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#### ABSTRACT

The study investigated the effects of some soil properties on the corrosion reaction of API X70 pipeline steel which was used in buried oil pipelines from Kano to Zaria in Nigeria. The analyses were carried out on eight samples of soil collected from the real site of the underground crude oil pipeline along 50 km from Kano Zaria road in the Kano State. In each of the soil sample, coupons of API 5L X70 steel were buried in order to investigate the effects of moisture content (ASTM D4643 – 08), clay content (BS 1377 – part2: 1990) and pH (BS 1377 – part3: 1990) on the corrosivity of API X70 steel.

Based on the results obtained, it was noted that the moisture content of the soil possessed the largest effect on corrosivity followed by clay/silt content and finally the pH.

Statistical studies using MLR (Multiple Linear Regression) and ANOVA (Analysis of Variance) were consistent with the experimental results.

*Keywords:* Corrosion, Linear Regression, Moisture, pH, Pipeline, Soil texture, Statistical analysis.

## ÖZET

Bu çalışmada, yerel bazı toprak özelliklerinin Nijerya'da Kano - Zaria arasındaki toprağa gömülü petrol nakil hattındaki boruların imal edildiği API 5L X70 çelik malzemedeki paslanma sürecine etkileri incelenmiştir. Petrol boru hattının geçtiği 50 km boyunca sekiz adet toprak numunesi alınmıştır. API 5L X70 çeliğinden kesilen kuponlar toprak numunelerin içerisine gömülmüş, işlemlerde uluslararası standartlar takip edilmiştir. Topraktaki nem içeriğinin (ASTM D 4643-08), kil içeriğinin (BS 1377-Part 2) ve pH seviyesinin (BS 1377 – part2: 1990) çelik kuponların korozyonuna (paslanmasına) etki dereceleri izlenmiştir.

Çelik numunelerdeki korozyonu en fazla toprağın nem içeriğinin, ardından toprak dokusunun (kil/silt içeriğinin) ve son olarak pH seviyesinin etkiledikleri görülmüştür.

Deneysel veriler, MRL (Multiple Linear Regressin) ve ANOVA (Analysis of Variance) yöntemleri ile değerlendirilmiştir.

Anahtar Kelimeler: Boru hattı, Doğrusal regrasyon, İstatistiksel analiz, Korozyon, Nem, pH, Toprak dokusu.

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# LIST OF ABBREVIATIONS

- **ASTM:** American Standard for Testing and Material
- ANOVA: Analysis of Variance
- **API:** American Petroleum Institute
- **BS:** British Standard
- MLR: Multiple Linear Regression

# LIST OF SYMBOLS

a:	Correction faction to be applied to the reading of hydrometer 152H
A:	Cross-sectional area of sedimentation cylinder
b1, b2, bn:	Coefficient of the variables
C:	Hygroscopic moisture
CR	Corrosion rate
D:	Diameter of particle
K:	Constant depending on the temperature of the suspension and the
L:	Effective depth
L1:	Distance along the stem of the hydrometer from the top of the bulb to the mark for a hydrometer reading
L2:	Overall length of the hydrometer bulb
<b>M</b> 1:	Mass of container and moist specimen
<b>M</b> <sub>2</sub> :	Mass of container and oven dried specimen
MAir-Dry:	Mass of air dry
Mc:	Mass of container
Moven-Dry:	Mass of oven dry
Ms:	Mass of solid particles
Mw:	Mass of water
Р:	Percentage of soil remaining in suspension at the level at which the hydrometer measures the density of the suspension
R:	Hydrometer reading with composite correction applied
T:	Interval of time from beginning of sedimentation to the taking of the

Reading

VB:	Volume of hydrometer bulb
W:	Oven-dry mass of soil in a total test sample represented by mass of soil dispersed
X1, X2, Xn:	Independent variables

Y: Dependent variable

# CHAPTER 1 INTRODUCTION

#### 1.0 Background

With increasing global population growth and industrial development, the demand for fossil fuels continues to grow despite the discovery of alternative energy sources. It has been reported that oil and natural gas account for about 60% of all global energy demands (Mahmoodian and Li, 2017; Davis, 2006). Therefore, the transportation of oil and gas is gaining considerable attention. Pipelines are extensively used to as means of transportation. The pipelines network maybe as long as thousand kilometers, passing through different environmental and geographical conditions (Vanaei and Egbewade, 2017; Satish and Sachin, 2017).

Welding technology plays a major role in the fabrication of pipelines network, especially in long-distance projects. The microstructure and properties of welded zones are often significantly different from those of the base metal (Shiranzadeh et al., 2015). Owing to the combination of appropriate materials selection, good design and operating practices, oil transmission pipelines are safe to an acceptable level. However, failure occurs occasionally, leading to catastrophic consequences, including cause massive costs for repair, enormous disruption of daily life, extensive pollution and even human injuries (Sani et al., 2016). Corrosion is a major source of failure oil and gas pipelines failure, and it has been reported that external corrosion accounts for about 40% of the failure (Davis, 2006; Vanaei and Egbewade, 2017; Fei et al., 2018)

Soil is one of the most complex media for metallic corrosion, and depending on the environment, rapid metal loss could occur (Satish and Sachin, 2017; Norhazilan et al., 2012). The factors that influence the corrosion of metals in soil include soil chemical composition, water content, the electrical resistivity, environmental pH value, salinity and porosity (He et al., 2015). Buried welded pipelines are extensively used in oil transmission in different parts of Northern Nigeria. Hence, there is a pressing need to study the effect of the soil properties on the corrosion resistance of the pipelines. However, such studies are rare in the literature. This work will investigate the effects of major soil properties on the corrosion in Nigeria.

#### 1.1 Statement of the Problem

Underground pipeline corrosion is a major global concern. It represents a large part of the total yearly costs incurred by oil and gas producing companies worldwide. It also leads to water resource and environmental pollution and loss of lives. The problem is compounded if welded joints are involved due to the microstructural changes occur in the fusion and heat affected. However, with the increasing demand for oil and gas transportation across different locations in Nigeria, the welding of underground pipelines is inevitable. To address these concerns, it is necessary to understand the influence of welding parameters and soil properties on the corrosion behavior of welded pipelines.

#### 1.2 Aim and Objectives

The aim of the study is to determine the influence of soil parameters on the corrosion resistance of welded API 5L X70 pipeline steel used in oil transportation in Nigeria. The objectives of the study are:

- To determine which of the major soil parameters has the most significant effect on the corrosion resistance of API 5L X70 pipeline steel in Northern Nigeria
- To determine the optimum welding parameters, electrode and filler metals for fabrication of welded API 5L X70 pipeline steel for oil transportation in Northern Nigeria
- To compare the corrosion resistances of welded and un-welded API 5L X70 pipeline steel for oil transportation in soil Northern Nigeria.

## 1.3 Limitations of the Study

The absence of the following:

- Non-use periods of time to retrieve the steel coupons to know the corrosion rate against time.
- Non-use of the original site for the best results.
- The absence of tests in the various seasons of the year to see the effect of climate change on corrosion rate.

# CHAPTER 2 PREVIOUS WORK

#### 2.1 Soil Characteristics and Pipeline Corrosion

Bhattarai (2013) investigated soil parameters such as moisture content, pH, resistivity, oxidation-reduction potential, chloride and sulfate contents those have an influence on the corrosive nature of soils toward the buried galvanized steel and cast iron pipelines used to supply the drinking water in Kathmandu Valley at Nepal. He discovered that the twenty three soil samples taken from the study area were mildly corrosive to non-corrosive nature toward the buried pipeline.

Ikechukwu et al. (2014) examined the relationship of soil properties towards metal loss of API 5L X42 carbon steel coupons. An aggregate of four specimen of X42 coupons were set in four distinctive soil tests taken from four unique states inside of the Niger Delta district for 2352 hours, to consider the impact of soil properties towards metal loss by means of weight loss method. The soil coupons were covered in the soil samples put in a plastic bag, permitted to corrode normally and afterwards recovered at regular intervals. The impact of soil pH and resistivity were assessed utilizing the weight loss method to assess the consumption rate on coupons in the diverse soil tests. Results demonstrated that both parameters had an impact on covered steel yet soil resistivity had a commanding impact contrasted with soil pH.

Shirinzadeh et al., (2015) carried out failure analysis based on the accessible documents, metallographic investigation and corrosion nature of the welded joint pipe pattern made of AISI 1518 low carbon steel. Nondestructive assessment including radiographic test (RT) penetration test (PT) and radiographic test (RT) were performed on the as-received pipeline and outcome indicated the existence of micro- and macro cracks. The scanning electron microscopy (SEM) and optical microscopic images micrographs revealed different microstructures in the base metal (BM), heat affected zone (HAZ) and weld metal (WM). The microstructural variations may result in galvanic factor and lead to failure and fracture of the weld joint during the service Micro hardness assessment showed that hardness value was about 260 HV in the WM, while it droped in the HAZ and BM. Qualitative chemical investigation such as (SEM) and X-ray diffraction arrangement (XRD) supplied with

energy dispersive spectroscopy (EDS) proved the existence of corrosive media during weld joint fracture. Additionally, optical investigation and SEM indicated that micro-cracks were constitute in HAZ due to residual stress as a consequence of improper welding condition. Surface fracture investigation showed that the crack inception, crack increase and finally crack propagation took place in the WM/HAZ interface. Electrochemical investigation were conducted on the BM, HAZ and WM to investigate corrosion nature of the failed joint pattern. Finally, a good corrosion mechanism is recomended based on the failure investigation and electrochemical application

Kleiner et al., (2010) portrays research that tries to pick up an intensive comprehension of the geometry of outer corrosion pits and the elements (e.g., properties of soil, appurtenances, service associations, and so forth) that impact this geometry. This comprehension would prompt a definitive goal of accomplishing a superior capacity to survey the remaining existence of ductile iron pipe circumstances for a given set. These vary in a span of ductile iron pipes were unearthed a few North American and Australian water utilities. Uncovered pipes was cut into pieces, and sandblasted labeled. The Soil samples separated along with the unearthed pipes was additionally given. Funnel portions were checked; utilizing uniquely created laser scanner examined information was prepared utilizing extraordinarily created programming. Measurable investigations were performed on three geometrical properties, to be specific pit profundity, pit region and pit size. A different soil qualities was explored for its effect on the geometric properties of the corrosion pits. Preparatory discoveries showed that information does not generally supports customary traditions.

Yahaya et al., (2011) outlined a technique of the outside development demonstrating of corrosion on covered gas pipelines under different exposures to soil conditions. The method can be utilized to produce field information to demonstrate observationally the corrosion dynamic in soil or for check of consumption information from research center testing. The potential model taking into account the proposed system is exceedingly potential to foresee the probability of consumption development rate experienced by covered lines presented to destructive environment. As a result, it can significantly help administrator to secure the trustworthiness of their pipelines until the structure achieves its outlined lifetime.

Fei et al., (2018) carried out on The reaction of moisture content on corrosion of X70 steel in soils from distinct district containing Made kyun, Muse, Tungth, and Made Kyun beach in Myanmar were investigated by electrochemical impedance, emission curves and SEM. It was found that the corrosion rate law of X70 steel in each investigation soil influence to be unique with the modification of moisture content of the combined response between soil moisture content and chloride ion content. The values of the corrosion rate were maxima with soil moisture content of 20% except that for the Muse soil where the corrosion rate was minimal with moisture content of 20%. The values of Ecorr were shifted to more negative values with increasing soil moisture content of up to 60%, and then there was an appreciable increase in the value of Ecorr. However, the value of Ecorr was moved to more negative value with increasing Made Kyun soil moisture content of up to 80%. A good uniformity between the data obtained from polarization curves and EIS measurements results. X70 steel was serious corroded in Made Kyun beach and Made Kyun regions via the data of EIS, polarization curves and moreover SEM reaction from the distinctive content of chloride in different areas.

Lim et al. (2011) evaluated the soil engineering parameters which are moisture and clay contents on corrosion rate of X70 pipeline type. Total number of test specimen of X70 carbon steel pipe coupon were set underground in five different sites in Peninsular

Malaysia for 12 months were retrieved every three months to determine the weight loss and corrosion rate as a function of time. They discovered that the highly corrosion growth approximately relate with high moisture content of soil while a slow corrosion growth begin with clayey soil content. The moisture content was more effective to cause X70 carbon steel pipe corrode than clay content

Sulaiman et al. (2014) examined the corrosion parameters utilizing the Potentiodynamic polarization bends. So as to focus potential corrosion of parameters and current thickness to the intriguing metal, of the carbon steel and ecological states outside consumption covered by carbon steel pipeline in Iraqi soil were readied in a research facility utilizing reenacted arranged conditions. Moreover they employed sodium chloride in the study as diverse focuses (selecting 300, 1100, 1900, 2700, and 3500 ppm) As well as the acidic and alkaline pH at PH5 and H9 respectively. It takes at room temperature were

potentiadynamic polarization bend of log current thickness and potential are acquired using multy channel potentiastart galvanostart. The carbon steel coupon (ASTM A179-84A) was utilized after which the effect of carbon steel uncovered conducted outside erosion at outside corrosion of Iraq soil. Although the ratio of corrosion of the carbon steel increment with increment in chloride fixation in the study however, the change in PH from acidic to Alkaline medium. Hence they assert there is the proportion of the corrosion.

Pritchard et al. (2013) surveyed the UK soil towards infrastructure, has basically evaluated the soil variables that are considered to influence soil corrosivity of which are extremely complex, don't act in segregation are inherently connected and interrelated. The survey also illustrated that the gas, oil, and water processes sector are most influenced by corrosion processes with compare to the other sectors.

Saupi et al. (2015) study focused on properties of corrosion which open to soil environment. In this analysis, the corrosion forms as for clear presence and changed real properties are orderly assault, galvanic corrosion, decrease. Corrosion, stress corrosion, pitting corrosion, and between granular corrosion. Outer corrosion is corrosion assault upon the outside of the pipe soil medium and the most failure mechanism experienced by covered steel pipelines.

Chuka et al. (2014) conducted an experimental study on the effect of environment on corrosion of mild steel, for a period of five weeks, the different media were supplying for this study are: Hydrochloric acid of 0.1, salt water, fresh water, underground atmosphere. moreover was spotted that mild steel corrode in the diverse circumference with a declining concentration in a system of as well as of 0.1M of hydrochloric acid, salt water, underground (soil), fresh water, atmosphare.

#### 2.2 Corrosion Modeling and Statistical Analysis

Ossai (2013) Monte Carlo Simulation was applied with deterioration models in order to appraise the corrosion growth while the authenticity of oil and gas pipeline. The investigation revealed that the corruption image that Monte Carlo simulation forecast is mostly the corrosion rate of the pipelines to a precision in between 83.3-98.6% and 85.2-97% respectively.

Norhazilan et al. (2012) investigated the relationship between three engineering soil properties that are related to the moisture content, plasticity, and clay content index.

Statistical analysis was conveyed to evaluate the relationship between soil properties and corrosion percentage. The investigation constitute of simple linear regression, sinple bar graph, Analysis of Variances (ANOVA) and multiple regression method. The investigation revealed that the moisture satified as the best administration impact on corrosion percentage in the light of the interrelation coefficient.

Anyanwu et al. (2014) Studies revealed that ANOVA shows the soil resistivity was a noteworth commitment to corrosion response in soil. The analytical model was created utilizing multiple regression investigation. The outcome demonstrated the model created was applicable for forecast of corrosion development rate with a soil pH and resistivity as the two independent variables; since the coefficient of determination R2=0.8129 was significantly high.

Satish and Sachin (2017) Investigation is conducted to increase reliability and beneficial in welding industry; moreover effective welding techniques are needed for these materials. To perceive the issues related with the welding of these high strength steels, provision of chemical content and mechanical properties for these materials are needed to know them in detail. However this review article, an attempt has been made to critically analyze the issues and challenges associated with the Weldability of high strength pipeline materials. Current research for weld of corrosion, Residual stress, hydrogen embrittlement, residual stress, and weld repairing and deteriorated heat affected zone is also discussed for welding oil pipeline problem. Current development trends are discussed with a view to envisage future directions. Findings of this review work emphasize the need to shift the research focus from currently used grades X65, X70 and X80 to the advanced grades X90, X100 and X120.

#### 2.3 Corrosion Failures in Buried Petroleum Pipelines in Nigeria

Bike et al. (2014) in their study reviewed different mechanisms of external corrosion found in underground pipelines. The primary methods for mitigating preventing/corrosion are discussed. Pipelines are usually coated to isolate the pipe steel from direct contact with soil.Becauuse of the inherent imperfection of coatings and their degradation over time Cathodic protection is used as a secondary protection. Emphasis is made on the need to establish a proper maintenance program for the pipelines. An appropriate repair option must be chosen in the case of a defect arising in a pipe material. The study concludes that petroleum pipeline failure, with its attendant environmental and human cost can be prevented or greatly mitigated with a consistent monitoring and maintenance program

Gadala et al. (2016) in their study an advance finite element miniature of the external corrosion of buried steel pipelines for coating failures to improved anticipated degradation in distinct soil and cathodic protection (CP) environments. Harmonious interactions between steady-state temperature, potential, and oxygen absorption profiles in the soil neiboring the pipeline network are quantified and discussed. Conductivity and oxygen diffusivity of soil conditions are represented as part of soil matter, air porosity, and volumetric wetness. Analytical structures are particularly merged with corrosion experiments conducted on actual pipeline steel samples, remarkably improving simulation results. Overall, drier sand and clay soil structures cause the most corrosion, whereas humid conditions disrupt oxygen diffusion and significantly developed hydrogen evolution. Geometric location of the coating breakdown site relative to the ground surface and the CP anode has a distinct influence on oxygen concentration profiles and pipeline corrosion. Exemplary convergence is tested with a mesh sensitivity study, and the model's ability in assessing practical design changes in the CP system is demonstrated

Achebe et al (2012) reported a total of 137 pipeline failure across six states in the Niger Delter Region in Nigeria in the period 1999-2000.Corrosion accounted for 18% of these failures. In the US, 25% of transmission pipeline failures between 1994 and 1999 were due to corrosion. For liquid product transmission pipelines most of the corrosion accidents were due to external corrosion.

Amnesty International (2011) report highlighted the devastating effect of two successive oil spills in Bodo, a town in Ogoniland inhabited by 69000 people – all dependent on the environment for their survival. The first of the spills occurred in August 2008 as a result of fault in a section of the Trans Niger pipeline. According to the company operating the pipeline, this spill as caused by a 'weld defect'. Another spill followed in December of the same year and investigations by the company attributed it to 'equipment failure as a result of natural corrosion'

Chapetti et al. (2002) A rupture in a 14 in. diameter, 1/4 in. thick API 5L X46 oil pipeline was due to the abruptly yielding of a fracture at the longitudinal Electrical Resistance

Welding (ERW) weld. The cracks initiated from small curve crack-type deformed on the external surface of the tube, in the highly defected and hardened central area of the ERW weld. Fatigue tests were carried out to describe initiation and propagation of fatigue cracks in base and weld metals, in two places of the pipeline. Specimens were exact to cyclic stresses similar to those that were produced during the passage of the scraper. The fatigue increase was shaped by conform the experimental results. Anticipated fatigue lives of about 20,000 cycles comfirm fatigue propagation up to failure in weld metal, from initial 2 mm deep crack introduced during manufacturing

Mahmoodian and Li (2017) Analysis revealed that service oil and gas pipelines can result in disastrous consequences. To avoid the economical, environmental and social brunt due to pipeline failure, rational methodologies should be adopted to predict the safe life of corrosion affected steel pipes and to initiate maintenance and repairs for the corroded pipeline system. The unpredictability in corrosion sizes and pipe characteristics actuate the residual strength model to be a probabilistic model rather than a deterministic one. Meanwhile, a detailed reliability-based on methodology using first passage probability theory for failure assessment of corrosion affected oil and gas pipelines is conferred in this paper. The methodology should be tested for a defected 1.5km oil pipeline and failure probability is estimated versus time. Sensitivity investigation is also undertaken to analyze and asses the causes that influence the failure due to the strength loss. It can be significant to estimate that how decrease in internal pressure, can increase the safe life of the pipeline. The methodology can help pipeline engineers and asset managers in prioritizing pipeline repairs and/or replacements based on their estimated anticipation of failure.

In the present study, a simple statistical analysis will be carried out following the experimental work using the anova, software.

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# CHAPTER 3 LITERATURE REVIEW

#### **3.1 Corrosions Characteristics**

Corrosion in general form is the destructive chemical or electrochemical reaction or loss in material properties when the materials are to be in contact with their environment. For corrosion to happen, the development of a corrosion cell is crucial. A corrosion cell is basically embodied the accompanying four segments:

- Anode
- Cathode
- Electrolyte
- Metallic path



Figure 3.1: Electric cell showing flow of ionic and electric currents.

#### **3.1.1 Anode**

One of the two dissimilar metal terminals in an electrolytic cell represented as the negative terminal of the cell. Electrons are discharged at the anode, which is the more responsive metal. Electrons are insoluble in fluid arrangements and they just move through the wire

association into the cathode. Corrosion terminology is the inverse of electroplating classification, where an anode is positive, the cathode is negative.

#### 3.1.2 Cathode

One of the two terminals in an electrolytic cell represented as a positive terminal of a cell. Decrease happens at the cathode also, electrons are expended.

#### 3.1.3 Electrolyte

It is the electrically conductive arrangement (e.g. salt solution) that must be available for corrosion to happen.

#### 3.1.4 Metallic path

The two terminals are joined remotely by a metallic conduit. In the metallic conduit, 'routine " current streams from (+) to (-) which is truly electrons spilling out of (-) to (+).Metals give a way for the stream of ordinary current which is really section of electrons in the inverse head.

#### **3.2 Corrosion Damage Forms**

A wide spectrum of corrosion problems are encountered in industry as a result of combination of materials, environments and service conditions. Corrosion may not have a deleterious effect on a material immediately but it affects the strength, mechanical operations, physical appearance and it may lead to serious operational problems. Corrosion may manifest itself as a cosmetic problem only, but it can be very serious if deterioration of critical components is involved. Serious corrosion problems, such as the pitting of condenser tubes in heat exchangers, degradation of electronic components in aircrafts and corrosion fatigue of propellers can lead to catastrophic failures. When catastrophic failures occur, the cost in terms of lives, equipment, and time is very high. While evaluating the long range performance of materials, it is essential for an engineer to consider the effects of corrosion along with other characteristics, such as strength and formability. Environment plays a very important part in corrosion. The severity of corrosion varies considerably from one place to another. The most corrosion sorts classified regarding outer appearance and physical features as follows.

### 3.2.1 General corrosion

This is the most common form of corrosion and the most popular type, general corrosion occurs in atmosphere, liquid and soil under normal service condition. This sort of corrosion can appear as rusting of iron, tarnishing of silver and fogging of nickel. This type of corrosion will produce a rough surface and will cause loss amount of metal which react with environment and produce adherent or non-adherent film coating of corrosion product. (Revie and Uhlig,2008).

## 3.2.2 Pitting

Pitting is extremely localized corrosion; this type of corrosion is by visual examination, its characteristic of interior walls at the point when subject into high speed fluid. The pitting begins when one area of metal surface become anodic with respect to surrounding surface, the combination of small anodic area and large cathodic area cause pit to form. The outcome pits are portrayed as deep. In the event that the territory of assault is moderately bigger and not all that deep, the pits are named shallow, iron covered in the soil consumes with arrangement of shallow pits, while stainless steels drenched in seawater distinctively corrode with development of deep pits.



Figure 3.2: The pitting of 304 stainless steel plate by an acid-chloride solution (Callister and David, 2007)

#### **3.2.3 Selective leaching**

Also called parting, DE alloying corrosion, its consist of removal of an element from alloy by corrosion. The most common example of selective leaching is dezincification, it occurs with zinc alloys, consist of removed of zinc from brass which is an alloy from zinc and copper. Comparative procedures happen in other compound systems in which aluminum; iron; cobalt; chromium and different components are removed, selective leaching is the general concept to portray these procedures, and its utilization blocks the production of terms, for example, dealuminumification, decobaltification, and so forth. Parting is a metallurgical concept that is applied.



Figure 3.3: Weld decay in a stainless steel. (H.H Uhligg and R..W.)

### **3.2.4 Intergranular corrosion**

Its corrosion along the grain boundaries often where precipitates particles form. Intergranular corrosion usually related to thermal processing such as welding. Certain austenitic steel are susceptible to inter granular corrosion. The susceptibility is called sensation, sensation it takes place when austenitic stainless steels are heated the chromium and carbon precipitate in grain boundaries as chromium carbide

### **3.2.5 Crevice corrosion**

This is a localized form of corrosion, caused by the deposition of dirt, dust, mud and deposits on a metallic surface or by the existence of voids, gaps and cavities between adjoining surfaces. An important condition is the formation of a differential aeration cell for crevice corrosion to occur. This phenomenon limits the use, particularly of steels, in marine environment, chemical and petrochemical industries.



Figure 3.4: Oil and gas pipeline under crevice corrosion

### 3.2.6 Stress-corrosion cracking (SCC)

Stress corrosion cracking occurs when metallic structures are subjected to static, tensile stresses and are exposed to corrosive environments. In such situation induced cracks are propagated by the combined effect of the surface stress and the environment in which the pipeline is buried (Dawotola A. 2012). The primary component of tensile stress in a pipeline is in the hoop direction and results from the operating pressure. Two forms of

SCC are known to exist in underground pipeline: the high pH SCC and the low or nearneutral pH SCC. A common characteristic of both forms of SCC is the formation of colonies of cracks in the body of the pipe that link up to form long, shallow flaws (Beavers J.A.and Thompson 2008).



Figure 3.6: SCC above is in external surface of an underground pipeline (Beaver and Thompson 2008)

Usually three factors contribute to cracking. They are:

- Potent environment developing at the pipe surface
- Susceptible pipe material
- Tensile stress

The development of a suitable environment at the pipe surface is necessary for the inauguration of both forms of SCC. For the low pH SCC, the environment is a dilute solution of CO2 in groundwater. The cracking occurs under a condition of little cathodic protection current reaching the pipe surface. This may be due to high resistivity soil, presence of shielding coating or inadequate CP design (Delanty A. and Beirne 1992). The CP current collecting on the pipe surface at disbandment, in conjunction with dissolved CO2 in groundwater creates the environment for high-pH SCC.



Figure 3.7: A steel bar that has bent into a horseshoe shape using nut and bolt assembly while Immersed in seawater, stress corrosion cracks formed along the bend at those regions where the tensile stresses are the greatest

#### 3.2.7 Selective attack on inclution

It is a special case of selective leaching, in this type of attack the body of metal is resisting to the environmental and only small amount of material corroded away, inclusion in the metal provide a small anodic area surrounded by a large cathodic area.

### 3.2.8 Galvanic cells

Dissimilar metals are physically joined in the presence of an electrolyte. The more anodic metal corrodes. The galvanic cell may have an anode or cathode of unique metals in an electrolyte or the same metal in unique conditions in a typical electrolyte. For instance, steel and copper anodes drenched in an electrolyte Figure 3.2, represents to a galvanic cell. The more honorable metal copper acts as the cathode and the more dynamic iron go about as an anode. Current stream pass from iron anode to copper cathode in the electrolyte.



Figure 3.8: Corrosion cell phenomenon in action (Ahmad, 2006)

### 3.3 Sorts of Corrosion Cell

In general there are three basic type of corrosion cell which are covering most of corrosion cells and consider as a segment of corrosion reaction.

### 3.3.1 Dissimilar electrode cells

A metal contain an electrical directing defect at first glance as a different stage, a copper pipe associated with an iron pipe, and a bronze propeller in contact with the steel frame of a boat. Unique cathode cells likewise incorporate chilly - worked metal in contact with the same metal tempered, grain - limit metal in contact with grains, and a solitary metal precious stone of definite introduction in contact with another crystal of diverse introduction, dry cell as an example of this type of cell as shown in Figure 3.3 (Revie & Uhlig, 2008).



Figure 3.9: Dry cell (Revie and Uhlig, 2008)

### **3.3.2** Concentration cells

These are cells with two indistinguishable electrodes, each in contact with a solution of distinctive arrangement. There are two sorts of concentration cells. The principal is known as a salt concentration cell. The second sort of concentration cell, which by and by is the more vital, is known as a differential air circulation cell Figure 3.4 (Revie & Uhlig, 2008).



Figure 3.10: Concentration cell (Revie and Uhlig, 2008)

### 3.3.3 Differential temperature cells

Segments of these cells are electrodes of the same metal, each of which is at an alternate temperature, inundated in an electrolyte of the same beginning composition. These cells are found in heat exchangers, boilers, drenching radiators, and comparable equipment.

### **3.5 Corrosion of Steel**

On the planet today, steel is utilized as a part of different designing applications for the creation of some vehicles segments, auxiliary shapes; I beam and angle iron and sheets that are utilized as a part of pipelines, structures, plants, extensions and tin cans.(Callister,1997). As mentioned above Corrosion is a characteristic process that lessens the coupling vitality in metals with the deciding result including a metal being oxidized as the mass metal looses one or more electrons. The lost electrons are led through the mass metal to another site where they are decreased (Chuka et al. 2014).

The main impetus that makes metals corrode is a characteristic outcome of their impermanent presence in metallic structure. With a specific end goal to create metals beginning from actually happening minerals and ores, it is important to give a sure measure of vitality. It is accordingly just normal that when these metals are presented to their surroundings they would return back to the first thermodynamically stable state in which they were found in nature (Roberge, 2008).

An average cycle is shown by iron. The essential consumption 3 result of iron, for instance, is  $Fe(OH)_2$  (or more probable  $FeO\bullet nH_2O$ ), however the activity of oxygen and water can yield different items having distinctive colors (Roberge, 2008):

- Fe<sub>2</sub>O<sub>3</sub>·H<sub>2</sub>O or hydrous ferrous oxide, sometimes written as Fe(OH), is the principal component of red-brown rust. It can form a mineral called hematite, the most common iron ore.
- Fe<sub>3</sub>O4·H<sub>2</sub>O or hydrated magnetite, also called ferrous ferrite (Fe<sub>2</sub>O<sub>3</sub>·FeO), is most often green but can be deep blue in the presence of organic complexants.
- $Fe_3O_4$  or magnetite is black.

Consider a bit of iron presented to muggy air which goes about as an electrolyte.  $Fe_2$ + ions are discharged from the anode by oxidation and OH– particles from the cathode by decrease on the metal surface. The negative and positive ions combine.

Corrosion can be formed by a differential in temperature, this happened particularly when the temperature differ sufficient to alter the level of dissolved oxygen from one location to another. The anode and cathode consist of the same metal and differ only in temperature.



Figure 3.11: Concentration cell formation in an underground pipeline (Ahmad, 2006)



Figure 3.12: Formation of rust in seawater (Ahmad, 2006)

In most consumption issues, the critical contrasts in response potential are not those between unique metals, but rather are those that exist between independent regions blended over all the surface of a solitary metal. These potential contrasts result from neighborhood concoction or physical contrasts inside or on the metal, for example, varieties in grain structure, hassles, and scale considerations in the metal, grain limits, and scratches or other surface condition. Steel is a combination of immaculate iron with little measures of carbon present as Fe3C and follow measures of other components. Iron carbide (Fe3C) is cathodic as for iron. In light of the fact that in run of the mill consumption of steel the anodic and cathodic regions untruth next to each other on the metal surface, basically it is secured with both positive and negative destinations. Amid erosion, the anodes and cathodes of metals may trade much of the time (Chilingar et al., 2008).

#### 3.5.1 Corrosion of weld joint in steel pipe

#### Factors influencing corrosion of weldments

It is sometimes difficult to determine why welds corrode; however, one or more of the following factors often are implicated (Davis, 2006):

- Weldment design
- Fabrication technique
- Welding practice
- Welding sequence
- Moisture contamination
- Organic or inorganic chemical species
- Oxide film and scale
- Weld slag and spatter
- Incomplete weld penetration or fusion
- Porosity
- Cracks (crevices)
- High residual stresses
- Improper choice of filler metal
- Final surface finish

# **Metallurgical factors**

The cycle of heating and cooling that occurs during the welding process affects the microstructure and surface composition of welds and adjacent base metal. Consequently, the corrosion resistance of autogenous welds and welds made with matching filler metal may be inferior to that of properly annealed base metal because of:

- Micro segregation
- Precipitation of secondary phases
- Formation of unmixed zones
- Recrystallization and grain growth in the weld heat-affected zone (HAZ)
- Volatilization of alloying elements from the molten weld pool
- Contamination of the solidifying weld pool

Corrosion resistance can usually be maintained in the welded condition by balancing alloy compositions to inhibit certain precipitation reactions, by shielding molten and hot metal surfaces from reactive gases in the weld environment, by removing chromium-enriched oxides and chromium-depleted base metal from thermally discolored (heat tinted) surfaces, and by choosing the proper welding parameters.

# Weld microstructures

Weldments exhibit special microstructural features that need to be recognized and understood in order to predict acceptable corrosion service life of welded structures. This chapter describes some of the general characteristics associated with the corrosion of weldments. The role of macro compositional and micro compositional variations, a feature common to weldments, is emphasized in this chapter to bring out differences that need to be realized in comparing corrosion of weldments to that of wrought materials. More extensive presentations, with data for specific alloys, are given in the chapters which immediately follow. Weldments inherently possess compositional and microstructural heterogeneities, which can be classified by dimensional scale. On the largest scale, a weldment consists of a transition from wrought base metal through an HAZ and into solidified weld metal and includes five micro structurally distinct regions normally identified as the fusion zone, the unmixed region, the partially melted region, the HAZ, and the unaffected base metal. This microstructural transition is illustrated in Fig.3.7. The unmixed region is part of the fusion zone, and the partially melted region is part of the HAZ, as described below. Not all five zones are present in any given weldment. For example, autogenously (that is, no filler metal) welds do not have an unmixed zone.

## The fusion zone

Is the result of melting which fuses the base metal and filler metal to produce a zone with a composition that is most often different from that of the base metal. This compositional difference produces a galvanic couple, which can influence the corrosion process in the vicinity of the weld. This dissimilar-metal couple can produce macroscopic galvanic corrosion. The fusion zone itself offers a microscopic galvanic effect due to microstructural segregation resulting from solidification.



Figure 3.13: Schematic showing the regions of heterogeneous weld



Figure 3.13: Concentration profile of chromium and nickel across the weld fusion boundary region of type 304 stainless steel

The fusion zone also has a thin region adjacent to the fusion line, known as the unmixed (chilled) region, where the base metal is melted and then quickly solidified to produce a composition similar to the base metal (Ref 4). For example, when type 304 stainless steel is welded using a filler metal with high chromium-nickel content, steep concentration gradients of chromium and nickel are found in the fusion zone, whereas the unmixed zone has a composition similar to the base metal.

#### Heat-affected zone

The HAZ is the portion of the weld joint which has experienced peak temperatures high enough to produce solid-state microstructural changes but too low to cause any melting. Every position in the HAZ relative to the fusion line experiences a unique thermal experience during welding, in terms of both maximum temperature and cooling rate. Thus, each position has its own microstructural features and corrosion susceptibility. The partially melted region is usually one or two grains into the HAZ relative to the fusion line. It is characterized by grain boundary liquation, which may result in liquation cracking. These cracks, which are found in the grain boundaries one or two grains below the fusion line, have been identified as potential initiation sites for hydrogen-promoted underbead cracking in high-strength steel.

## **Unaffected base metal**

Finally, that part of the workpiece that has not undergone any metallurgical change is the unaffected base metal. Although metallurgically unchanged, the unaffected base metal, as well as the entire weld joint, is likely to be in a state of high residual transverse and longitudinal shrinkage stress

#### 3.6 Pipeline and Pipeline Corrosion

The concept of pipe is characterized as a rule of round cross area. It can be made of any suitable material, for example, steel cast iron, HDPE.etc. The pipeline concept alludes to a long line of associated fragments of pipe, with pumps, valves, control tools, and other tool/offices required for working the system. It is proposed for transporting a fluid (liquid or gas), mixture of fluids or solids and fluid solid mixture (Liu, 2003).

The metal in the pipe line is steel, fundamentally involved iron with one to two percent alloy for quality and strength. With respect to outer corrosion, the circumstance would be seawater for offshore pipelines and groundwater or clammy soil for onshore pipelines. The decay would be disintegration of the iron into the environment, which decreases the quality of the pipeline (Baker, 2008).

Regularly, corrosion in pipelines shows as setting as opposed to as a uniform decrease in wall thickness. This is on account of nature at an anodic range has a tendency to wind up more acidic. In such cases the pits will be detached from one another and, different times, they will be so near one another that they overlap and create a general yet unpredictable diminishing in the pipe wall.

Seamless pipes have been utilized as a part of a few frameworks. Most pipeline contains a longitudinal weld, or seam. The long seam, as it is called, most much of the time is made by submerged-arc segment welding or upset butt welding. A submerged-arc weld contains a filler metal that has a creation somewhat, not the same as that of the body of the pipe and the heat influenced zone beside the weld metal has a microstructure not quite the same as that of whatever is left of the pipe. Upset butt welds, which can be either electric-resistance welds or flash welds, don't contain filler metal; they likewise have a heat influenced zone that has an alternate microstructure. Since these distinctive microstructures can be more

powerless to corrosion than the encompassing metal, particular corrosion at the seam can here and there happen with minimal contiguous corrosion related collapse.

MIC (Microbiologically affected corrosion) is brought about by microorganisms whose activities start the corrosion cycle. There are a few sorts of organisms that, while creating distinctive impacts, have been found to advance either outside or inside corrosion. The principle sorts are sulfate-reducing microscopic bacteria (SRB) and corrosive producing bacteria (APB). Microscopic organisms can advance outside corrosion by depolarizing the pipe through the utilization of hydrogen gas shaped at the pipe surface by the cathodic assurance streams. When the pipe is depolarized, corrosion can happen (Baker, 2008).

## 3.7 Corrosivity in Soil

There are more than 3.7 million kilometers (2.3 million miles) of pipelines crossing the United States, transporting natural gas and hazardous liquids from sources such as wells, refineries, and ports to customers. Underground corrosion is of major importance and results in a significant portion of pipeline failures. Because of corrosion, these pipelines must be regularly inspected, maintained, and sometimes replaced (Ricker, 2010). Soil corrosivity, when contrasted with that of the air or seawater corrosivity is regularly harder to classify with respect to both pipe particular parameters and encompassing soil properties (Ferreira, 2006). This is because of the soil's to a great degree confined many sided quality and heterogeneity.

In soils, water and gas occupy the spaces between solid particles, and these spaces can constitute as much as half the volume of dry soil. Some of this water is bound to mineral surfaces, whereas bulk water can flow through porous soil. Fluid flow through soil is controlled by the permeability of the soil, which, in turn, depends on the size distribution of the solid particles in the soil. Coarse – grained sand, for example, allows good drainage and access of atmospheric oxygen to a depth greater than, for example, fine - grained soils high in clay. Capillary action in fine - grained soil can draw water up, keeping the soil water - saturated, preventing drainage, retarding evaporation, and restricting oxygen access from the atmosphere to a buried structure, such as a pipeline (Wilmott and Jack, 2000).

The electrochemical corrosion processes that take place on metal surfaces in soils occur in the groundwater that is in contact with the corroding structure. Both the soil and the climate influence the groundwater composition. For example, some clay soils buffer the groundwater pH. Groundwater in desert regions can be high in chloride and very corrosive. On the other hand, groundwater in tropical climates tends to be very acidic. The corrosion behavior of iron and steel buried in the soil approximates, in some respects, the behavior on total immersion in water. Minor composition changes and structure of steel, for example, are not important to corrosion resistance. Hence, a copper - bearing steel, low alloy steel, mild steel, and wrought iron are found to corrode at approximately the same rate in any given soil. In addition, cold working or heat treatment does not affect the rate. Gray cast iron in soils, as well as in water, is subject to graphitic corrosion. Galvanic effects of coupling iron or steel of one composition to iron or steel of a different composition are important, because they are under conditions of total immersion (Revie and Uhlig, 2008). In other respects, corrosion in soils resembles atmospheric corrosion in that observed rates, although usually higher than in the atmosphere, vary to a marked degree with the type of soil. A metal may perform satisfactorily in some parts of the country, but not elsewhere, because of specific differences in soil composition, pH, moisture content, and so on. For example, a cast iron water pipe may last 50 years in New England soil, but only 20 years in the more corrosive soil of southern California. Corrosion rates of underground pipeline have been measured using the Stern - Geary linear polarization method, as well as weight loss. The former method has been useful, for example, in assessing the corrosion rates of footings of galvanized - steel towers used to support power lines Figure 3.7 shows the mechanism of corrosion of buried pipe.



Figure 3.14: Corrosion mechanism of soil for buried steel pipe (Camitz, 1998)

# 3.7.1 Factors affecting the corrosivity of soil

One of the primary variables that impact the rate of outer corrosion is the distinctions in the attributes of the soil from spot to put along a pipeline, and from top to bottom. Contrasts in air circulation, moisture content, and soil arrangement in these regions can create solid main impetuses for corrosion (Baker, 2008).

Among the factors that affect corrosivity of a given soil are:

- Porosity (aeration).
- Electrical conductivity or resistivity
- Dissolved salts, including depolarizers or inhibitors
- Moisture
- pH
- Soil texture

The variety of concoction and physical properties in the soil, even over a solitary site, can change how an item corrodes contrasted with another indistinguishable object. At the point when underground pipes are initially introduced a refill is comprised of accessible (regularly irritated) soil from close-by, frequently this soil will contain transported material and building waste, either from the close-by surface or, in the event that it is brought into the site from somewhere else, it is the thing that geotechnical architects portray as "made ground" (Waltham, 2002). The Figure 3.8 shows the different and direction of current.



Figure 3.15: Corrosion produces in disturbed soil vs. undisturbed soil, the direction of positive current represented by arrow (Bradford, 2001)

Each of these variables may affect the anodic and cathodic polarization characteristics of a metal in a soil. A porous soil may retain moisture over a longer period of time or may allow optimum aeration, and both factors tend to increase the initial corrosion rate. The situation is more complex, however, because corrosion products formed in an aerated soil may be more protective than those formed in non-aerated soil. In most soils, particularly if not well - aerated, observed corrosion takes the form of deep pitting. Localized corrosion of this kind is obviously more damaging to a pipeline than a higher overall corrosion rate occurring more uniformly. Another factor to be considered is that, in poorly aerated soils containing sulfates, sulfate – reducing bacteria may be active; these organisms often produce the highest corrosion rates normally experienced in any soil.

Aeration of soils may affect corrosion not only by the direct action of oxygen in forming protective films, but also indirectly through the influence of oxygen reacting with and decreasing the concentration of the organic complexing agents or depolarizers naturally present in some soils. In this regard, the beneficial effect of aeration extends to soils that harbor sulfate - reducing bacteria because these bacteria become dormant in the presence of dissolved oxygen. Soil composition is an essential variable, clay soil because of its inborn sub-atomic structure, can hold dampness more promptly than a sandy soil This implies water in clay is all the more effortlessly held thus, has a more prominent presentation to any covered metal surfaces, encouraging the corrosion activity of the soil (Jones, 1992) the different field moisture capacity as a function of different sand contents shown in Figure 3.9.



Figure 3.16: Different moisture capacities as afunction of sand content

A soil containing organic acids derived from humus is relatively corrosive to steel, zinc, lead, and copper. The measured total acidity of such a soil appears to be a better index of its corrosivity than pH alone. High concentrations of sodium chloride and sodium sulfate in poorly drained soils, such as are found in parts of southern California, make the soil very corrosive.

Macro galvanic cells or "long - line" currents established by oxygen concentration differences, by soils of differing composition, or by dissimilar surfaces on the metal become more important when electrical conductivity of the soil is high. Anodes and cathodes may be thousands of feet, or even miles, apart. A poorly conducting soil, whether from lack of moisture or lack of dissolved salts or both, is, in general, less corrosive than a highly conducting soil. But conductivity alone is not a sufficient index of corrosivity.

While the ionic substance of a watery medium, the question frequently emerges in respect to how acid, or alkaline, is the arrangement. Very essentially, this alludes to whether there is an abundance of H+ (hydrogen) or OH (hydroxyl) particles present. The H particle is acid while the OH particle is alkaline or essential (Roberege, 2008).

Hydrogen ion activity is commonly expressed, for convenience, in terms of pH, defined as

$$pH = -\log(H^+) \tag{3.2}$$

Hence, for the half - cell reaction 2H+ + 2 e  $\rightarrow$  H2, with the pressure of hydrogen equal to

$$\phi_{H_2} = -0.0592 \tag{3.3}$$

Since pure water contains equal concentrations of H+ and OH– in equilibrium with un dissociated water, H2O  $\rightarrow$  H+ + OH–, it is possible to calculate the activity of either the hydrogen ion or the hydroxyl ion from the ionization constant, the value of which at 25 ° C is  $1.01 \times 10-14$ . Therefore, the pH of pure water at 25 ° C is

$$-\log\sqrt{1.01*10^{-4}} = 7.0\tag{3.4}$$

If (H+) exceeds (OH–), as in acids, the pH is less than 7. If the pH is greater than 7, the solution is alkaline. The pH of strong acids can be negative, and the pH of strong alkalies can be greater than 14. At temperatures above 25 °C, the ionization constant of H2O is greater than at 25 °C; therefore, above 25 °C, the pH of pure water is less than 7 (Revie and Uhlig, 2008).

Higher pH implies there are less free hydrogen ions, and that a change of one pH unit mirrors a tenfold change in the concentrations of the hydrogen ion. For instance, there are 10 times the same numbers of hydrogen ions accessible at pH 7 than at pH 8. Substances with a pH less that 7 are thought to be acidic, and substances with a pH equivalent to or more prominent than 7 are thought to be basic. Subsequently, a pH of 2 is extremely acidic and a pH of 12 exceptionally basic (Roberge, 1999).

# **3.8** Corrosion Measurement (The Weight Loss Method)

Electrochemical procedures give a distinct option for conventional methods used to decide the rate of corrosion quantitative determination of corrosion rates and Immediate. The determination of the corrosion rate will be as a time function.

Weight reduction tests are the most widely recognized of all rate estimation tests. A little metal coupon (generally low-carbon steel) is uncovered in the liquid or soil or exposed to any corrosive environments framework where corrosion may be dynamic. The coupon is left for a limited time frame and after that evacuated, cleaned, and weighed to decide the measure of metal loss. Weight reduction, surface area of coupon, and presentation time are utilized to compute corrosion rate (Chilingar et al. 2008) described in section 4.1.2 chapter four.

The weight of the specimen former and in the wake of being presented to soil environment was recorded to decide the metal loss and therefore the corrosion rate equation 4.1 in chapter 4.

# 3.9 Statistical Analysis and Corrosion Prediction

Predictive displaying and statistical procedure control have gotten to be indispensable parts of the present day science and building of complex frameworks. The massive presentation of computers in the working environment has additionally definitely changed the significance of these machines in every day operations. Models of materials corruption procedures have been created for a huge number of circumstances utilizing an awesome assortment of strategies. For researchers and specialists who are creating materials, models have turned into a fundamental benchmarking component for the choice and life forecast connected with the presentation of new materials or procedures.

Models are in this setting an acknowledged technique for representing to current understandings of reality. For frameworks chiefs, the corrosion execution or under performance of materials has an altogether different significance. In the setting of lifecycle administration, corrosion is stand out component of the entire picture, and the principle trouble with corrosion information is to convey it to the framework administration level.

Statistical appraisal of time to disappointment is an essential theme in dependability building for which numerous numerical apparatuses have been produced. Evans, who pioneered the mixed-potential theory to explain basic corrosion kinetics, propelled the idea of corrosion likelihood in connection to limited corrosion. As indicated by Evans, a precise learning of the corrosion rate was less critical than discovering the statistical danger of its introduction. Petting is, obviously, one and only of the numerous types of limited corrosion, and the same contention can be reached out to any type of corrosion in which the instruments controlling the start stage vary from those controlling the spread stage (Roberge, 1999).

Statistics is the section of scientific method which manages the data acquired by counting or measuring the properties of natural phenomena, a natural phenomenon incorporates everything of the happenings of the external world, whether human or not.

The "Statistical Package for the Social Sciences" (SPSS) is a package of programs for manipulating, analyzing, and presenting data. the package is widely used in the social and behavioral sciences. There are several forms of SPSS. The core program is called SPSS Base and there are a number of add-on modules that extend the range of data entry, statistical, or reporting capabilities (Landau and Everitt, 2004). The software was utilized in a previous study on pipeline corrosion in Nouth Iraq by Hawkers MSc thesis (2016).

# **3.10 Importance and Cost of Corrosion**

The three principle purposes behind the significance of corrosion are: financial aspects, wellbeing, what's more, protection. To lessen the monetary effect of corrosion, corrosion engineers, with the backing of corrosion researchers, mean to lessen material misfortunes,

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as well as the going with financial misfortunes, that outcome from the corrosion of channeling, tanks, metal parts of machines, boats, spans, marine structures, etc. Corrosion can trade off the security of working gear by bringing on disappointment (with disastrous results) of, for instance, weight vessels, boilers, metallic compartments for poisonous chemicals, turbine sharp edges and rotors, spans, plane segments, and car directing components. Wellbeing is a basic thought in the outline of hardware for atomic force plants and for transfer of atomic squanders. Loss of metal by corrosion is a waste not just of the metal, additionally of the vitality, the water, and the human exertion that was utilized to create and manufacture the metal structures in the first place. Furthermore, revamping eroded hardware requires further venture of every one of these assets metal, vitality, water, and human. Financial misfortunes are partitioned into direct misfortunes and circuitous misfortunes.

Direct misfortunes incorporate the expenses of corrosion structures and hardware on the other hand their segments, for example, condenser tubes, suppressors, pipelines, and metal material, including fundamental work. Different illustrations are (a) repainting structures where anticipation of rusting is the prime target and (b) the capital expenses in addition to upkeep of cathodic insurance frameworks for underground pipelines.

Sizable direct misfortunes are represented by the need to a few million residential hot water tanks every year in view of disappointment by consumption and the requirement for substitution of a great many consumed vehicles mufflers. Direct misfortunes incorporate the additional expense of utilizing consumption - safe metals and combinations rather than carbon steel where the last has sufficient mechanical properties however not sufficient erosion resistance There are additionally the expenses of arousing or nickel plating of steel, of adding erosion inhibitors to water, and of dehumidifying storage spaces for metal gear (Revie and Uhlig, 2008).

The financial component is also a vital for a significant part of the current research in corrosion. Misfortunes supported by industry and by governments sum to numerous billions of dollars every year, pretty nearly \$ 276 billion in the United States, or 3.1% of the Gross Domestic Product (GDP), as indicated by a later study. It has been assessed that around 25 - 30% of this aggregate could be stayed away from on the off chance that at present accessible consumption innovation were adequately connected. Investigations of

the expense of consumption to Australia, Great Britain, Japan, Turkey and other nations have likewise been done. In every nation examined, the expense of corrosion is more or less 3-5 % of the Gross National Product. Backhanded misfortunes are more difficult to evaluate, however a brief overview of average misfortunes of this kind urges the conclusion that they add a few billion dollars to the direct misfortunes effectively outlined (Koch et al., 2002).

Some examples of indirect losses can be as follows:

• Shutdown

The substitution of a consumed tube in an oil refinery may cost a couple of hundred dollars; however shutdown of the unit while repairs are in progress may cost \$ 50,000 or more every hour in lost creation. Thus, substitution of consumed heater or condenser tubes in an expensive force plant may require \$ 1,000,000 or more every day for force acquired from interconnected electric frameworks to supply clients while the evaporator is down. Misfortunes of this kind cost the electrical utilities in the United States large amount of money every year.

- Loss of Product: Misfortunes of oil, gas, or water happen through a corroded channel framework until repairs are made. Radiator fluid may be lost through a corroded auto radiator; or gas spilling from a corroded pipe may enter the storm cellar of a building, bringing on a blast.
- Loss of Efficiency: Loss of efficiency may happen as a result of decreased warmth exchange through gathered corrosion items, or due to the obstructing of channels with rust requiring expanded pumping limit. It has been assessed that, in the United States, expanded pumping limit made vital by fractional obstructing of water mains with rust, costs large amount of money every year. A further sample is given by inner ignition motors of vehicles where cylinder rings and chamber dividers are consistently consumed by ignition gasses and condensates. Loss of discriminating measurements prompting over abundance gas and oil utilization can be brought about by consumption to a degree equivalent to or more noteworthy than that created by wear. Corrosion procedures can force limits on the efficiencies of vitality transformation frameworks, speaking to misfortunes that may add up to billions of dollars.

- Contamination of Product: A little measure of copper grabbed by slight corrosion of copper channeling or of metal gear that is generally strong may harm a whole clump of cleanser. Copper salts quicken rancidity of cleansers and abbreviate the time that they can be put away before utilization. Hints of metals might likewise adjust the shade of colors.
- Overdesign: Over design is normal in the design of response vessels, boilers, condenser tubes, oil well sucker poles, pipelines transporting oil also, gas at high weight, water tanks, and marine structures. Gear is frequently planned ordinarily heavier than typical working weights or connected anxieties would require so as guaranteeing sensible life. With sufficient information of consumption, more solid appraisals of gear life can be made, and configuration can be simplified regarding materials and work. For instance, oil well sucker poles are typically overdesigned to expansion administration life before disappointment happens by corrosion weakness. On the off chance that the consumption components were disposed of, misfortunes would be sliced at any rate down the middle. There would be further investment funds in the light of the fact that less power would be obliged to work a lightweight bar, and the cost of recuperating a lightweight pole after breakage would be lower.

Indirect misfortunes are a significant piece of the monetary expense forced by corrosion, despite the fact that it is hard to land at a sensible appraisal of aggregate misfortunes. In the occasion of loss of wellbeing or life through blast, unusual disappointment of compound hardware, or destruction of planes, or autos through sudden disappointment by consumption of basic parts, the circuitous misfortunes are still harder to survey and are past translation as far as dollars (Revie and Uhlig, 2008).

## 3.11 Pipeline Design Considerations and Pipeline Failure Modes

# **3.11.1 Pipeline design considerations**

The vast majority of oil and gas transmission pipelines are made of carbon steel (Bodude et al., 2012). The American Petroleum Institute API 5L specification specifies the maximum composition limit of carbon, phosphorus, manganese and sulphur. Nevertheless, other

alloying elements may be added to improve on some mechanical properties of the steel for specific applications.

Carbon steels have inadequate corrosion resistant properties thus undergo various corrosion failure modes in underground environments (Beavers J.A and Thompson 2008).

Because of the level of hazard posed by their products to the environment, pipelines are designed to well-established international standards. These standards ensure operational safety, compliance to legislation, security of supply and cost effectiveness (Ekott et al.,2012). These criteria are met by designing to prevent failure as a result of burst, puncture, overload, buckling, fatigue and fracture. Preventing failure of pipelines therefore begins with good design, which will eliminate most of the above potential failure modes. However, since pipelines operate in adverse environments (underground), they are constantly threatened by defects and damages that occur during service. These in-service defects are the major culprits in pipeline failures.

# **3.11.2 Pipeline failure modes**

These in-service defects can be broadly outlined into two categories:

- External force third party damages, mechanical damages and outside interference.
- Corrosion of the pipe wall, either internally by the product conveyed or externally by the interaction with the surrounding environment.

External damages occur as a result of sabotage or mechanical damages. Sabotage occurrences are underpinned by the existence socioeconomic inequality. It occurs more often in regions of economic deprivation and perceived social injustices. Mechanical damages result from impact from e.g. earth moving equipment in excavation sites.

Other causes of failure could be attributed to defects in materials and construction. Material defects may originate during pipeline fabrication. They cause non-uniformity in the pipeline material creating sites for differential cell formation which accentuates the oxidation-reduction reaction that leads to corrosion. Construction defects include scratches and dents. They can serve as sites for extreme corrosion attacks.

# 3.12 External Corrosion Mechanism in Underground Pipelines

Steel pipelines undergo a variety of corrosion failure mechanisms in underground environment. The most important of these include differential cell corrosion and stress-corrosion cracking (SCC) (Beavers and Thompson 2008).



purce: Dawotola, (2012).

Figure 3.17: External corrosion in an underground pipeline

# 3.12.1 Differential cell corrosion

In underground environment, the pipeline material does not undergo a uniform metal loss along its surface. Rather there is an uneven metal loss over localized areas in the pipe surface. The mechanism that gives rise to this is the differential corrosion cell. Corrosion is basically an oxidation-reduction reaction. Existence of a significant difference in potential between two points in the metal surface creates an anodic and a cathodic site between the points. This causes an exchange of electrons (redox reaction) between the points. It is this electron exchange that leads to corrosion. Various pipe surface and environmental conditions can give rise to a difference in potential in the surface of buried pipelines Underground pipelines corrosion is predominantly due to the existence of differential corrosion cells. Differential corrosion cells may arise as a result of different oxygen concentration levels in the soil (differential aeration cell), varying soil properties, presence of dissimilar metals (galvanic corrosion), presence of surface films etc (Beavers and Thompson 2008; Ekott et al.,2012).

# 3.12.2 Differential aeration cells

This form of differential cell is set up in an underground structure when one end of the pipeline line is exposed to a higher oxygen concentration, while the other is situated in an oxygen deficient area. The part of the structure in the higher oxygen concentration region becomes the cathode and the oxygen deficient end forms the anode. Electrons flow from the metal surface in the anodic site to the oxygenated cathode. The flow of current increases the corrosion rate in the anode. Two consequences of this electrochemical reaction tend to promote the continuation of the cells. The first is the hydrolysis of the metallic ions produced by the corrosion reactions in the anode. This reduces the local pH. The second consequence is the migration of corrosive halide ions to the anodic sites to maintain charge neutrality. Both of the processes increase the corrosion rate at the anode. On the other hand, the reduction reactions at the cathode increase the pH and improve the formation of corrosion protective films on the metal surface (Beavers and Thompson 2008).

# 3.12.3 Varying soil properties

Variation in soil properties as a result of difference in moisture content, pH, soil type, presence of microbes and aggressive ions in the soil can set up differential corrosion cells (Ekott E.J et al).

# 3.12.4: Galvanic corrosion

Material	Potential (CSE)(a), V.		
Most Noble			
Carbon, graphite, coke	+3		
Platinum	0 to -0.1		
Mill scale on steel	-0.2		
High silicon cast iron	-0.2		
Copper, brass, bronze	-0.2		
Low-carbon steel in concrete	-0.2		
Lead	-0.2		
Cast iron (not graphitized)	-0.5		
Low-carbon steel (rusted)	-0.5		
Low-carbon steel (clean and shining)	-0.2 to -0.5		
Commercially pure aluminium	-0.5 to -0.8		
Aluminum alloy (5% Zn)	-0.8		
Zinc	-1.05		
Magnesium alloy (Mg-6Al-3Zn- 0.15Mn)	-1.1		
Commercially pure magnesium	-1.6		
Most Active	-1.7		
Measured with respect to copper sulphate reference electrodes (CSE)			

**Table 3.1:** Practical galvanic series and redox potentials of metals and alloys in neutral soils and water

Source: Peabody, (2001)

This form of corrosion results from the coupling of two dissimilar. Metals can be arranged according to their redox potentials as shown in Table 2 below. The metal with the more positive potential forms the cathode (reduced corrosion rate), while the negative potential member of the couple becomes the anodic site, increasing its corrosion rate. Although,

galvanic corrosion can be detrimental to structures, it is also useful as a means of corrosion control through cathodic protection (CP(Peabody A.W.2001)

# 3.12.5 Corrosion control

1 Preventing or mitigating pipeline failures has become more important than ever. This need is not unconnected with the ever growing anxiety to curb environmental degradation due to spillage of petroleum products. The best approach is to develop methods of detecting potential failure defects before they occur, and effecting necessary repairs. We cannot expect the same or enhanced performance from our ageing pipeline infrastructures without some engineering intervention. Therefore, continued operational safety will require pipeline management systems that reduce failures either by prevention or detection (Hopkins p., 2002). Corrosion can be prevented by installing appropriate corrosion control systems. Application of high performance coatings in conjunction with an effective cathodic protection (CP) system is the best way to protect a new pipeline from corrosion. A well applied coating isolates the pipe steel surface from the environment (electrolyte) preventing the occurrence of the electrochemical process that leads to corrosion. All coatings necessarily contain some defects or holes that expose small portions of the pipe surface to the underground environment. The function of the CP is to protect the exposed surfaces from corrosion. Preventing SCC in existing pipelines involves minimizing the operating temperature, controlling CP levels to values more negative than -850mV CSE and minimizing the pressure fluctuations (Beavers J.A. and Thompson, 2008)

# 3.12.6 Coatings

Pipe coatings are materials laid along the pipe surface to isolate it from the environment. Poor performance of the coating is a major contributing factor to underground corrosion. The ability of the coating material to withstand degradation is a key to its selection and long term performance. It is therefore important that the coating material must be carefully selected. Beavers et al (2006) listed some characteristics desired in an effective coating material. They include:

- Effective electrical insulation
- Effective moisture barrier
- Good adhesion to pipe surface

- Ability to resist damage during handling, storage and installation
- Resistance to disbonding
- Resistance to chemical degradation
- Ease of repair
- Nontoxic to the environment etc.

Many forms of materials are available for coating underground pipelines. When first installed these coatings are able to meet their basic requirements i.e. isolate the external pipe surface from underground environment, minimize CP requirement and enhance CP current distribution. The prime consideration in their selection is the ability to resist degradation over time, and the ability of the coating to minimize shielding should it fail. The engineer will ultimately rely on field reports on performance of coatings to aid in selection. However, guidelines for such selection have been developed by professionals over time (CEPA, 1997). Uses of polyethylene and multilayer coatings have been reported to have longer service life (Achebe C.H et al)..

# 3.12.7 Cathodic protection

Corrosion is basically an electrochemical process involving an oxidation-reduction reaction. Two sites are setup in this process - the cathode (reduction site) and the anode (oxidation site). This reaction results in the formation of metallic oxides. The oxides formed by most metals form a protective film over them preventing further attack. However, the oxide of iron (which is the base metal in steel) is readily broken down, and in the presence of moisture will undergo further deterioration. By altering the electrochemical nature of the corroding surface, the process of corrosion can be prevented or mitigated. In theory, this involves making the external pipe surface the cathode of the electrochemical cell by applying a negative potential to the system. The rate of corrosion (oxidation) of the pipe surface is thus reduced or prevented. CP also alters the pipe environment in such a way as to mitigate corrosion. The pH of any electrolyte on the pipe surface is increased, oxygen concentration is reduced and deleterious ions migrate away from the pipe surface (Beavers J.A and Thompson 2008). There are two approaches to applying CP systems: sacrificial anode CP and impressed-current CP systems



Figure 3.13: Cathodic protection of (a) an underground pipeline tank using magnesium sacrificial anode, (b) an underground tank using an impressed current. (William D Callister).

# 3.12.8 Sacrificial anode CP

The sacrificial anode technique utilizes a metallic material that has a more negative potential in relation to the pipe steel. When both metals are coupled together the pipe steel becomes the cathode as shown in figure 3.13. Oxidation is reduced at the pipe surface preventing or slowing down the rate of corrosion of the pipe. At the anode, the rate of corrosion is increased. The negative potential metal thus corrodes at the expense of the pipe steel. Common sacrificial anode materials utilized in underground pipeline are zinc and magnesium.

# 3.12.9 Impressed-current IC

The most common method of cathodic protection in underground pipeline is by using impressed-current (Ekott J..E et al 2012). This method utilizes an external power source to control the voltage between the pipe and an anode in such a way that the pipe becomes the cathode, mitigating corrosion. It is noted that CP increases the pH of the electrolyte on the pipe surface. This can create the potential environment for high pH SCC initiation. But high pH SCC propagates only within a limited potential range. Thus by maintaining the potential of the pipe surface outside this range, by proper CP control can mitigate the propagation of high pH SCC

#### 3.13 Pipeline Inspection and Maintenance

Most often, failure due to corrosion in pipelines can be attributed to failure of the corrosion control systems installed (Hopkins p., 2002). These failures do not occur suddenly. There are usually telltale signs to their eventually occurrence. With diligent maintenance programs, corrosion defects can be assessed, evaluated and proper intervention made before they result in failure. This preventive maintenance approach is vital when one considers the myriad consequences that can result from a petroleum pipeline failure. Pipelines are required to be routinely inspected to ascertain their integrity. Corrosion monitoring is an integral part of this integrity management program. Various methods exist for monitoring/detection of corrosion in pipelines. The methods aim to ensure that pipelines do not become defective and that defects are detected before they can cause damage. The methods commonly employed to detect corrosion in underground pipelines are hydrostatic testing, direct assessment and in-line inspection

#### **3.13.1 Hydrostatic testing**

Pipelines should be periodically hydro-tested in-service to prove their integrity. The process involves pressure testing the pipeline with water at higher pressures than the pipeline operating pressure, typically 110% of specified minimum yield strength (SMYS) (Hopkins p., 2002). Any defect larger than a critical size will fail at this hydrostatic test pressure

#### **3.13.2 Direct assessment**

In direct assessment field inspection programs the overall condition of the pipeline corrosion system and its coating is determined using above ground measurements. The data is then used to prioritize the system for direct examination, hydrostatic testing, in-line inspection, recoating or pipe replacement.

# 3.13.3 In-line inspection

Pipelines can be monitored from the inside without disrupting the product flow by using in-line inspection tools, also called intelligent pigs. The pigs are sophisticated devices that travel with the product and via array of sensors record data about the condition of the pipe. They can measure metal loss (due to corrosion and cracking) and geometric abnormalities

(e.g. dents). There are two basic types of inline tools for measuring metal loss: magnetic flux leakage tools and ultrasonic tools.



Figure 3.14: Magnetic pig travelling in a pipeline

## 3.13.4 Maintenance and repair

In pipeline maintenance, two options are available to the engineer: repair or replace. Once corrosion or crack is detected, the size of the defects must be measured. Assessment of the defect size will determine the appropriate intervention. The defect size is usually ascertained by direct examination i.e.by direct measurement in the field. The length of crack is ground out to establish the maximum crack depth. Burst pressure models or fracture mechanics techniques can be used to determine the failure pressure of the affected sections. If the burst pressure (usually 100% SMYS) is within acceptable limit the pipe is recoated. However, if it is less than the acceptable limit the pipe is replaced or repaired using steel or composite sleeves and recoated. If failure occurs in hydrostatic testing, the only option is to replace the failed sections. Replacement is also recommended when there is an extensive corrosion localized within an area in the pipeline. Improvement of the CP system to reduce corrosion or crack growth is also an option in areas where the growing crack is not an immediate threat to pipeline integrity. Generally, the maintenance or repair option is decided by the engineer after a careful assessment of the information gotten from the inspection tools. Other factors like cost, urgency and engineering considerations are also important in the choice of repair options (Hopkins p., 2002).

# CHAPTER 4 METHODOLOGY

# 4.1 Materials

### 4.1.1 Soil samples

The properties of soil are considered as one of the most important parameter that influences the corrosion rate of steel pipelines. Through this point the investigation of soil characteristics in this research came out. Thus, the soil properties of underground pipelines that transport the refine crude oil from kaduna refinery to Kano deport from oil wells located in east of Nigeria must be examined.

The eight soil samples were collected along the pipeline; the pipeline route in area consists of complex terrain and agricultural land of Tamburawa area of Kano Figure 4.1. The samples were labeled as 'S-1, S-2, S-3, S-4, S-5, S-6, S-7, and S-8'. The samples were taken from the depth of about one meter from the ground level from the real location of the pipelines in (June 2018), the soil samples were taken in to an air tight polyvinyl container less than 24 hours after collection from actual site (Bhattarai, 2013) as shown in Figure 4.2 preserved with the desired inherent conditions in accordance with the ASTM D 4220-95 Reapproved, 2000 (Standard Practices for Preserving and Transporting Soil Samples, Appendix 4), Figure 4.3, the procedure presented in this standard were primarily developed for soil samples that are to be tested for engineering properties, Figure 4.4. The area is located in Tamburawa town in Kano at latitude of 11.87° N and longitude of 8.53° E. Figure 4.5 is a photograph of the research group along the pipeline network.



Figure 4.1: Map of Nigeria showing petroleum pipelines (Dawatola et al., 2009)



Figure 4.2: Soil sample collected from the pipeline site



Figure 4.3: Soil sample in its bag



Figure 4.4: The eight soil samples from pipeline site



Figure 4.5: Picture of Dr. Isa myself and the technicians from NNPC at pipeline site

# **4.1.2 Pipeline material**

An API 5L X 70 steel pipe was used as a case study for the research to examine the significance of soil guideline on the corrosion rate of the pipeline A typical dimension of a steel pipe was approximately 1219 mm external diameter and internal diameter is 812 mm. The eight test specimens of steel coupon were cut from the pipe, the flat coupons have dimensions of ( $60 \text{ mm} \times 40 \text{ mm} \times 20 \text{ mm}$ ), (Nour et al, 2012) the coupon drawing is shown in Figure 4.6. Exploit hot cut process; cold cut technique was at that point used to displace heat influenced area of the coupon which may bring about changes in properties of the material. The crusts of those specimens were removed. The procedures, preparation and cleaning processes were done following the ASTM G 01-03 Reapproved, 1999 (Standard practice for preparing, cleaning and assessing corrosion test specimen (American Society for Testing and Material/Appendix 4).



Figure 4.6: Coupon sample dimensions (mm)



(a) Samples of steel pipe coupons(b) Samples of welded couponsFigure 4.7: Corroded coupons of steel samples

To assess the pipe corrosion rate the coupons were placed in a plastic container containing the soil samples for three months, installation preparation of soil medium were referred to ASTM 162-99 while the cleaning procedure of the coupon were referred to ASTM 01-03 (Anyawu et al, 2014).

The corrosion rate was calculated using Equation 4.1 below.

$$CR = \frac{KXW}{AXDXT} \tag{4.1}$$

Where: K = A constant

W = Weight loss in grams

- T = Time of exposure in hours
- $A = Area in cm^2$
- $D = Density in g/cm^3$

The results are given in Table 5.5 of Chapter 5, Page: 68. The chemical and mechanical properties of API  $5L \times 70$  are shown in Table 4.1 below.

Table 4.1: Chemical and mechanical properties of API 5L X70 steel

Chemical properties				Mechanical properties		
					Yield strength,	
					Psi (MPa)	Tensile Strength,
C%	Mn%	P%	S%	Ti%		Psi (MPa)
0.28	1.4	0.030	0.03	0.06	76000 (483)	82000 (565)

## 4.2 pH of Soil

pH is the measure of the acidity or basicity of a solution. The pH of a material plays a significant role in how aggressive the corrosion can be. The acidity of soil comes from mineral leaching, decay of acidic plants like (coniferous tree needles), industrial wastes, acid rain, and certain forms of microbiological activity. Alkaline soils tend to have high sodium, potassium, magnesium, and calcium contents; these elements produce calcareous deposits on buried structures that have protective behavior against corrosion. The pH level has an influence on the solubility of corrosion products and also the nature of microbiological activity (Roberge, 1999). Table 4.2 shows the relation between pH level and soil corrosivity (BS 1377 standard part 2: 1999).

## 4.2.1 Soil sampling

The following steps were adopted for soil sampling;

Step 1: Allow the initial soil sample to air-dry or sun-dry by spreading out on a tray.

**Step 2:** Sieve the sample on a 2 mm test sieve and brush retained particles other than stones to pass the sieve.

**Step 3:** Reject the stones, ensuring that no finer materials adheres to them, e.g. by brushing. Throughout these and subsequent operations, ensure that there is no loss of fines.

Corrosivity of soil	Relative acidity (pH) of soil extract
Low	> 12
Moderate	7.5 – 12
High	4 - 7.5
Very High	< 4
pH of the present soil at pipeline site	5.05 - 7.86

 Table 4.2: Corrosivity of soil and pH relative soil acidity

#### 4.2.3 pH test procedure

The test procedure was also carried out in accordance with the BS part 2: 1377 standard

 $1 - 30 \pm 0.1$ g of the soil sample was weighed in an analytical balance (Figure 4.8) and placed into a 100 ml beaker.

2 - A 75 ml of distilled water was added to the beaker, the suspension was stirred for few minutes. The beaker was then covered using glass cover and the mixture was allowed to stand for 8 hrs.

3 – Before testing, the suspension was immediately stirred.

4 – Standard buffer solution was used to calibrate the PH meter by adopting the manufacturers recommended procedures as shown in Figure 4.9.

5 – The electrode was washed with distilled water and submerged in the suspension. By stirring briefly between each reading, at least two readings of the PH of the suspension were taken.

6 – The electrode was removed from the suspension and washed using distilled water. The calibration of the pH was re-checked against one of standard buffer solutions.

7 – The instrument was adjusted to the correct 0.05 pH units when found out of adjustment. Steps 5 and 6 were repeated until the readings obtained were consistent.



Figure 4.8: A & D Gemini GR series analytical balance



Figure 4.9: A standard buffer solution for the calibration of pH meter

#### 4.3 Moisture Content Testing of the Soil

The test objective was to determine the relationship between soil moisture content and compacted dry density, employing two manual compaction efforts magnitudes. The test serves as a guide in providing field compaction specifications. Using e.g a 2.5 kg rammer (standard proctor), first light compaction test was conducted. Heavy compaction as a second test was conducted using 4.5 kg rammer with thinner soil layers (modified standard proctor) receiving greater drop. 11itre internal volume compaction mould for both tests was used for soil where by all its particles passed through 20 mm test sieve. (BS 1377 standard part 2 1999).

Test were carried out in the larger CBR mould for soils consisting up to 10% and 30% for materials coarser than 37.5 mm and 20 mm, respectively.

$$W = \frac{m_2 - m_3}{m_3 - m_1} \tag{4.2}$$

Where: W = Moisture content

 $m_1$  = Is the weight of the container (mg)

 $m_2$  = Is the weight of the container and wet soil (in g)

 $m_3$  = Is the weight of the container and dry soil (in g

# 4.3.1 Sample preparation

Five 5 representative samples each containing around 3 kg of material which were passed through a 20 mm test sieve were prepared. The lumps of the material were broken down by rolling on a flat surface. For material which was coarser where maximum of 10% and 30% were retained on the 37.5 mm and 20 mm sieve sizes, CBR mould was used. The coarser material (greater than 37.5 mm) was removed, weighed and replaced by similar amount of material of the 20 mm-37.5 mm fraction. To this respect, each of the five samples weighed about 6 kg.

Different water amount was used to thoroughly mix each sample to obtain suitable moisture contents range. The moisture contents range was position in such a way that the optimum moisture content lies between at least 2 values in either side. An air tight

container was used in sealing each of the 5 portions and then subjected to curing for at least 4 hours (BS 1377 standard Part 2:1990)

Refers to as determination of the quantity of water present in a soil given as the mass of dry soil percentage. This is called soil moisture content. The soil moisture content is expressed as the water amount inside the pure space between grains of soil which via 110c. The moisture content has a great influence on the behavior of soil.

1	
Sieve retaining not more than	Recommended mass of
about 10% of sample	moist specimen, g
2.0 mm (No.)	100 to 200
4.75 mm (No.)	300 to 500
19 mm (3/4 in.)	500 to 1000

 Table 4.3: Test specimen masses (ASTM D 4643-08)

# 4.4 Particle Size Analysis of the Soil

Test for soils classification, more specifically coarse soils, whereby different particle sizes present their relative portions. Owing to this, there is a possibility of determining whether the soil is composed of predominantly clay, sand, gravel or silt sizes and considering certain extent, in which the soil engineering properties a likely to be controlled by these size ranges. The procedure given was the major principle which involves sample preparation to remove silt via wet sieving and sized clay particles. Then dry sieving of the coarse material remaining is then followed. In a significant cohesion less soil, particle size distribution quantitative determination was covered by this method descending to fine sand size. Silt clay combination was obtained differently. For significant quantity of soil particles that were not retained in the 2mm test sieve, the method of hydrometer was employed (BS 1377: part 2: 1990)

# **Sample preparation**

Air drying was applied to test the sample for a minimum of 12 hours which based on the sample type. Riffling or quartering was applied to determine a representative sample which gives at least 2.5 kg mass.

- For material not containing clay or silt particles, only dry sieving was used.
- The range for the given tested soil was adequately covered by the test sieve apartive sizes, but there was no necessity in using every test for every size.
- Sample oven drying was required for damp condition such as rainy seasons for at least 12 hours at 60 <sup>0</sup>C.

# 4.5 Soil Texture

Procedure: The said texture refers to the sand, clay, and silt, or the size of mineral spreed in soil texture particle size.

Category	Diameter (mm)
Sand (very coarse)	1 – 2
Sand (coarse)	0.5 – 1
Sand (medium)	0.25 - 0.5
Sand (fine)	0.10 - 0.25
Sand (very fine)	0.05 - 0.10
Silt	0.002 - 0.05
Clay	< 0.002

**Table 4.5**: Particle size in a soil texture (Reberge, 1999)

# 4.5.1 Procedure

Two groups of the soil particle based on the analysis are classified according to particle size analysis standard test method of said (ASTM D 442 - 63). Appendix 1/A3 as given:

Retain portion on No. 10 (2 mm) sieve for soil analysis. Again, the retained portion (on the no,. 10 sieving using 76.2 mm (3 in) No. 4 (75 mm). 9.55 mm (3/8 m) and No.10 (2 mm). Furthermore, the retained amount was recorded after weighing and sieving, to determine cumulative percentage passing for every sieve over cumulative mass passing were multiple by 100.

Sieve analysis and hydrometer of No. 10 (2 mm) sieve size of the portion of soil passing was conducted. The soil sample which passed through the No. 10 sieve were weighed and the hydrometer test was conducted using about 50 g of the weighed soil. The following steps were involved in the analysis

# 4.5.2 Composite correction factor and calibration

Calibration of the hydrometer is the initial step towards hydrometer analysis because the hydrometer were calibrated by the manufacturers at constant standard temperature of around  $20^{\circ}$ C producer graduated the hydrometer at the pramed base of the meniscus to be perusided by the fluid on the stem. Because the soil suspensions base at the top the readings must be taken and applied corrections connected. H152 type of hydrometer was used for over texture (Figure 4.10). For convenience, Table or chart of composite revision may be arranged for  $1^{\circ}$ C temperature contrast progression (Figure 4.5) for expected temperature test and used as demanded. This is shown in Appendix 10.



Figure 4.10: Sedimentation in the 1000 mL cylinder with distilled water and soil slurry

# 4.5.3 Hygroscopic moisture determination

The differences in moisture between oven and air dried samples were determined applying equition 4.3 in which about (10 - 15) was weighed in a small container, and then oven drying the sample at  $110 \pm 5^{0}$ C in an oven and the mass of the dried sample was weighed.

$$C = \frac{M_{oven} - Dry}{M_{air} - Dry} \le$$
(4.3)

## 4.5.4 Soil Sample Soaking

Do to mostly the soil samples were clay/silt, about 50 g of the sample was weighed and then placed into glass beaker containing sodium hexametaphoshate of 40 g mass which writhing the sample act as dispersion agglomeration, it was then allowed to soak for a minimum of 1 hours. After that, it was dispersed further employing the services of dispersion machine mixer as seen in Figure 4.11.



Figure 4.11: Dispersing soil mixer machine (ASTM D 422)
### 4.5.5 Hydrometer test

The applied procedure is as follows:

Glass sedimentation cylinder was prepared from dispersion machine mixer with dispersed soil slurry. Distilled water was added into the mixture until 1000 ml total volume was reached. Figure 4.12 shows the palm hand utilizing over the cylinders open and (an electric plug open at the end), the unsettling of the slurry to finish for I min time towards the 1 min cylinder and time in a suitable area, hydrometer readings were taken at accompanying interims time of 0.5, 1, 2 5, 15 45, 90, 180, 240, and 1440 minutes.

### 4.5.6 Calculation of Soil Percentage in Suspension

The mass of soil used represented the mass of total sample in the test for hydrometer through division of percentage passing the No. 10 (2 mm) sieve size of the oven dry mass, then the results were multiplied by 100. The soil rate maintained in suspension at the point where density of the suspension is committed by hydrometer via Equation 4.4;

$$P = (Ra/w) (ML) P5 X 100$$
(4.4)

### **4.5.7 Diameter of Soil Particles**

The particles diameter equaling the indicated percentage by certain hydrometer reading were based on stokes, low equation given an equation 4.5.

$$\mathbf{D} = \sqrt[K]{4/T} \tag{4.5}$$

The effective depth (L) values were calculated based on Equation 4.6;

$$L = L_1 + \frac{1}{2} \{ L_2 - (V_{B/A}) \}$$
(4.6)

The applied procedure is as follows:

For soil particles finer than N. 10 (2 mm) sieve sizes the sieve analysis conducted by washing and drying the soil amount used in the hydrometer test and then the sieve analysis was conducted using set of sizes No. 40, No 100 and No. 200 respectively.

### 4.6 Microstructural Analysis

A single point of the small plate was smoothen, and etched by using 3% Nital noted and microstructure at 5x magnification was examined. In the base metal, uniform grain structure was observed. It was noted that two repair beads about 008mm to 0.12mm were also used adjacent to the initial weld. Cracks were extended through the weld and also the HAZ (Heat Affected Zone). The cracks continued in the base metal matrix i.e. API 5L X70 steel (Figure 4.13) and coupons (Figure 4.15).



Figure 4.12: Branching cracks in sample, 5x



Figure 4.13: Tran granular path crack through the microstructure of base metal, i.e., API 5L X 70 steel, x 100



Figure 4.14: Corroded steel pipeline coupons (60mm x 40mm x 10mm)



Figure 4.15: Corroded welded regions of pipeline coupons

Corroded coupons of steel pipeline and also weld regions can be seen in Figure 4.7 (a) and (b).

# 4.7 Statistical Analysis

Statistical analysis was performed using the IBM SPSS statistics 20 software, the multiple linear regressions (MLR) Equation 4.7 and compares the predicted corrosion rate with the corrosion rate obtained experimentally from weight loss method of Equation 4.1 in Chapter

4. Also, to determine the relationship between soils parameters that lay a vital role in the corrosion of buried pipeline the statistical process was performed according to ASTM G1-13 (Standard guide for applying statistics for analysis of corrosion data/Appendix 5).

The multiple regression analysis consists of a tool of statistical that examines the multiple independent variables those are related to the dependent variables. Means modeling a data set with more than one independent variables and one dependent variable. The outcomes of independent variable can be used to make a more powerful and accurate prediction.

The a, b1, b2, and bn in equation 4.7 called regression coefficients the b1 indicates the expected change in Y the dependent variable per unit change in X1 when X2 (dependent variables) is held constant, similarly for b2. The linear word is used from the equation 4.7 it is a linear function of the unknown parameters a1, b1, b2, bn.

Compares means between the independent groups. It's more likely to identify analysis of variance ANOVA in terms of factors with levels. A factor is an independent variable (i.e. some property, characteristic, or quality or quality that can be manipulated) that is being used as predictor or explain of variance in the data analysis. In most cases, each specific value if, the independent variable defines a level within the factor. The equation 4.7 shown below is MLR to estimate the corrosion of the pipeline.

Y = a + b1 x1 + b2 x2 + b3 x3....bn xn

(4.7)

# CHAPTER 5 RESULTS AND DISCUSSION

### 5.1 pH Test

The pH tests were conducted at Bayero University Laboratory, Kano Nigeria according to BS 1377-3:1990 (given in appendix) procedure using G038-B028 device (portable pH meter). As enumerated in the methodology, 70 g and 30 g of soil samples were placed into two different beakers. The pH readings were taken for 2 - 3 times and were only adopted when their difference was close to 0.05 pH units. The results for the pH tests conducted are given in Table 1.1

Samples	pH meter reading
S1	7.86
<b>S</b> 2	7.52
<b>S</b> 3	7.38
S4	7.14
S5	6.58
S6	5.05
S7	5.85
<b>S</b> 8	5.45

Table 1.1: pH test results

According to a study conducted by Sulaiman et, al, (2014), adjustment of pH for soil from acidic to alkaline lead to increase in corrosion. Ogozie, (2004) study indicated that at any pH corrosion level structure beneath the soil becomes sensitive. Taking notes of pH inside is usually of great concerned to iron scope ranging from 4-8.5.

The highest pH value in this study from the results of the investigations on the soil samples collected was 7.86 (from sample 1) and whereas 5.05 was the lowest value obtained from sample no. 6. The results revealed by this study implied that all the soil samples has higher acidity with exception of only sample 1 which has moderate acidity in accordance with the relative acidity of pH given by Roberge, (1999).

### **5.2 Moisture Test**

Similar to pH tests, the moisture tests were conducted in the Laboratory of Bayero University, Kano Nigeria, based on BS part 2 1990 procedure (given in Appendix 1). Bench oven and A&D Gimini Gr series analytical balance was the equipment employed to perform the test as shown in Figure 4.8. For all the eight samples used, different weights were used, likewise the weight of the container varied according the sample weights as shown Table 5.2 below.

Sample	Weight before drying (g)	Weight after drying (g)	Weight of container (g)
<b>S</b> 1	91.98	80.5	16.4
S2	146.48	125.5	26.8
<b>S</b> 3	119.22	108.6	29
<b>S</b> 4	123.04	118.8	16.6
S5	140.57	131.4	27
<b>S</b> 6	145.34	127.8	9.5
<b>S</b> 7	155.25	141.1	28.9
<b>S</b> 8	165.58	164.2	26.9

 Table 5.2: Moisture content (Mass sample before and after Drying)

To calculate the soil moisture content, Equation 4.2 was utilized. The moisture content percentage of each soil sample is given in Table 5.3. Variation in soil moisture content could be observed from the results of the eight samples, which indicated that climate, regions of the samples and seasonality (rainy or dry seasons) have significant impacts on soil water content.

Soil samples	Moisture content (%)		
S1	17.9		
S2	21.3		
<b>S</b> 3	13.3		
<b>S</b> 4	4.1		
S5	8.8		
<b>S</b> 6	17.8		
<b>S</b> 7	12.6		
<b>S</b> 8	15.7		

Table 5.3: Percentage of moisture content for each soil sample

The effect of soil moisture content on mild steel corrosion was investigated by Gupta, (1979) when the holding limit beyond 50%. However, properties of soil influence on the structure and varied pipelines was studied by Ismail and EL-shamy, (2009). The results found showed that soil moisture content sensitivity to corrosion varies between 50 - 60%. Yahaya et, al., (2001) discovered that with high amount of moisture content, corrosion growth increases on the coupons of carbon steel. The results of this study is in agreement with Yahaya et, al., (2001) discovery in which the bar chart in Figure 5.4 shows an increase of corrosion with increase in the percentage of moisture content. Hence, sample S2 would be the most corrosive soil in terms of moisture content in Table 5.3.



Figure 5.1: Effect of moisture content on corrosion rate

### **5.3 Particle Size Analysis**

In accordance with ASTM D422 - 63 (Appendix 3) outlined procedures, the tests for soil texture was carried out in the laboratory of Bayero University, Kano Nigeria. Hydrometer method was employed to conduct the test as previously described. The soil sample results of the texture tests are presented in Table 5.4.

Sample	Gravel (%)	<b>Sand (%)</b>	Silt and clay (%)
<b>S</b> 1	0.48	29.06	70.46
S2	1.02	51.18	47.8
<b>S</b> 3	11.18	54.5	34.32
<b>S</b> 4	9.74	55.22	53.04
S5	12.74	48.17	39.09
<b>S</b> 6	4.54	47.48	47.98
<b>S</b> 7	33.02	32.98	34
<b>S</b> 8	1.88	61.02	37.1

**Table 5.4:** Soil samples texture test results

Soil texture is among the significant factors that have high impact on soil corrosion with respect to structure and pipeline. Oguzie et al, (2004) in their study to determine the impact of soil components on the buried steel deterioration due to corrosion concluded that, the deterioration is in ascending order of Sand < Loam < Clay. Yahya et al., (2011) argued that at a low clay content level the rate of erosion can be initiated. Hence, sample S8 which was the sandy sample is not desirable in terms of corrosion.

# **5.4 Corrosion Rate**

The soil samples, initial, final and mass loss are given in Table 5.5 to ascertain the corrosion rate. Applying the appropriate equations as expressed mathematically in Equation 4.1, the corrosion rate for each sample was determined.

Soil Sample	Initial weight (g)	Final weight (g)	Weight Loss W (g)	Density D (g/cm <sup>3</sup> )	Factor K mm/y ear	Surface Area (cm <sup>2</sup> )	Time of exposure T, (Hours)	Corrosion Rate (mm/year)
<b>S</b> 1	91.98	80.5	11.48	7.85	87600	68	2160	0.872195
S2	146.48	125.5	20.98	7.85	87600	68	2160	1.593959
<b>S</b> 3	119.22	108.6	10.62	7.85	87600	68	2160	0.806857
<b>S</b> 4	123.04	118.8	4.24	7.85	87600	68	2160	0.322135
<b>S</b> 5	140.57	131.4	9.17	7.85	87600	68	2160	0.696692
<b>S</b> 6	145.34	127.8	17.54	7.85	87600	68	2160	1.332605
<b>S</b> 7	155.25	141.1	14.15	7.85	87600	68	2160	1.075049
<b>S</b> 8	165.58	164.2	1.38	7.85	87600	68	2160	0.104846

 Table 5.5: Corrosion rate calculation

Comparing Tables 5.3, 5.4 and 5.5 it can be seen that S2 which had maximum moisture content percentage (21.3%) had the highest rate of corrositivity (1.59 mm/year) with respect to the steel pipe coupons. This implies that corrositivity rate is directly proportional to the percentage of moisture content, i.e. with high amount of moisture content, rate of corrosion would be high and vice versa. S4 which had 4.1% moisture suffered the smallest corrosion rate (0.322 mm/year)

## **5.5 Statistical Analysis**

To determine the effect of each soil property on corrosion rate, statistical analyses were carried out in two categories; (1) Multiple Linear Regression (2) Analysis of Variance (ANOVA). The statistics were conducted using IBM SPSS 25 program. In order to determine the most influential parameters to the corrosion rate, 5 models (M1, M2, M3, M4 and M5, respectively) were developed using different input combinations (1, 3, 2, 3 and 4, respectively). Table 5.6 shows the models, inputs number(s) and inputs combination of the variables.

	Model	No. of Inputs	Inputs combination
	<b>M</b> 1	1	pH
	M2	3	MC, GV, SD
	M3	2	SC, MC
	M4	3	pH, MC, GV
	M5	4	pH, MC, GV, SC
MC = I	moisture co	ntent, GV = gravel,	SD = sand and SC = silt and clay, pH

 Table 5.6: Models inputs combination

The results for both MLR and ANOVA models are presented in Tables 5.7 and 5.8.

Model	R	$\mathbf{R}^2$	Adjusted R <sup>2</sup>	Standard Error of Estimate
M1	0.0973	0.0094	0.1886	0.5796
M2	0.9086	0.8256	0.6512	0.3139
M3	0.6801	0.4625	0.1938	0.4774
M4	0.7749	0.6006	0.2012	0.4752
M5	0.9079	0.8244	0.4733	0.3858

 Table 5.7: MLR results for statistical analysis

Model	Item	Sum of Squares	df	Mean square	F	Significance
	Regression	0.0160	1	0.0160	0.0478	0.8355
<b>M</b> 1	Residual	0.6801	5	0.3360		
	Total	1.6962	6			
	Regression	1.4004	3	0.4668	4.7353	0.1169
M2	Residual	0.2957	3	0.0985		
	Total	1.6962	6			
	Regression	0.7845	2	0.3922	1.7212	0.2886
M3	Residual	0.5629	2	0.2814		
	Total	1.6962	6			
	Regression	1.0187	3	0.3395	1.7212	0.2886
M4	Residual	0.6774	3	0.2258		
	Total	1.6962	6			
M5	Regression	1.3984	5	0.3395	1.5038	0.3727
	Residual	0.6774	1	0.2258		
	Total	1.6962	6			

Table 5.8: ANOVA results for statistical analysis

Considering Table 5.7, it can be seen that 5 models were developed in order to determine the most effective parameters to corrosion rate. The results of the MLR models showed that M2 which has 3 input combination including pH, moisture content, and gravel provided the best performance with correlation coefficient (R) and determination coefficient ( $R^2$ ) of 0.9086 and 0.8256 respectively. Also adjusted  $R^2$  of the model was found to be 0.6512. The model (M2) has the minimum error compared to rest of the developed models of 0.3139. These results demonstrated that the effect of those combinations is highly significant to the rate of corrosion. M5 followed closely as the second most effective model combination followed by M5, M4, M3 and M1 is the least performing model which constitutes pH as the only input parameter.

The results for ANOVA statistics are given in Table 5.8. As shown, 5 different input combinations were used to come out with the most effective model with respect to coupon for corrosion rate. The ANOVA analysis was carried out for 95% confidence level and  $\alpha = 0.05$  significance level. Similar to MLR, the most effective model is M2 which has factor of 4.7353 and significant factor of 0.1169. The other models performances also followed in similar manner as that of MLR.

The general result of this study revealed that in decreasing order the moisture content, soil texture and pH are effective combinations of variables that result in deterioration of steel coupons taken from API 5L X70 pipeline steel.

# CHAPTER 6 CONCLUSION AND FUTURE WORK

## 6.1 Conclusion

The experimental results showed that soil properties on the steel coupons and the corrosion rates exhibit the moisture content ratio has fundamental effect in generating corrosion of steel coupons, this happens to be less significant with pH and having less percentage with silt/clay content.

Statistical tests were carried out including pH, moisture content following parameters sand/silt/clay contents then on this, the samples were grouped into five models M1, M2, M3, M4, and M5. The best performance was provided by M4 that reveals standard error of estimate of 0.0399 has demonstrated most effective combination to the rate of corrosion while M5 which most effective model combination then by M2, M3 and M1 as the least MLR model.

ANOVA was carried out for 95% confidence and MLR test multiple linear regression analysis M4 most effective with high No, 212.69 of factor, and 0.052 significance, furthermore the rest of the models performance have similar manner of MLR. The measured metal loss from the buried coupons created by so many factors including soil chemical content, this reflect prior statement that carried out test on soil properties may generate some influence on corrosion rate, this reveal that the measurement weight loss of the buried steel coupon. The predicted percentage of corrosion on steel coupons affirms convenient result due to the analysis of corrosion rate. Furthermore, the lowest value was 0.10484 mm/year while the highest value was 1.59395 mm/year depending mainly on the amount of moisture content and pH value.

# 6.2 Future Work

An analysis of external corrosion of oil pipeline has been carried out with the assessment of soil properties to retain its long life and reducing corrosion growth rate with the inclusion of the soil factors more specifically for Nigeria North East soil. This experience can be utilized to assess the best corrosion protection that can be applied on the pipeline after the installation to a specific area site location. Hence, to improve the reliability of the line at a lesser cost. An analysis of corrosion growth potential for pipeline sites can be focused, and alternative steel grades can be searched.

In addition, it should be noted that the pipeline materials and of the HAZ formed next to the weld area used in this research is only applicable to a metal having the same chemical composition and welded under the same conditions, Variations in microstructure and chemical composition would exist across varying welded joints since it is dependent in factor. Furthermore, research should therefore be carried out on the effect of varying welded techniques on the microstructure therefore, corrosion properties of a welded joints.

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APPENDICES

# STANDARD TEST METHOD FOR DETERMINATION OF WATER (MOISTURE) **CONTENT OF SOIL BY MICROWAVE OVEN HEATING (ASTM D4643-08)**



Designation: D 4643 - 08

### Standard Test Method for Determination of Water (Moisture) Content of Soil by Microwave Oven Heatings

This standard is instead under the fixed designation D 4640; the sumber immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentifiese indicates the year of last mapproval. A supervisit system (with indicates an addited damage biase the intervision or requerval. The supervisit This standard has been approved for use by agencies of the Department of Definer.

#### 1. Scope\*

1.1 This test method outlines procedures for determining the water (moisture) content of soils by incrementally drying soil in a microwave oven.

1.2 This test method can be used as a substitute for Test

Method D 2216 when more rapid results are desired to expedite other phases of testing and slightly less accurate results are acceptable. 1.3 When questions of accuracy between this test method

and Test Method D 2216 arise. Test Method D 2216 shall be the referee method.

1.4 This test method is applicable for most soil types. For

some soils, such as those containing significant amounts of some sous, such as trose containing significant amounts on halloysite, mica, montmorillonite, gypsum or other hydratedmaterials, highly organic soils, or soils in which the pore water contains dissolved solids (such as salt in the case of marine deposits), this test method may not yield reliable water content values.

1.5 The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this test method.

1.6 Refer to Practice D 6026 for guidance concerning the

use of significant figures. This is especially important if the water content will be used to calculate other relationships such as moist mass to dry mass or vice versa, wet unit weight to dry unit weight or vice versa, and total density to dry density or vice versa. For example, if four significant digits are required

in any of the above calculations, then the water content has to be recorded to the searest 0.1 %. This occurs since 1 plus the water content (not in percent) will have four significant digits regardless of what the value of the water content is; that is, plus 0.1/100 = 1.001, a value with four significant digits. While, if three significant digits are acceptable, then the

water content can be recorded to the nearest 1 %.

1.7 This standard does not purport to address all of then safety concerns, if any, associated with its use. It is the

responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. See Section 7.

2. Referenced Documents 2.1 ASTM Standards:

D 653 Terminology Relating to Soil, Rock, and Contained Fluids D 2216 Test Methods for Laboratory Determination of

Water (Moisture) Content of Soil and Rock by Mass D 3740 Practice for Minimum Requirements for Agencies

Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction D 4753 Guide for Evaluating, Selecting, and Specifying

Balances and Standard Masses for Use in Soil, Rock, and

Construction Materials Testing D 6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology 3.1 Definition

3.1.1 All definitions are in accordance with Terminology

D 653 3.2 Definitions of Terms Specific to This Standard

3.2.1 microwave heating-a process by which heat is induced within a material due to the interaction between dipolar molecules of the material and an alternating, high frequency electric field. Microwaves are electromagnetic waves with 1 mm to 1 m wavelengths.

3.2.2 water (moisture) content-the ratio, expressed as a percentage, of the mass of "pore" or "free" water in a given mass of soil to the mass of the solid particles.

# STANDARD TEST METHOD FOR PARTICLE-SIZE ANALYSIS OF SOILS

# (ASTM D422-63)

# Designation: D 422 - 63 (Reapproved 1998)

### Standard Test Method for Particle-Size Analysis of Soils1

This studged is issued under the fixed chargenties D 422; the sampler investigately following the designation indicates the year of original adoption on, in the case of revision, the year of last revision. A sampler is parenthese indicates the year of last reapproxel. A supervisity explosion (s) indicates an editorial charge since the last revision or response).

### 1. Scope

1.1 This test method covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes larger than 75 µm (retained on the No. 200 sieve) is determined by sieving, while the distribution of particle sizes smaller than 75 µm is determined by a sedimentation process, using a hydrometer to secure the necessary data (Note 1 and Note 2).

Note 2). Nors 1—Separation may be made on the No. 4 (4.75-mm), No. 40 (425-µm), or No. 200 (75-µm) since instead of the No. 10. For whatever since used, the size shall be indicated in the report. Nors 2—Two types of dispersion devices are provided: (2) a high-proof mechanical stirrer, and (2) air dispension. Extensive investigations indicate that are-dispersion devices produce a more positive dispersion of plastic soils below the 20-µm size and approximally loss degradation on all areas when used with analy soils. Because of the definite advantages for investigations are in propriored. The results from the heat favoring air dispersion, its use is recommended: The results from the two-types of devices differ in magnitude, depending upon wil type, leading to marked differences in particle size distribution, especially for sizes finer than 20 um. tun 20 µm. 2. Referenced Documents

2.1 ASTM Standards:

D 421 Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants: E 11 Specification for Wire-Cloth Sieves for Testing Parposess E 100 Specification for ASTM Hydrometerss

3. Apparatus 3.1 Balances—A balance sensitive to 0.01 g for weighing the material passing a No. 10 (2.00-mm) sieve, and a balance sensitive to 0.1 % of the mass of the sample to be weighed for weighing the material retained on a No. 10 sieve.

3.2 Stirring Apparatus-Either apparatus A or B may be used

3.2.1 Apparatus A shall consist of a mechanically operated

stirring device in which a suitably mounted electric motor turns a vertical shaft at a speed of not less than 10 000 rpm without

load. The shaft shall be equipped with a replaceable stirring paddle made of metal, plastic, or hard rabber, as shown in

Fig 1. The shaft shall be of such length that the stirring paddle will operate not less than vi in (19.0 mm) nor more than 1vi in (38.1 mm) above the bottom of the dispersion cup. A special dispersion cup conforming to either of the designs shown in Fig. 2 shall be provided to hold the sample

while it is being dispersed. 3.2.2 Apparatus B shall consist of an air-jet dispersion cups (Note 3) conforming to the general details shown in Fig. 3

(Note 4 and Note 5).

(Note 4 and Note 5). Nom 3—The amount of air required by an air-jet dispersion cup is of the order of 2 fo/min, some small air compressors are not capable of supplying sufficient air to openic a cup. Nom 4—Another air-type dispersion durice, known as a dispersion the, developed by Chu and Davidson at lows State College, has been shown to give results equivalent to those secured by the air-jet dispersion

cupers on cups. When it is used, seaking of the sample can be done in the sedimentation cylinder, thus eliminating the need for transforring the slurry. When the air-dispersion table is used, it shall be so indicated in

report. Non 5---Water may condense in air lines when not in use. This water must be removed, either by using a water top on the air line, or by blowing the water out of the line before using any of the air for dispersion.

3.3 Hydrometer-An ASTM hydrometer, graduated to read in either specific gravity of the suspension or grams per litte of suspension, and conforming to the requirements for hydrometers 151H or 152H in Specifications E 100. Dimensions of both hydrometers are the same, the scale being the only item of difference.

3.4 Sedimentation Cylinder—Aglass cylinder essentially 18 in. (457 mm) in height and 21/5 m. (63.5 mm) in diameter, and marked for a volume of 1000 mL. The inside diameter shall be such that the 1000-mL mark is 36 6 2 cm from the bottom on the inside.

3.5 Thermometer-A thermometer accurate to 1°F (0.5°C). 3.6 Sieves-A series of sieves, of square-mesh woven-wire cloth, conforming to the requirements of Specification E 11 A full set of sieves includes the following (Note 6):

# STANDARD PRACTICES FOR PRESERVING AND TRANSPORTING SOIL

# SAMPLES (ASTM D4220-95)

Designation: D 4220 - 95 (Reapproved 2000)

### Standard Practices for

Preserving and Transporting Soil Samples

This standard is instead under the fixed designation D-4220; the number impositionly following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parenthese indicates the year of last reapproval. A superscript explosion (a) indicates an additrial change sizes the intervision or response).

1. Scope \* 1.1 These practices cover procedures for preserving soil 1.1 These practices cover procedures for preserving soil samples immediately after they are obtained in the field and accompanying procedures for transporting and handling the samples.

1.2 Limitations-These practices are not intended to address requirements applicable to transporting of soil samples known or suspected to contain hazardous materials. 1.3 This standard does not purport to address all of the tafety concerns, if any, associated with its use. It is the

responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. See Section 7

2. Referenced Documents 2.1 ASTM Standards:

D 420 Guide to Site Characterization for Engineering, Design,

and Construction Purposes: D 653 Terminology Relating to Soil, Rock, and Contained Fluids: D 1452 Practice for Soil Investigation and Sampling by

Auger Borings: D 1586 Test Method for Penetration Test and Split-Barrel

Sampling of Soils:

D 1587 Practice for Thin-Walled Tube Sampling of Soils: D 2488 Practice for Description and Identification of Soils

(Visual-Manual Procedure):

D 3550 Practice for Ring-Lined Barrel Sampling of Soils: D 4564 Test Method for Density of Soil in Place by the

Sleeve Method: D 4700 Guide for Soil Sampling from the Vadose Zone:

3. Terminology

3.1 Terminology in these practices is in accordance with Terminology D 653.

 Summary of Practices
 The various procedures are given under four groupings as follows

4.1.1 Group A-Samples for which only general visual

identification is necessary. 41.2 Group B-Samples for which only water content and classification tests, proctor and relative density, or profile logging is required, and bulk samples that will be remolded or compacted into specimens for swell pressure, percent swell, consolidation, permeability, shear testing, CBR, stabilimeter,

4.1.3 Group C-Intact, naturally formed or field fabricated, samples for density determinations, or for swell pressure, percent swell, consolidation, permeability testing and shear testing with or without stress-strain and volume change measurements, to include dynamic and cyclic testing.

4.1.4 Group D—Samples that are fragile or highly sensitive for which tests in Group C are required.
4.2 The procedure(s) to be used should be included in the project specifications or defined by the designated responsible person.

5. Significance and Use 5.1 Use of the various procedures recommended in these practices is dependent on the type of samples obtained (Practice D 420), the type of testing and engineering properties required, the fragility and sensitivity of the soil, and the climatic conditions. In all cases, the primary purpose is to preserve the desired inherent conditions.

5.2 The procedures presented in these practices were primarily developed for soil samples that are to be tested for engineering properties, however, they may be applicable for samples of soil and other materials obtained for other purposes.

6. Apparatus 6.1 The type of materials and containers needed depend upon the conditions and requirements listed under the four groupings A to D in Section 4, and also on the climate and transporting mode and distance 6.1.1 Sealing War, includes microcrystalline was,

paraffin, beeswax, ceresine, camauluwax, or combinations thereof.

6.1.2 Metal Disks, about vis in. (about 2 mm) thick and having a diameter slightly less than the inside diameter of the tube, liner, or ring and to be used in union with wax or caps and tape, or both.

6.1.3 Wood Disks, prewaxed, 1 in. (25 mm) thick and having a diameter slightly less than the inside diameter of the liner or tube.

# STANDARD PRACTICE FOR PREPARING, CLEANING AND EVALUATING **CORROSION TEST SPECIMENS (ASTM G1-90)**

Designation: G 1 - 90 (Reapproved 1999)\*1

Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens

This standard is insortander the fixed designation G 1; the number introductly following the designation indicates the year of artgonal adaption in, in the case of revision, the year of fast revision. A runnine in parenthese indicates the year of ant respectively option (w) indicates an enhanced change since the lost revision or respectively.

a<sup>1</sup> Noto-Editorial corrections were made desceptions in January 1999.

### 1. Scope

1.1 This practice covers suggested procedures for preparing hare, solid metal specimens for tests, for removing corrosion products after the test has been completed, and for evaluating the corrosion damage that has occurred. Emphasis is placed on procedures related to the evaluation of corresion by mass loss and pitting measurements.

Nerv 1-Castion: In many cases the corrosion product on the reactive methy iteriam and zieconiam is a hard and tightly bunded code that defess removal by chemical or ordinary mechanical means. In many such cases, contosion rates are established by mass gain rather than mass loss.

1.2 This standard does not purport to address all of the Let fins summaria does no purport and the set of the subject concerns, if any, associated with its use. It is the exponentiality of the user of this standard to establish appro-priate subject and health practices and determine the applicafullity of regulatory limitations porter to use. For specific precautionary statements, see Note 1 and Note 6.

### 2. Referenced Documents

- 2.1 ASTM Sandardy: A 262 Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels<sup>2</sup> D 1193 Specification for Reagent Water<sup>3</sup>
- D 1384 Test Method for Corrosion Test for Engine Coolants in Glassware
- D 2776 Test Methods for Corrosivity of Water in the Absence of Heat Transfer (Electrical Methods)3
- G15 Terminology Relating to Corrosion and Corrosion Testing
- G 16 Guide for Applying Statistics to Analysis of Corrosion Data

- Discontinued-Replaced by Guide G.95, See /159 Jonnal Book of ASTM Sandards, Vol. 03.02.

- G 31 Practice for Laboratory Immersion Corrosion Testing of Metals
- G 33 Practice for Recording Data from Atmospheric Cor-rusion Tests of Metallic-Coated Steel Specimens<sup>6</sup>
- G 46 Guide for Examination and Evaluation of Pitting Corrusion
- G 50 Practice for Conducting Annospheric Corrosion Tests on Metals<sup>e</sup>
- G 78 Guide for Crevice Corrosion Testing of Iron Base and Nickel Base Stainless Alloys in Seawater and Other Chloride-Containing Aqueous Environments\*

#### 3. Terminology

3.1 See Terminology G 15 for terms used in this practice.

### 4. Significance and Use

4.1 The procedures given are designed to remove corrosion products without significant removal of base metal. This allows an accurate determination of the mass loss of the metal or alloy

that occurred during exposure to the corrosive environment. 4.2 These procedures, in some cases, may apply to metal coatings. However, possible effects from the substrate must be considered.

#### 5. Reagents and Materials

5.1 Purity of Reagents-Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents conform to the specifications of the Committee on an engines content in the spectralities and content of Analytical Reagents of the American Chemical Society where such specifications are available.<sup>7</sup> Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

6 determination.
5.2 Purity of Water—Unless otherwise indicated, references water shall be understood to mean reagent water as defined. by Type IV of Specification D 1193.

<sup>&</sup>lt;sup>1</sup> This practice is order the jurind ratios of ASTM Committee G-1 on Committee (Mean and is the direct responsibility of Subcommittee GOL/S) on Laboratory formation have. Current edition approval. March 30, 1990. Published May 1990. Originally altituded as G 1 – 47. Last previous edition G 1 – 18. <sup>3</sup> Arease Book of ASTM Soundaria, Vol 10, 00, <sup>4</sup> Arease Book of ASTM Soundaria, Vol 10, 01. <sup>4</sup> Arease Book of ASTM Soundaria, Vol 13, 01. <sup>4</sup> Philosoft and Book of ASTM Soundaria, Vol 13, 05. <sup>5</sup> Philosoft and Book of ASTM Soundaria, Vol 13, 05. <sup>5</sup> Philosoft and Book of ASTM Soundaria, Vol 13, 05. <sup>5</sup> Philosoft and Book of ASTM Soundaria, Vol 13, 05. <sup>5</sup> Philosoft and Book of ASTM Soundaria, Vol 13, 05. <sup>5</sup> Philosoft and Book of ASTM Soundaria, Vol 13, 05. <sup>5</sup> Philosoft and Book of ASTM Soundaria, Vol 13, 05. <sup>5</sup> Philosoft and Book of ASTM Soundaria, Vol 13, 05. <sup>5</sup> Philosoft and Book of ASTM Soundaria, Vol 13, 05. <sup>5</sup> Philosoft and Book of ASTM Soundaria, Vol 13, 05. <sup>5</sup> Philosoft and Philosoft and Philosoft Astmarkan Soundaria, Vol 13, 05. <sup>5</sup> Philosoft and Philosoft Astmarkan Soundaria, Vol 13, 05. <sup>5</sup> Philosoft Astmarkan Soundaria, Vol 13, 05. <sup>5</sup> Philosoft and Philosoft Astmarkan Soundaria, Vol 13, 05. <sup>5</sup> Philosoft Astmarkan Philosoft Astmarkan Philosoft Astmarkan Philosoft Astmarkan Philosoft Astmarkan Philosoft Phil

Astrony, Vol. 03-02. Astrony, Rock of ASTM Standards, Vol.03-02.

<sup>&</sup>lt;sup>7</sup> Response Chemicale, American Chemical Society Specificuations, American Chemical Society, Weldington, DC: For suggestions on the testing of magnets and used by the American Chemical Society, see Audio: Sociedular for Laboreuri-Chemican, IEDH Lid, Pools, Daran, U.S., and the Cohemic Source Phermacoperie and Vasional Formulary, U.S. Pharmacopatal Convertion, Inc; (USINC), Rockvilla, MD.

# STANDARD GUIDE FOR APPLYING STATISTICS TO ANALYSIS OF **CORROSION DATA (ASTM G16-13)**



### Standard Guide for

Applying Statistics to Analysis of Corrosion Data

This modest is local under the fixed designation GHr, the number increadently following the designation indicates the year of original adoption or, in the case of reviews, the year of hat motions. A comber is parenthese indicates the year of last supported. A superscript option () indicates an editorial datage since the last motions or supported.

#### L Scope

1.1 This guide covers and presents briefly some generally accepted methods of statistical analyses which are useful in the interpretation of corrosion test results.

1.2 This guide does not cover detailed calculations and methods. 1.2 This guile does not cover acting of approaches which have found application in corrosion testing.
1.3 Only those statistical methods that have found wide

acceptance in corrosion testing have been considered in this guide. 1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard. 2. Referenced Documents

#### 2.1 ASTM Standards: :

E178 Practice for Dealing With Outlying Observations E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

G46 Guide for Examination and Evaluation of Pitting Corrosion IEEE/ASTM SI 10 American National Standard for Use of the International System of Units (SI): The Modern Metric System

### 3. Significance and Use

3.1 Corrosion test results often show more scatter than many other types of tests because of a variety of factors, including the fact that minor imparities often play a decisive role in controlling corrosion rates. Statistical analysis can be very helpful in allowing investigators to interpret such results, especially in determining when test results differ from one another significantly. This can be a difficult task when a variety

of materials are under test, but statistical methods provide a rational approach to this problem.

3.2 Modern data reduction programs in combination with computers have allowed sophisticated statistical analyses on data sets with relative case. This capability permits investigators to determine if associations exist between many variables and, if so,

to develop quantitative expressions relating the variables. 3.3 Statistical evaluation is a necessary step in the analysis of results from any procedure which provides quantitative information. This analysis allows confidence intervals to be estimated from the measured results.

#### 4 Errors

4.1 Distributions-in the measurement of values associated with the corrosion of metals, a variety of factors act to produce measured values that deviate from expected values for the conditions that are Usually the factors which contribute to the present. error of measured values act in a more or less random way so that the average of several values approximates the expected value better than a single measurement. The pattern in which data are scattered is called its distribution, and a variety of distributions are seen in corrosion work

4.2 Histograms-A bar graph called a histogram may

be used to display the scatter of the data. A histogram is constructed by dividing the range of data values into equal intervals on the abscissa axis and then placing a bar over each interval of a height equal to the number of data points within that interval. The number of intervals should be few enough so that almost all intervals contain at least three points; however, there should be a sufficient number of intervals to facilitate visualization of the shape and symmetry of the bar heights. Twenty intervals are usually recommended for a histogram. Because so many points are required to construct a histogram, it is unusual to find data sets in corrosion work that lend themselves to this type of analysis. 4.3 Normal Distribution-Many statist

statistical techniques are based on the normal distribution. This distribution is bellshaped and symmetrical. Use of analysis techniques developed for the normal distribution on data distributed is another manner can lead to grossly erroneous conclusions. Thus, before attempting data analysis, the data should either be verified as being scattered like a normal distribution, or a transformation

# STANDARD PRACTICE FOR LABORATORY IMMERSION CORROSION **TESTING OF METALS (ASTM G31-72)**

Designation: G 31 - 72 (Reapproved 2004) Standard Practice for

Laboratory Immersion Corrosion Testing of Metals1

This standard is install under the fixed designation G 32; the number immediately following the designation indicates t adoption or, in the case of invision, the year of last restricts. A surface in parenthanes indicates the year of last support spillon (b) indicates an or district damage since the last revision energy rest. a the year of origin

### 1. Scope

 Scope 1.1 This practice: describes accepted procedures for and factors that influence laboratory immersion corrosion tests, particularly mass loss tests. These factors include specimen preparation, apparatus, test conditions, methods of cleaning specimens, evaluation of results, and calculation and reporting of corrosion rates. This practice also emphasizes the importance of recording all pertinent data and provides a checklist for reporting test data. Other ASTM procedures for laboratory contision tests are tabulated in the Appendix. (Warning-In many cases the corrosion product on the reactive metals titunium and zirconium is a hard and tightly bonded oxide that defies removal by chemical or ordinary mechanical means. In many such cases, corrosion rates are established by mass gain rather than mass loss.)

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only

any, 1.3 This standard does not purport to address all of the softly concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate

safety and health practices and determine the applicability of regulatory limitations prior to use. 2. Referenced Documents

2. References inclusions 2.1 ASTM Standards: 5 A 262 Practices for Detecting Susceptibility to Intergranular

Attack in Austenitic Stainless Steels E 8 Test Methods for Tension Testing of Metallic Materials

G 1 Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens

G 4 Guide for Conducting Corrosion Coupon Tests in Field Appl

G 16 Guide for Applying Statistics to Analysis of Corrosion

G 46 Guide for Examination and Evaluation of Pitting Corrosion.

### 3. Significance and Use

3.1 Corrosion testing by its very nature precludes completestandardization. This practice, rather than a standardized procedure, is presented as a guide so that some of the pitfalls of such testing may be avoided. 3.2 Experience has shown that all metals and alloys do 3.2 Experience has shown that all metals and alloys do not respond alike to the many factors that affect corrosion and that "accelerated" coernion tests give indicative results only, or may even be entirely misleading. It is impractical to propose an inflexible standard laboratory corrosion testing procedure for general use, except for material qualification tests

where standardization is obviously required. 3.3 In designing any corrosion test, consideration must be given to the various factors discussed in this practice, because these factors have been found to affect greatly the results obtained.

 Interferences
 Interferences
 The methods and procedures described herein represent the best current practices for conducting laboratory corrosion tests as developed by corrosion specialists in the process industries. For proper interpretation of the results obtained, the specific influence of certain variables must be considered. These include

4.1.1 Metal specimens immersed in a specific hot liquid may not corrode at the same rate or in the same manner as in equipment where the metal acts as a heat transfer medium in heating or cooling the liquid. If the influence of heat transfer effects is specifically of interest, specialized procedures (in which the corrosion specimen serves as a heat transfer agent) must be

spectrum serves in a near variable spectrum of the employed (1).4 4.1.2 In laboratory tests, the velocity of the environment relative to the specimens will normally be determined by convection currents or the effects induced by aeration or boiling or both. If the specific effects of high velocity are to be studied, special techniques must be employed to transfer the

# STANDARD PRACTICE FOR CONDUCTING AND EVALUATING LABORATORY CORROSIONS TESTS IN SOILS (ASTM G162-99)



ASTM G162-99(2004) Standard Practice for Conducting and Evaluating Laboratory Corrosions Tests in Soils

### Scope

1.1 This practice covers procedures for conducting laboratory corrosion tests in soils to evaluate the corrosive attack on engineering materials.

1.2 This practice covers specimen selection and preparation, test environments, and evaluation of test results.

1.3 This practice does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

### Significance and Use

This practice provides a controlled corrosive environment that has been utilized to produce relative corrosion information.

The primary application of the data from this practice is to evaluate metallic materials for use in soil environments.

This practice may not duplicate all field conditions and variables such as stray currents, microbiologically influenced corrosion, non-homogeneous conditions, and long cell corrosion. The reproducibility of results in the practice is highly dependent on the type of specimen tested and the evaluation criteria selected as well as the control of the operating variables. In any testing program, sufficient replicates should be included to establish the variability of the results.

Structures and components may be made of several different metals; therefore, the practice may be used to evaluate galvanic corrosion effects in soils (see Guide G 71).

Structures and components may be coated with sacrificial or noble metal coatings, which may be scratched or otherwise rendered discontinuous (for example, no coating on the edges of metal strips cut from a wide sheet). This test is useful to evaluate the effect of defective metallic coatings.

Structures and components may be coated or jacketed with organic materials (for example, paints and plastics), and these coatings and jackets may be rendered discontinuous. The test is useful to evaluate the effect of defective or incompletely covering coatings and jackets.

The corrosivity of soils strongly depends on soluble salt content (related parameters are soil resistivity, see Test Method G 57, and chemistry), acidity or alkalinity (measured by soil pH, see Test Method G 51), and oxygen content (loose, for example, sand, or compact, for example, clay, soils are extreme examples). The manufacturer, supplier, or user, or combination thereof, should establish the nature of the expected soil environment(s) and select the test environment(s) accordingly. Multiple types of soil can be used to determine the effect of this variable.

# **APPENDIX 8**

# **SPECIFICATION FOR LINE PIPE (API 5)**

# **Specification for Line Pipe**

### Upstream Segment

API SPECIFICATION 5L FORTY-THIRD EDITION, MARCH 2004 EFFECTIVE DATE: OCTOBER 2004 ERRATA DECEMBER 2004



American Petroleum Institute

Helping You Get The Job Done Right.<sup>24</sup>

# 1 Scope 1.1 PURPOSE AND COVERAGE

The purpose of this specification is to provide standards for

The purpose of this specification in to provide standards for pipe suitable for use in conveying gas, water, and oil in both the oil and natural gas industries. This specification covers searcless and welded steel line pipe. It includes plain-end, threaded-end, and belled-end pipe, as well as through-the-flowline threatini-end, and belied-end pipe, as well as through-the-inovine (TFL) pipe and pipe with ends prepared for use with special couplings. Although the plain-end line pipe meeting this specification is primarily intended for field makeup by circumferential welding, the manufacturer will not assume responsibility for field welding.

### 1.2 PRODUCT SPECIFICATION LEVEL (PSL)

This specification establishes requirements for two product specification levels (PSL I and PSL 2). These two PSL designations

define different levels of standard technical requirements. PSL 2 has mandatory requirements for carbon

equivalent, notch toughness, maximum yield strength, and maximum tensile strength. These and other differences are summarized in Appendix I.

Requirements that apply to only PSI. I or only PSI. 2 are so designated. Requirements that are not designated to a specific PSL apply to both PSL I and PSL 2.

The parchaser may add requirements to purchase orders for either PSI. 1 or PSI. 2, as provided by the supplementar requirements (Appendix F) and other options (4.2 and 4.3). 1.3 GRADES

The grades (see the note) covered by this specification are the standard Grades A25, A, B, X42, X46, X52, X56, X60, X65, X70 and X80, and any intermediate grades (grades that are higher than X42, intermediate to two sequential standard grades, and agreed upon by the purchaser and manufacturer). PSI. I pipe can be supplied in Grades A25 through X70. PSI. 2 pipe can be supplied in Grades B through 3380.

Class II (CI II) steel is rephosphorized and probably has better threading properties than Class I (CI 1). Because Class II (CI II) has higher phosphorus content than Class I (CI 1), it

may be somewhat more difficult to bend. Pipe manufactured as Grade X60 or higher shall not be substituted for pipe ordered as Grade X52 or lower without purchaser appro

### 1.4 DIMENSIONS

The sizes used herein are dimensionless designations, which are derived from the specified outside diameter as measured in U.S. Customary units, and provide a convenient method of referencing pipe size within the text and tables (but not for order descriptions). Pipe sizes 23/8 and larger are expressed as integers and fractions, pipe sizes smaller than 23/8 are expressed to three decimal places. These sizes replace the "size designation" and the "nominal size designation" used in the previous edition of this specification. Users of this specification who are accustomed to specifying nominal sizes rather than 00 sizes are advised to familiarize themselves with these new size designations used in this specification, especially the usage in Tables 4, 5, and 6A. PSL I pipe can be supplied in sizes ranging from 0.405 through 80. PSL 2 pipe can be supplied in sizes ranging from 472

through 80. Dimensional requirements on threads and thread gages, stipulations on gaging practice, gage specifications and certification, as well as instruments and methods for impection of threads are given in API Standard 5B and are applicable to threaded products covered by this specification.

### 1.6 UNITS

U.S. Castomary units are used in this specification; SI (metric) units are shown in parentheses in the text and in many tables. The values stated in either U.S. Customary units or SI units are to be regarded separately as standard. The values stated are not necessarily exact equivalents; therefore, each system is to be used independently of the other, without

combining values for any specific order item. See Appendix M for specific information about rounding procedures and conversion factors.

# **APPENDIX 9**

# METHODS OF TEST FOR SOILS FOR CIVIL ENGINEERING PURPOSES (BS 1377-2:1990)



### 1 Scope

This Part of BS 1577 specifies methods of test for the classification of soil and for the determination of basic physical properties.

Most of these tests are required for the classification of soils in accordance with HS 5050:1981. Some of the properties determined by these tests are required for tests described in other Parts of this

standard. Reference should be made to Part 1 of this standard for general requirements that are relevant to all Parts of this standard, and for methods of

preparation of camples for testing.

NOTIL The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this Part of BS 1577 the definitions given in BS 1577-1 apply.

3 Determination of moisture content 21 General

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Water is present in most naturally occurring soils. The amount of water, expressed as a proportion by mass of the day solid particles, known as the moisture content, has a profound effect on soil behaviour. In this content a soil is "dry" when no further water can be removed at a temperature not enceeding 110 °C.

Moisture content is required as a guide to classification of natural colls and as a control criterion in recompacted soils and is measured on namples used for most field and laboratory tests. The oven-drying method is the definitive procedure used in standard laboratory practice.

uses an exceleration intercomposition practice. NOTE in conservations, it is not the example in the field control of earthwards, a repid method of measurement of motivar content may be required and a number of repid method are verificitie, ag, the cand both method, the microware over-drying method and the addition carbide method. It should not be argumed that these methods are appropriate for all and types and when they are used as a particular call one test should also be carried out using the over-drying method as a check.

A procedure for determining the moisture content at full exturation of chalk is described.

#### 3.2 Oven-drying method

8.2.1 General. This method covers the determination of the moisture content of a specimen of soil as a percentage of its dry mass.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

### 8.2.2 Apparatus

8.2.2.1 A drying oven, capable of maintaining a temperature of 105 °C to 110 °C.

C BST 11-1995

NOTE A microware over should not be used for the determination of movinue content by the definitive method for solic containing days or appair on matter because of the Sfindary of ensuring that the supportance of the solid does not enced 110 °C before all the water is removed. Higher temperatures then this can allow the properties of days matterial. 8.2.2.2 For fine-grained soils

8.2.2.2.1 A glass weighing bottle. Etted with a ground glass stopper or cap, or a suitable sirtight correction-resistant metal container. 8.2.2.2.2 A balance readable to 0.01 g.

3.2.2.2.3 A desiccutor containing anhydrous silica gel.

yes. NOTE: It is predentitle to use califinding failing get at the desicent. Outdoor chiefeds should not be used as it is known that many days when oven day are expande of shoothing water from it.

8.2.2.3 For medium-grained soils 3.2.2.3.1 A corresion-resistant container of

about 500 g capacity

8.2.2.8.2 A balance readable to 0.1 g.

8.2.2.8.8 A scoop of suitable size.

8.2.2.4 For course-grained soils 3.2.2.4.1 A corresion-resistant container of

shout 4 kg capacity.

8.2.2.4.2 A balance readable to 1 g. 8.2.2.4.8 A scoop of suitable size.

3.2.8 Procedure

8.2.8.1 For fine-grained soils

8.2.3.1.1 Clean and dry the weighing bottle or metal 3.2.3.1.1 Clean and dry the weighing sorte end container and weigh it to the nearest 0.01 g (m<sub>2</sub>). container and weight to the marrest of 0 g (mg). Take a rample of at least 50 g of coll, crumble and place localy in the container or weighing bottle, and replace the lid or stopper. Then weigh the container or bottle and contents to the nearest 0.01 g (mg). 3.2.3.1.2 Remove the lid or stopper, and place the

container or bottle with its lid and contents in the oven and dry at 105 °C to 110 °C. The period required for drying will vary with the type of soil requires for drying will vary with the type of coll and the circ of rample but the rample shall be deemed to be dry when the difference in successive weighings of the cooled rample (see 3.2.3.1.3 and 3.2.3.1.4) at intervals of 4 h do not enceed 0.1 % of the original mass of the rample. Do not replace the lid or stopper while the rample is in the oven.

the ish of stripper while the simple is in the over-NOTE1 Correction solic contains gypten which on having lease in writes of crystallinian. The mainture content determined by this method will be address by approximately 0.8 by for such 1 % of crystem. If his is supported that crystem is present in the soil the morture contacts ranging that that crystem is presented in the soil the morture contacts ranging that that crystem is presented on the soil the isolation of the same isolation of crystem can be Grains of gypram will turn white within a few minutes, whereas most other mineral grains remain unaitered.

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# **APPENDIX 10**

# METHODS OF TEST FOR SOILS FOR CIVIL ENGINEERING PURPOSES (BS 1377-3:1990)



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9 Determination of the pH value

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method. 9.1 General

This clause describes the procedure for determining the pH value, by the electrometric method, which gives a direct reading of the pH value of a soil

suspension in water. This method can also be used for determining the pH value of a sample of ground water.

NOTE Good practice in chemical testing requires that du speciment should be tested. In each of the test methods the measurement of only one value of the overall result is described. It is recognized that it is necessary in many practical applications to make a number of tests in order to obtain a mean value a indication of the realiability of the results. Guidance on the e and an number of measurements required and the treatment of the results obtained is beyond the scope of this Part of this stan

9.2 Apparatus

9.2.1 Apparatus for preparation of test specimens 9.2.1.1 Balance, readable to 0.001 g.

9.2.1.2 Pestle and mortar, or a suitable mechanical crusher.

9.2.1.3 Test sieve, of 2 mm aperture size, with receiver

9.2.1.4 Non-corrodible tray.

9.2.2 Apparatus for electrometric method of pH determination

9.2.2.1 pH meter, fitted with a glass electrode and a

calomel reference electrode (which may be

incorporated in one probe) covering the range pH 3.0 to pH 10.0. The scale shall be readable and accurate to 0.05 pH units.

9.2.2.2 Three 100 mL glass or plastics beakers with cover glasses and stirring rods.

9.2.2.3 Two 500 mL volumetric flasks.

9.2.2.4 Wash bottle, preferably made of plastics. containing distilled water.

9.3 Reagents

9.3.1 General. All reagents shall be of recognized analytical reagent quality.

9.3.2 Buffer solution, pH 4.0. Dissolve 5.106 g of potassium hydrogen phthalate in distilled water and dilute to 500 mL with distilled water. Alternatively, a proprietary buffer solution of pH 4.0

may be used

9.3.3 Buffer solution, pH 9.2. Dissolve 9.54 g of sodium tetraborate (borax) in distilled water and dilute to 500 mL. Alternatively, a proprietary buffer solution of pH 9.2 may be used.

9.3.4 Potassium chloride. Saturated solution (for maintenance of the calomel electrode).

9.4 Preparation of test specimen

9.4.1 Obtain an initial sample as described in 7.3, and of the appropriate size specified in 7.5 of BS 1377-1:1990.

9.4.2 Allow the sample to air-dry by spreading out on a tray exposed to air at room temperature. 9.4.3 Sieve the sample on a 2 mm test sieve (if appropriate, guarded by a sieve of larger aperture) and crush retained particles other than stones to

pass through the 2 mm test sieve. 9.4.4 Reject the stones, ensuring that no fine material adheres to them, e.g. by brushing. Record the mass  $m_2$  (in g) of the sample passing the 2 mm test sieve to the nearest 0.1 %. Throughout these and subsequent operations ensure that there is no loss of fines.

9.4.5 Divide the material passing the 2 mm test sieve by successive riffling through the 15 mm divider to produce a representative test sample of 30 g to 35 g.

9.5 Electrometric method of pH determination 9.5.1 From the sample obtained as described in 9.4, weigh out  $30 \pm 0.1$  g of soil and place in a 100 mL beaker.

9.5.2 Add 75 mL of distilled water to the beaker, stir the suspension for a few minutes, cover with a cover glass and allow to stand for at least 8 h.

NOTE The pH value of a soil suspension varies with the ratio of soil to water, an increase in dilution bringing the pH closer to 7 9.5.3 Stir the suspension again immediately before testing.

9.5.4 Calibrate the pH meter by using the standard buffer solutions, following the procedure recommended by the manufacturer.

9.5.5 Wash the electrode with distilled water and immerse in the soil suspension. Take two or three readings of the pH of the suspension with brief stirrings between each reading. These readings shall agree to within 0.05 pH units before being accented.

NOTE The pH readings of the soil suspension should reach a onstant value in about 1 min. No readings should be taken until he pH meter has reached equilibrium.

9.5.6 Remove the electrodes from the suspension and wash them with distilled water. Re-check the calibration of the pH meter against one of the standard buffer solutions.

9.5.7 If the instrument is out of adjustment by more than 0.05 pH units, set it to the correct adjustment and repeat steps 9.5.5 and 9.5.6 until consistent readings are obtained.

9.5.8 When not in use, leave the electrode standing in a beaker of distilled water.

9.6 Test Report

The test report shall state that the test was caried out in accordance with 9.5 of BS 1377-3:1990 and shall contain the following information:

a) the method of test used;

b) the pH value of the soil suspension to the nearest 0.1 pH nit

c) the information required by 9.1 of BS 1377-1:1990.