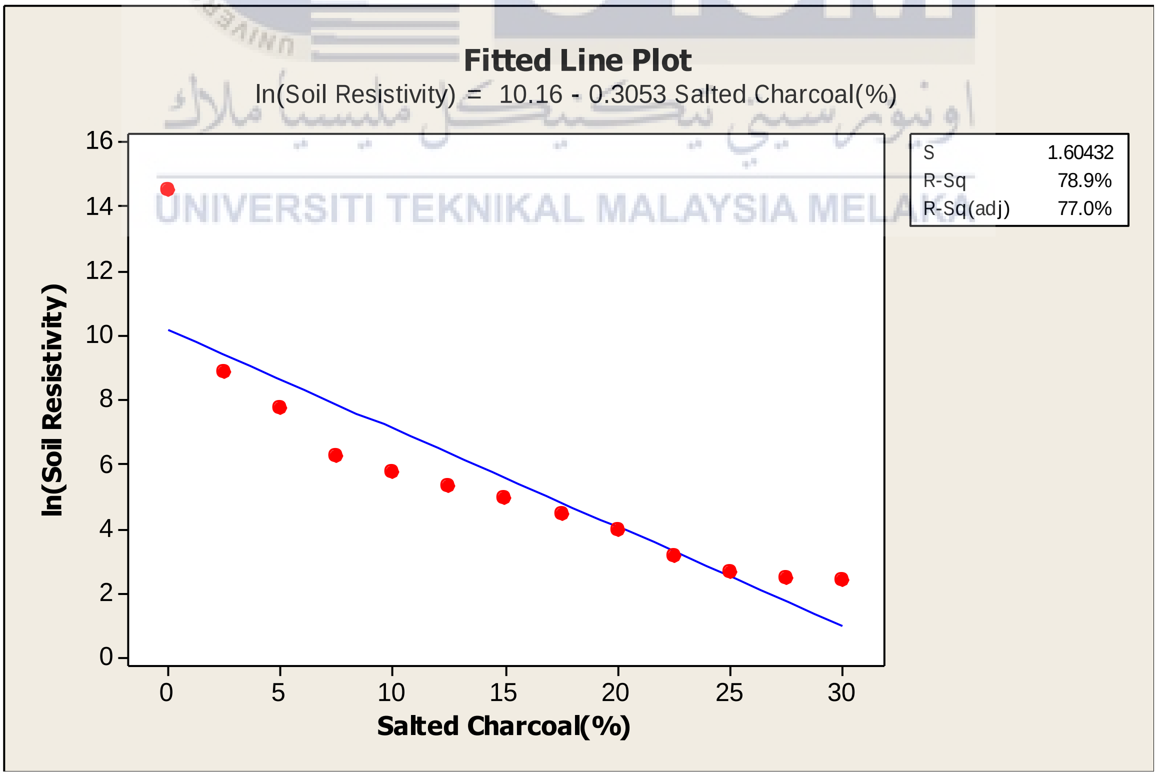

Figure B18: Fitted line plot of clay $\log_e$ (soil resistivity) versus salted charcoal content.

APPENDIX C

Preparation of Materials

Figure C1: Exposure of wet molded clay to sunlight.

Figure C2: Molded clay in dry condition.

Figure C3: Clay is crushed into very small size.

Figure C4: Crushing the charcoal.

Figure C5: Charcoal powder.