

**QUALITY ASSURANCE OF CRUDE OIL PRODUCTION AT EXPORT  
TERMINALS**

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**BENIN CITY**

**JULY, 2025.**

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**A REPORT SUBMITTED TO THE DEPARTMENT OF INDUSTRIAL  
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**DEPARTMENT OF INDUSTRIAL ENGINEERING**

**UNIVERSITY OF BENIN**

**BENIN CITY**

**JULY, 2025.**

## CERTIFICATION

This is to certify that this research work on the “Quality assurance of crude oil at export terminals” was carried out by ENG2002340 of the department of Industrial engineering, University of Benin city.

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**PROF.R.O.EDOKPIA**

**SUPERVISOR**

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**PROJECT COORDINATOR**

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**DATE**

## **DEDICATION**

This project is dedicated to God Almighty for His infinite grace, wisdom, and provision throughout this journey.

## ACKNOWLEDGEMENT

I wish to express my profound gratitude to God for his mercies and guidance throughout this project. I also want to thank my Supervisor Prof.R.O.Edokpia for his advice and counsel.

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## LIST OF ABBREVIATIONS AND SYMBOLS

API – American Petroleum Institute

ASTM – American Society for Testing and Materials

BS&W – Basic Sediment and Water

°C – Degree Celsius

CL – Center Line (Control Chart)

C<sub>pk</sub> – Process Capability Index

C<sub>n</sub> – Concentration of hydrocarbon with carbon number n

D<sub>3</sub>, D<sub>4</sub> – Control Chart Constants for Range Charts

°F – Degree Fahrenheit

FID – Flame Ionization Detector

GC – Gas Chromatography

GDP – Gross Domestic Product

H<sub>2</sub>S – Hydrogen Sulphide

HOD – Head of Department

IP – Institute of Petroleum

ISO – International Organization for Standardization

LCL – Lower Control Limit

LOD – Limit of Detection

MS – Mass Spectrometry

mL – Millilitre

mm – Millimetre

NNPC – Nigerian National Petroleum Company

OPEC – Organization of Petroleum Exporting Countries

QA – Quality Assurance

QC – Quality Control

R-Chart – Range Control Chart

RCA – Root Cause Analysis

rcf – Relative Centrifugal Force

SPC – Statistical Process Control

SOP – Standard Operating Procedure

SG – Specific Gravity

TAN – Total Acid Number

UCL – Upper Control Limit

UNIBEN – University of Benin

### **Symbol**

$\rho$  – Density

$\eta$  – Viscosity

$^{\circ}\text{API}$  – Unit for API Gravity

$\Delta$  – Change/difference between values

$\Sigma$  – Summation

R – Range (Max – Min of subgroup)

$\bar{X}$  – Mean (Average of subgroup)

## ABSTRACT

The aim of this project was to evaluate the effectiveness of the crude oil Quality Assurance (QA) system at the NNPC E&P Ltd Oil & Gas Processing Facility/Utapete Crude Oil Export Terminal by analyzing its process stability. Maintaining the quality assurance of crude oil at export terminals is critical for preserving product value, ensuring customer satisfaction, and complying with contractual and environmental standards. This evaluation was necessary to determine if the production process was in a state of statistical control, which is essential for ensuring predictable and reliable export quality.

The methodology employed Statistical Process Control (SPC) techniques to analyze the data. Specifically, laboratory data for two key quality parameters—API Gravity and Basic Sediments & Water (BS&W)—were collected for a two-month period encompassing July and August 2025. The data was subsequently analyzed using (mean) and (range) control charts to statistically assess the central tendency and the consistency of the production process, respectively.

The analysis revealed that the process averages (X bar-charts) for both API Gravity and BS&W were highly unstable and out of statistical control, with numerous data points exceeding the upper and lower control limits. This instability signifies that the process is unpredictable and influenced by significant special (assignable) cause variation. Conversely, the process variability (R-charts), which reflects the consistency of measurement and sampling, was found to be largely stable and in-control. This study concludes that the terminal's production process is not in statistical control, leading to a high risk of producing non-conforming crude oil, and demonstrates an urgent need to investigate the root causes of instability in the production and blending operations, rather than the laboratory procedures.

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background to the study

Petroleum (also called crude oil) is the term used to describe a wide variety of naturally occurring hydrocarbon-rich fluids that has accumulated in subterranean reservoirs and which exhibits considerably simple properties such as specific gravity/API gravity) and the amount of residuum more detailed inspections show considerable variations in color, odor, and flow properties that reflect the diversity of the origin of petroleum. From further inspections, variations also occur in the molecular types present in crude oil, which include compounds of nitrogen, oxygen, sulfur, metals (particularly nickel and vanadium), as well as other elements (ASTM D4175) (Speight, 2015). Consequently, it is not surprising that petroleum can exhibit wide variations in refining behavior, product yields, and product properties (Speight, 2014).

Petroleum meaning literally rock oil is the term used to describe a myriad of hydrocarbon-rich fluids that has accumulated in subterranean reservoirs and which vary dramatically in properties .The terminology and definitions applied to petroleum have been defined elsewhere in this work and will not be repeated here. General aspects of petroleum quality (as a refinery feedstock) are assessed by measurement of physical properties such as relative density (specific gravity), refractive index or viscosity, or by empirical tests such as pour point or oxidation stability that are intended to relate to behavior in service. In some cases the evaluation may include tests in mechanical rigs and engines either in the laboratory or under actual operating conditions. (Speight,2007.)

Crude oil remains one of the most vital energy resources globally, serving as the backbone of industrialization, transportation, and economic development. From exploration and production to transportation and refining, the petroleum value chain demands high levels of quality control to ensure safety, compliance, and economic value. Quality assurance (QA) in crude oil production and export terminals is not just about maintaining consistency in product specifications; it also ensures operational efficiency, environmental protection, and customer satisfaction.

Quality assurance in crude oil production encompasses a wide range of activities, including accurate sampling, laboratory analysis, compliance with international standards (e.g., API, ASTM), and proper documentation. Export terminals play a crucial role as the final checkpoint before crude oil is shipped to international markets. Here, quality assurance becomes even more critical due to legal and commercial obligations tied to the specifications of delivered crude.

In recent years, increased regulatory scrutiny, the demand for cleaner energy, and competitive global markets has elevated the importance of robust QA systems in upstream operations and export logistics (Speight, 2014). The implementation of reliable QA protocols reduces operational risk, minimizes contamination, enhances traceability, and ensures that the crude meets contractual specifications.

## **1.2 Statement of the problem**

Despite the economic importance of crude oil to national and global markets, several production and export terminals in oil-producing countries like Nigeria face critical challenges in maintaining consistent product quality. These challenges include equipment

degradation, inadequate inspection protocols, contamination (e.g., water, sediments, sulfur), and non-compliance with international quality standards such as API gravity specifications. As a result, crude oil shipments risk being rejected or downgraded in value on the international market, leading to revenue losses, reputational damage, and environmental hazards.

Therefore this study seeks to identify parameters that do not conform to quality standards and aim to improve on areas that are out of control.

### **1.3. Aim and objectives**

The aim of quality assurance in crude oil production and export terminals is to ensure that the oil being produced, stored, and exported meets established standards for quality, quantity, and traceability.

Objectives of the study:

- I. To visit the oil and gas processing facility laboratory.
- II. To collate of data from the laboratory log books for a span of two months (July and August 2025.)
- III. To analyse the data using a control chart in Microsoft Excel 2010.

### **1.4 Scope of study**

This research focuses on monitoring quality assurance of crude oil production at export terminals, considering parameters such as API gravity and Basic sediments and water content for a production span of two months. Experimental validation will be derived at NNPC E&P LTD Oil and gas processing facility\Utapete crude oil export terminal, through

the use of instruments such as hydrometers, thermometers, hydrometers cylinder, centrifuges, centrifuge tubes and a bath.

### **Significance of the study**

1. Ensures Product Quality and Consistency systems for quality assurance (QA) ensuring that crude oil satisfies requirements that are essential to its classification and market value, such as API gravity, sulfur content, and BS&W (basic sediment and water).

To satisfy customer expectations and reduce refinery processing interruptions, consistent quality is crucial.

### 2. Compliance with Regulatory and Contractual Standards

QA guarantees adherence to contractual commitments between manufacturers and purchasers as well as international standards (such as ASTM D86 and ISO 29001). Rejected shipments or legal issues may arise from noncompliance.

### 3. Environmental Stewardship

Proper quality controls reduce the risk of spills, emissions, or accidental discharges. This demonstrates corporate responsibility and protects fragile ecosystems especially vital for offshore terminals and coastal loading points.

### 4. Operational Efficiency and Safety

QA practices like equipment calibration, regular testing, and process controls prevent issues such as pipeline corrosion, contamination, or explosions. This reduces downtime, extends asset life, and ensures the safety of personnel and surrounding communities.

## CHAPTER TWO

### LITERATURE REVIEW

#### **What is crude oil?**

Petroleum crude is bitumen which is composed of hydrocarbon and it is a natural mixture of hydrocarbons, generally in the liquid state, that may also include compounds of sulfur, nitrogen, oxygen, and metals and other elements. The inorganic sediment and water may also be present. A crude oil product is any product that is manufactured during petroleum refining. As a result, it is not surprising that petroleum can vary in composition properties and produce wide variations in refining behavior as well as product properties. Petroleum crude oil means literally rock oil and refers to hydrocarbons that occur widely in the sedimentary rocks in the form of gases, liquids, semisolids, or solids. In chemical point of view, petroleum is an extremely complex mixture of hydrocarbon compounds, usually with minor amounts of nitrogen, oxygen, and sulfur-containing compounds as well as trace amounts of metal-containing compounds. The high energy density of crude oil, easy transportability and relative abundance, oil has become the world's most important source of energy since the mid-1950's. Petroleum is also the raw material for many chemical products, including pharmaceuticals, solvents, fertilizers, pesticides and plastics. . (Vignesh,*et al.*, 2019.)

Oil is a crucial energy source for modern economies and remains a major energy commodity traded in the international market. The demand and supply of oil depends on the internationally determined market price which can be affected by unpredictable global events (Nwosu, *et al.*,2020). Thus, the price and production of crude oil remains an important component influencing the world's economic development, modern turn of

events, food cost, poverty, and other financial factors, other than its elements is the primary list exhibiting oil market conditions; (Sule-Iko & Nwoye, 2023). Crude oil in this study is believed to be the main driver of the economic condition of developing countries especially Africa continents Nigeria to be precise such that a rise in the price of crude oil significantly improves the country's revenue and a fall also affects the nation's revenue negatively (Sule-Iko & Ibrahim, 2021). According to Baumeister and Kilian (2016), oil price fluctuations are an unanticipated component of a substantial change in the price of oil, defined as the difference between the expected and realized oil prices. In the simplest term, a change in oil price could boost economic growth in that it could make the price of crude oil in the international market appreciate at the expense of domestic oil prices. However, the general impact of crude oil price fluctuations on enterprises and economic growth is mainly determined by how the government manages its previous and current revenue (Ighosewe, Akan, & Agbogun, 2021). The Nigerian economy has been heavily reliant on the production and export of crude oil as its main source of foreign exchange earnings and government revenue. Thus, changes in crude oil prices and production have a significant impact on the performance of the Nigerian Gross Domestic Product (GDP) (Igbodika, Jessie, & Andabai, 2016). According to the World Bank Report (2023), Nigeria's projected current account deficit will remain at an average of 0.3% of Gross Domestic Product (GDP) in 2013-25 due to declining prices and stagnant oil production. Despite oil prices trading at an average of \$101 per barrel per year, the decline in oil production in 2022 exposed Nigeria's fragile state, as real growth of the country's oil GDP stood at -19.2% at the end of the year (National Bureau of Statistics, 2022). Before corona pandemic, Nigeria's oil sector alone accounted for about 9% of the country's gross domestic product (GDP).

Between October and December 2020, the oil industry contributed 5.9% to the total real GDP, a decrease of roughly three percentage points compared to the previous quarter in July-September (Sasu, 2023). Fluctuations in crude oil production levels also have a significant impact on the performance of Nigeria's economy. Nigeria is the largest oil producer in Africa and the sixth-largest oil-producing country in the world (World Bank, 2022; Olofinbiyi et al., 2021). Attacks on oil infrastructure in the Niger Delta region, pipeline vandalism, and oil theft have led to significant disruptions in crude oil production, leading to a decline in government revenue and negatively affecting the country's GDP (Iwayemi et al., 2019). Effects of crude oil price as well as its production on Nigeria economy (GDP) since its discovery in 1956 in Oloibiri, Niger Delta after half a century of exploration by Shell B. P. cannot be over emphasized following that Nigeria's economy since the 1970s is incomplete without recounting the swings in crude oil prices (BudgIT, 2014). Apart from unrest and insecurity issues the oil price glut globally has become one of the biggest challenges deterring the Nigerian economy (Umoru et al. (2023) proofed in their study that crude oil price volatility has a significant negative impact on the Nigerian economy using Generalized Auto regressive Conditional Heteroscedasticity (GARCH) model. In the same vein (Obi & Nwezeaku, 2021) affirmed that the relationship between crude oil production and the Nigerian GDP is positively significant using Johansen cointegration test and error correction model. The study concludes that crude oil production has a significant impact on the Nigerian economy. The above findings supported (Oyewole & Oloni, 2019) found out that Nigerian economy was more responsive to changes in crude oil prices than changes in production levels using vector auto-regression model approach to the impact of crude oil prices and on Nigerian GDP. The impact of oil price fluctuation is

different between oil-importing and exporting countries. Hence, through transmission mechanisms of demand and supply, oil prices have a significant effect on the economic activities of oil producing nations. From the supply side effects, crude oil serves as the primary input to production, and a sudden increase in its price may result in a rise in the production costs of firms, resulting in lower output. Therefore, from the demand side effects, oil price changes affect consumption and investment. Thus, consumption is affected indirectly through its positive relationship with the amount of money that households have available for spending and saving after income taxes have been accounted for (i.e. disposable income). For example, a report shows that oil price fall contributed to economic slump in 2015 with an estimated 2.8% GDP growth rate in Nigeria (Manasseh et al., 2019). The impact of crude oil prices and production levels on Nigeria's economy is not limited to the oil sector alone. The oil sector contributes significantly to government revenue, which, in turn, supports other sectors of the economy. Therefore, fluctuations in crude oil prices and production levels can have a ripple effect on the performance of other sectors of the economy, such as manufacturing, agriculture, and services (Adejumo et al., 2021). Changes in crude oil prices and production can have either positive or negative effects on the Nigerian economy. Thus, there is a need for the Nigerian government to diversify the economy and reduce its reliance on crude oil as its main source of revenue to mitigate the effects of fluctuations in crude oil prices and production (Jayathilaka et al., 2022).

## **2.1 Chemical composition of crude oil**

The petroleum crude also exhibits a wide variations in composition and properties, and these variations not only occur in petroleum from different fields but may also be

manifested in petroleum taken from different production depths in the same well. The mixture of hydrocarbons is highly complex. Paraffinic, naphthenic, and aromatic structures can occur in the same molecule, and the complexity increases with the boiling range of the petroleum crude fraction.

Petroleum is a mixture of a very large number of different hydrocarbon and non-hydrocarbon molecules. Each petroleum crude variety has a unique mixture of molecules, which define its physical and chemical properties. Hydrocarbon component and Non hydrocarbon content The Hydrocarbon component composed of paraffin, naphthenic, aromatic or asphaltic. That is Normal and branched alkane series, Cycloalkanes, Aromatic series, Asphalts, Asphaltene & resins. The Non- hydrocarbon component there are infinite mixtures of hydrocarbon compounds that are from crude oil , sulphur, nitrogen, metals nickel vanadium and oxygen are usually present. These impurities are removed during refining. Sulphur is the most abundant atomic constituent of crude oils. The sulphur is associated with only with carbon and hydrogen, while in the heavier fractions is intercorporated in large polycyclic molecules that contain nitrogen and oxygen.

The oxygen content of crude oil is usually less than 2% by weight and is present as part of the heavier hydrocarbon component in most cases. For this reason the heavier oil contain more oxygen.

Nitrogen is present in almost all crude oils , usually it is less than 0.1% by weight.

## **2.2 Classification Of Crude Oil**

Petroleum crude oil is referred to generically as a fossil energy resource and is further classified as a hydrocarbon resource, coal and oil shale kerogen have also been included

in this classification. However, the petroleum crude is classified based by the raw crude by the in other words oil is classified with geographic region. The classification of petroleum crude oil is derived from the density of the raw petroleum (API gravity) and its various non- hydrocarbon components (especially sulphur), is then added to the geographic designation. End result of all this classification that helps to determine the price of a specific barrel of crude as well as how much demand there is for that particular oil. Also the crude oil is classified on the basis of these three:

On the basis of Density

On the basis of compound type

Based on content of sturates, Asphaltenes, Rasins,  
Parafins and Naphthenes.

### **2.3 Physico-Chemical Characterisation Of Crude Oil**

**Color:** Color of crude oil is transmitted light varies from yellow to red. Some very dark oil is opaque. Higher the specific gravity draker oil. Not all crude oil black-higher quality oils can be golden colour.

**Odour:** Crude oil having larger proportion of aromatic compounds gives pleasant odour. The paraffin and naphthene based oil, the odour agreeable while oil having amount of complex heavier HCs, with Sulphur , Nitrogen and Oxygen component gives disagreeable one.

Water Content: Water content of crude oil is important in the refining or transfer of crude oils. Water and sediments content of crude oil is significant because it can cause corrosion of equipment and problems in processing. (Vignesh,*et al.*, 2019.)

## **2.4 Production of crude oil**

According to OECD (2021) crude oil production can be defined as the quantities of oil that is extracted from the ground after the removal of inert (impurities). The oil production is focused on the exploration and processing of the crude oil. After the discovery of oil in Niger Delta around 1956, Nigeria started oil exploration. Shell-BP was a sole concessionaire when it discovered the crude oil in Nigeria. In 1958, Nigeria became part of the oil producing countries with 5100 bpd initial production (Akinyetun, 2016). The exploration and production of the crude oil soar higher every year due to the operations of the streams like the Upstream, Mid-stream and downstream sector. Crude oil production refers to the extraction and processing of raw, unrefined petroleum from underground reservoirs. This process typically begins with the drilling of exploratory wells to locate and assess the size and quality of an oil deposit. Once a deposit is found and deemed economically viable, production wells are drilled to extract the crude oil. The extracted crude oil is then transported to a processing facility, where it is refined into various products such as gasoline, diesel fuel, and jet fuel. (Olalekan, *et al.*, 2016.) (Sule-Iko,*et al.*,2023.)

## 2.5 Quality assurance

The Analytic Quality Glossary defines quality assurance as ‘the collections of policies, procedures, systems and practices internal or external to the organisation designed to achieve, maintain and enhance quality’. Quality assurance can be both an internal and external process. However, Harvey observes that ‘it has become a shorthand term for ‘for all forms of external quality monitoring, evaluation or review’ and indeed, many commentators actually mean ‘external quality assurance’. Indeed, the former chief executive of the UK’s Quality Assurance Agency, Peter Williams, argued that there was in fact ‘no single common definition of the phrase “quality assurance”’ and that ‘quality assurance, therefore, has become a catch-all phrase; it is asked to do too many different things and as a result it can do few of them to anyone’s satisfaction’ (Williams, 2011). There are certainly different emphases given to quality assurance. Several authorities state that the purpose of quality assurance is to ensure that higher education reaches stated standards. However, some authorities focus on accountability, a term in itself that is seldom defined with respect to higher education. Indeed, quality assurance appears to be understood by many colleagues and institutions as another phrase for ‘accountability’. (Collini ,2012,) refers to accountability in the same breath as quality assurance. Anecdotally, this view is often expressed by colleagues in conversations across the sector. For others, quality assurance is about ensuring the quality of teaching and others focus more on the processes to achieve quality: quality assurance is in fact a meta-process. For Harvey in the Analytic Quality Glossary, quality enhancement ‘is a process of augmentation or improvement’. It has two strands: first it is the ‘enhancement of individual learners; the augmentation or improvement of learners’ attributes, knowledge, ability, skills

and potential.’ Second, it is ‘the improvement in the quality of an institution or programme of study.’ The use of the words ‘enhancement’ and ‘improvement’ are often interchangeable, as they are in the Oxford English Dictionary, but the terms are often used in subtly different ways. Improvement is often used to refer to a process of bringing an activity up to standard whereas enhancement is about raising to a higher degree, intensifying or magnifying it. Several definitions of quality enhancement focus on students’ learning. The UK Quality Assurance Agency (QAA) defined Quality enhancement as an aspect of institutional quality management that is designed to secure, in the context of the constraints within which individual institutions operate, steady, reliable and demonstrable improvements in the quality of learning opportunities. (QAA, 2006). The QAA’s Handbook for Enhancement-led Institutional Review: Scotland (QAA, 2003) defined enhancement as ‘taking deliberate steps to bring about continual improvement in the effectiveness of the learning experience of students’. However, there is also an argument that enhancement can be seen as a definition of quality (Vlăsceanu, et al., 2007.) and this is critiqued by Harvey in the Analytic Quality Glossary because, he argues, quality is more than ‘the continuous search for permanent improvement’. For critics such as Collini, even the notion of continuous quality improvement in higher education is ‘conceptually incoherent’ because, he argues, there is a limit to how far an activity that is already regarded as excellent can practically be improved. (Williams, 2016.)

### **2.5.1 Importance of quality assurance**

To deliver high-quality goods and services that fully satisfy the needs and expectations of their clients, contract research organization must establish, maintain, and closely monitor their quality control (QC) and quality assurance (QA) systems, as well as their integral

standard operating procedures and other quality documents. The primary quality systems incorporate both quality assurance and control systems. Control and quality assurance are essential parts of quality management. Quality assurance ensures that the standards are met, whereas quality control ensures that they are met. The organization's business goals and model need to be in line with the quality systems. To ensure that quality systems are accessible, suitable, and maintained, senior management dedication and active engagement are essential. The ideal outcome of a standardization process is a set of standards, which in the context of quality systems are comprised of papers that are either connected to or of high quality. Excellent quality is a crucial essential requirement, not an extra benefit. Ensuring the effectiveness and continuous improvement of work processes is the responsibility of every employee across all organizational units.

### **2.5.2 Benefits of quality systems**

The significance of meticulously organized and managed QC and QA systems, along by their inherently well-drafted standard operating procedures and other superior documentation, cannot be overstated in attaining the business objectives of the organization. Serving as the company's success passport, they help in achieving high-quality systems, people, processes, and procedures— all of which lead to high-quality goods and services. They also enhance the following: employee understanding and motivation towards the company's quality policy and work objectives, as well as engagement in continuous quality enhancement.[38]

Protection Against Employee Loss: Let's say your company employs the top workers. However, assume you have the most competent employees for your company. But for some reason, the organization's head manager, who used to supervise everything, abruptly quits.

This will leave you in the dark about how to run the business, which will result in chaos. On the other hand, if everything is documented in the documents as SOP, you can prevent this loss of knowledge.[32]

Convenient Training: It's challenging for new hires to comprehend how things operate in your company: They may receive some information from one person and exactly the opposite from the other. But there won't be any space for miscommunication or confusion once everything is well documented. All they have to do is adhere to the procedures and guidelines stated.[28]

To furnish individuals with all the necessary safety, health, environmental, and operational information needed to do a task accurately: Long-term costs result from valuing productivity above everything else and disregarding environmental, health, and safety concerns. Employees should get comprehensive training on all facets of their jobs rather than risk mishaps, penalties, and legal action down the road.[14]

To guarantee that production activities are carried out reliably in order to preserve process and product quality control: Customers of all stripes demand goods that meet uniform standards for quality and functionality. SOPs provide task steps that assist standardize the quality of products.[31]

To guarantee that procedures run smoothly and are finished within the allotted time: Following SOPs can assist prevent process shutdowns caused by malfunctioning equipment or other harm to the facility.[27]

To guarantee that no manufacturing or other process failures take place that might harm anyone in the neighborhood: Adhering to both health and environmental protocols outlined in SOPs protects against leaks and pollutants that could endanger nearby plants and provoke public indignation.[29]

To guarantee that authorized protocols are adhered to in accordance with business and governmental guidelines: SOPs that are well-drafted help to assure that legal requirements are met. They also demonstrate a firm's real intention to behave ethically. Writing and implementing inadequate SOPs will only give the impression to government authorities that your company does not take compliance seriously.[27]

To act as a guide for users to learn about the procedure for which the SOP was created: Comprehensive SOPs can serve as the foundation for standardizing training for both new hires and retraining staff in a particular job.[40]

To reinforce appropriate performance by acting as a checklist for colleagues who notice job performance: Actively caring for co-workers entails one employee mentoring another in all facets of effective work performance. Any colleague can coach another and aid enhance work skills by using a well-written standard operating procedure (SOP) that outlines the necessary methods.[26]

To act as an auditor's check list: Similar to the previously indicated observation, work performance auditing typically entails record-keeping. SOPs need to be a strong starting point for creating comprehensive audit checklists.[9]

To serve as a historical log of the what, why, and how of each stage in an ongoing procedure: This provides a strong basis for revising the steps when a process or piece of equipment is altered. Unwritten knowledge and skills leave the workplace when workers change jobs both inside and across firms. Written SOPs that are kept up to date can document the greatest knowledge that can be passed on to new employees after more experienced ones leave.[23]

To serve as a guide for reviewing procedures in accident investigations: Even if accidents are regrettable, see them as teaching moments for better conditions. An effective SOP provides a foundation for beginning accident investigations. .[24]

(Tanya et al.,2024.)

## **2.6 The quality of the crudes.**

A crude oil is a naturally occurring mixture, consisting predominantly of hydrocarbons, sulphur, nitrogen and metals. Quality (Bawazeer *et al.*, 1997) of the petroleum products is playing the major role of consumer satisfaction and speaks about the performance of the refineries. To identify and predict the behaviour of the crude oil and finished petroleum products in particular circumstances, it is necessary to measure Physico chemical properties (Robert *et al.*, 1995) and to compare the measured values with International Standards. The

typical nature of crude oil from different sources is different or less identical. The same is true for crude oil also; the individual oil even from the same well at different time of extraction is differing in the characteristics in term of chemical composition (Roussel and Boulet, 1995) and Physico-chemical behaviour though the basic trend is almost same for each type of crude oil. It is known that crude oil, the basic raw material of refining industries is not only unique but the entire organic chemistry can be studied. Crude oil contains almost all known hydrocarbons and non-hydrocarbons. As it is drawn from the earth, it also contains impurities like water, mud and salts during its exploration and transportation. Crude oils are complex but mainly paraffinic, naphthenic and aromatic (Wang et al., 1994). Crude oils contain all normal alkenes from (Khanorkar et al., 1996) C1 to C120. However, this percentage rises to 35% in highly paraffmic and decreases to zero in highly biograded oils (Ali et al., 1989). Methane is predominant component of natural gas and alkanes ranging from pentane to pentadecane are the chief constituents of straight run (uncracked) gasoline or petrol. Above C17, the alkanes are solid wax like substances and crude oils, which contain high concentrations of paraffin wax, will be viscous and have high cloud and pour points. These Paraffins consists of isoalkanes and methyl cycloalkanes. Most commonly found naphthenes are five and six membered rings and occasionally a few rings with seven carbon atoms. Among these, methyl derivatives are the most abundant compounds as compared with the parent bicycle compounds. Crude oils contains up to 50% of such naphthenes. Aromatic compounds rarely amount to more than 15% of the crude oils. These are concentrated in heavy fractions such as gas oil, lubricating oils and the residuum. The alkyl derivatives of the benzene namely toluene and xylene are most common aromatic compounds in petroleum. The other derivatives of benzene include fused compounds, the

di-aromatics (naphthalene) and tri-aromatics (Phenanthrene or anthracene). Naphtho-aromatic compounds have also been identified in crude oils. These compounds are abundant in shallow and immature oils. Many of these compounds can be related to steroid and triterpenoid structures. Sulphur compounds (Wang and Huang, 1992) like thiols, sulphides and thiophenes also occur in crude oils. Sulphides (Komine and Tomoike, 1997) are fairly evenly distributed over medium and heavy fractions of crude oils. Compounds of nitrogen in crude oils are unwelcomed because of catalyst poisoning and formation of gum in fuel oils. Nitrogen compounds, which can easily separate, include pyridines, quinolines, indoles, pyroles and carazoles. Oxygen compounds in the form of organic acids occur in young and immature crude oils (Maldonado et al., 2006). These organic acids range in size from C1 to C30 and have isoprenoid structures with members such as carboxylic acids, phenols, cresol anhydride etc. Among the techniques, high-resolution capillary Gas Chromatography (GC) (Yasin et al., 2012) equipped with flame-ionization detection (FID) and capillary GC-MS are the most important and most widely used techniques for oil compounds separation, characterization, and identification. Crude oil and oil-spill related samples are extremely complex mixtures in which the boiling points of components can vary over a wide range from a few to several hundred degrees. Complete separation of such complex samples into individual components is difficult or impossible even with high resolution capillary gas chromatography.

**2.7 Physico-chemical** of crude oil characteristics such as API (American Petroleum Institute) gravity, specific gravity, pour point, calorific value, kinematic viscosity, Reid vapour pressure, copper corrosion, Conradson carbon, water and sediments (BS&W), total

sulphur, and hydrocarbons contents (saturates, aromatics and polar) were determined and used to check for the quality of crude.

## **2.8 API gravity**

The greater is the yield of light fractions by distillation. Therefore, higher API gravity crude oil have higher price and is of good quality. It means that crude oil samples collected from Punjab are better in quality than Sindh crude oils. On the basis of API gravity, Pakistani crude oils (22.30-47.38) are of better quality international crude oils (30.7-36.5) indicated in Table 6. Generally speaking, oil with API gravity between 40 and 45 commands the highest prices. Above 45° the molecular chains become shorter and less valuable to refineries (dnr.louisiana.gov, 1989). Crude oil is classified as light, medium or heavy, according to its measured API gravity. Light crude oil is defined as having API gravity higher than 31.1° API. Medium oil is defined as having API gravity between 22.3° API and 31.1° API. Heavy oil is defined as having API gravity below 22.3° API. Heavy crude oil has been defined as any liquid petroleum with API gravity less than 20° (dnr.louisiana.gov, 1989). North region (Punjab) crude oils (Table 4) vary widely in ranging from 34.97-47.37 (39.94) API gravity. Whereas South region (Sindh) crude oils (Table 5) oils have API gravity ranges 22.30-42.54 (38.18). The specific gravity of the crude oil gives a rough measure of the amount of lighter hydrocarbons present. Lower the specific gravity and higher API gravity, the greater is the yield of light fractions by distillation. Therefore, higher API gravity crude oil have higher price and is of good quality. It means that crude oil samples collected from North region (Punjab) are better in quality than South region (Sindh) crude oils. On the basis of API gravity, all the tested samples of North (Punjab)

regions belong to the class light crude oil having API gravity greater than 31.1°. All the tested samples of South (Sindh) regions belongs to the class light crude oil one sample N (Badin Well#8, Table 5) having API gravity 22.30°.

Table 5. General Physico-chemical characteristics of South Region (Sindh) crude oils.

Characteristics	Test method (ASTM)	Crude oil										
		H	I	J	K	L	M	N	O	P	Range	Mean
SP. Gravity@60/60°F	D-1298	0.8310	0.8360	0.8350	0.8088	0.8135	0.8130	0.9320	0.8453	0.8133	0.8088-0.9320	0.8364
API Gravity@60/60°F	D-1298	38.77	37.75	37.96	43.45	42.43	42.54	22.30	35.90	42.48	22.30-42.54	38.18
Sulfur (wt %)	D-4294	0.018	0.276	0.2360	0.2793	0.8267	0.2630	0.6800	0.9000	0.0300	0.018-0.900	0.390
Water Contents (Vol %.)	D-95	0.05	0.05	0.05	7.0	7.0	6.0	0.05	0.05	0.05	0.05-7.0	2.26
Pour Point												
Kin. Viscosity@40°C (cSt)	D-445	1.99	2.00	1.95	1.29	1.28	1.27	6.70	7.95	1.28	1.27-7.95	2.86
Kin. Viscosity@ 50°C (cSt)	D-445	1.46	1.47	1.42	1.14	1.15	1.14	5.27	6.0	1.15	1.14-6.0	2.24
Pour Point.( °C)	D-97	+18	+18	+21	+6	+12	+12	+12	+36	+12	+12-+36	16.33
Carbon Residue (wt%)	D-189	0.64	0.55	0.62	0.03	0.03	0.03	0.68	0.90	0.03	0.03-0.90	0.39
R.V.P. @37.7°C (Psi)	D-323	6.4	6.6	6.3	4.8	3.0	3.0	4.3	4.0	3.0	3.0-6.6	4.54
Copper Strip Corrosion	D-130	1a	1a	1a	1a	1a	1a	1a	1a	1a	-	1a
Calorific Value (Btu/lb)	D-240	18955	18960	18950	18780	19650	19650	18680	18880	19655	18680-19655	19128.9
Distillation	D-86											
I.B.P.( °C)		52	53	54	50	77	77	65	65	77	52-77	63.33
10% Recovery (°C)		96	97	96	101	122	122	144	144	122	96-144	116.00
30% Recovery (°C)		143	144	143	142	151	151	239	292	151	142-292	172.89
50% Recovery (°C)		212	213	212	188	186	186	289	-	186	186-289	185.78
70% Recovery (°C)		280	283	285	248	239	239	-	-	239	239-285	201.44
Recovery at 300°C (Vol %)		73	70	74	83	86	87	-	-	85	70-86	62.00
Total saturates (wt %)		16.71	22.64	18.54	24.27	17.46	15.97	14.47	8.47	15.85	8.47-24.3	17.15
Total polyaromatic hydrocarbons (wt %)		11.453	7.675	5.478	2.353	5.681	13.279	5.133	14.545	13.146	2.353-14.545	8.749
Total Aromatics (wt %)		17.48	16.92	11.11	6.489	20.10	15.74	12.17	16.72	16.89	6.489-20.1	14.85
Total Polars (wt %)		12.31	14.85	16.26	16.95	22.27	14.86	15.10	10.46	14.83	10.46-22.27	15.34

## 2.9 Water content

Water in crude oil lead to the corrosion of the plant. Water in crude oil is either in the form of emulsion or in large droplets. Emulsified water in heavy asphaltic crude is difficult to separate. There is a variation from low to high in both Northern (Punjab) and Southern (Sindh) crude oils. North region (Punjab) crude oils have water contents 0.05-0.85 (0.314) Vol%. Whereas South region (Sindh) crude oils have water contents 0.05 -7.0 (2.26) Vol%. So North region (Punjab) crude oil is of better quality on the basis of water contents than South region (Sindh) crude oils. It is clear that Pakistani crude oils have more water (0.05-7.0 Vol%) contents than international crude oils (trace). On the basis of water contents Pakistani crude oils are of poor quality.

### 2.1.0 Sulphur

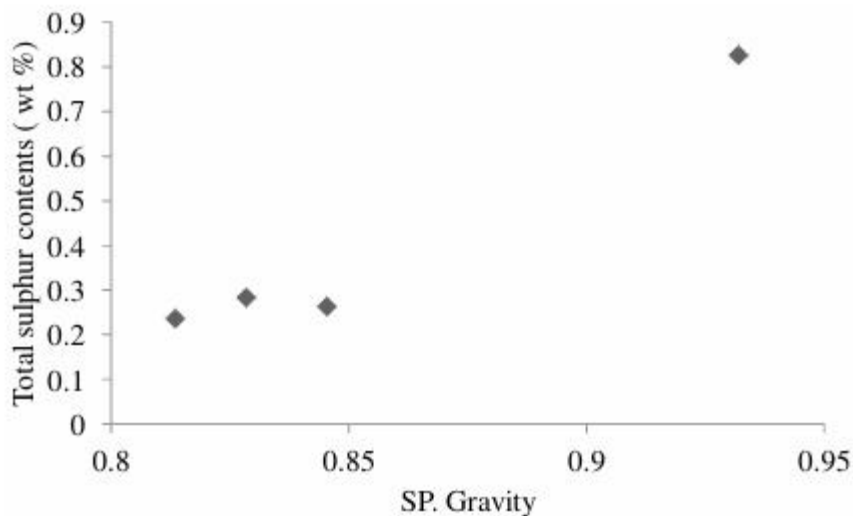
Sweet crude oil is considered "sweet" if it contains less than 0.5% sulfur,

Sour crude oil is that when it contains total sulfur contents greater than 0.5%, Sulphur is highly poisonous, cause foul smelling, corrosion and plant rusting. Sulphur is one of the major concerns of refineries. Certain crudes evolve hydrogen sulphide, low boiling sulphur compound and decomposition products of heavy sulphur compounds during processing. However, most of the sulphur compounds concentrate in the distillation residue. Alkali washing and hydro treating remove the sulphur in the distillate. Most of the indigenous crudes are free from dissolved (H<sub>2</sub>S) sulphur. South region (Sindh) crude oils have sulphur contents 0.018-0.900 (0.390) wt%. The range of sulphur content in North region (Punjab) crude oils is 0.0187-0.2840 (0.096) wt%, it means that, on the basis of sulphur contents, North region (Punjab) crude oils are of good quality than South region (Sindh) crude oils. All the samples of crude oil of North region (Punjab) are of sweet crude oils having sulfur contents less than 0.5 % while sample L, N, and O (Table 2) South region (Sindh) belong to sour crude oils having total sulfur more than 0.5% and others belong to sweet crude oils having total sulfur contents less than 0.5%. International crude oils have sulphur range 0.14-1.48 wt% and Pakistani crudes have lesser sulphur (0.01-0.90). So Pakistani crude oils are better in quality on the basis of sulphur than international crude oils. Generally, there is a direct relationship between the specific gravity and the sulphur. As the specific gravity increases, the sulphur contents also increases and vice versa as shown in Figure 1.

(Ghulam, Y. *et al.*, 2013).

**Table 6.** Reported values of physical parameters of some international crude oils.

Characteristics	Texas Gulf Coast Mix.	Nigerian (Bonney)	Canada (Red water)	Venezuela (Lagemar)	Pakistan (Min.-Max.)
API Gravity at 60/60 °F	36.5	38.1	34.9	30.7	22.30-47.38
Viscosity SUS at 77 °F	41.0	38.4	47.8	107.0	-
Viscosity SUS at 100°F	37.3	35.7	41.7	64.3	-
Sulphur wt %	0.16	0.14	0.56	1.48	0.018-0.90
Water & Sediments Vol %	0.1	trace	trace	trace	0.018-0.8267
Reid Vapour Pressure at 100°F	3.2	6.9	8.4	2.5	3.0-7.0
Distillation (°F)					
I.B.P.	<50	<50	<50	<50	113-170.6
10% recovery	245	220	230	269	204.8-291.2
30% recovery	398	375	382	422	287.6-557.6
70% recovery	654	684	792	907	462.2-545.0
F.B.P.	1033	1045	1050	1083	-
Total recovery vol %	96	96	92	84	35-86



**Figure 1.** Effect of specific gravity on total sulphur contents.

## Export terminals

A crude oil export terminal is a facility located near oil producing regions or refineries, specifically designed for storage, handling, and loading of crude oil onto ships for export to international markets. Examples of a crude oil terminal include The Nembe crude oil export terminal in Nigeria and the Otakikpo onshore terminal.

Specialized facilities or sites created for the loading, unloading, and transfer of products meant for international shipping are known as export terminals. These terminals facilitate the export of goods from one nation to another and are important links in the supply chain (Bowers, 2019).

### **2.11 Export Terminal Functions**

1. Loading and Unloading: Export terminals have the infrastructure needed to load cargo onto ships or move it to other shipping methods like trucks or rail. This feature guarantees the safe and timely handling of freight.

2. Storage: Before products are dispatched, these terminals usually offer short-term storage. This is essential for inventory control and making sure that goods are delivered on schedule (Ferdinand, 2018).

3. Customs Clearance: To speed up the export process, export terminals frequently have customs facilities that allow for the speedy processing of shipping paperwork and customs clearance (Smith, 2020).

4. Quality Control: To guarantee adherence to global standards, certain export terminals provide facilities for examining and verifying the quality of items prior to shipment (Jones, 2021).

5. Logistics Management: To improve supply chain efficiency, a lot of export terminals provide logistics services to plan the distribution and transportation of commodities (Davis, 2022).

## **CHAPTER THREE**

### **METHODOLOGY**

#### **3.1 RESEARCH DESIGN**

The research technique used to investigate the quality assurance procedures in crude oil production and export terminals is presented in this chapter. It describes the study's methodology, data sources, data collection strategies, sample tactics, and data analysis processes.

#### **3.2 STUDY AREA**

“NNPC E&P Ltd Oil & Gas Processing Facility/Utapete Crude Oil Export Terminal” located in Oil Mining Lease 13, Akwa-Ibom State.

#### **3.3 QUALITY PARAMETERS OF CRUDE OIL**

Some parameters that define crude oil quality include the following:

API gravity (American petroleum institute)

Sulphur content

Basic sediments and water (BS&W)

Heavy metals

Pour point

Gas solubility

Total acid number (TAN)

Viscosity

Vapor pressure

But for this study we will look out for these two parameters namely:

API gravity (American petroleum institute)

Basic sediments and water (BS&W)

### **3.4 SOURCE OF DATA**

Laboratory log book

### **3.5 DATA COLLECTION INSTRUMENTS**

For API gravity

1. Hydrometers
2. Thermometers
3. Hydrometer Cylinder

For Basic sediments and water (BS&W)

1. Centrifuge
2. Centrifuge tube
3. Bath
4. Pipet

### **3.6 DATA COLLECTION PROCEDURE**

**Procedure for API gravity test:**

1. For referee testing, use the long plain form of hydrometer (1H to 10H). For field testing, use the thermohydrometer method in Test Method.

2. Adjust the temperature of the sample for field testing. The hydrometer cylinder shall be approximately the same temperature as the sample to be tested.

3. Transfer the sample into the clean hydrometer cylinder without splashing, so as to avoid the formation of air bubbles and to reduce to a minimum the evaporation of the lower boiling constituents of the more volatile samples. (Warning— extremely flammable. Vapors may cause flash fire.) For the more volatile samples, transfer to the hydrometer cylinder by siphoning. (Do not start the siphon by mouth.) Use a rubber aspirator bulb. Remove any air bubbles formed, after they have collected on the surface of the sample, by touching them with a piece of clean filter paper or other suitable means before inserting the hydrometer. For field testing, make the gravity measurement directly in the sampling thief. Place the cylinder containing the sample in a vertical position in a location free from air currents. Take precautions to prevent the temperature of the sample from changing appreciably during the time necessary to complete the test. During this period, the temperature of the surrounding medium should not change more than 5°F (2°C).

4. Lower the hydrometer gently into the sample and, when it has settled, depress it about two scale divisions into the liquid and then release it; keep the rest of the stem dry, as unnecessary liquid on the stem changes the effective weight of the instrument, and so affects the reading obtained. With samples of low viscosity, a slight spin imparted to the instrument on releasing assists in bringing it to rest, floating freely away from the walls of the hydrometer cylinder. Allow sufficient time for the hydrometer to become completely

stationary and for all air bubbles to come to the surface. This is particularly necessary in the case of the more viscous samples.

5. When the hydrometer has come to rest, floating freely, and the temperature of the sample is constant to  $0.2^{\circ}\text{F}$  ( $0.1^{\circ}\text{C}$ ), read the hydrometer to the nearest scale division. The correct reading is that point on the hydrometer scale at which the surface of the liquid cuts the scale. Determine this point by placing the eye slightly below the level of the liquid and slowly raising it until the surface, first seen as a distorted ellipse, appears to become a straight line cutting the hydrometer scale.

6. To make a reading with nontransparent liquids, observe the point on the hydrometer scale to which the sample rises above its main surface, placing the eye slightly above the plane surface of the liquid. This reading requires a correction. Determine this correction for the particular hydrometer in use by observing the height above the main surface of the liquid to which the sample rises on the hydrometer scale when the hydrometer in question is immersed in a transparent liquid having a surface tension similar to that of a sample under test.

7. Observe the temperature of the sample to the nearest  $0.25^{\circ}\text{F}$  ( $0.1^{\circ}\text{C}$ ) immediately before and after the observation of the gravity, the liquid in the cylinder being thoroughly but cautiously stirred with the thermometer (Note 2), and the whole of the mercury thread being immersed. Should these temperature readings differ by more than  $1^{\circ}\text{F}$  ( $0.5^{\circ}\text{C}$ ), repeat the temperature and gravity observations when the temperature of the sample has become

more stable. Record the mean of the thermometer reading before and after the final hydrometer reading, to the nearest 1°F, as the temperature of the test.

NOTE 2—When thermohydrometers are used, stir the sample by carefully raising and lowering the hydrometer. It is satisfactory in this case to read the thermometer scale after the hydrometer reading has been observed. Read the thermometer to the nearest 1°F (0.5°C).

**TABLE 2 Limiting Conditions and Testing Temperatures**

Sample Type	Gravity Limits	Initial Boiling Point Limits	Other Limits	Test Temperature
Highly volatile	lighter than 70° API			Cool to 35°F (2°C) or lower in original closed container.
Moderately volatile	heavier than 70° API	below 250°F (120°C)		Cool to 65°F (18°C) or lower in original closed container.
Moderately volatile and viscous	heavier than 70° API	below 250°F (120°C)	Viscosity too high at 65°F (18°C)	Heat to minimum temperature for sufficient fluidity.
Nonvolatile	heavier than 70° API	above 250°F (120°C)		Any temperature between 0 and 195°F (-18 and 90°C) as convenient.
Mixtures of nonpetroleum products or essentially pure hydrocarbons				60 ± 0.25°F (15.56 ± 0.1°C)

### 3.6.2 Procedure for Basic sediments and water test:

1. Fill each of two centrifuge tube to the 50mL mark with sample directly from the sample container. Using a pipet or other suitable volume transfer device, add 50mL ± 0.05mL of toluene, which has been water saturated at 60°C (140°F) or 71°C (160°F). read the top of the meniscus at both the 50mL and 100mL marks. Add 0.2mL pipet of demulsifier solution to each tube, using a 0.2mL or other suitable volume transfer devices, such as an automatic pipettor. Stopper the tube tightly and invert the tubes ten times to ensure that the oil and solvents are mixed uniformly.

2. In the case where the crude oil is very viscous and mixing of the solvent with the oil would be difficult, the solvent may be added to the centrifuge tube first to facilitate mixing. Take care to not fill the centrifuge tube past the 100mL mark with the sample.

3. Loosen the stoppers slightly and immerse the tubes to the 100mL mark for at least 15 minutes in the bath maintained at  $60^{\circ}\text{C} \pm 3^{\circ}\text{C}$  ( $140^{\circ}\text{F} \pm 5^{\circ}\text{F}$ ). secure the stoppers and again invert the tubes ten times to ensure uniform mixing of oil and solvent.(caution-the vapor pressure at  $60^{\circ}\text{C}$ ( $140^{\circ}\text{F}$ ) is approximately double that at  $40^{\circ}\text{C}$ ( $104^{\circ}\text{F}$ )).
  
4. Place the tubes in the trunnion cups on opposite side of the centrifuge to establish a balance condition. (If the tubes cannot be counter-balanced by eye, place them in their trunnion cups, on either side of a balance and equalize their masses by the addition of water of the trunnion cups). Retighten the corks and spin for 10minutes at a minimum relative centrifugal force of 600 calculated previously.
  
5. Immediately after the centrifuge comes to rest following the spin, read and record the combined volume of the water and sediment at the bottom of the tube, to the nearest 0.05mL from 0.1mL to 1mL graduations, and to the nearest 0.1mL above 1mL graduations. Below 0.1mL, estimate to the nearest 0.025mL. return the tubes without agitation to the centrifuge and spin for another 10 minutes at the same rate.
  
6. Repeat this operation until the combined volume of water and sediment remains constant for two consecutive readings. In general, not more than two spinning are required.
  
7. The temperature of the sample during the entire centrifuging procedure shall be maintained at  $60^{\circ}\text{C} \pm 3^{\circ}\text{C}$  ( $140^{\circ}\text{F} \pm 5^{\circ}\text{F}$ )

8. To avoid the danger of tubes breaking in the cups, care must be taken that the tubes are bedded onto the bottom cushion so that no part of the tubes is in contact with the rim of the cup.

### 3.7 VALIDITY AND RELIABILITY OF THE INSTRUMENT

#### 3.7.1 For API gravity instrument

Hydrometers of glass, calibrated in degrees API and conforming to Specification E100. The user should ascertain that the instruments used for this method conform to the requirements set out above with respect to materials, dimensions, and scale errors. In cases where the instrument is provided with a calibration certificate issued by a recognized standardizing body, the instrument is classed as certified and the appropriate corrections for the meniscus effect, the thermal glass expansion effect, and alter native calibration temperature effects shall be applied to the observed readings prior to corrections. Instruments that satisfy the requirements of this test method, but are not provided with a recognized calibration certificate, are classed as uncertified.

**TABLE 1 Available Hydrometers Scaled, Degrees API**

Designation	Type	API Range, deg		Scale	
		Series Total	Each Unit	Division	Error
1H to 10H	long plain	-1 to 101	12	0.1	0.1
21H to 40H	short plain	0 to 101	6	0.1	0.2
51H to 60H	thermo	-1 to 101	12	0.1	0.1
71H to 74H	thermo	-1 to 41	12	0.1	0.1
<sup>A</sup>	thermo	15 to 51	8		

Thermometers having a range from  $-5$  to  $+215^{\circ}\text{F}$  and conforming to the requirements for Thermometer 12F as prescribed in Specification E1 or Thermometer 64F of the Specification for IP Standard Thermometers, Alternate measuring devices or systems may be used, provided that the total uncertainty of the calibrated system is no greater than when using liquid-in-glass thermometers. The stated repeatability and reproducibility values are not applicable if alternate fluids are used in the liquid-in-glass thermometers. NOTE 1—The ASTM Gravity Thermometer 12F has  $0.5^{\circ}\text{F}$  subdivisions and allowable  $60.25^{\circ}\text{F}$  scale error.

Hydrometer Cylinder of clear glass, plastic, or metal. The inside diameter of the cylinder shall be at least 25mm greater than the outside diameter of the hydrometer and the height shall be such that the appropriate hydrometer floats in the test portion with at least 25mm clearance between the bottom of the hydrometer and the bottom of the cylinder. Hydrometer cylinders constructed of plastic materials shall be resistant to discoloration or attack by oil samples and shall not affect the material being tested. They shall not become opaque under prolonged exposure to sunlight.

### **3.7.2 For basic sediments and water**

A centrifuge capable of spinning two or more filled cone-shaped, 203 mm (8 in.) centrifuge tubes at a speed that can be controlled to give a relative centrifugal force (rcf) of a minimum of 600 at the tip of the tubes shall be used. The revolving head, trunnion rings, and trunnion cups, including the cushions, shall be soundly constructed to withstand the

maximum centrifugal force capable of being delivered by the power source. The trunnion cups and cushions shall firmly support the tubes when the centrifuge is in motion. The centrifuge shall be enclosed by a metal shield or case strong enough to eliminate danger if any breakage occurs. The centrifuge shall be heated and controlled thermostatically to avoid unsafe conditions. It shall be capable of maintaining the sample temperature during the entire run at  $6^{\circ}\text{C} \pm 3^{\circ}\text{C}$  ( $140^{\circ}\text{F} \pm 5^{\circ}\text{F}$ ). The thermostatic control shall be capable of maintaining the temperature within these limits and operate safely if there is a flammable atmosphere. Electric powered and heated centrifuges must meet all safety requirements for use in hazardous areas. Calculate the necessary minimum speed of the rotating head in revolutions per minute (r/min) as follows:  $r/\text{min} = 1335 \sqrt{\text{rcf}/d}$  (1) where: rcf = relative centrifugal force and d = diameter of swing measured between tips of opposite tubes when in rotating position, mm, or  $r/\text{min} = 265 \sqrt{\text{rcf}/d}$  (2) where: rcf = relative centrifugal force and d = diameter of swing measured between tips of opposite tubes when in rotating position in. Calculate the relative centrifugal force from a measured speed (r/min) as follows:  $\text{rcf} = \left(\frac{d}{1335}\right)^2 \left(\frac{r/\text{min}}{5}\right)^2$  (3) where: d = diameter of swing measured between tips of opposite tubes when in rotating position, mm, or  $\text{rcf} = \left(\frac{d}{265}\right)^2 \left(\frac{r/\text{min}}{5}\right)^2$  (4) d = diameter of swing measured between tips of opposite tubes when in rotating position.

Centrifuge Tubes — Each centrifuge tube shall be a 203 mm (8in.) cone-shaped tube, conforming to dimensions and made of thoroughly annealed glass. The graduations, numbered shall be clear and distinct, and the mouth shall be constricted in shape for closure with a cork. Scale error tolerances and the smallest graduations between various calibration marks are given and apply to calibrations made with air-free water at  $20^{\circ}\text{C}$  ( $68^{\circ}\text{F}$ ), when

reading the bottom of the shaded meniscus. The accuracy of the graduations on the centrifuge tube shall be volumetrically verified, before use of the tube. The verification shall include calibration at each mark up to the 0.25mL mark and at the 0.5mL, 1.0mL, 1.5mL, 2.0mL, 50mL, and 100mL marks. The tube shall not be used if the scale error at any mark exceeds the applicable tolerance.

Bath —The bath shall be either a solid metal block bath or a liquid bath of sufficient depth for immersing the centrifuge tube in the vertical position to the 100mL mark. Means shall be provided for maintaining the temperature at  $60^{\circ}\text{C} \pm 3^{\circ}\text{C}$  ( $140^{\circ}\text{F} \pm 5^{\circ}\text{F}$ ). For some crude oils, temperatures of  $71^{\circ}\text{C} \pm 3^{\circ}\text{C}$  ( $160^{\circ}\text{F} \pm 5^{\circ}\text{F}$ ) may be required to melt wax crystals in crude oils. For these crude oils, the test temperature shall be maintained high enough to ensure the absence of wax crystals.

A 50mL Pipet, Class A, or equivalent volume dispensing device, capable of delivering a volume of  $50\text{mL} \pm 0.05\text{mL}$ .

### **3.8.METHOD OF DATA ANALYSIS**

The data collected for this research is going to be analyzed using a control chart specifically the Mean and Range control charts the application to be used is Microsoft Excel 2010, This will then help to determine if the process is in statistical control or not and what actions are to be taken if the process is found to be out of control.

In a control chart some limits are required to determine accurately at what points the values begin to move out of control these limits are upper control limit (UCL), center line (CL) and lower control limit (LCL).

To calculate these limits have formulas and they are as follows:

### **3.8.1 For X-bar**

Upper control limit (UCL):  $\text{Average X-bar} + A2 * \text{Average Range}$

Center line (CL):  $\text{All means value} \backslash \text{number of days}$

Lower control limit (LCL):  $\text{X-bar} - A2 * \text{Average Range}$

### **3.8.2 For Range chart**

Upper control limit (UCL):  $D4 * \text{Average range}$

Center line (CL):  $\text{All ranges value} \backslash \text{number of days}$

Lower control limit (LCL):  $D3 * \text{Average range}$

And the unknowns in the formulas for both X-bar and Range chart are derived from a

**Control chart factor table**

Day	Value_1	Value_2	Value_3	Value_4	Mean (X Bar)	Range (R Bar)	Mean (X Bar)	UCL	CL	LCL	Range (R Bar)	UCL	CL	UCL
1	46.8729	46.7459	46.9031	47.0781	46.900	0.332	46.900	46.389	46.110	45.830	0.332	0.876	0.384	0
2	45.9893	45.9893	46.3519	46.1896	46.130	0.363	46.130	46.389	46.110	45.830	0.363	0.876	0.384	0
3	47.0289	47.2313	47.0301	47.0297	47.080	0.202	47.080	46.389	46.110	45.830	0.202	0.876	0.384	0
4	48.3763	47.9453	47.9829	48.2155	48.130	0.431	48.130	46.389	46.110	45.830	0.431	0.876	0.384	0
5	45.9684	46.2338	45.9893	45.8885	46.020	0.345	46.020	46.389	46.110	45.830	0.345	0.876	0.384	0
6	46.319	45.9807	46.0394	45.7409	46.020	0.578	46.020	46.389	46.110	45.830	0.578	0.876	0.384	0
7	48.1516	48.2826	48.0302	48.3356	48.200	0.305	48.200	46.389	46.110	45.830	0.305	0.876	0.384	0
8	47.082	47.1437	47.0817	47.5725	47.220	0.491	47.220	46.389	46.110	45.830	0.491	0.876	0.384	0
9	45.8108	45.6019	45.978	45.5693	45.740	0.409	45.740	46.389	46.110	45.830	0.409	0.876	0.384	0
10	47.1359	46.7022	46.8285	47.3335	46.950	0.434	46.950	46.389	46.110	45.830	0.434	0.876	0.384	0
11	45.863	45.7496	45.6922	45.6551	45.740	0.208	45.740	46.389	46.110	45.830	0.208	0.876	0.384	0
12	45.5244	45.6761	45.728	46.0315	45.740	0.507	45.740	46.389	46.110	45.830	0.507	0.876	0.384	0
13	46.7327	46.3114	46.7288	46.587	46.590	0.421	46.590	46.389	46.110	45.830	0.421	0.876	0.384	0
14	43.9998	44.2575	44.3413	44.3214	44.230	0.342	44.230	46.389	46.110	45.830	0.342	0.876	0.384	0
15	45.4542	45.5602	45.6883	45.8172	45.630	0.363	45.630	46.389	46.110	45.830	0.363	0.876	0.384	0
16	45.1325	45.1912	45.0071	44.9891	45.080	0.202	45.080	46.389	46.110	45.830	0.202	0.876	0.384	0
17	46.6875	46.7962	46.5106	46.7257	46.680	0.286	46.680	46.389	46.110	45.830	0.286	0.876	0.384	0
18	45.2015	45.0002	45.2015	45.4368	45.210	0.437	45.210	46.389	46.110	45.830	0.437	0.876	0.384	0
19	44.6163	44.9364	44.0995	44.7878	44.610	0.837	44.610	46.389	46.110	45.830	0.837	0.876	0.384	0
20	48.1828	48.1056	48.1837	47.7679	48.060	0.416	48.060	46.389	46.110	45.830	0.416	0.876	0.384	0
21	45.9312	46.0466	46.2707	45.8715	46.030	0.399	46.030	46.389	46.110	45.830	0.399	0.876	0.384	0
22	46.2216	46.283	46.5664	46.4491	46.380	0.345	46.380	46.389	46.110	45.830	0.345	0.876	0.384	0
23	44.4316	44.6402	44.557	44.7313	44.590	0.300	44.590	46.389	46.110	45.830	0.300	0.876	0.384	0
24	45.6539	45.7287	45.7158	45.5016	45.650	0.227	45.650	46.389	46.110	45.830	0.227	0.876	0.384	0
25	46.4728	46.4658	46.4146	46.3667	46.430	0.106	46.430	46.389	46.110	45.830	0.106	0.876	0.384	0
26	44.786	44.9849	45.0005	44.9086	44.920	0.215	44.920	46.389	46.110	45.830	0.215	0.876	0.384	0
27	46.6026	46.7156	47.0121	46.6697	46.750	0.409	46.750	46.389	46.110	45.830	0.409	0.876	0.384	0
28	45.7196	45.6532	45.2844	45.6628	45.580	0.435	45.580	46.389	46.110	45.830	0.435	0.876	0.384	0
29	45.8304	46.311	45.7799	45.8787	45.950	0.531	45.950	46.389	46.110	45.830	0.531	0.876	0.384	0
30	45.5385	45.3117	45.774	45.6958	45.580	0.462	45.580	46.389	46.110	45.830	0.462	0.876	0.384	0
31	45.7441	45.404	45.8664	45.3055	45.580	0.561	45.580	46.389	46.110	45.830	0.561	0.876	0.384	0
TOTAL					1429.400	11.899								
AVERAGE X BAR					46.110									
R BAR						0.384								
X-BAR														
UCL					46.389									
CL					46.110									
LCL					45.830									
R-CHART														
UCL								0.876						
CL								0.384						
LCL								0						

Figure 3.1 :The data samples for API gravity for July 2025

Day	Value_1	Value_2	Value_3	Value_4	Mean (X Bar)	Range (R Bar)	Mean (X Bar)	UCL	CL	LCL	Range (R Bar)	UCL	CL	UCL
1	48.5729	48.4459	48.6031	48.7783	48.600	0.332	48.600	46.517	46.237	45.958	0.332	0.876	0.384	0
2	46.2193	46.2193	46.5819	46.4396	46.360	0.363	46.360	46.517	46.237	45.958	0.363	0.876	0.384	0
3	45.0589	45.2613	45.0601	45.0597	45.110	0.202	45.110	46.517	46.237	45.958	0.202	0.876	0.384	0
4	47.6163	47.1853	47.2229	47.4555	47.370	0.431	47.370	46.517	46.237	45.958	0.431	0.876	0.384	0
5	44.8584	45.1238	44.8793	44.7785	44.910	0.345	44.910	46.517	46.237	45.958	0.345	0.876	0.384	0
6	46.929	46.5907	46.6494	46.3509	46.630	0.578	46.630	46.517	46.237	45.958	0.578	0.876	0.384	0
7	43.9816	44.1126	43.8602	44.1656	44.030	0.305	44.030	46.517	46.237	45.958	0.305	0.876	0.384	0
8	44.652	44.7137	44.6517	45.1425	44.790	0.491	44.790	46.517	46.237	45.958	0.491	0.876	0.384	0
9	46.6908	46.4819	46.858	46.4493	46.620	0.409	46.620	46.517	46.237	45.958	0.409	0.876	0.384	0
10	47.4559	47.0222	47.1485	47.4535	47.270	0.434	47.270	46.517	46.237	45.958	0.434	0.876	0.384	0
11	46.713	46.5996	46.5422	46.5051	46.590	0.208	46.590	46.517	46.237	45.958	0.208	0.876	0.384	0
12	46.0244	46.1761	46.228	46.5315	46.240	0.507	46.240	46.517	46.237	45.958	0.507	0.876	0.384	0
13	46.1627	45.7414	46.1588	46.017	46.020	0.421	46.020	46.517	46.237	45.958	0.421	0.876	0.384	0
14	44.3798	44.6375	44.7213	44.7014	44.610	0.342	44.610	46.517	46.237	45.958	0.342	0.876	0.384	0
15	45.3442	45.4502	45.5783	45.7072	45.520	0.363	45.520	46.517	46.237	45.958	0.363	0.876	0.384	0
16	45.8825	45.9412	45.7571	45.7391	45.830	0.202	45.830	46.517	46.237	45.958	0.202	0.876	0.384	0
17	47.6575	47.7662	47.4806	47.6957	47.650	0.286	47.650	46.517	46.237	45.958	0.286	0.876	0.384	0
18	46.7815	46.5802	46.7815	47.0168	46.790	0.437	46.790	46.517	46.237	45.958	0.437	0.876	0.384	0
19	44.2663	44.5864	43.7495	44.4378	44.260	0.837	44.260	46.517	46.237	45.958	0.837	0.876	0.384	0
20	46.8928	46.8156	46.8937	46.4779	46.770	0.416	46.770	46.517	46.237	45.958	0.416	0.876	0.384	0
21	45.8212	45.9366	46.1607	45.7615	45.920	0.399	45.920	46.517	46.237	45.958	0.399	0.876	0.384	0
22	45.4116	45.473	45.7564	45.6391	45.570	0.345	45.570	46.517	46.237	45.958	0.345	0.876	0.384	0
23	46.9516	47.1602	47.077	47.2513	47.110	0.300	47.110	46.517	46.237	45.958	0.300	0.876	0.384	0
24	47.6239	47.6987	47.6858	47.4716	47.620	0.227	47.620	46.517	46.237	45.958	0.227	0.876	0.384	0
25	47.5428	47.5358	47.4846	47.4367	47.500	0.106	47.500	46.517	46.237	45.958	0.106	0.876	0.384	0
26	45.236	45.4349	45.4505	45.3586	45.370	0.215	45.370	46.517	46.237	45.958	0.215	0.876	0.384	0
27	45.8626	45.9756	46.2721	45.9297	46.010	0.409	46.010	46.517	46.237	45.958	0.409	0.876	0.384	0
28	46.9196	46.8532	46.4844	46.8628	46.780	0.435	46.780	46.517	46.237	45.958	0.435	0.876	0.384	0
29	47.4304	47.911	47.3799	47.4787	47.550	0.531	47.550	46.517	46.237	45.958	0.531	0.876	0.384	0
30	45.7585	45.5317	45.994	45.9158	45.800	0.462	45.800	46.517	46.237	45.958	0.462	0.876	0.384	0
31	46.3241	45.984	46.4464	45.8855	46.160	0.561	46.160	46.517	46.237	45.958	0.561	0.876	0.384	0
TOTAL					1433.360	11.899								
AVERAGE X BAR					46.237									
R BAR						0.384								
X-BAR							R-CHART							
UCL					46.517		UCL					0.876		
CL					46.237		CL					0.384		
LCL					45.958		LCL					0		

Figure 3.2 :The data samples for API gravity for August 2025

Day	Value_1	Value_2	Value_3	Value_4	mean (X Bar)	range (R Bar)	mean (X Bar)	UCL	CL	LCL	range (R Bar)	UCL	CL	UCL
1	0.4891	0.47103	0.46867	0.47121	0.475	0.020	0.475	0.458	0.440	0.422	0.020	0.056	0.025	0
2	0.44666	0.43649	0.43949	0.44935	0.443	0.013	0.443	0.458	0.440	0.422	0.013	0.056	0.025	0
3	0.47236	0.46332	0.49351	0.49881	0.482	0.035	0.482	0.458	0.440	0.422	0.035	0.056	0.025	0
4	0.51292	0.52929	0.53198	0.52981	0.526	0.019	0.526	0.458	0.440	0.422	0.019	0.056	0.025	0
5	0.41917	0.44343	0.45325	0.43615	0.438	0.034	0.438	0.458	0.440	0.422	0.034	0.056	0.025	0
6	0.45278	0.42631	0.41893	0.45397	0.438	0.035	0.438	0.458	0.440	0.422	0.035	0.056	0.025	0
7	0.53328	0.52278	0.53345	0.5265	0.529	0.011	0.529	0.458	0.440	0.422	0.011	0.056	0.025	0
8	0.48833	0.47051	0.49205	0.50111	0.488	0.031	0.488	0.458	0.440	0.422	0.031	0.056	0.025	0
9	0.4258	0.42081	0.43026	0.43113	0.427	0.010	0.427	0.458	0.440	0.422	0.010	0.056	0.025	0
10	0.49352	0.47755	0.45965	0.47727	0.477	0.034	0.477	0.458	0.440	0.422	0.034	0.056	0.025	0
11	0.42749	0.45005	0.41902	0.41144	0.427	0.039	0.427	0.458	0.440	0.422	0.039	0.056	0.025	0
12	0.43007	0.42804	0.42614	0.42375	0.427	0.006	0.427	0.458	0.440	0.422	0.006	0.056	0.025	0
13	0.45334	0.46717	0.46318	0.46431	0.462	0.014	0.462	0.458	0.440	0.422	0.014	0.056	0.025	0
14	0.34357	0.35945	0.34356	0.36942	0.354	0.026	0.354	0.458	0.440	0.422	0.026	0.056	0.025	0
15	0.37348	0.34475	0.35552	0.38225	0.364	0.037	0.364	0.458	0.440	0.422	0.037	0.056	0.025	0
16	0.43996	0.40812	0.4266	0.41332	0.422	0.032	0.422	0.458	0.440	0.422	0.032	0.056	0.025	0
17	0.40605	0.40031	0.37852	0.41112	0.399	0.033	0.399	0.458	0.440	0.422	0.033	0.056	0.025	0
18	0.47088	0.45462	0.48128	0.45722	0.466	0.027	0.466	0.458	0.440	0.422	0.027	0.056	0.025	0
19	0.38798	0.41483	0.41549	0.40171	0.405	0.028	0.405	0.458	0.440	0.422	0.028	0.056	0.025	0
20	0.36113	0.36644	0.39112	0.39731	0.379	0.036	0.379	0.458	0.440	0.422	0.036	0.056	0.025	0
21	0.5087	0.5372	0.51446	0.53164	0.523	0.028	0.523	0.458	0.440	0.422	0.028	0.056	0.025	0
22	0.44018	0.44362	0.4458	0.42641	0.439	0.019	0.439	0.458	0.440	0.422	0.019	0.056	0.025	0
23	0.4539	0.45605	0.44237	0.45968	0.453	0.017	0.453	0.458	0.440	0.422	0.017	0.056	0.025	0
24	0.36681	0.37757	0.39038	0.38124	0.379	0.024	0.379	0.458	0.440	0.422	0.024	0.056	0.025	0
25	0.42317	0.42293	0.41114	0.43475	0.423	0.024	0.423	0.458	0.440	0.422	0.024	0.056	0.025	0
26	0.45212	0.44737	0.46628	0.45823	0.456	0.019	0.456	0.458	0.440	0.422	0.019	0.056	0.025	0
27	0.40205	0.39185	0.38617	0.38792	0.392	0.016	0.392	0.458	0.440	0.422	0.016	0.056	0.025	0
28	0.45232	0.47137	0.47685	0.47546	0.469	0.025	0.469	0.458	0.440	0.422	0.025	0.056	0.025	0
29	0.40795	0.4142	0.43226	0.42559	0.420	0.024	0.420	0.458	0.440	0.422	0.024	0.056	0.025	0
30	0.43942	0.4384	0.43682	0.42536	0.435	0.014	0.435	0.458	0.440	0.422	0.014	0.056	0.025	0
31	0.41729	0.42751	0.40247	0.43273	0.420	0.030	0.420	0.458	0.440	0.422	0.030	0.056	0.025	0
					TOTAL	13.637	0.760							
					AVERAGE X BAR	0.440								
					R BAR	0.025								
					X-BAR		R-CHART							
					UCL	0.458	UCL	0.056						
					CL	0.440	CL	0.025						
					LCL	0.422	LCL	0						

Figure 3.3: The data samples for Basic sediments and water gravity for July 2025

Day	Value_1	Value_2	Value_3	Value_4	(X Bar)	(R Bar)	(X Bar)	UCL	CL	LCL	(R Bar)	UCL	CL	LCL
1	0.285	0.308	0.3	0.294	0.297	0.023	0.297	0.359	0.341	0.324	0.023	0.055	0.024	0
2	0.374	0.374	0.37	0.402	0.380	0.032	0.380	0.359	0.341	0.324	0.032	0.055	0.024	0
3	0.352	0.356	0.329	0.367	0.351	0.038	0.351	0.359	0.341	0.324	0.038	0.055	0.024	0
4	0.299	0.274	0.273	0.273	0.280	0.026	0.280	0.359	0.341	0.324	0.026	0.055	0.024	0
5	0.314	0.322	0.319	0.313	0.317	0.009	0.317	0.359	0.341	0.324	0.009	0.055	0.024	0
6	0.416	0.397	0.404	0.407	0.406	0.019	0.406	0.359	0.341	0.324	0.019	0.055	0.024	0
7	0.242	0.255	0.231	0.244	0.243	0.024	0.243	0.359	0.341	0.324	0.024	0.055	0.024	0
8	0.333	0.311	0.333	0.316	0.323	0.022	0.323	0.359	0.341	0.324	0.022	0.055	0.024	0
9	0.366	0.401	0.402	0.395	0.391	0.036	0.391	0.359	0.341	0.324	0.036	0.055	0.024	0
10	0.302	0.294	0.317	0.307	0.305	0.023	0.305	0.359	0.341	0.324	0.023	0.055	0.024	0
11	0.302	0.317	0.299	0.334	0.313	0.035	0.313	0.359	0.341	0.324	0.035	0.055	0.024	0
12	0.329	0.345	0.331	0.339	0.336	0.016	0.336	0.359	0.341	0.324	0.016	0.055	0.024	0
13	0.397	0.383	0.414	0.406	0.400	0.031	0.400	0.359	0.341	0.324	0.031	0.055	0.024	0
14	0.318	0.316	0.304	0.317	0.314	0.014	0.314	0.359	0.341	0.324	0.014	0.055	0.024	0
15	0.319	0.323	0.317	0.328	0.322	0.011	0.322	0.359	0.341	0.324	0.011	0.055	0.024	0
16	0.32	0.315	0.338	0.319	0.323	0.023	0.323	0.359	0.341	0.324	0.023	0.055	0.024	0
17	0.422	0.432	0.416	0.442	0.428	0.026	0.428	0.359	0.341	0.324	0.026	0.055	0.024	0
18	0.41	0.446	0.438	0.415	0.427	0.036	0.427	0.359	0.341	0.324	0.036	0.055	0.024	0
19	0.358	0.39	0.386	0.387	0.380	0.032	0.380	0.359	0.341	0.324	0.032	0.055	0.024	0
20	0.373	0.345	0.356	0.346	0.355	0.028	0.355	0.359	0.341	0.324	0.028	0.055	0.024	0
21	0.385	0.375	0.363	0.353	0.369	0.032	0.369	0.359	0.341	0.324	0.032	0.055	0.024	0
22	0.392	0.393	0.409	0.405	0.400	0.017	0.400	0.359	0.341	0.324	0.017	0.055	0.024	0
23	0.317	0.3	0.286	0.31	0.303	0.031	0.303	0.359	0.341	0.324	0.031	0.055	0.024	0
24	0.392	0.384	0.392	0.381	0.387	0.011	0.387	0.359	0.341	0.324	0.011	0.055	0.024	0
25	0.3	0.296	0.28	0.283	0.290	0.020	0.290	0.359	0.341	0.324	0.020	0.055	0.024	0
26	0.3	0.325	0.312	0.319	0.314	0.025	0.314	0.359	0.341	0.324	0.025	0.055	0.024	0
27	0.389	0.363	0.369	0.383	0.376	0.026	0.376	0.359	0.341	0.324	0.026	0.055	0.024	0
28	0.285	0.279	0.287	0.282	0.283	0.008	0.283	0.359	0.341	0.324	0.008	0.055	0.024	0
29	0.339	0.334	0.327	0.336	0.334	0.012	0.334	0.359	0.341	0.324	0.012	0.055	0.024	0
30	0.314	0.289	0.317	0.303	0.306	0.028	0.306	0.359	0.341	0.324	0.028	0.055	0.024	0
31	0.341	0.345	0.321	0.313	0.330	0.032	0.330	0.359	0.341	0.324	0.032	0.055	0.024	0
					TOTAL	10.583	0.746							
					AVERAGE X BAR	0.341								
					R BAR		0.024							
					X-BAR		R-CHART							
					UCL	0.359	UCL	0.055						
					CL	0.341	CL	0.024						
					LCL	0.324	LCL	0						

Figure 3.4: The data samples for Basic sediments and water gravity for August 2025

### **3.9 LIMITATION OF THE METHODOLOGY**

#### **1. Difficulty in Controlling All Variables**

In real-world operational environments like oil terminals, it is challenging to control all external variables (e.g., weather conditions, equipment failures, staffing changes), which can affect the outcome and reduce the internal validity of the experiment.

#### **2. Limited Access to Multiple Terminals**

Gaining permission to implement changes (e.g., introducing a new QA system) in multiple terminals may be restricted due to company policies, safety concerns, or cost. This can limit the scope of the experiment and reduce generalizability.

#### **3. Short Duration of Study**

The experimental period might not be long enough to observe long-term effects of the new QA method. For example, some quality problems may only become apparent over months, not weeks.

#### **4. Potential Bias in Implementation**

Staff in the experimental terminal may behave differently simply because they know they're being observed (known as the Hawthorne effect), which may skew the results and not reflect typical operating behavior.

#### **5. High Cost of Experimental Interventions**

Implementing a new quality assurance system (e.g., automated sampling) often involves high costs, making it difficult to scale the experiment across multiple locations or replicate it.

## **CHAPTER FOUR**

### **RESULTS AND DISCUSSION**

This chapter presents and analyzes the quantitative data collected to assess the effectiveness of the quality assurance (QA) protocols for crude oil at the export terminal. Specifically, it employs Statistical Process Control methods, using mean ( $\bar{X}$ ) and range (R chart) control charts, to evaluate the stability, consistency, and reliability of key crude oil quality parameters over the study period of July and August 2025.

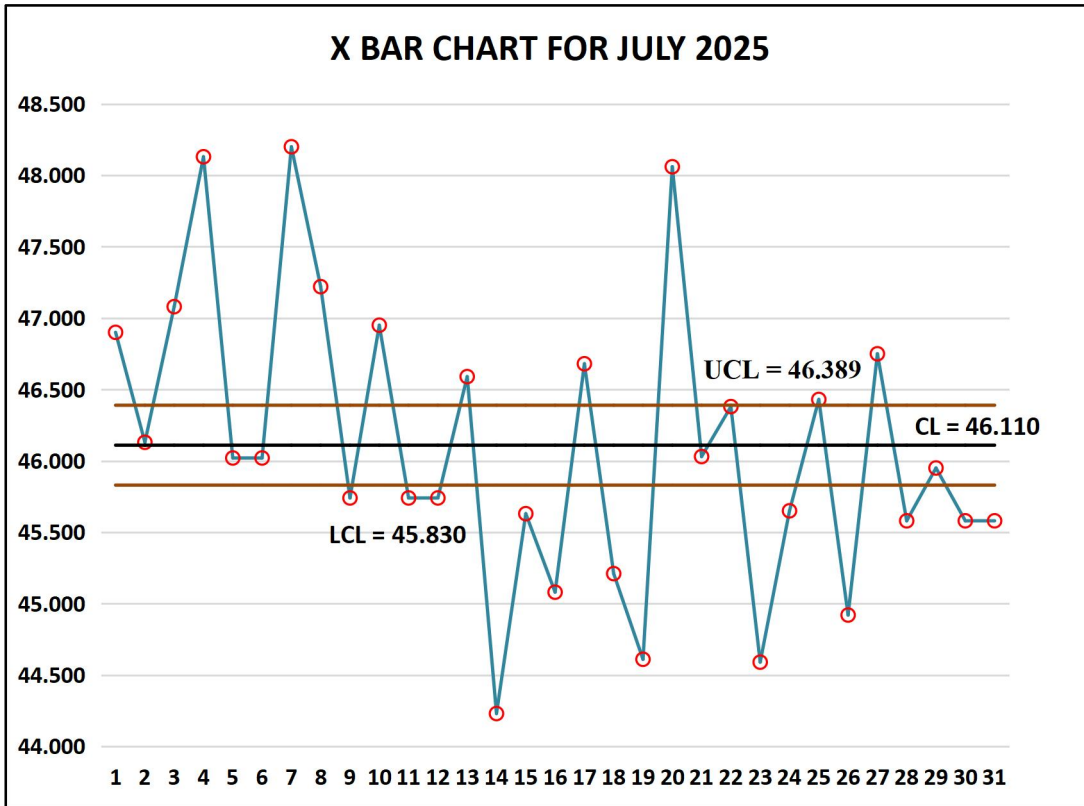
#### **4.1 Objectives**

The primary objective of this analysis is to transition from raw measurement data to actionable interpretations regarding process control. Two critical quality parameters, likely representing contaminant levels and valuation properties are examined.

The  $\bar{X}$ -bar charts analyze the central tendency (average quality) of the crude oil batches, identifying any non-random shifts that suggest a failure in the treatment or blending process. Conversely, the R charts assess the consistency of the testing procedures by monitoring the daily variability (range) within subsamples. By comparing observed data points against statistically derived Upper Control Limits (UCL) and Lower Control Limits (LCL), the chapter determines whether the terminal's quality assurance process is operating "in statistical control" a state necessary for predictable and reliable export quality.

#### **4.2 Analysis of Quality Parameter A (API gravity).**

This parameter likely represents an overall quality indicator that drives valuation, API Gravity measured in degrees.



**Figure 4.1: X BAR-Chart Process Average - July**

OBSERVATION for July

This is a (X-bar) Chart for the month of July 2025, which is a type of Statistical Process Control chart used to monitor the mean (average) of a process.

X- bar Points: These points represent the average of samples taken from the process at different times (likely daily, as there are 31 points for July). The values range roughly from 44.300 to 48.200.

CL (Center Line): The horizontal line in the middle, labeled  $CL = 46.110$ . This represents the average or mean value of the process when it is operating in a state of statistical control.

UCL (Upper Control Limit): The upper horizontal line, labeled  $UCL = 46.389$ . This is the maximum expected variation for the sample means when the process is stable.

The formula to derive this is :  $\text{Average } \bar{X} + A_2 * \text{Average Range}$

LCL (Lower Control Limit): The lower horizontal line, labeled  $LCL = 45.830$ . This is the minimum expected variation for the sample means when the process is stable.

The formula to derive this is :  $\text{Average } \bar{X} - A_2 * \text{Average Range}$

#### Interpretation of Process Control

The primary purpose of a mean chart is to distinguish between common cause variation (inherent, random, and acceptable variation within the control limits) and special cause variation (assignable, non-random variation that requires investigation).

#### Out-of-Control Signals

A process is generally considered "out of control" if any of the following standard rules are violated, indicating a special cause that needs to be found and eliminated:

##### Points Outside the Control Limits (UCL or LCL):

Above UCL (46.389): Points 1, 3, 4, 6, 7, 10, 12, 20, 22, and 27 are clearly above the UCL. Some are extremely high (e.g., points 4, 7, and 20 around 48.000).

Below LCL (45.830): Points 14 and 24 are clearly below the LCL. Point 14 is extremely low (around 44.300).

Runs/Patterns (e.g., a trend of 7 or more points all above or all below the CL):

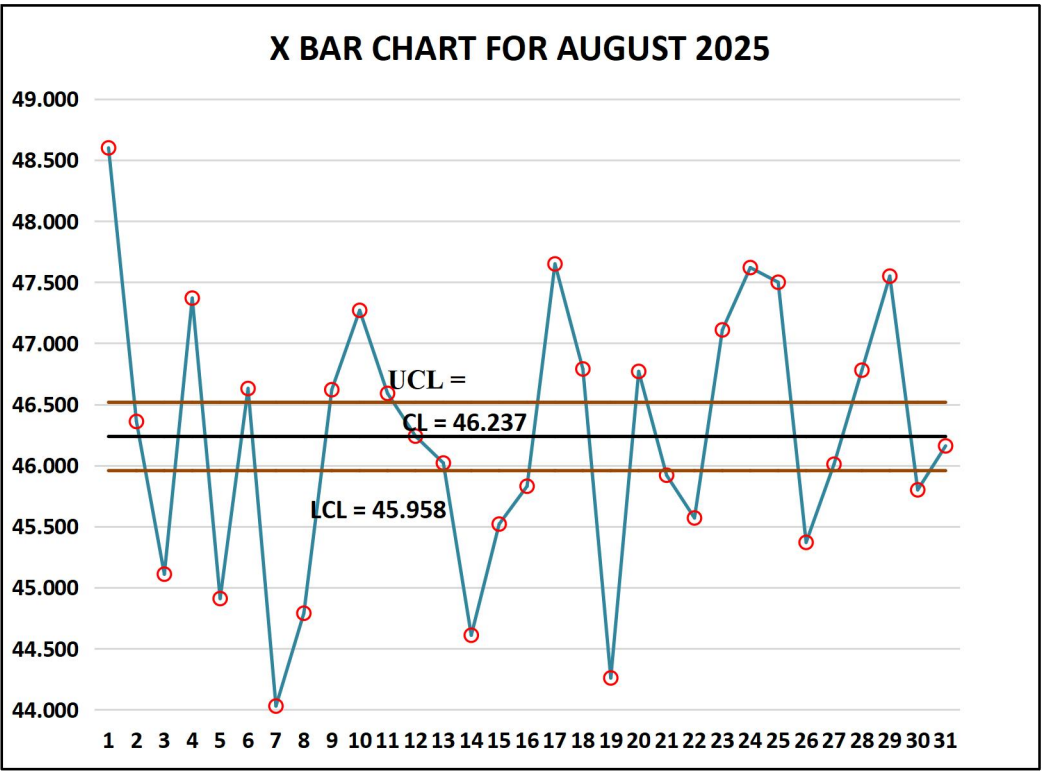
The chart shows high volatility but doesn't immediately show a long run of points only on one side of the CL. However, the consistent, large swings are also often considered an out-of-control pattern.

**Conclusion on Process Stability**

The large number of points exceeding both the Upper and Lower Control Limits indicates that the process is not in a state of statistical control.

The variation is too large and unpredictable. The process is highly unstable, characterized by frequent, large swings that fall outside the expected boundaries. This suggests that multiple special causes are influencing the process throughout the month of July (perhaps changes in machine settings, raw material quality, operator performance, etc.).

FOR August



**Figure 4.2: X BAR-Chart Process Average August 2025**

Control Limits:

UCL (Upper Control Limit): 46.517

CL (Center Line): 46.237 (Represents the overall process average)

LCL (Lower Control Limit): 45.958

These limits define the expected range of variation for the sample averages when the process is in control (stable and only subject to common cause variation).

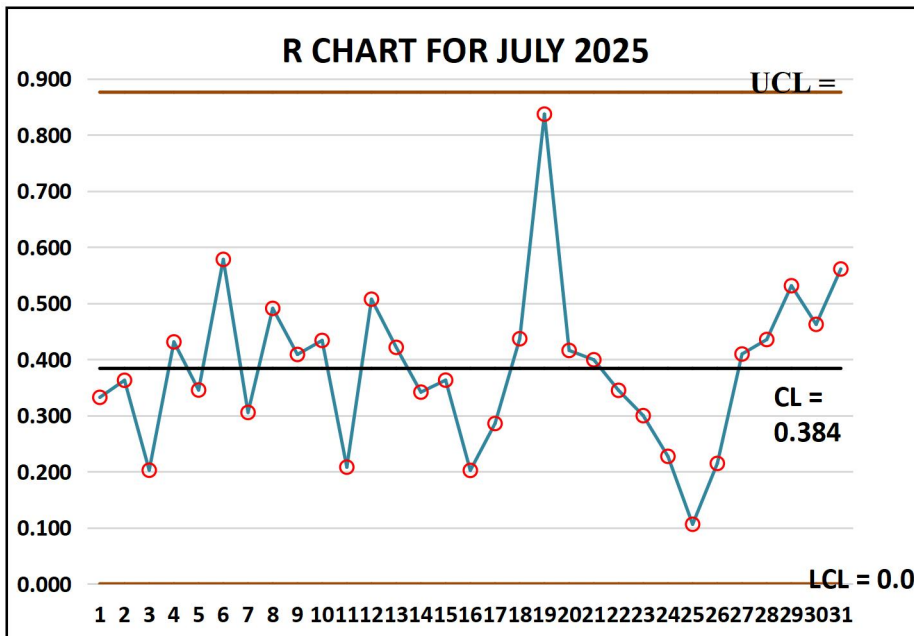
Out-of-Control Points (Special Cause Variation):

Points above the UCL: Days 1, 4, 10, 17, 18, 24, 25, 29

Points below the LCL: Days 7, 14

Since there are numerous points outside the control limits, this indicates the process is out of statistical control. These points suggest the presence of special (assignable) cause variation, meaning an unusual or non-routine event has affected the process average.

The chart shows that the process for which these averages were collected is unstable and not predictable. The frequent occurrences outside the control limits require immediate investigation to identify the special causes (e.g., equipment malfunction, material change, new operator, etc.) and eliminate them to bring the process back into a stable state.



**Figure 4.4 Range Chart Process Average for July 2025**

The chart plots the range (R) of subgroups over 31 days against calculated control limits.

The range is the difference between the largest and smallest measurements in each sample.

Control Limits:

UCL (Upper Control Limit): 0.876

The formula used to derive this is  $D4 \times \text{Average range}$

CL (Center Line): 0.384 (Represents the average range)

LCL (Lower Control Limit): 0.0

The formula used to derive this is  $D3 \times \text{Average range}$

These limits define the expected variation in the spread of the data when the process's variability is in control (stable).

Out-of-Control Points (Special Cause Variation):

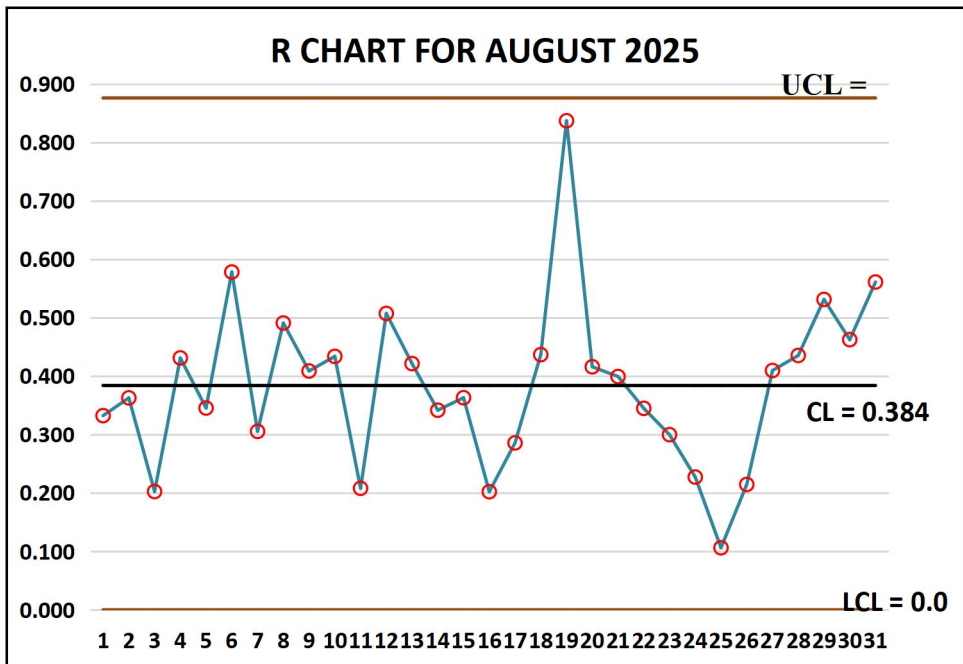
Points outside the control limits: There are no points above the UCL (0.876) or below the LCL (0.0).

The highest point on Day 19 (0.835) is very close to the UCL, but still within the limit.

Process State:

Since all plotted points are within the control limits and there are no clear non-random patterns (like seven points in a row above or below the center line, or a consistent trend), the process's variability is considered to be in statistical control.

The R-Chart indicates that the variation (or spread) of the process for July 2025 is stable and predictable. Although stable, the average range (average range = 0.384) may or may not be acceptable to the customer; that assessment requires comparing the control limits to product specifications, but from a purely statistical control standpoint, the process variability is under control.



**Figure 4.5: Range Chart Process Average for August 2025**

The chart plots the range (R) of subgroups (samples) over 31 days against calculated control limits.

Control Limits:

UCL (Upper Control Limit): 0.876

CL (Center Line): 0.384 (This is the average range)

LCL (Lower Control Limit): 0.0

These limits define the expected, "normal" amount of variation in the process's spread when it is stable.

Process State:

No Out-of-Control Points: All 31 data points are within the control limits. The highest point (Day 19, approximately 0.835) is very close to the upper limit but does not cross it.

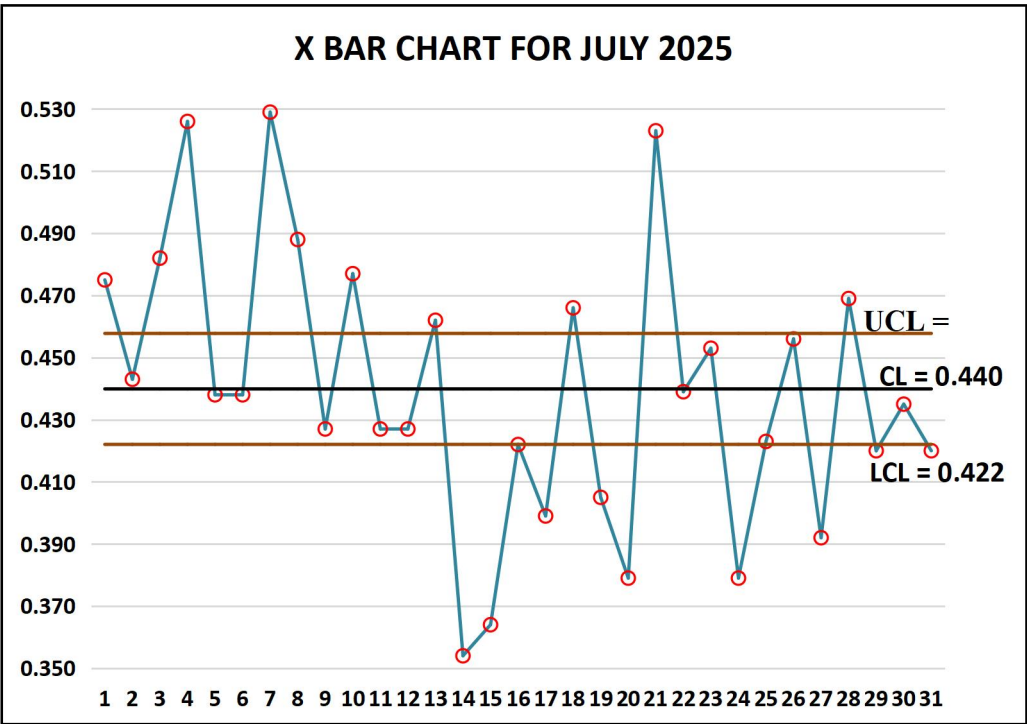
No Obvious Patterns: There are no clear non-random patterns (like long runs on one side of the center line or consistent trends) that would suggest an unstable process.

This R-Chart indicates that the process variability (spread) for August 2025 is in statistical control.

This means the spread of the process is stable and predictable. The variation you see is common cause variation (the inherent, random "noise" in the system), and there is no evidence of special (assignable) causes affecting the process variability.

**4.3 Analysis of Quality Parameter B (Basic sediment and water content)**

This parameter likely represents a critical specification with a low limit, such as Basic Sediment and Water (BS&W) content or Salt Content in crude oil measured in percent.



**Figure 4.6: X BAR-Chart Process Average for July**

The chart displays sample averages (mean values) plotted over 31 days against calculated control limits.

Control Limits:

UCL (Upper Control Limit): 0.458

CL (Center Line): 0.440 (Represents the overall process average)

LCL (Lower Control Limit): 0.422

These limits define the expected range of variation for the sample averages when the process is in control.

Out-of-Control Points (Special Cause Variation):

Points above the UCL (0.458): Days 2, 3, 6, 13, 18, 21, and 27.

Points below the LCL (0.422): Days 9, 14, 15, 17, 19, 20, 24, and 26.

Process State:

The chart shows many points falling outside both the upper and lower control limits. This is a clear indication that the process is out of statistical control.

Conclusion:

The process for July 2025 is highly unstable and unpredictable. The frequent points outside the control limits show that the process average is being influenced by special (assignable) cause variation, rather than just the natural, random variation of the system. An immediate investigation would be required to identify the root causes of this instability and bring the process under control.

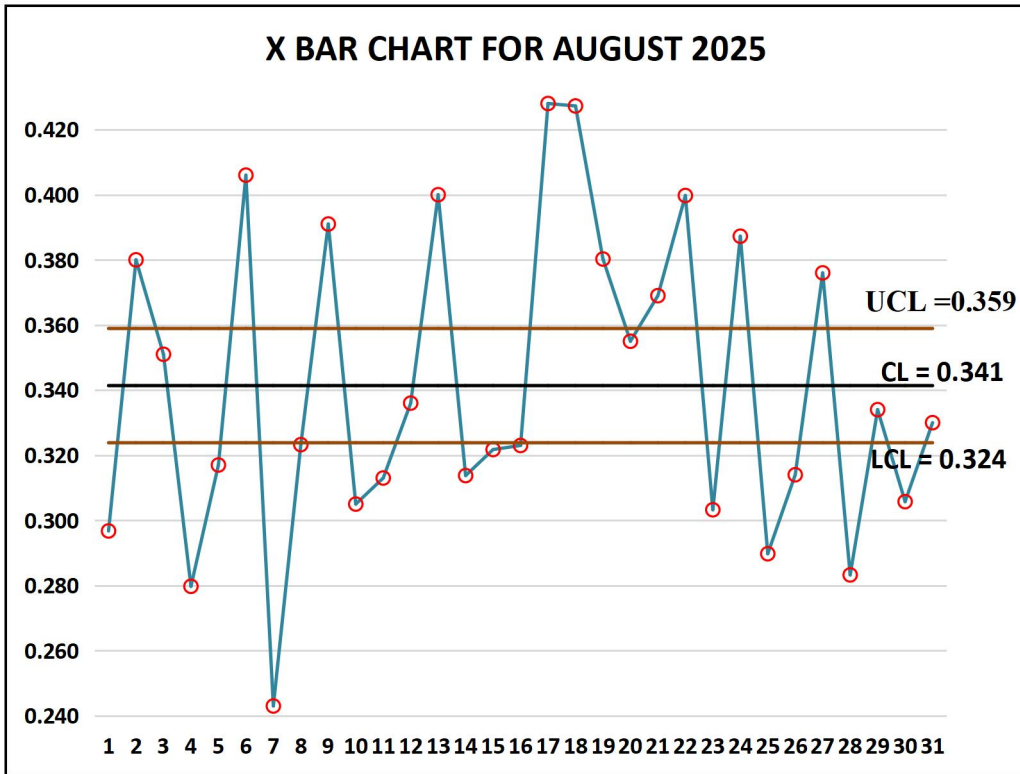
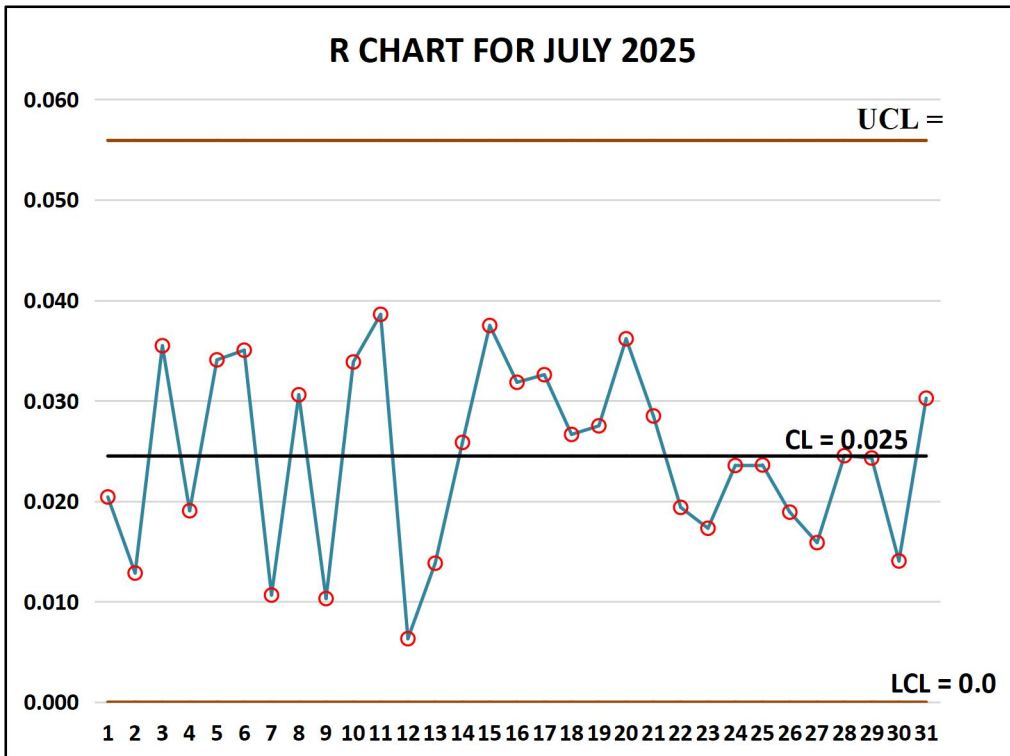


Figure 4.7: X BAR-Chart (Process Average - July & August 2025)



### **Figure 4.8: Range-Chart (Process Average - July & August 2025)**

The chart plots the range (R) of subgroups for 31 days against calculated control limits.

Control Limits:

UCL (Upper Control Limit): 0.056

CL (Center Line): \$0.025\$ (This is the average range)

LCL (Lower Control Limit): 0.0

Process State:

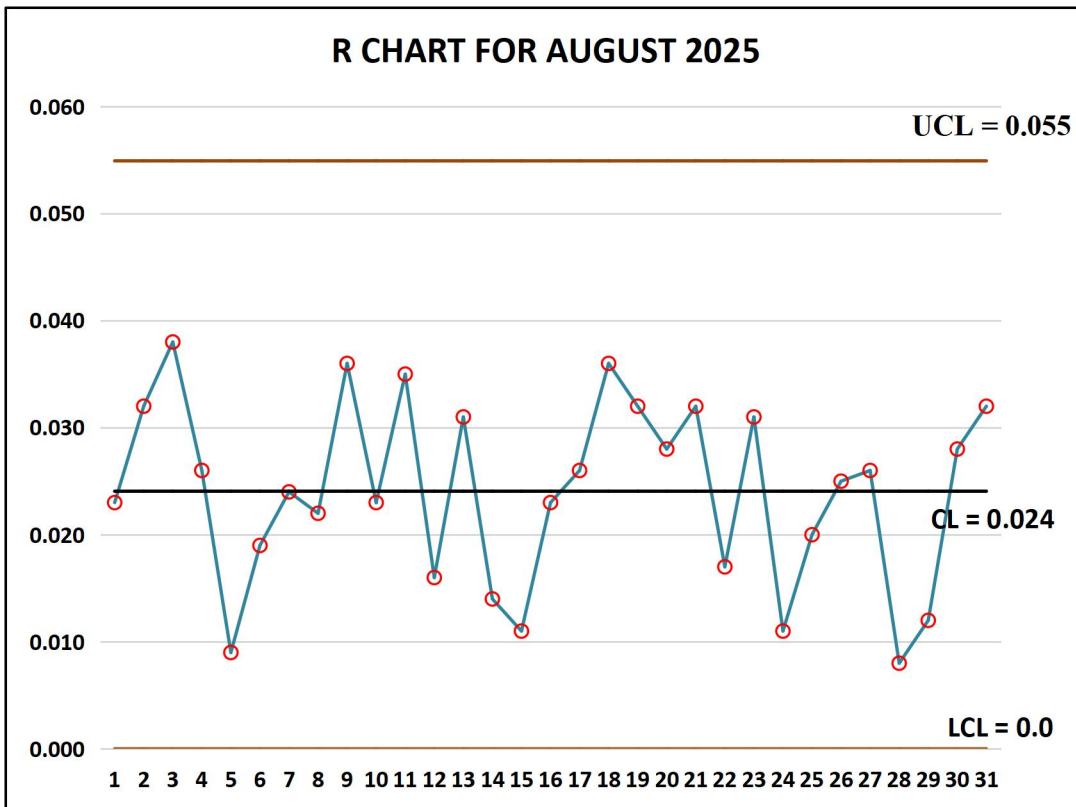
While there are no points that fall outside the upper or lower control limits, this process is still considered out of statistical control.

Reason for Instability (Non-Random Pattern):

There is a run of 7 consecutive points (from Day 14 to Day 20) that are all above the Center Line (CL = 0.025). This is a non-random pattern, which indicates that a special (assignable) cause affected the process during this period, causing a sustained shift to higher-than-average variability.

Conclusion

The process variability for July 2025 is unstable and not predictable. The run of 7 points above the center line is a clear signal of special cause variation that needs to be investigated to find and eliminate the root cause.



**Figure 4.9: Range-Chart Process Average for August 2025**

The chart plots the range (\$R\$) of subgroups for 31 days against calculated control limits.

Control Limits:

UCL (Upper Control Limit): 0.055

CL (Center Line): 0.024 (This is the average range)

LCL (Lower Control Limit): 0.0

These limits define the expected, natural variation in the process's spread when it is stable.

Process State:

No Out-of-Control Points: All 31 data points are within the control limits. No point is above the UCL (0.055) or below the LCL (0.0).

No Obvious Patterns: The points appear to fluctuate randomly around the center line, showing no clear trends, runs, or other non-random patterns.

#### Conclusion

This R-Chart indicates that the process variability (spread) for August 2025 is in statistical control.

This means the variation in the process is stable and predictable. The fluctuations seen are due to common cause variation (the inherent, random "noise" in the system), and there is no evidence of special (assignable) causes that need investigation.

#### 4.4 Findings

The statistical analysis presented in Chapter 4, based on the control charts for the two-month study period, revealed significant insights into the state of process control at the terminal. The findings are summarized as follows:

1. API Gravity (Process Average - X-bar Chart): The process average for API gravity was found to be out of statistical control for *both* July and August 2025. Both charts showed numerous data points falling outside the Upper and Lower Control Limits (UCL/LCL). This indicates that the process average is highly unstable, unpredictable, and subject to "special cause" variation.
2. API Gravity (Process Variability - R-Chart): In stark contrast to the process average, the R-charts for API gravity were in statistical control for both months. This is a critical finding, as it suggests that the *measurement process* (i.e., the method of sampling and testing for API gravity in the lab) is consistent and reliable. The

problem, therefore, does not lie in the measurement but in the *production process* itself (e.g., inconsistent blending or variability in crude feedstock).

3. Basic Sediments & Water (Process Average - X-bar Chart): Similar to API gravity, the X-bar charts for BS&W were out of statistical control for both July and August 2025. The process average for BS&W fluctuated wildly, with many points outside the control limits. This indicates a significant lack of control over the processes responsible for water and sediment removal.
4. Basic Sediments & Water (Process Variability - R-Chart): The variability of the BS&W parameter showed mixed results. The R-chart for July 2025 was deemed out of statistical control, not for exceeding a limit, but for exhibiting a clear non-random pattern (a run of seven consecutive points above the center line). This suggests an inconsistency or shift in the *testing procedure itself* during July. This issue appeared to be resolved, as the R-chart for August 2025 was in statistical control.

## CHAPTER FIVE

### CONCLUSION AND RECOMMENDATION

This project was undertaken to evaluate the quality assurance systems for crude oil production at the NNPC E&P Ltd Utapete Export Terminal. The primary aim was to assess the statistical control of key quality parameters specifically API Gravity and Basic Sediments & Water (BS&W) to identify non-conformities and highlight areas for process improvement.

By collating and analyzing laboratory data from July and August 2025 using Statistical Process Control (SPC) methods (specifically X-bar and R charts), this study sought to determine the stability, consistency, and predictability of the terminal's export quality. The analysis in Chapter 4 provided a clear statistical answer to the problem statement, and this chapter will summarize those findings, draw a final conclusion, and propose actionable recommendations.

#### 5.1 Conclusion

The central conclusion of this engineering project is that the crude oil production and export process at the Utapete terminal is not operating in a state of statistical control.

While the *consistency* of the terminal's laboratory measurements is generally stable (as shown by the R-charts, with the exception of BS&W in July), the *actual quality average* of the final product (both API gravity and BS&W content) is highly unstable and unpredictable.

This confirms the problem statement that the terminal faces significant, quantifiable challenges in maintaining consistent product quality. The presence of rampant special cause variation in the process averages (the X-bar charts) means the terminal is at constant risk of

producing non-conforming batches. This instability can lead directly to the outcomes identified in the problem statement: revenue loss from rejected or downgraded shipments, customer disputes, and reputational damage.

Therefore the initial goal of this study to identify parameters that do not conform to quality standards and aim to improve on the areas that are out of control was fulfilled.

The current quality assurance system, as monitored, is effective at *identifying* these deviations after they have occurred. However, the findings show it has not yet been effectively integrated into a system that *prevents* these deviations, which is the ultimate goal of quality assurance. The process is not predictable and therefore cannot be reliably "assured."

## **5.2 Recommendations**

Based on the statistical findings, the following actionable recommendations are proposed to bring the process into statistical control and enhance the quality assurance framework at the terminal:

1. Prioritize Root Cause Analysis (RCA) for Special Causes: Since both API and BS&W X-bar charts are significantly out of control, an immediate investigation into the special causes of this variation is required. A cross-functional team (involving Operations, Maintenance, and Laboratory staff) should be formed to investigate each out-of-control point. This RCA should correlate the data with operational logs (e.g., which crude-gathering flow station was active, which storage tank was used, or if separator equipment was down for maintenance).
2. Focus on Production and Blending, Not Just Measurement (for API): The stable R-chart for API gravity proves the lab's measurements are reliable. Therefore,

resources should *not* be wasted on re-calibrating lab instruments for API gravity. Instead, all efforts should be directed upstream to the production and blending processes that are causing the *actual* product average to fluctuate.

3. Implement Real-Time Control Charting: The control charts should be migrated from a historical analysis tool (as used in this project) to a real-time operational dashboard in the laboratory and control room. When a point on the X-bar chart is plotted and found to be out of control, there should be a clear, documented action plan for operators to follow *immediately* to investigate and bring the process back toward the center line.
4. Maintain Vigilance on BS&W Test Consistency: The R-chart instability for BS&W in July indicates a potential vulnerability in the testing procedure. While this appeared to stabilize in August, the lab must maintain strict adherence to Standard Operating Procedures (SOPs) and regular calibration for centrifuges and sampling equipment to ensure this stability is permanent.
5. Re-establish Control Limits After Improvement: After these recommendations are implemented and the special causes of variation are eliminated, the process should be allowed to run for a period (e.g., another 30 days). New data should then be used to recalculate "tighter," more representative control limits. This forms the basis of a continuous improvement cycle (Plan-Do-Check-Act) and is a fundamental principle of Industrial Engineering.

### **5.3 Suggestions for Further Research**

This study provided a foundational analysis of the terminal's quality assurance data. Further research could expand on this work in several valuable ways:

1. Expand Scope of Parameters: Conduct a similar SPC analysis on other critical quality parameters not covered in this study, such as Sulphur content, Total Acid Number (TAN), and Pour Point, to gain a more holistic view of product quality.
2. Perform Process Capability Analysis (Cpk, Ppk): Once the process has been brought into a state of statistical control (as recommended above), the next logical step is to perform a capability analysis. This would compare the "in-control" process data to the customer's specification limits to determine if the process, even when stable, is *capable* of consistently meeting customer requirements.
3. Conduct Correlation and Regression Analysis: A more advanced statistical study could be performed to mathematically correlate the identified out-of-control points with specific operational variables (e.g., "separator temperature," "blending tank levels," "source well"). This could move the process from simple detection to predictive quality control.

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