STUDY ON THE CORROSION OF CARBON STEEL PIPE UPON DIFFERENT TYPE OF SOILS

HENG CHENG LIANG

Thesis submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Chemical Engineering (Gas Technology)

Faculty of Chemical & Natural Resources Engineering
UNIVERSITI MALAYSIA PAHANG

JANUARY 2014

ABSTRACT

Pipelines are one of the economical ways to transport large quantities of fluids such as natural gas, oil and others. However pipelines for transportation need to consider factors such as strength of material, cost, corrosion caused by carrier fluid and soil properties on corrosion. It is essential to have knowledge about the soils which may cause corrosion to the pipelines. Analysis on the soils are done for investigate the physical properties such as structure or texture and permeability of soils and also the chemical properties for example soil pH and conductivity. Structure of soil is studied by using sedimentation separation method to distinguish weight percent of clay, sand and silt. Permeability of soil is determined by constant head and falling head permeability test. Soil chemical properties are determined by pH meter and conductivity meter. Corrosion rate can be determined by weight-loss method that determined the metal loss during corrosion. Moisture content of soils is determined by weighting initial and final weight after drying in oven. One-way ANOVA test of the corrosion data with factor which type of soil showed that the model developed is limited to certain type soil. Result analysis will be done by linear and non-linear correlation regressions such as Weibull and exponential growth and decay to study the relationships of corrosion rate with time. Result of comparison of three curve fitting method showed that clay and silty clay loams is moderately fitted with exponential fit, while sand and silt is largely deviated from all three curve fit method. Trend analysis result of soil type clay and silty clay loam only can be used to model the correlation dynamic for corrosion control with reasonable accuracy. Corrosion model developed from averaged observed data yield unsatisfied fit of model to observed data. However, by further eliminate extreme observed data for each month for each type of soils the adjusted exponential model for all type of soil yield high R^2 value.

Key words*:* carbon steel pipe, clay, sand, silt, corrosion process

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ABSTRAK

Talian paip adalah salah satu cara yang ekonomi untuk menyalurkan bendalir seperti gas asli, petroleum dan lain-lain. Walau bagaimanapun talian paip yang digunakan untuk penyaluran perlu mengambil kira faktor-faktor seperti ketahanan bahan , kos, kakisan yang disebabkan oleh cecair dan harta tanah pada kakisan. Oleh sebab itu, pengetahuan mengenai tanah yang boleh menyebabkan karat ke atas paip adalah penting. Analisis di tanah dilakukan untuk mengkaji sifat-sifat fizikal seperti struktur atau tekstur dan kebolehtelapan tanah dan juga sifat-sifat kimia seperti pH tanah dan nilai conductivity. Struktur tanah dikaji dengan menggunakan kaedah pemisahan pemendapan untuk membezakan berat badan peratus daripada tanah liat, pasir dan kelodak. Kebolehtelapan tanah ditentukan dengan constant head dan falling head permeameter. Sifat-sifat kimia tanah ditentukan dengan meter pH dan meter conductivity. Pengaratan boleh ditentukan melalui kaedah kehilangan berat yang ditentukan kehilangan logam semasa proses karat. Kandungan lembapan tanah ditentukan dengan pemberatan berat awal dan akhir selepas pengeringan dalam oven . Sehala ujian ANOVA menunjukkan bahawa model yang diperolehi adalah terhad kepada jenis tanah tertentu. Analisis keputusan bagi pengaratan akan dilakukan oleh linear dan bukan linear correlation regression seperti Weibull dan pertumbuhan dan pereputan eksponen untuk mengkaji hubungan pengaratan dengan masa. Hasil daripada perbandingan tiga lengkung kaedah pemasangan menunjukkan bahawa tanah liat dan tanah liat berkelodak loams adalah sederhana muat dengan eksponen, manakala pasir dan kelodak terdapat permuatan yang teruk dengan ketiga-tiga kaedah lengkung patut. Hasil analisis trend jenis tanah tanah liat dan tanah liat berkelodak lempung boleh digunakan untuk model korelasi dinamik untuk kawalan karat kepada saluran paip dengan ketepatan yang munasabah. Model pengaratan daripada data purata kurang memuaskan. Walau bagaimanapun, dengan menghapuskan data yang ekstrim untuk setiap bulan bagi setiap jenis tanah selanjutnya, model eksponen diselaraskan untuk semua jenis tanah dapat menghasil nilai R^2 yang tinggi.

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A	cross-sectional area of the sample of eq(3.1),(3.3)
h	constant head difference distance of eq(3.1)
L	length of the sample of eq(3.1)
a	cross-sectional area of the standpipe eq(3.2)
h_o	initial distance flow through the stand pipe eq(3.2)
h_1	final distance flow through the stand pipe eq(3.2)
K	constant, grams per square meter per hour (g/m2 ·h) eq(3.3)
T	time of exposure in hours eq(3.3)
W	mass loss in grams eq (3.3)
D	density in g/gm3 eq(3.3)
X	moisture content eq(3.4)
W	weight of wet soil eq(3.4)
Ws	weight of dry soil eq(3.4)
R^2	correlation coefficient

Subscripts

$_o$	initial
i	final

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
EDS	Energy Dispersive Spectrometer
ER	Electrical Resistance
PGU	Peninsular Gas Utilization
SEM	Scanning Electron Microscope
LPR	Linear Polarization Resistance
3-PYP	3,6-bis(3-Pyridyl)Pyridazine
SRB	Sulphate reducing bacteria
SSE	Sum of Squares for Error

1 INTRODUCTION

1.1 Motivation and statement of problem

Corrosion is a common problem in structure degradation that reduces strength of pipeline. Pipeline system commonly made from carbon steel and utilized to transport product such as natural gas and crude oil from point to another. This research is to find out which location contains the types of soil that is corrosive to pipe by sampling various soil samples from various locations. After conducting analysis on soil samples that reveal soil structure or texture, soil permeability. Soil properties are closely related to the corrosion of the pipe such as moisture content, pH, presence of sulphate reducing bacteria and more. Each types texture class of soils having different properties than the others. Therefore understanding the different type of soil in various locations can minimize the corrosion rate on any pipeline system.

Pipelines play important role in sustaining oil and gas industry in Malaysia. Malaysia has approximately 3 kilometers of condensate pipeline, 1,965 kilometers of gas pipeline, 31 kilometers of oil pipeline, and 114 kilometers of refined products pipelines which needed to be transport from places to places. One of the pipeline systems the Peninsular Gas Utilization (PGU) is the longest pipeline in Malaysia that owned by Petronas Gas Berhad has 1,700 kilometers of pipeline joining Kerteh refinery in Terengganu to other areas of peninsula Malaysia (The World Factbook “Malaysia”, 2010). Pipeline maintenance is crucial for avoid tragedy happen like in Mexican gas industry pipeline incident with 26 workers dying in a fire at a gas pipeline distribution center near to the United States and Kenyan slum razed when a pipeline nearby burst into flames, with 92 burnt bodies found. These tragedies have to be avoid at all cost by identify the causes of corrosion on pipelines and to have proper corrosion control.

United States of America is one the country that widely utilize pipeline for transport materials across the whole country. By observed their incident report chart, it shows that corrosion having 19.1% of all causes is one of the major causes that results disaster.

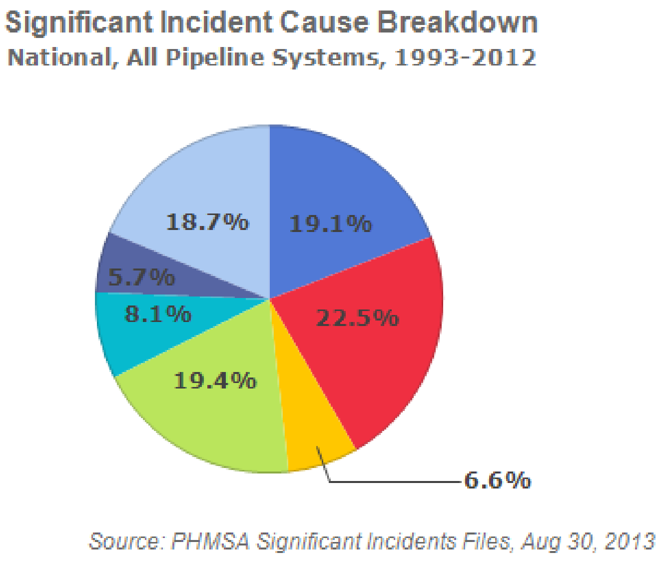

Figure 1-1: Significant Incident Report

Corrosion control is an important consideration in safety and economics. Accidents may happen from corrosion in such a manner as to result in injuries or even deaths. Because the choice of materials of the pipe, enforcement of manufacturing procedures, and quality control of products to diminish personal injury. By decisions, between the profits created by a certain level of corrosion control versus the costs is crucial to meet the balance. There are some cases such as severely corrosive environments that are required to be contained by high resistance metals such as gold and platinum, despite for its high costs, the inert properties that metal possessing is crucial for resist corrosion. The cost for installation is high but it is problem is solved by the ease of recovery of the metals cue to their high recycle value.

Corrosion monitoring is significant in pipeline system; it is about corrosion measurement, control, and prevention actions. There are choices for examples like cathodic and anodic protection, materials variety, chemical additives to carrier fluid and also the installation of internal and external coatings. Corrosion measurements require a range of methods to regulate the level of corrosive in the environment and identifying the rate metal loss. Corrosion control and prevention action are to be optimized from feedback corrosion measurement which is measureable value for prevention action to be carry out. There are many existing corrosion monitoring techniques. Most common methods which are used in industrial applications are Weight loss measurements, Electrical Resistance (ER), Linear Polarization Resistance (LPR), Galvanic (ZRA) /

Potential, Hydrogen Penetration, Microbial, Sand/Erosion and many other techniques. Nevertheless nearly all need some expert operation, otherwise are not satisfactorily adaptable to industry applications.

Corrosion monitoring will be more effective if a model is developed to predict the corrosion rate of pipe on different types of soils. Unplanned corrosion monitoring on site required manpower and extra cost which is undesirable in industry. Prediction from the model may act as a warning to conduct corrosion monitoring. The deterministic linear regression equation is to develop a prediction model. However many research shown that the provided information from the corrosive environment is full of uncertainties and often produced poor correlation result of corrosion rate against time (Nordin. Y *et al*., 2013). Nevertheless, the research is still able to demonstrate the optimization of the data for corrosion growth prediction.

1.2 Objectives

The aim of this research is to investigate the relationship of soil types towards corrosion rate as experienced by buried pipeline. Thus, the objectives of this research are as followed:

- o To determine the metal loss of carbon steel that installed underground in different types of soil.
- o To classify the type of soil against metal loss value.

1.3 Scope of this research

The following are the scope of this research:

i) 4 class sand, silt, clay, and silt clay loam of soil

ii) Parameters pH and soluble salts content are controlled

iii) Corrosion rate will be determined by weight-loss method

iv) All the experiment will be conducted in the laboratory

1.4 Main contribution of this work

The following are the contributions:

i) To develop a correlation prediction model to predict the corrosion rate for different type of soils.

ii) The model may assist the pipelines operators in making accurate decisions on what, when and where of future inspection, repair and maintenance resources to be deployed.

1.5 Organisation of this thesis

The structure of the reminder of the thesis is outlined as follow:

Chapter 2 provides a description of the overview of features corrosion, carbon steel pipe and soils. A general description on the corrosion process, as well as properties of carbon steel and soil characteristics are presented. This chapter also provides a brief discussion of the advanced corrosion control techniques available for time being, mentioning their applications and limitations for on-site corrosion control. A summary of the previous experimental work on effect of environmental factors on corrosion behaviour is also presented.

Chapter 3 gives a review of various analyses applied for soil texture analysis, permeability test, and weight loss method and moisture content analysis. The corrosion rate of function of three different factors namely time, moisture content and soil permeability were compared in experimental data. The results of experiments are for developing dynamic model for predicts corrosion on different type of soils.

Chapter 4 discuss the results from experimental work where the soil classification, characterization and prepared carbon steel coupons for weight loss corrosion rate test are done. Discussion and comparison of various analyses of corrosion data are also presented.

Chapter 5 draws together a summary of the thesis and outlines the future work which might be derived from the model developed in this work.

2 LITERATURE REVIEW

2.1 Overview

This paper presents the experimental studies corrosion rate of carbon steel pipe upon different type of soils. Some literatures are studied to provide support to result and discussion afterward. First will introduce general corrosion process, second is the chemical and physical properties of carbon steel to withstand the corrosion rate, third is soil properties and the environment of carbon steel that will affect the corrosion rate. Lastly researched work regarding the development model on corrosion rate on metal is studied and compared to results in section discussion.

2.2 Introduction

This paper presents a study of corrosion rate on carbon steel. This research focus on different soil structure from various location soils that can be determined by using Textural Triangle and 4 class sand, silt, clay, and silty clay loam of soil is determined by sedimentation separation method. After soil texture is known, some analysis is done to relate the corrosion rate on carbon steel and type of soils with different factors: soil permeability, moisture content and soil particle size. Experimental data is used for developing a simplify model the correlation dynamic according to soil classification by statistical method such as least square regression to construct a model for corrosion rate prediction based on soil parameter.

2.3 Corrosion process

Up to the 1960s, the term corrosion was classified to metals and alloys. However it did not include materials such as ceramics, polymers, composites and so on. The term corrosion now covers all types of natural and man-made materials including even biomaterials and nanomaterial, and it is no longer restricted to metals and alloys alone. Corrosion is a common problem in structure degradation that reduces strength of pipeline. Pipeline system commonly made from carbon steel and utilized to transport product such as natural gas and crude oil from point to another. This research is to find out which location contains the kinds of soil that is corrosive to pipe by sampling various soil samples from various locations. After conducting analysis on soil samples that reveal soil structure or texture, soil permeability. Soil properties are closely related to the corrosion of the pipe such as moisture content, pH, presence of sulphate reducing bacteria and more. Each kind texture class of soils having different properties than the others. Therefore understanding the different type of soil in various locations can minimize the corrosion rate on any pipeline system.

Consequences of corrosion can be disastrous; corrosion may severely affect the metal or alloy of the pipeline in aspects of functionality. Once the metal is corroded, in term of impermeability the metal transition occur from impermeable to porous form. Secondly, the corrosion render the mechanical strength weaken and no longer capable withstand specified loads. Thirdly, maintaining dimensions is critical to engineering design which corrosion brings negative impact to dimensional integrity of metal. Fourth, in efficient operation, the physical properties such as thermal conductivity and electrical properties of plant and equipment can be adversely affected by corrosion.

Corrosion is a natural, costly and common process of damaging in pipeline system. Several definitions are suggested by Fontana, M.G. (1986) that corrosion is the superficial depletion that happens when metals are exposed to reactive surroundings. Corrosion of metal, for example iron, Fe undergoes simple reaction. Firstly,

$$Fe \rightarrow Fe^{n+} + n \text{ electrons}$$

The Fe atom loses some electron and become a positive charged ion. The positive ions can bond to negative ions OH^- which come from water dissolved with oxygen,

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

Positive and negative ions combine to form iron hydroxide,

$$2Fe + O_2 + 2H_2O \rightarrow 2Fe(OH)_2$$

Oxygen is usually in excess due to its quite readily dissolved in water. Therefore,

$$4Fe(OH)_2 + O_2 \rightarrow 2H_2O + 2Fe_2O_3.H_2O$$

Iron hydroxide reacts with excess oxygen to form water and hydrated iron oxide which is also known as brown rust.

Corrosion is the result of contact between a metal and environments that lead to continuing destruction. Corrosion in a pipe contains anode which linked to the cathode by the pipe wall that permit electrons flow from the anode to the cathode. To allow flow of ions electrolyte is the conducting solution, in cases it might be water or solution contains soluble salts or such. The cathode and anode reaction with aids of electrolytes cause corrosion to pipes. Corrosion is chemical reaction between pipes with its environment. Major causes of corrosion are salt water which is an excellent electrolyte with chloride source that enhanced corrosion process. H_2S, acid gas with iron sulfide the by-product. CO_2 is common problem of produced gas corrosion, high partial pressure of CO_2 is very corrosive to pipe.O_2, and oxygen is the key corrosion element in moisture due to high solubility in water. Corrosion has many types namely galvanic, crevice corrosion, pitting, stress corrosion, erosion corrosion, hydrogen sulfide corrosion, hydrogen embrittlement and hydrogen corrosion. Corrosion control is essential to prevent accidents happened.

2.3.1 Corrosion rate correlation dynamic

Development of correlation dynamic of weight loss and corrosion growth rate over time required extensive experiment data to support it. Accuracy for the experiment data is directly affecting the accuracy of model developed. Large numbers of samples and precise calibrated equipment is one of the ways to reduce to variance of experiment data. To develop a model it is crucial to identifying the parameters that will affect the corrosion rate whether accelerate or inhibits corrosion from happening. Corrosion along time can be classified as uniform corrosion and localised corrosion. As the name suggested, uniform corrosion is corrosion in steady and predictable rate, On the other hand, localised corrosion is corrosion happened without warning after short period of use.

Moisture content in soil is the most affecting factors among all like permeability of soils, pH, soluble salts and more. Moisture has significant influence and can affects corrosion growth directly on the determination of corrosion growth (Yahaya. N *et al.*, 2011). The data grouped according to types and if no information regarding the corrosion initiation time it is suggested to estimate the corrosion rate is by using the ‘defect-free’ method with the addition of hypothesised corrosion initiation time (Nordin. Y *et al.*, 2013). Corrosion initiation time is initiation phase that time taken for conditions to become conducive to corrosion or can be seen as loss of passivation leading to the onset of corrosion, the latent or hidden damage phase of the metal. Assumptions are important to such as contamination by species of chemical that results in a more localised breakdown of the passive layer leading to depassivation of the steel through pitting corrosion.

The corrosion of a metal is a process of oxidation or loss of electrons, is supported by a cathodic reactant or oxidizing agent such as hydrogen ions in acid, dissolved oxygen and water, which is reduced in performing the cathodic reaction. In short, the stronger the oxidizing reaction is, in terms of thermodynamically and kinetically, the more the induced corrosion rate on the metal (Stansbury & Buchanan, 2000).

2.4 Carbon steel

Carbon steel is an alloy – a mixture or metallic solid solution of two or more elements. Alloys vary both in the way they are made and in the proportions of the materials added to the iron. All steels, however, contain small amounts of carbon and manganese. Carbon steel is by far the most widely used by many due to its excellent strength and durability. The properties of carbon steel depend primarily on the amount of carbon it contains. There are 3 main types of plain carbon steel: low carbon steel, medium carbon steel, high carbon steel, and as their names suggests the main different is in the amount of carbon they contain, most of them has a carbon content of less than 1%, the highest carbon content known is a plain carbon steel having a maximum carbon content of 1.5% along with small percentages of silica, sulphur, phosphorus and manganese (S eblin. B *et al.*, n.d). Carbon steel is widely used in many application including structural beams, car bodies, kitchen appliances, and cans.

2.4.1 Physical properties of plain carbon steel

Low carbon steel, comprising carbon content up to 0.25% responds to upgrading in the ductility is concerned nonetheless has no effect in its strength properties. Medium carbon steels, having carbon content ranging from 0.25 to 0.70% improves in the machinability by heat treatment. Overall ductility and strength is obvious improved and surface hardness is desirable especially in machinery work. High carbon steels, containing carbon in the range of 0.70 to 1.05% and is especially classed as high carbon steel. In the fully heat-treated condition it can withstand very high stress without facing deformation and it will withstand high shear and wear. However high toughness and strength is at cost of ductility which render it more brittle and vulnerable to crack damage.

Table 2-1: Effect of increasing carbon content in steel

Material	Density 10^3 kgm^{-3}	Thermal Conductivity $Jm^{-1}K^{-1}S^{-1}$	Thermal expansion $10^{-6}K^{-1}$	Young's modulus GNm^{-2}	Tensile strength MNm^{-2}	% elongation
0.2% C steel	7860	50	11.7	210	350	30
0.4% C steel	7850	48	11.3	210	600	20
0.8% C steel	7840	46	10.8	210	800	8

2.4.2 Carbon steel limitation

Carbon steels do have some appreciable properties in terms of strength but also come along with some weaknesses. Carbon steels have poor corrosion resistance especially in pipeline system that materials surrounded by reactive environments. Some literature also shows that corrosion process enhanced carbon steel at elevated temperatures. However there are still ways to improve the corrosion resistance of carbon steel such as applied corrosion inhibitors 3,6-bis(3-Pyridyl)Pyridazine. This organic compound is a good corrosion inhibition and that the inhibition efficiency is directly proportional to inhibitor concentration. In the presence of 3-PYP, The 3- PYP organic compound are attributed to the double layer charging and adsorption of the inhibitor. Inhibition of corrosion by 3-PYP is mainly relied to the formation of a chemisorbed film on the carbon steel surface (Bentiss *et al*., 2011).

Corrosion process doesn't always give negative impact on the material. For instances, the reaction between sulfur and alloy can produce a layer of protective layer scale that can prohibit the corrosion progress. However that is dependent on the material of pipe, which is chromium content. Unfortunately, carbon steel commonly has less than one percent chromium content. Sulfidation corrosion is slower and less significant in higher weight percent of chromium content in alloy due to the formation of protective layer while lower weight percent of chromium has significant sulfidation corrosion. Thus, carbon steel corrodes is more vulnerable to corrosion then high chromium alloy.

Other than without protective layer during corrosion process, carbon steel is also inherently faster rate of sulfidation corrosion when compared with higher silicon content steel. Figure below showed that carbon steel pipe corrode at accelerated rates up to sixteen times faster than carbon steel pipe that containing higher percentage of silicon.

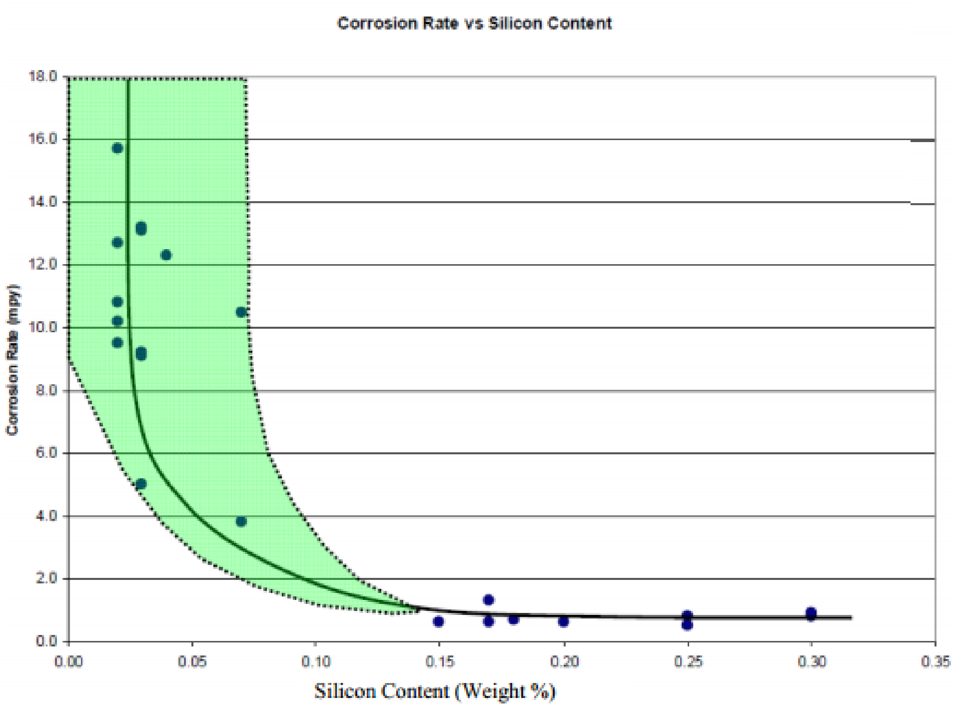

Figure 2-1: Corrosion rate versus silicon content.

Some others limitations of carbon steel are, first it cannot be strengthening beyond about 100000 psi without significant loss in impact resistance or also known as toughness and ductility. Other than that, it has been reported that rapid quench rates are will leads to shape distortion and cracking in full hardening in carbon of steels. Carbon steels like any other materials have poor ductility at low temperatures.

2.5 Soil

Reactive environment surrounding could be soils or transport fluid inside the pipeline is one of the reasons that lead to corrosion. Different locations have different type of soils, mainly distinguishable by soil structure. Three main components in soil: Clay, Sand and Silt.

Soil properties that have effect on corrosion of metal are soil electrical resistivity, pH value, redox potential and sulphate in the soil solution. However soil corrosivity cannot be measured in direct way due to its randomness of various human actions and natural phenomenon. Kleiner, Y. (2010) research shown that there is no explicit relationship between soil with the corrosion and most models are largely based on empirical observations.

Each class of soil has different physical properties such as clay has small grain size compare to sand while silt is in between clay and silt. Permeability of soil is closely related with grain size distribution of soil. Soil ability of containment of water is dependent on its structure and level of moisture determines the corrosivity of the soil. Pipe corrosion on soils closely related with soils texture along with characteristics to enhance or slow down corrosion process.

Texture classes of soil are designed for many reasons such as pipe corrosion in soil, define classes of grain size distributions and are based on the experience of generations of soil mappers. Soil texture is the relative proportions of sand, silt, or clay in a soil. The soil textural class is a grouping of soils based upon these relative proportions. Soils with the finest texture are called clay soils, while soils with the coarsest texture are called sands. Soil that has a relatively even mixture of sand, silt, and clay and exhibits the properties from each separate is called a loam. Textural triangle can used to determine the texture class of soil if the percentages of clay, silt, and sand in a soil are known. Sedimentation separation method or both sieve shaker for larger grain-size particle and Bouyoucos hydrometer for smaller grain-size particles for soil texture analysis.

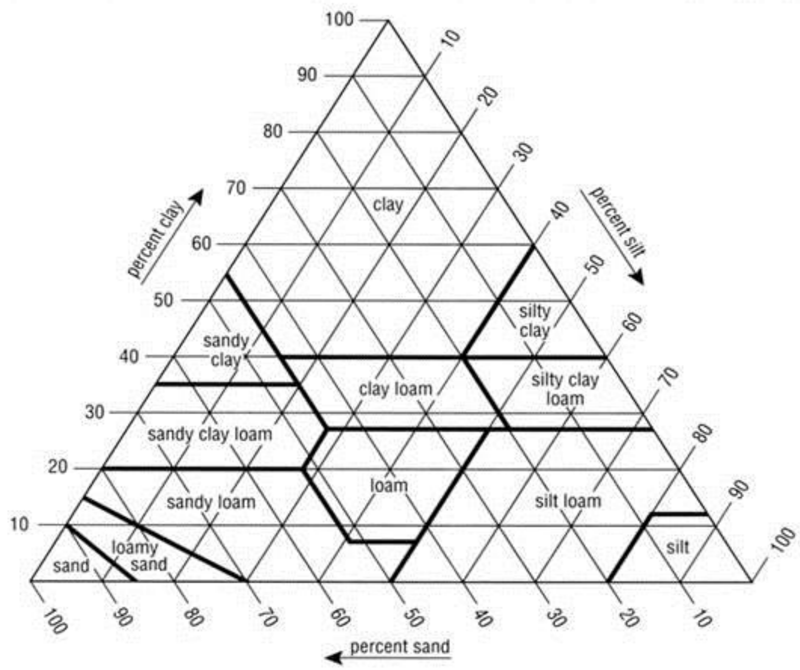

Figure 2-2: Textural Triangle for classify types of soil.

H. Bormann (2010) claimed that in different areas of the world, different soil texture classification systems have been established. Texture classification has not been intended for hydrological mapping purposes. Therefore, it is necessary to have another ways to achieve the required similarity in hydrological behaviour in texture classification schemes. Soil structure analysis is done to distinguish different type of soil that have different weight ratio of clay, slit and sand. Soil conditions and characteristics for example like water movement, heat transfer, aeration, and porosity are much dependent to soil structure. The arrangement of particles in a soil mass is known as soil structure. Quantity of water and air present in soil is relevant to the soil structure. Bacterial activities also depend on the containment of water and air in the soil.

Soil properties that have been concerned related to corrosion is comprise of soil electrical resistivity, pH value, redox potential, and sulfates in the soil solution, chloride concentration, moisture conditions, shrink/swell properties and many more. Nevertheless, the soil corrosivity is not a directly computable parameter and pipe corrosion is mainly a random phenomenon. Pipe corrosion in soil has no explicit relationships among these soil properties and soil corrosivity as well as between soil corrosivity and pipe corrosion rate (Kleiner *et al.*, 2010). Almost all the models that attempt to propose such relationships are empirical. P. Melidis (2005) suggested that all waters are corrosive to some degree. Water corrosive tendency is largely depends on its physical and chemical characteristics for example saline water contain in soil will greatly reduce soil resistivity and thus increase the metal loss rate or corrosion.

2.5.1 Soil permeability

Soil permeability has important role in designing of geotechnical engineering projects, one of the essential soil properties of importance to engineers is permeability. To certain extend, permeability is related in the migration of contaminant and on the design of almost any structure such as compacted clay liners are frequently used to lessen potentially contaminated leakage from the base of tailings impoundments. Robertson (2003) explained that soils are permeable because soils consist of solid particles also a network of interconnected pores. Permeability of soil depends on many factors, for example soil type, grain size distribution, and water content, degree of compaction and soil history. This degree of permeability is characterized by the hydraulic conductivity. There are a few permeability testing methods such as laboratory tests, empirical methods that based on grain diameter and grain size distribution and field tests. Field tests are by far the most reliable for they permit the testing of larger volumes of soils. In the field, the permeability of a soil can either be measured in existing monitoring well. Pump and slug tests are typically used for determining the permeability of the soil aquifer material by recording the drawdown or change in well head over time. Laboratory test, two common tests are preform to determine permeability. Depending on the type of soil tested for soils sands and gravel which normally has high permeability a constant head test is normally used. For soils like clay with low permeability, a falling head test is usually used.

2.5.2 Moisture content in soil

Water is one of the important components for corrosion to happen. There are many sources that provide the soil moisture namely free ground water, gravitational water, and capillary water. The free ground water is located in the soil under the external and usually only river nearing pipelines are affected by ground water. Corrosion is observed to occur in an aqueous environment that provided electrolyte for corrosion to happen. Second sources are gravitational water which are rainfall, irrigation and flood. This kind of water moves through the soil, depending on soil permeability that including pore and capillary spaces in the soil profile. The capillary water is an important reservoir of water in soil. Water is an vital component which acts as electrolyte for the corrosion process it is a strong function of corrosion growth rate (Yahaya *et al*., 2011).

Moisture content in soil is essential element microbial activity. Organic matter is the huge collection of carbon compounds in soil. Formerly produced by plants, microbes, and other organisms, these compounds are important aspect in nutrient, water, and biological cycles. SRB, sulphate reducing bacteria is one of the organic matters in soil that encourage the changes of medium state parameters in soil, for example changes in concentration of sulfides, pH value, and redox potential.

2.6 Previous work of the corrosion rate of carbon steel

Study of corrosion rate has been done by many researchers to improve and understanding the factors and effects of corrosion. Previous work shows that reduction of water or reduction of dissolved O_2, it produced OH species that increased the interfacial pH and, if dissolved O_2 was involved, the O_2 concentration at the interface decreased as O2 was consumed during corrosion process. The concentration gradients depend on mass transport limitation effects and are anticipated to increase if the rate of transport is small. Which is highly possible related with soils properties and therefore the steel and soil interface composition may have been continuously modified by polarization while the cathodic polarization level was increased (Barbalat *et al*., 2012).

Temperature is a key parameter in any chemical reaction including corrosion process. On the electrochemical behaviour carbon steel, the increase of temperature the driving forces of the anodic and cathodic reaction were raised. The diffusion of the aggressive ions was enhanced in the process. Therefore dissolution of the sample was aggravated. and the ion was gradually increased (Zhang *et al*.,2009). Hence in this research it is best to control the temperature for the samples to obtain an accurate correlated data for corrosion.

Researcher Robert (1999) explained that the general character of the data has a relatively uniform rate of corrosion that after a period of two to five years exposure which led to the linear model provided on the basis that long-term corrosion was influenced by anaerobic conditions, that is, those which dominate after extensive build-up of corrosion products on the samples' surface. A probabilistic model for corrosion is often constructed from a mean value expression and an expression picking up random and other uncertainties not modelled in the mean value expression. The proposed phenomenological model has been explained by (Robert, 1999). The main feature of the model consists of the following parts which are first, initial corrosion; followed by oxygen diffusion controlled by corrosion products and micro-organic growth; limitations on food supply for aerobic activity and lastly the anaerobic activity. Therefore it is expected that six month time corrosion data is not in linear behaviour. The overview of phenomenological model is as figure followed: