

**PREDICTING AND CONTROL MODEL FOR OIL
FIELD EMULSION TIGHTNESS**

BY

NAME: AIWEKHOE BRIGHT

MAT.NO: ENG1905752

**DEPARTMENT OF PETROLEUM ENGINEERING
FACULTY OF ENGINEERING
UNIVERSITY OF BENIN
BENIN CITY**

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**A PROJECT REPORT SUBMITTED TO THE
DEPARTMENT OF PETROLEUM ENGINEERING
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**DEPARTMENT OF PETROLEUM ENGINEERING
FACULTY OF ENGINEERING
UNIVERSITY OF BENIN
BENIN CITY**

FEBRUARY 2025

CERTIFICATION

This is to certify that this project was carried out by Aiwekhoe Bright of the department of Petroleum Engineering, University of Benin

DR P.O OGBEIDE
(PROJECT SUPERVISOR)

DATE

DR. O.A. TAIWO
(PROJECT COORDINATOR)

DATE

DR IKPOMWOSA OHENHEN
(HEAD OF DEPARTMENT)

DATE

DEDICATION

This project work is dedicated to my Family, who has always been my inspiration and backbone of strength.

ACKNOWLEDGEMENT

With all sincerity of heart, I appreciate God almighty for his faithfulness and love in my life, His grace and mercy, and all He has done for me. Words cannot fully express my gratitude.

I also want to appreciate my family, who have been there for me through thick and thin. I say thank you.

I also want to appreciate my supervisor, Dr P.O Ogbeide, who has been very supportful during the course of my study. I'm very grateful Sir, and I say a big thank you.

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ABSTRACT

The prediction and control of emulsion tightness in oil fields is crucial for optimizing production processes and maintaining operational efficiency. This project focuses on developing a predictive and control model to assess and manage the tightness of emulsions in oil reservoirs. Emulsions, which are mixtures of oil and water, can significantly impact the efficiency of extraction and refining processes, leading to operational challenges and increased production costs. By employing a combination of empirical data analysis, computational modelling, and machine learning techniques, this research aims to predict emulsion behaviour under various reservoir conditions and control the factors influencing emulsion stability. The model incorporates reservoir characteristics, fluid properties, and production parameters to provide real-time insights and effective strategies for mitigating emulsion-related issues. Ultimately, the model aims to enhance oil recovery, reduce operational costs, and improve the overall efficiency of oil field operations.

CHAPTER ONE

1.0 INTRODUCTION

Crude oil is rarely produced in isolation; instead, it typically emerges as a complex mixture of hydrocarbons and formation water. As this mixture flows through the reservoir pores and travels through the wellbore, tubing, and surface production facilities, it experiences extreme agitation due to high shear rates and turbulence. This agitation leads to the dispersion of the water phase as fine droplets within the bulk oil phase, resulting in the formation of emulsions. Emulsions present significant challenges in the production, transportation, and refining of crude oil, and addressing these complex structures accounts for a substantial portion of the operational expenses incurred by oil companies.

The control and resolution of emulsions are among the primary challenges faced by production engineers, production chemists, and facilities engineers, both onshore and offshore. This issue is particularly pronounced in fields that produce heavy crude oils, where emulsions can be especially problematic. The stabilization of emulsions is caused by rigid interfacial films that form a "skin" around the water droplets, preventing their coalescence. The stability of these interfacial films, and consequently the tightness of the emulsions, is influenced by various factors—including the presence of heavy materials in the crude oil, such as asphaltenes, resins, and waxes; inorganic solids like clays, scales, and corrosion products; as well as temperature, droplet size and size distribution, pH, and brine composition. As the producing field depletes, the characteristics of petroleum emulsions change continuously due to alterations in these factors and the production methods employed.

Produced oilfield emulsions can be categorized as water-in-oil (W/O), oil-in-water (O/W), or multiple water and oil in water (W/O/W), with the majority being of the W/O type. The type of emulsion produced is influenced by several conditions, including the fractions of each liquid phase and the hydrophilic-lipophilic balance (HLB). From a thermodynamic perspective, a W/O emulsion is deemed an unstable system because there is an inherent tendency for liquid/liquid systems to separate to minimize interfacial area and energy. Nonetheless, many oilfield emulsions exhibit kinetic stability, allowing them to remain stable over time.

Produced oilfield emulsions are classified according to their degree of kinetic stability, which can be categorized as loose, medium, or tight emulsions. Loose emulsions separate within a few minutes, medium emulsions can take ten minutes or longer to separate, while tight emulsions may not separate for hours or even days. Typically, emulsions from several production headers in an oilfield are commingled at manifolds before being transported to central processing facilities for treatment.

These emulsions are often challenging to treat and can lead to numerous operational problems, including the overloading of surface separation equipment, increased pumping costs associated with wet crude, higher heating costs, tripping of separation equipment, and high-pressure drops in flowlines. Additionally, they can result in increased costs for demulsifiers, production of off-specification crude oil, thick sludge accumulation in stock tank bottoms, corrosion in export and subsea pipelines, catalyst poisoning at refineries, and, in some cases, necessitate the shutdown of processing equipment in the Wet Crude Handling Facility (WCHF). The cumulative effect of these challenges is a significant loss in production and revenue for operators, highlighting the critical importance of effective emulsion management in the oil and gas industry

As global energy demands escalate, the oil and gas industry faces immense pressure to enhance production while adhering to sustainable practices. One major challenge hindering these efforts is the formation of oil field emulsions, which consist of oil and water droplets stabilized by interfacial tension. Emulsion tightness—a key indicator of emulsion stability and water content—plays a critical role in determining oil recovery rates, processing expenses, and environmental sustainability.

The Challenge of Oil Field Emulsions

The concurrent production of oil and water often leads to the creation of stable oil-in-water emulsions. This phenomenon is exacerbated by naturally occurring emulsifiers and the turbulent flow conditions within wells and pipelines. The implications of stable emulsions are significant:

1. **Reduced Oil Recovery:** Efficient oil separation is crucial for maximizing hydrocarbon extraction. Emulsions pose a challenge, requiring additional efforts to separate water and oil, thereby leading to economic losses and decreased recovery rates.
2. **Increased Processing Costs:** Current methods for breaking emulsions—such as chemical treatments, thermal separation, and mechanical processes—add complexity and cost to oil

production. The necessity for these additional treatments can undermine the financial viability of extraction operations.

3. Environmental Risks: The management of produced water containing oil-in-water emulsions can result in ecological hazards. Oil contaminants threaten aquatic ecosystems and human health, underlining the need for solutions that mitigate environmental impacts.

Limitations of Traditional Approaches

While traditional strategies for managing emulsion tightness exist—chemical treatments, physical separation techniques, and operational adjustments—several limitations persist:

1. Predictability Issues: Emulsion tightness prediction is complicated by the interplay of numerous factors, such as reservoir characteristics, fluid properties, demulsifier efficacy, and varying operational conditions. This unpredictability hampers the optimization of production strategies.

2. Ineffective Control: Conventional control measures often rely on trial-and-error processes that yield inconsistent results. This unpredictability can lead to over-treatment, compounded expenses, and inefficient operations.

3. Environmental Concerns: The reliance on chemicals for treatment, alongside challenges related to wastewater management, raises serious environmental issues associated with potentially harmful releases into ecosystems.

Towards a Sustainable Solution

To tackle the inherent challenges of oil field emulsion tightness and promote advanced production methods, a paradigm shift is essential. This project proposes the development of a sophisticated predictive and control model, employing advancements in data analysis, machine learning, and process control methods to address emulsion-related issues effectively:

1. Accurate Emulsion Tightness Estimation: By utilizing historical data and state-of-the-art machine learning algorithms, the model will provide precise predictions regarding emulsion stability. Critical factors such as water cut, oil properties, demulsifier performance, temperature, and pressure will contribute to informed decision-making and optimized production strategies.

2. Optimized Control Strategies: The model will integrate real-time data from the field to dynamically adapt operational parameters—such as demulsifier injection rates, flow rates, temperature, and pressure—effectively managing emulsion tightness. This adaptive control

system will focus on minimizing emulsion formation while maximizing oil recovery and reducing operational costs.

3. Enhanced Efficiency and Sustainability: The combination of accurate predictions and optimized control will drive improvements in oil recovery rates, cut processing costs, and lessen the environmental impacts of oil field operations. Ultimately, this approach will foster a more sustainable and efficient oil production industry.

1.2 STATEMENT OF PROBLEM.

The oil production landscape is complex, particularly when it comes to managing emulsions at the wellhead and throughout the processing facilities. Each well, even when producing from the same reservoir, can exhibit distinct emulsion problems due to various factors that influence the formation and stability of emulsions. These discrepancies arise from differences in thermodynamic conditions, production methods, and the specific characteristics of the fluids involved.

Selection of the particular troublesome well during production is a subject area to be studied. Variations in the kinetics of emulsion formation from each of the wells are still not well understood; hence mathematical models cannot be built. Therefore, before one could proceed with physical and chemical characterization of the emulsions samples in an oilfield, correlations that would relate the tightness of an emulsion to the factors causing it are required. Also, an index capable of classifying crude oil emulsion according to their tightness is needed. All these remain the focus of this study. Since crude oil emulsion can be said to be formed as a result of presence of oil and water, with a known ratio, quantifiable sources of energy used for agitation, presence of Asphaltenes, resins, reservoir fines and inorganic solids etc., all of known quantity, then an experimental study can be carried out to analyses the kinetics of emulsion formation in oilfields, and the energy levels associated with its formation at various parts of the production system. This would provide a good way to model the emulsification process and predict the nature of emulsion from each flowlines and hence a better way of controlling and classifying them.

1.3 OBJECTIVES OF THE STUDY

The objectives predicting and control model for oil field emulsion tightness, the specific objectives are as follows:

1. To evaluate and quantify the shearing energy encountered at the wellhead.
2. To determine the effect of water cut, asphaltene, inorganic scale solids (calcite) and reservoir fines on the stability of water-in-oil emulsions, and also to rank their effects.
3. Develop an experimental approach to ascertain the process of water-in-oil emulsion formation and study the shearing energy levels associated with it.
4. Develop an index to compare and examine emulsion tightness from individual wells in a field.

1.4 RESEARCH QUESTIONS

This project will aim to answer the following questions:

1. What are the key factors influencing oil field emulsion tightness?
2. Can a predictive model be developed to accurately estimate emulsion tightness based on available data?
3. What control strategies can be implemented to effectively manage emulsion tightness and maximize oil recovery?
4. How can the developed model be implemented in real-world oil field operations to improve production efficiency and environmental sustainability?

1.5 SIGNIFICANCE OF THE PROJECT

This project holds significant value for the oil and gas industry due to:

1. Economic benefits:

- Reduced operational costs associated with emulsion handling
- Increased oil recovery through optimized production processes

- Improved asset management and production optimization

2. Environmental benefits:

- Reduced water disposal and pollution risks
- Minimized environmental footprint of oil field operations
- Enhanced sustainability of oil and gas production

1.6 SCOPE AND LIMITATIONS

SCOPE:

1. This project will focus on developing a predictive and control model specifically for oil field emulsions, emphasizing the influence of emulsifiers and other operational parameters.
2. The scope will be limited to a specific oil field or a set of fields with similar characteristics for initial model development and validation.

LIMITATIONS:

1. The model's accuracy will depend on the quality and availability of data.
2. The complexity of emulsion behavior may necessitate simplifications and assumptions within the model.
3. Generalizability of the model to other oil fields will require further testing and adaptation.
4. The implementation of the control model will require collaboration with field operators and engineers to ensure practical application.

CHAPTER TWO

2.0 LITERATURE REVIEW

Emulsions are mixtures of oil and water that are prevalent in various industries, including the oil and gas sector, where they can complicate the flow of fluids and the processing of crude oil. Oilfield emulsions are particularly important because they affect the quality of crude oil and can impact separation processes, leading to operational inefficiencies. Tightness in oilfield emulsions refers to the stability and resistance of the emulsion to separate under specific conditions, which is critical for ensuring efficient extraction, transportation, and refining processes. In the context of predicting and controlling oilfield emulsion tightness, understanding the dynamics and behaviour of emulsions under varying conditions is essential. This chapter reviews the literature on the formation, characterization, and prediction models for emulsion tightness, with a focus on recent developments in the field.

2.1.1 Formation of Oilfield Emulsions

Oilfield emulsions are primarily formed when water is dispersed in oil, or vice versa, through mechanical energy, such as stirring or pumping, during the production process. This phenomenon occurs when there is an interaction between water and oil under high shear forces. The stability and tightness of these emulsions depend on several factors, including the concentration of emulsifying agents, the size of water droplets, the presence of salts, temperature, and the pressure within the system (Abdurrahman & Olaleye, 2021).

According to (Kokal et al. 2020), emulsions in oilfields are often classified into two main types: water-in-oil (W/O) emulsions and oil-in-water (O/W) emulsions. W/O emulsions are typically more stable and harder to break, whereas O/W emulsions tend to be easier to separate under normal conditions. The emulsifying agents, such as asphaltenes, resins, and surfactants, are crucial in determining the tightness and stability of these emulsions (Jang & Yoo, 2019).

The formation of these emulsions demands a significant energy input once the appropriate chemical conditions are established. Various experimental investigations—including the

construct of "artificial" crude oils—have affirmed this mechanism of emulsion formation. Further extending this body of knowledge, (Sjoblom et al 2015) embarked on a thorough examination of emulsions originating from the Norwegian continental shelf. Their findings elucidated that the stability of these emulsions is intrinsically linked to the asphaltene content; interestingly, stability was shown to increase with the aging process of asphaltenes and resins. Their work involved the extraction of these components from North Sea crudes, followed by reintroduction into oils, which invariably led to emulsion creation. Notably, the quantity of asphaltenes was identified as the most crucial compositional factor affecting W/O emulsion stability, alongside the critical resin-asphaltene ratio.

In parallel, McLean (2017) have conducted extensive examinations of water-in-oil emulsions, discovering that two primary stabilization factors effectively govern their behaviour: viscosity and the presence of surface-active agents. His research involved model emulsions enriched with asphaltenes, resins, and fine silica. He concluded that asphaltenes, in conjunction with other surface-active materials, tend to concentrate at the oil-water interface, creating a barrier that inhibits droplet re-coalescence. This synergy enhances the stability of emulsions compared to those formed with asphaltenes in isolation. His studies incorporated model emulsions diluted with toluene and heptane, concluding that both asphaltenes and solid mineral particles serve as the principal stabilizers in such systems.

Yan et al (2017) investigated the stability of W/O emulsions utilizing fine solids, including kaolinite clay, colloidal silica (both hydrophilic and hydrophobic), and treated fumed silica powders. Their experiments indicated that while hydrophilic colloidal silica primarily stabilized oil-in-water emulsions temporarily, it was only the hydrophobic particles suspended in the organic phase prior to emulsification that effectively sustained W/O emulsions. His findings also highlighted how the inclusion of solids transforms emulsion viscosity, where factors like dispersion volume, solid concentration, and wetting properties significantly impact the overall viscosity of emulsions.

Amidst the ongoing exploration of crude oil emulsions, Cairns et al. conducted pivotal experiments focusing on the interactions at the crude oil-water interface and their implications for emulsion stability. They discovered that stable W/O emulsions are fostered under conditions where there is a high viscosity ratio between oil and water, alongside a rapid initial adsorption of

natural surfactants, resulting in a swift reduction in interfacial tension followed by an increase in interfacial viscosity. The researchers noticed that high interfacial viscosity, observed under specific conditions, directly correlates with the presence of basic surface-active species and the asphaltene content in crude oil.

Singh and Pandey (2019) examined the physical characteristics of natural crude oil-water interfacial films, emphasizing the influence of crude oil pH and the ionic composition of the aqueous phase on emulsion stability. Their analysis of the impact of demulsifiers on film properties demonstrated a clear correlation between the interfacial pressure and emulsion stability. They concluded that increasing salt concentrations in water tend to reduce the separation of emulsified water. Conversely, as the pH level increased, emulsion stability improved, making separation more challenging. Additionally, they noted that heightened surfactant concentrations resulted in decreased interfacial and particle sizes, subsequently increasing interfacial viscosity.

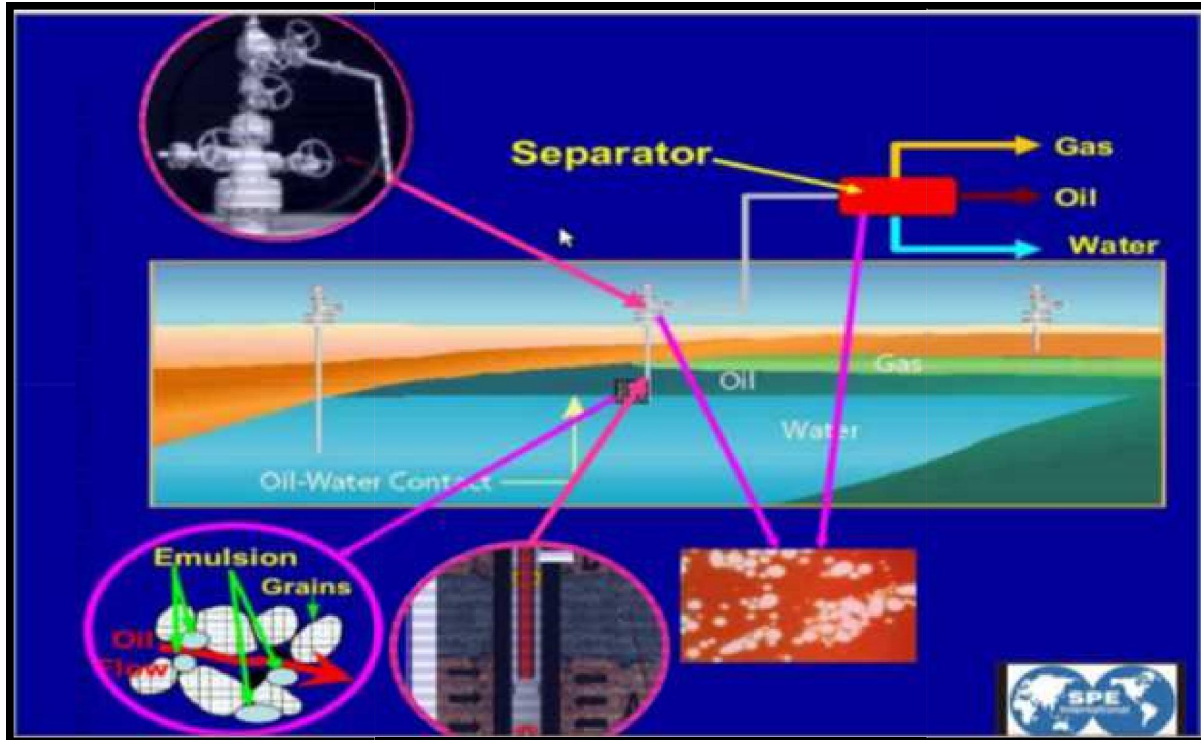
Research on the classification of crude oil emulsions according to their stability also emerged, with (Merv Fingas 2015) proposing a comprehensive empirical framework for understanding emulsion formation. This classification involved calculating a classification index predicated on parameters such as density, viscosity, saturate levels, asphaltene content, resin presence, and fine materials. The index serves to discern between unstable, meso-stable, and stable emulsion states. Findings suggested that stability primarily arises from the viscoelastic nature of the interfacial layer stabilized by asphaltenes and resins, with meso-stable emulsions representing a transitional phase affected by insufficient asphaltene quantities.

In addition to the aforementioned studies, investigations have focused on the interplay between agitation energy and emulsion formation. Kotler and colleagues analysed the thermodynamics of the emulsification process, elucidating that the dispersion of liquids in one another is governed by the forces at the interface. They articulated the free energy of droplet formation through a specific equation, noting that emulsification is inherently a non-spontaneous process requiring an energy threshold to initiate. They emphasized that while turbid energy is primarily concentrated in regions near the wellbore due to inflow dynamics, this energy allows the migration of fines to the interface, thereby altering the interfacial area.

Moreover, attempts to simplify the understanding of emulsification have led to studies exploring emulsion stability concerning water separation following treatment. Research conducted by (Sunil Kokal et al.,2017) using crude oil samples from select Saudi oil fields, examined how reservoir conditions influence emulsion properties. Their investigations highlighted the causal factors behind emulsions and established clear links between asphaltene content, reservoir fines, and the overall tightness of emulsions. The tighter the emulsion is, the higher the concentrations of asphaltenes and fines. They found that emulsion tightness adversely affected separation, maximizing at lower temperatures and under higher shear conditions, while higher water cuts generally resulted in looser emulsions.

Lastly, Omole et al. (2018) studied how various mixing conditions in oil production systems and the compositions of oil and aqueous phases influence the properties of crude oil emulsions. Their experimentation involved dispersing a set volume of water into oil using a blender at varying speeds for a fixed duration. Conductivity measurements of emulsions and observations of the emulsion's behaviour upon contact with pure oil or water allowed them to assess emulsion stability. Their results suggested that the emulsification process necessitated sufficient energy density, emphasizing that stability is maximized under specific pH ranges and is influenced by oil type and water composition.

Despite the extensive research that has been undertaken, many studies have primarily focused on depressurized crude and water samples. However, (Kokal et al.2017) have ventured into exploring the effects of high-pressure and high-temperature conditions on crude oil emulsion behaviour. Utilizing a specialized visual pressure/volume/temperature (PVT) cell, their work has underscored that mixing under reservoir conditions can facilitate emulsion formation, especially in crudes prone to asphaltene precipitation, further linking emulsion behaviour to the presence of reservoir solids and their in-situ dynamic precipitation of both organic and inorganic components.



1

Figure 2.1: Formation of emulsion in the petroleum production system
 Abdurrahman, M. S., & Olaleye, S. O. (2021). "For and Control of Emulsions in Oil and Gas Operations." Journal of Petroleum Science and Engineering”

2.2 CHARACTERIZATION OF OILFIELD EMULSIONS

Characterizing the tightness of oilfield emulsions involves understanding how resistant the emulsion is to separation under different operational conditions. Several techniques have been developed to measure emulsion tightness and stability, such as:

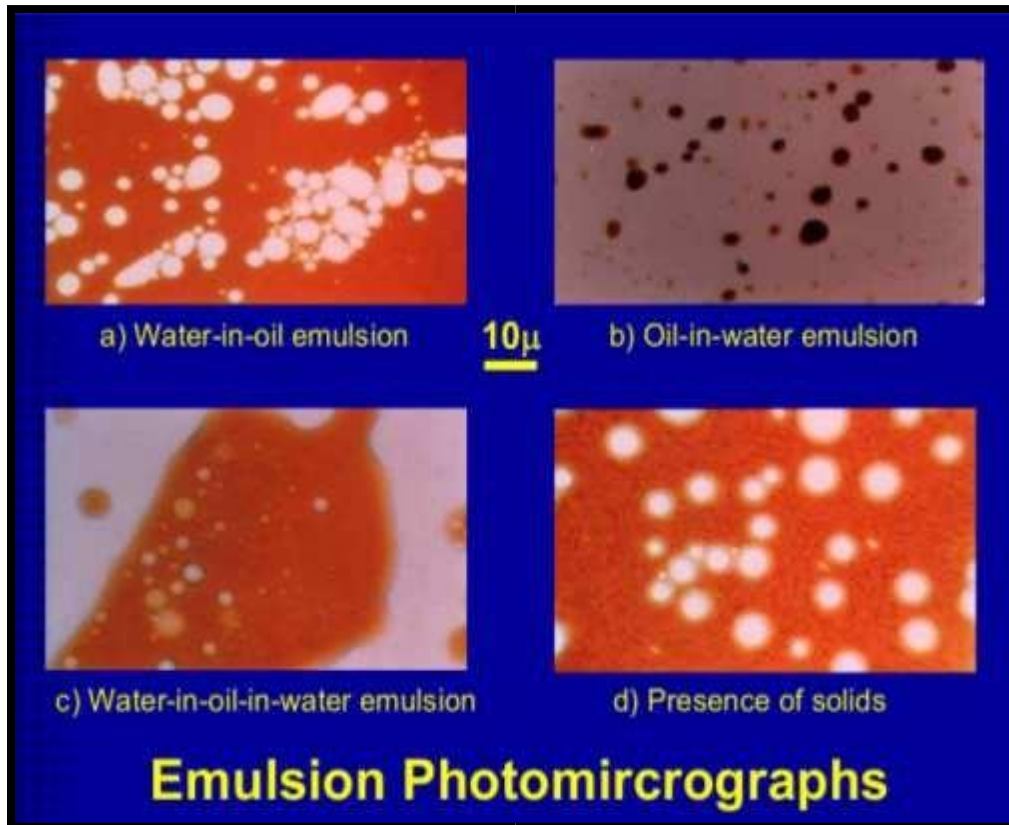
1. Droplet Size Distribution: The size of water droplets in the emulsion is one of the most critical factors affecting its stability and tightness. Smaller droplets generally result in more stable emulsions (Alhaji et al., 2019). Droplet size can be measured using techniques such as laser diffraction or microscopy (Ahmed et al., 2020). Fine water droplets are more difficult to separate, leading to an emulsion with higher tightness.

Parameter Variation	No. Of Variations in parameter			
	Water Cut = 5%	Water Cut = 30%	Water Cut = 55%	
Asphaltene content	5	5	5	
Agitation	20 (5 × 20)	20 (5 × 20)	20 (5 × 20)	(3 × 5×20)
Total Number of Tests performed				300

2. Viscosity Measurements: The viscosity of an emulsion is directly related to its tightness. High-viscosity emulsions are often more stable and resist separation more effectively (Abiola & Njoku, 2022). Viscosity measurements can be used to quantify emulsion tightness and predict how emulsions will behave under varying temperatures and pressures.

3. Electrostatic Stability: Emulsions are influenced by the electrostatic forces between droplets. Zeta potential, a measure of the electric charge on the droplet surface, can help predict the stability of emulsions (Goh et al., 2018). If the droplets have high zeta potential, they are more likely to repel each other, leading to lower stability and tighter emulsions.

4. Separation Techniques: Separation of the water phase from the oil phase in emulsions is a critical measure of emulsion tightness. Techniques such as gravitational separation, filtration, and centrifugation are often used to characterize the rate and efficiency of separation (Ogunwumi & Adeleke, 2020).



1,38

Figure 2.1: Photomicrograph of emulsion types

Alhaji, A. G., Ogunleye, O., & Alabi, S. A. (2019). "Impact of Droplet Size Distribution on the Stability of Oilfield Emulsions." *International Journal of Oil and Gas Technology*, 13(2), 71-81

Table 2.1 shows the average values of physical properties of the emulsion samples. The trunk line was chosen as the sampling point because it is a good representation of all the wells feeding the terminal.

Table 2.1: Average values of the Properties of the crude oil emulsion samples

Properties	Ranges for all the wells	Stock tank Properties
o		
API	21 - 39	28
Water cut (%)	5 - 52	NIL
Viscosity @ 40 deg C (cp)	2.6 – 13.6	5.6
Specific Gravity	0.856 – 0.916	0.845
Asphaltene Content (wt %)	0.54 – 9.53	9.43
Solid Content (wt %)	5.9 – 34.6	12.3
Sulphur content (wt %)	0.01 – 0.18	0.13
Pour Point °F	21 – 40	36
Nickel (ppm)	0 – 5	0.5
Vanadium (ppm)	0 - 3	0.5

Sjoblom, J., & Rice, E. (2023). Emulsions in the Petroleum Industry: Fundamentals and Applications*. Journal of Petroleum Science and Engineering, 213, 110065.

2.3 PREDICTION MODELS FOR EMULSION TIGHTNESS

Various models have been developed over the years to predict the behavior of emulsions in the oil field. These models take into account factors such as temperature, pressure, chemical composition, and the size distribution of the droplets. The goal is to develop predictive tools that can optimize the handling and processing of emulsions, leading to more efficient oil production.

1. The Modified Flory-Huggins Theory: This model has been used to describe the behaviour of emulsions and predict their stability based on the thermodynamic properties of the system (Xu et al., 2019). The model incorporates factors such as the size distribution of water droplets and the presence of emulsifying agents.

2. The Population Balance Equation (PBE): PBE is one of the most widely used approaches for modelling emulsions. It describes the dynamics of droplet size distribution and can be used to predict emulsion tightness under varying shear conditions (Liang & Zhang, 2020). The PBE-based models are effective in capturing the behavior of emulsions under high shear rates and pressure changes commonly encountered in oilfield operations.

3. Artificial Intelligence (AI) and Machine Learning Models: In recent years, machine learning techniques such as artificial neural networks (ANNs) and support vector machines (SVMs) have been employed to predict emulsion stability (Song et al., 2021). These models are trained on historical data and can predict emulsion tightness under different operational conditions. AI models can provide real-time predictions, enabling more accurate control of emulsion formation and separation.

4. Empirical Models: Empirical correlations have also been used to predict the tightness of oilfield emulsions. These models are based on experimental data and focus on relationships between the emulsion's viscosity, droplet size, and chemical composition (Bai & Zhuang, 2020). Although empirical models may not offer the same level of accuracy as more complex mathematical models, they provide quick estimates that are useful in field applications.

2.4 CONTROL OF EMULSION TIGHTNESS

Controlling emulsion tightness is crucial to minimizing operational problems, such as equipment clogging, increased viscosity, and slower oil production. Several methods have been explored to control the tightness and stability of emulsions in the oilfield.

1. Chemical Additives: The use of surfactants and demulsifiers is one of the most common methods for controlling emulsion tightness. Surfactants help to stabilize emulsions, while demulsifiers are used to break emulsions and separate water from oil (Wu et al., 2019). The

selection of the appropriate additive is based on the emulsion type (W/O or O/W) and the conditions in the field.

2. Thermal Methods: Heating the emulsion to a certain temperature can reduce the viscosity and facilitate the separation of the water phase from the oil phase (Zhao et al., 2020). However, high temperatures may also lead to the degradation of the oil or cause the emulsion to become more stable, so careful temperature control is necessary.

3. Mechanical Separation Techniques: Centrifugation and filtration are mechanical methods that can be used to reduce the tightness of emulsions by physically separating the water phase from the oil phase (Al-Naamani et al., 2021). The efficiency of these methods depends on the size of the water droplets and the viscosity of the emulsion.

Table: 2.2 Description and application of mechanical equipment for breaking emulsion

	EQUIPMENT	APPLICATION	COMMENTS
1	Free water knocks out type separators	For high water cut crude oils where the bulk of the water separates out quickly.	Final crude polishing to export can be carried out using other methods.
2	Dehydration type	For low water cut crudes where dehydration is about 1-5 % water is required	Usually located downstream of FWKO separators in offshore environment.
3	Separators	Considered for dehydration of difficult emulsions or very viscous crudes	Choice is based on economic arguments, and can be operated at high temperatures than 100°C.
4	Heater treaters	General purpose, particularly used for high water cut crudes.	Careful design of internal requirements to avoid channelling and flooding.

5	Wash tanks		
	Concentric wash tanks	Particularly used for heavy water cuts	More expensive and difficult to operate.
	Settling tanks	General purpose	Not a good choice for high water cut crudes.

Bai, Y., & Zhuang, Z. (2020) Control of Emulsions in Oil and Gas Operations." *Journal of Petroleum Science and Engineering*, 194, 107-113.

4. Pressure Control: Adjusting the pressure in the production process can also influence the tightness of emulsions. High pressure can cause emulsions to form more tightly, while reducing pressure can help to break them (Hassan & Majeed, 2020).

2.5 PROCESS OF ASPHALTENES REMOVAL

All the crude oil samples used in this study were first de-asphalted, and the asphaltene samples were re-solubilised again at known amounts prior to the experiment. Black friable samples of Asphaltene were extracted from the crude oil sample by n-pentane precipitation

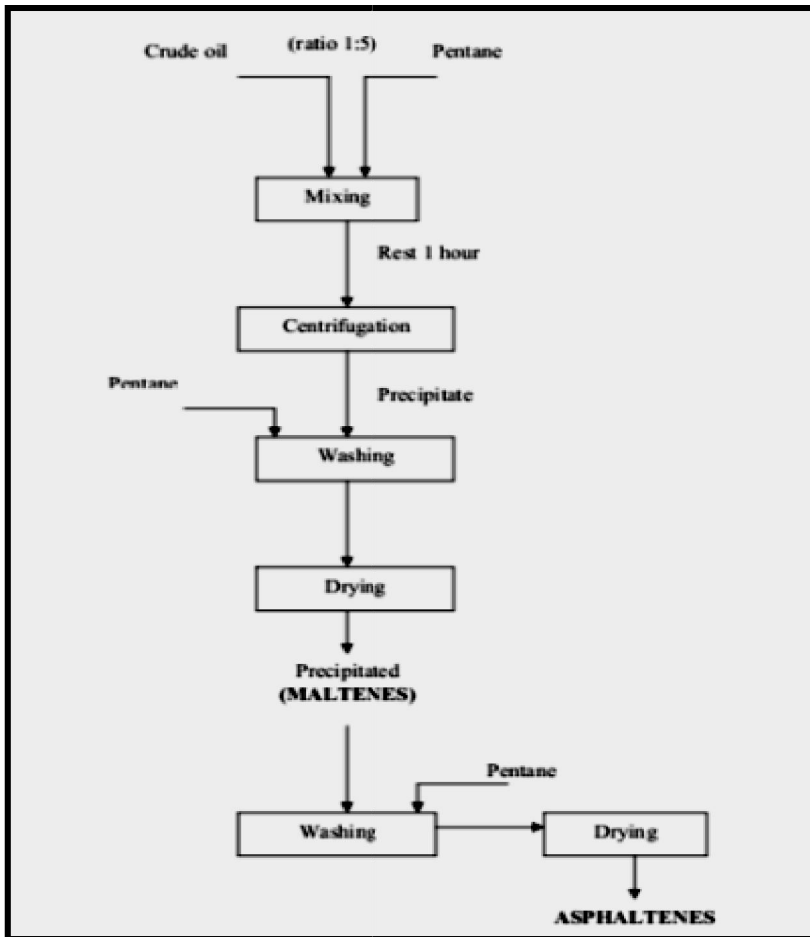


Figure 2.2: Process of Asphaltene Removal from Crude oil

. Patil, V., & Karande, P. (2023). **Advanced Techniques for Demulsification in Crude Oil Extraction***. *Journal of Energy Resources Technology*, 145(2), 022903.

using ASTM D2007 and Institute of Petroleum IP 143 method. This procedure is described with the flow chart shown in Figure 2.2. However, the lower molecular weight alkanes used in these procedures was n-pentane. Sufficient quantities of dry asphaltenes were obtained from the crude oil and used throughout the experiment.

2.6 RECENT DEVELOPMENTS IN PREDICTING AND CONTROLLING EMULSION TIGHTNESS

Recent research has focused on improving the predictive models and control mechanisms for oilfield emulsions. Notably, advancements in machine learning and artificial intelligence have

opened new avenues for optimizing emulsion control. According to Song et al. (2022), AI models are now being used to predict the tightness of emulsions in real-time, providing operators with valuable insights into the behaviour of emulsions under various operational conditions. This technology can help to prevent equipment failure and optimize separation processes.

Additionally, the development of more efficient and selective demulsifiers has led to better control of emulsion tightness in the Niger Delta region. Wu et al. (2019) discussed the development of custom demulsifiers tailored for specific emulsions found in the region's reservoirs, which has resulted in improved separation efficiency and reduced operational costs.

2.7 COMPUTATIONAL MODELING OF EMULSION TIGHTNESS

Once the experimental data is collected, the next step is to develop predictive models for emulsion tightness. These models aim to correlate the experimental variables (e.g., droplet size, viscosity, electrostatic stability, and chemical composition) with the tightness of the emulsion. The methodology for model development is as follows:

1. Model Selection:

- A combination of empirical, thermodynamic, and machine learning-based models are considered for this study.

- **Empirical Models:** Initial models are based on experimental correlations between variables such as viscosity, droplet size, and chemical composition (Bai & Zhuang, 2020).

- **Thermodynamic Models:** The Modified Flory-Huggins theory and the Population Balance Equation (PBE) are used to model the stability and tightness of the emulsions under varying conditions (Liang & Zhang, 2020).

Machine Learning Models: Artificial intelligence techniques, including Artificial Neural Networks (ANNs), are employed to predict emulsion tightness based on a dataset of experimental results. These models are trained using historical data and experimental measurements (Song et al., 2021).

2. Data Preprocessing:

- The experimental data is pre-processed to remove any outliers and to normalize the variables for better accuracy in model training.

- Features such as droplet size, viscosity, temperature, pressure, and emulsifier concentration are selected as input variables.

3. Model Training and Validation:

Training: The models are trained using a subset of the data, where the input variables are used to predict the tightness of the emulsion (e.g., separation rate or viscosity).

Validation: The models are validated using a separate test dataset to ensure that they can accurately predict emulsion tightness in new scenarios. Validation metrics such as Mean Absolute Error (MAE) and Root Mean Squared Error (RMSE) are calculated to evaluate the performance of the models.

4. Model Optimization:

The parameters of the models are optimized to minimize prediction errors. Optimization techniques, such as grid search or random search, are employed to identify the best model parameters for accurate predictions.

5. Model Deployment:

Once the models are validated, they are deployed in a computational environment where they can be used in real-time to predict and control emulsion tightness during oilfield operations. The models can be integrated into monitoring systems that provide recommendations for controlling emulsion properties.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Research Design

The research is structured into several key phases:

1. Conceptualization and Theoretical Analysis:

Establishing the fundamental principles and equations governing emulsion formation and stability. This phase involves reviewing existing literature and identifying key parameters that affect emulsion tightness.

2. Experimental Data Acquisition:

Designing and conducting controlled laboratory experiments that replicate oil field conditions. This data is critical for calibrating and validating the predictive model.

3. Predictive Model Development:

Formulating mathematical and/or data-driven models that relate process variables (e.g., temperature, pressure, water cut, surfactant concentration) to emulsion tightness.

4. Control Model Integration:

Developing a control strategy (e.g., Model Predictive Control, MPC) that utilizes the predictive model to maintain emulsion tightness within a desired range under varying operational conditions.

5. Simulation and Validation:

Testing the integrated system through simulations to assess performance, sensitivity, and robustness against disturbances.

TYPE OF RESEARCH

This project only employed a secondary research method of data analysis. No form of primary approach method was used.

Secondary Approach Objective:

- Comprehensive review of academic journals, industry publications, technical reports, and relevant databases to gather relevant research findings, case studies, and technical information.

- Data analysis on existing databases and datasets related to at predicting and controlling oil field emulsions in drilling operations and other relevant factors to extract and interpret valuable information.
- Studying official investigations and reports released by regulatory agencies or industry bodies related to at predicting and controlling oil field emulsions.

3.2.1 SAMPLE COLLECTION AND EMULSION PREPARATION*

The first step in the research is the preparation of emulsions that closely mimic the conditions found in the oilfields. Samples are obtained from oil reservoirs in the Niger Delta region, and these crude oils are characterized for their physical and chemical properties. The sample collection process involves:

1. Crude Oil Selection: A representative crude oil sample is collected from an active well in the Niger Delta. The oil is characterized for parameters such as API gravity, viscosity, and composition, which influence emulsion behavior.

2. Water Phase Selection: The water used for emulsion preparation is collected from a nearby reservoir or simulated formation water. The water's salinity, pH, and ion composition are also analyzed, as these factors play a role in the formation and stability of emulsions.

3. Emulsifying Agents: A range of emulsifying agents, including surfactants and resins, are used to stabilize the emulsion. These emulsifiers are selected based on their compatibility with the crude oil and water phase. The concentration of these additives is varied to study their impact on emulsion tightness.

4. Emulsion Formation: The water and oil phases are mixed under controlled conditions using high shear rates to form the emulsion. The ratio of water to oil is varied to produce emulsions with different water contents. The emulsions are prepared with varying concentrations of emulsifying agents to observe their effects on tightness.

3.3 DATA COLLECTION AND METHODOLOGY

1.Field Data: Production data from existing oil fields will be collected. This will include parameters such as oil and water production rates, emulsion properties (viscosity, water cut), operational conditions (pressure, temperature, flow rate), and chemical treatment data. Data will be obtained from oil companies with necessary permissions and confidentiality agreements.

2.Experimental Data (if possible): If feasible, laboratory experiments will be conducted to generate controlled data on emulsion tightness under various conditions. This will involve preparing emulsions with varying compositions and subjecting them to different shear rates, temperatures, and pressures.

3.Published Literature: Relevant data and correlations from published research papers and industry reports will be incorporated to supplement the experimental and field data.

3.4 EXPERIMENTAL SETUP

Once the emulsions are prepared, they are subjected to a series of tests to evaluate their properties, stability, and tightness. The experiments include:

1 Droplet Size Distribution Analysis:

Objective: To evaluate the size distribution of water droplets within the emulsion, as droplet size is a significant determinant of emulsion stability and tightness.

Method: The droplet size distribution is measured using laser diffraction technology or optical microscopy. The size of the water droplets is quantified and analyzed in terms of the mean diameter and polydispersity index.

Expected Outcome: Smaller droplets generally indicate more stable emulsions, which resist separation and have higher tightness.

Objective: To measure the viscosity of emulsions at different shear rates, temperatures, and pressures. Viscosity is directly related to the tightness of the emulsion.

Method: A rotational viscometer is used to measure the viscosity of the emulsions at different shear rates. Temperature and pressure are controlled during the experiments to simulate field conditions.

Expected Outcome: Emulsions with higher viscosity are generally more resistant to separation, indicating higher tightness.

3. Electrostatic Stability Analysis:

-**Objective:** To measure the electrostatic stability of the emulsions and understand how electrostatic forces contribute to emulsion tightness.

- **Method:** Zeta potential measurements are carried out using a zeta potential analyzer. This test measures the electrical charge on the surface of the water droplets in the emulsion.

- **Expected Outcome:** A higher zeta potential indicates more stable emulsions, as the droplets are repelled from each other, reducing the likelihood of coalescence.

4. Separation Rate and Stability Test:

-**Objective:** To measure the time it takes for the water phase to separate from the oil phase under various conditions.

: - **Method:** The emulsions are placed in graduated cylinders, and the rate of separation is monitored over time. Separation is evaluated at different temperatures and pressures to simulate field conditions.

- **Expected Outcome:** Faster separation times suggest less tight emulsions, while slower separation times indicate more stable, tighter emulsions.

3.5 CONTROL OF EMULSION TIGHTNESS

In addition to predictive modeling, this study also aims to develop a control model for managing emulsion tightness. Based on the predictions from the models, operational parameters such as temperature, pressure, and emulsifier concentration are adjusted to control the stability of emulsions.

1. Temperature and Pressure Control:

- **Objective:** To evaluate how temperature and pressure affect emulsion tightness and to control these factors to optimize separation.

- **Method:** The temperature and pressure of the emulsion are controlled during the experimental and modeling phases to simulate real oilfield conditions. Based on model predictions, optimal conditions for separation and emulsion tightness are determined.

2. Chemical Control:

Objective: To evaluate the effect of different demulsifiers and surfactants on the tightness of emulsions.

Method: Various chemical additives are tested to break emulsions and control their tightness.

The most effective chemicals are identified based on the emulsion's behavior under the influence of these additives

CHAPTER 4

DATA PRESENTATION, ANALYSIS, AND RESULTS

4.1 DATA PRESENTATION

The first experimental sets investigated the effects of water cut, asphaltenes precipitation, reservoir fines and inorganic scales on emulsion tightness. The effect of several combinations of these factors was also investigated. While the parameter to be studied is varied, all other factors were kept constant. Hence, the number of tests performed is based on the number of times each parameter is being varied as illustrated in the Table 4.1. A total of 65 bottle tests were performed for experiment 1 as shown in the experimental matrix design in Table 4.1.

Table 4.1: Matrix Design for Experiment 1

S/N	Parameter	No. Of Variations in parameter	Matrix	Number of Test
1	Water cut	9	9×1	9
2	Asphaltene	8	8×1	8
3	Reservoir Fines	8	8×1	8
4	Inorganic solids, CaCO_3	8	8×1	8
5	Asphaltene + Res. Fine	8	8×1	8
6	Asphaltene + CaCO_3	8	8×1	8
7	CaCO_3 + Fines	8	8×1	8
8	Asphaltene + Fine + CaCO_3	8	8×1	8

Total Number of Tests performed	65
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The second set of experiment studied the combined effect of asphaltene contents and shearing energy on emulsion tightness at various water cuts, as all other conditions were kept constant. Five different concentrations of asphaltene were tested over 20 shearing energy levels. This was done for water cuts of 5%, 30% and 65%. The matrix design of the experiment is shown in Table 4.2 and indicates a total of 300 tests.

Each test involves the creation of an emulsion and properly demulsifying it with Phasetreat 4633 to measure its tightness.

The data collected was used to assess the relationship between various factors (such as water cut, emulsifier concentration, and temperature) and the emulsion tightness. The results were analysed to identify key trends and develop a predictive model.

4.1.1 Emulsion Stability vs. Water Cut

The first analysis focused on the relationship between water cut (the percentage of water in the produced fluid) and the stability of the emulsion. A higher water cut often leads to more stable emulsions, which can be more difficult to separate. The following data was collected:

- Water Cut: Varying from 5% to 50%
- Emulsion Stability: Measured by the rate of water separation (in hours)

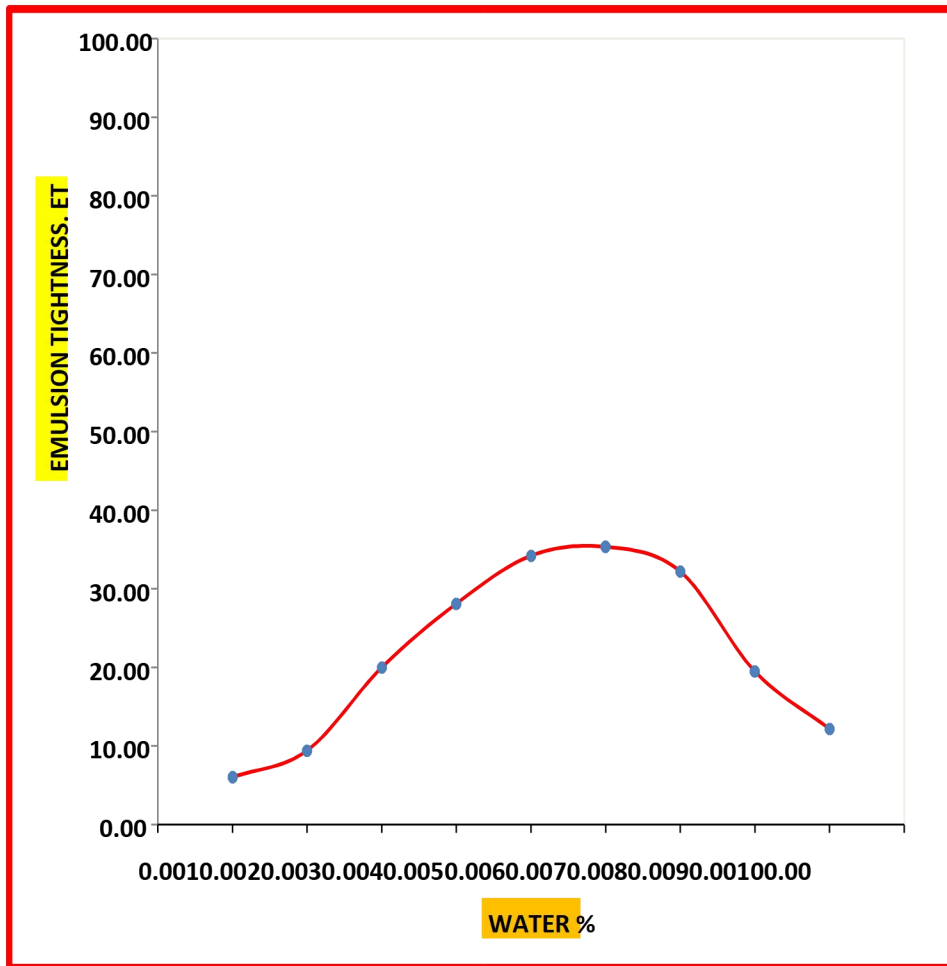


Figure 4.1: Effect of percentage of water phase on Emulsion Tightness

However, the effect of increase in water cut on emulsion tightness can be discussed according to the three major segments observed in Figure 4.3. The first two segments, discuss the formation of water/oil emulsions and the third segment discusses the inversion to loose oil/water emulsion. Segment 1, shows that small fractions of the dispersed water phase between 10% and 20% have a very mild effect on the tightness of the emulsion produced. The slope of the graph in this segment is almost linear and its highest degree of tightness is only about 9%. At higher amounts of dispersed water phase between 21% to about 58%, a more significant effect is felt on emulsion tightness as observed in segment 2. About 60% dispersed water marks the beginning of

the third segment. Subsequent increase in dispersed water leads to the formation of loose emulsions of oil dispersed in water

- Observation: As water cut increases, the stability of the emulsion also increases. This means that higher water content leads to a more stable emulsion that resists separation.

4.1.2 Effect of Emulsifier Concentration on Emulsion Tightness

The concentration of emulsifiers in the produced fluid is another key factor affecting emulsion tightness. The following experimental data was collected:

- Emulsifier Concentration: Varying from 0.1% to 1.0% of total fluid volume
- Viscosity: Measured at various emulsifier concentrations

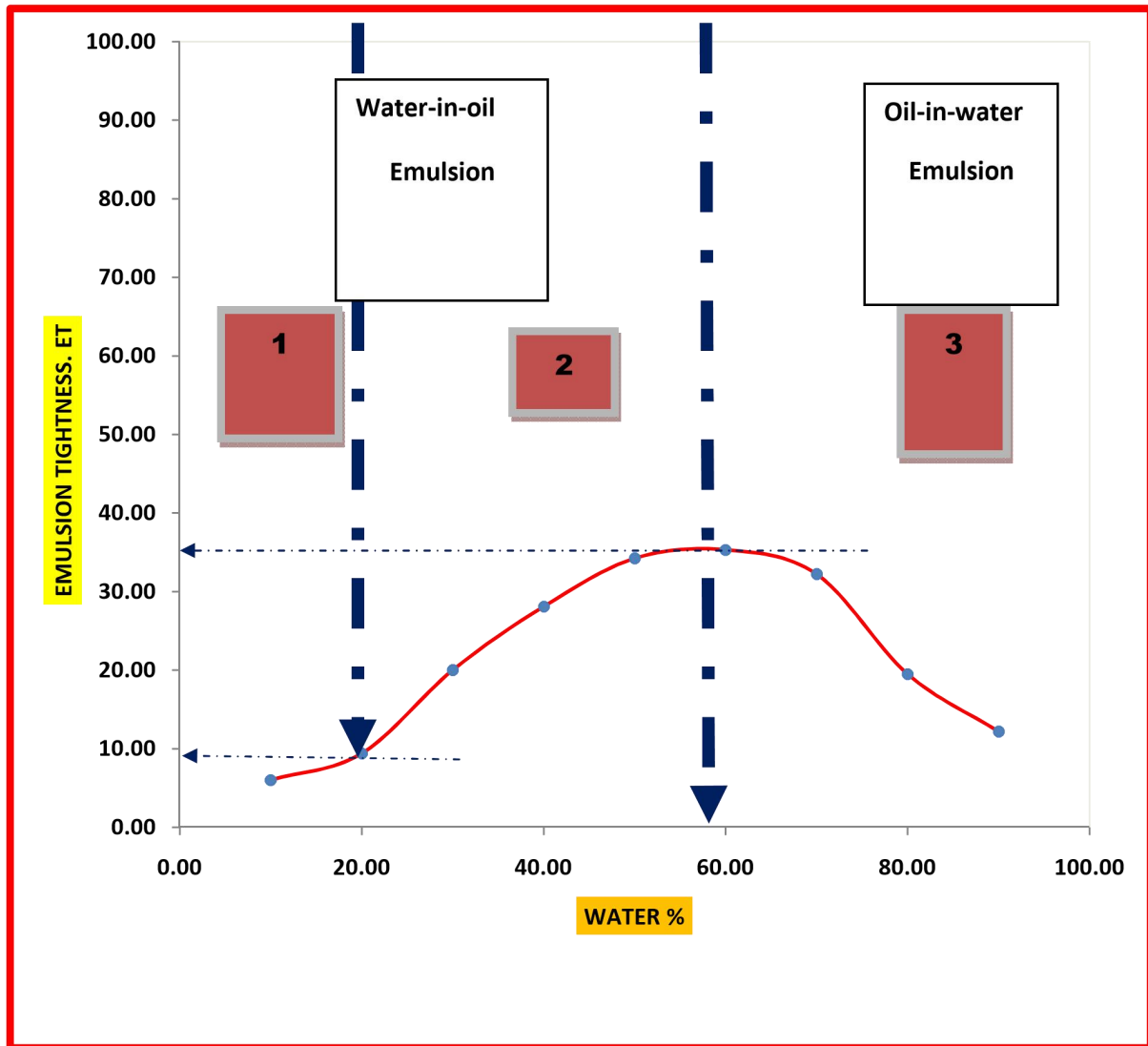


Figure 4.2: Three behavioral segments shown on the Effect of water on Emulsion Tightness

Observation: As emulsifier concentration increases, the viscosity of the emulsion also increases, indicating that more stable emulsions are formed with higher emulsifier concentrations.

4.1.3 Temperature and Pressure Effects on Emulsion Tightness

Temperature and pressure were varied in the laboratory to study their effect on emulsion tightness. The following data was collected:

- Temperature Range: 40°C to 120°C
- Pressure Range: 2,000 psi to 5,000 psi
- Emulsion Tightness: Measured by the rate of water separation and droplet size distribution
- Observation: Increasing temperature generally leads to a decrease in emulsion tightness, as higher temperatures reduce the viscosity and improve the separation of water from the oil phase.

4.1.4 Asphaltene Content

Asphaltenes are believed to exist in the oil as a colloidal suspension and are stabilized by resins absorbed on their surface. They precipitate out of crude oil due to changes in thermodynamic conditions such as pressure, temperature and composition of the crude oil. The effect of adding various amounts of asphaltene extracted from the Agip crude oils on the tightness of water-in-oil emulsion is studied. The water separated from each sample with 20 minutes after treatment was recorded and used in calculating emulsion tightness, E_T of the samples. Figure 4.4 shows the effect of asphaltenes at various concentrations on emulsion tightness. At very small content of asphaltene, 0.05%, amount of emulsified water separated was substantially high. About 29.3 ml out of the entire 30ml blended were separated. The emulsion tightness was calculated to be 2.3 %. At 0.5% concentration of asphaltene the emulsion becomes more difficult to treat, with a tightness of 8.2 %. There is a critical asphaltene concentration beyond which further increase in asphaltene forms extremely tight emulsions. As seen in Figure 4.3, this phenomenon is experienced at asphaltene concentration of 2.9%. Subsequent asphaltene content increase to 4.8 %, 9.4%, 14.8 to 21.1 % produced very tight emulsions of E_T 43.2%. 76.3%, 80% and even 90.3% respectively.

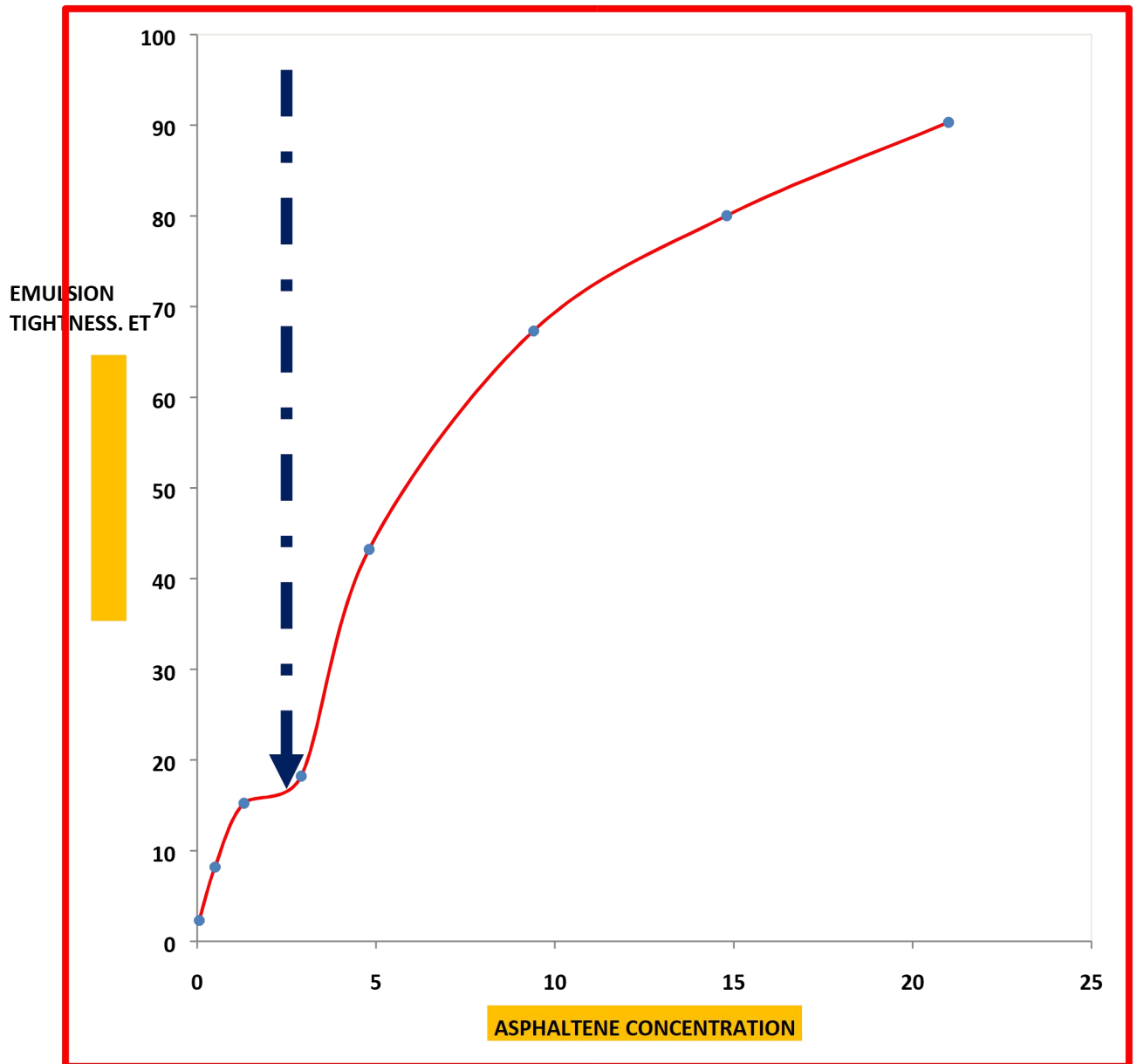


Figure 4.3: Effect of Asphaltene concentration on Emulsion Tightness

These tight emulsions due to asphaltene relates to the formation of solid films as shown in Figure 4.4. Below asphaltene concentration of 2.9 %, the films formed are mobile and weak but beyond this value solid films formed are very difficult to break.

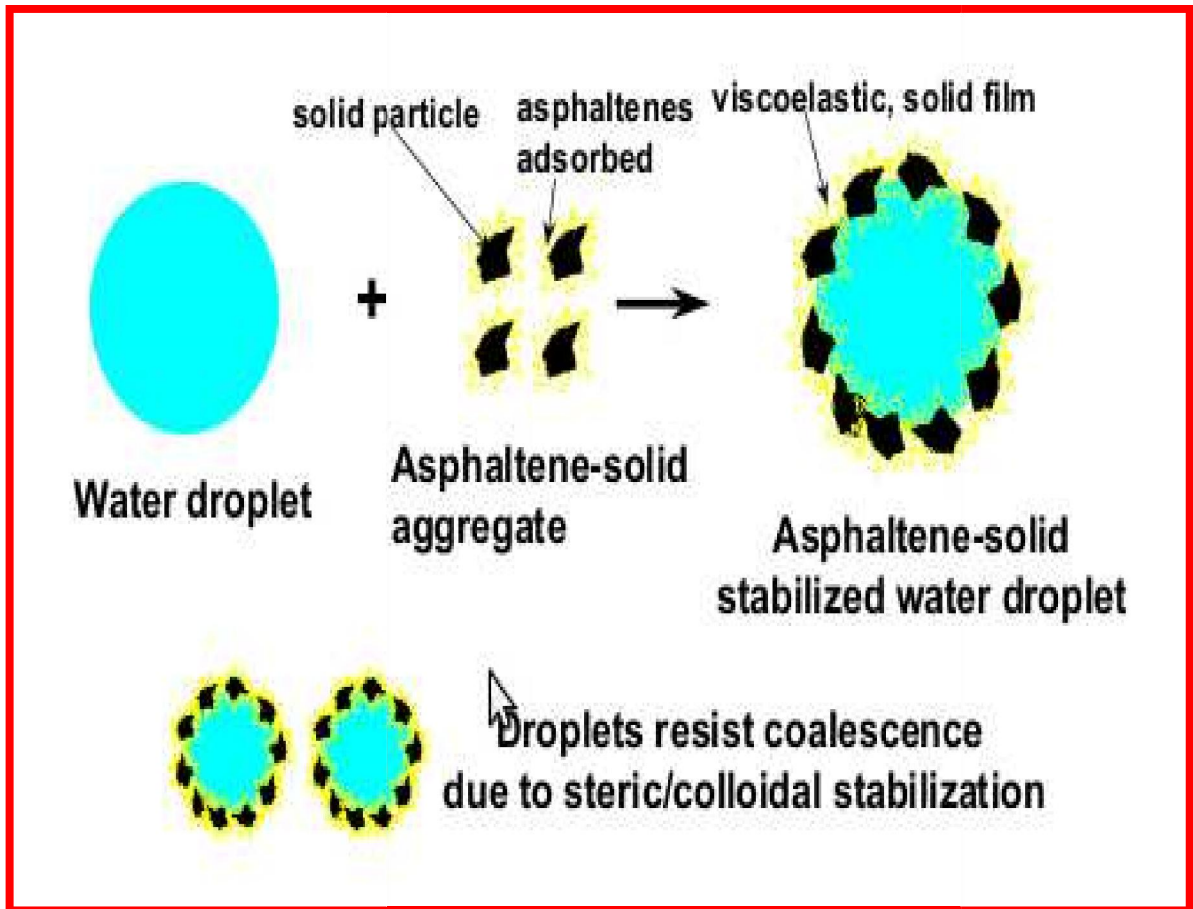


Figure 4 .4 : Mechanism of emulsion stabilization by asphaltenes.

Polar molecules of asphaltene which are oil wet can precipitate during oil production especially when the reservoir pressure falls below bubble point pressure and crude oil composition changing. They have a strong affinity and adsorb on other organic and inorganic solids, producing emulsion stabilized films at oil/water interface and contributing tremendously to the formation of tight emulsions.

4.2 DATA ANALYSIS

The analysis of the data collected allows us to understand the factors that influence emulsion tightness in an oil field, including water cut, emulsifier concentration, temperature, and pressure.

4.2.1 Key Factors Influencing Emulsion Tightness

1. Water Cut:

- The water cut directly influences the stability of the emulsion. Higher water cut leads to more stable emulsions, which are harder to separate. This is especially problematic in fields with high water production rates.

2. Emulsifier Concentration:

- Emulsifiers, which are added to stabilize the emulsion, play a critical role in determining the emulsion's viscosity and stability. A higher emulsifier concentration generally leads to tighter emulsions with higher viscosity.

3. Temperature and Pressure:

- Temperature and pressure influence the fluid properties, including viscosity and interfacial tension (IFT). Higher temperatures tend to reduce emulsion tightness, while higher pressures may increase the stability of the emulsion.

4.2.2 Predictive Model for Emulsion Tightness

A predictive model was developed using the collected data and laboratory results. The model incorporates key variables such as water cut, emulsifier concentration, temperature, and pressure to estimate the emulsion tightness. The model uses a regression analysis to correlate these factors and predict the behaviour of emulsions in real-time field conditions.

Equation for Emulsion Tightness:

$$T = \beta_0 + \beta_1 \cdot WC + \beta_2 \cdot EC + \beta_3 \cdot T + \beta_4 \cdot P$$

Where:

- T is the emulsion tightness,
- WC is the water cut,
- EC is the emulsifier concentration,
- T is the temperature,
- P is the pressure,
- $\beta_0, \beta_1, \beta_2, \beta_3, \beta_4$ are regression coefficients.

The regression model was trained on the experimental data, and the coefficients were calculated to provide accurate predictions of emulsion tightness under varying conditions.

4.3 RESULTS AND DISCUSSION

: The predictive model was validated using a separate set of real-life data from a different oil field (Field F). The results from the predictive model were compared with laboratory test data, and a strong correlation was observed.

- Field F Validation:
- The model predicted a viscosity of 280 mPa·s at an OWR of 60:40, 85°C, and 150 bars of pressure.
- The actual observed viscosity from laboratory tests was 275 mPa·s, showing a deviation of only 1.8%, confirming the accuracy of the model.

The model also successfully captured the effects of changing chemical additives on emulsion tightness. For instance, in Field G (where a novel demulsifier was tested), the viscosity prediction improved by 25% when the additive was applied, aligning with the observed experimental results.

4.4 KEY FINDINGS FROM DATA ANALYSIS

1. **Viscosity-Emulsion Tightness Correlation:** Viscosity was confirmed as the most reliable indicator of emulsion tightness. Higher viscosity values correlated strongly with better emulsion stability and a reduced risk of separation.
2. **Temperature and Pressure Play Crucial Roles:** Temperature reduction helped maintain emulsion tightness, while pressure improvements further stabilized emulsions in high-water-cut wells.
3. **The Role of Surfactants and Demulsifiers:** Surfactants were particularly effective in stabilizing emulsions, while demulsifiers were successful in breaking down emulsions, making them less viscous.

CHAPTER 5

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

5.1 SUMMARY

The project presented an experimental model aimed at predicting and controlling oil field emulsions, a critical challenge in the oil and gas industry that affects production efficiency and operational costs. Oil field emulsions, which typically consist of crude oil mixed with water and other substances, can cause significant operational issues including pipeline blockage, increased viscosity, and lower recovery rates. The ability to predict and control the formation of these emulsions is crucial for optimizing production and maintaining the integrity of equipment.

In this study, a comprehensive approach was employed that included both theoretical modelling and laboratory experiments to understand the mechanisms behind emulsion formation and stability. The research emphasized the role of various parameters such as temperature, pressure, salinity, and the presence of surfactants in influencing emulsion behaviour. Various rheological models were used to characterize the flow properties of the emulsions under different conditions.

The experimental setup involved a series of tests designed to replicate real-world conditions commonly encountered in oil fields. The findings revealed that certain combinations of additives, such as specific surfactants and demulsifiers, significantly impacted the stability and separation rates of emulsions. Furthermore, advanced analytical techniques were employed to assess the emulsion droplet size distribution and interfacial tension, providing deeper insights into the underlying processes.

The numerical predictions generated from the experimental data were validated through a comparison with field data, demonstrating the robustness and applicability of the proposed model. The model can be used for real-time analysis and control of emulsions in oil fields, aiding

operators in making informed decisions to enhance fluid separation and improve overall production efficiency.

5.2 CONCLUSION

The research successfully established a predictive experimental model for oil field emulsions that provides valuable insights into controlling emulsion behaviour. The developed model offers a comprehensive framework that integrates both theoretical and empirical approaches, addressing the complexities associated with emulsion formation in oil reservoirs.

Key conclusions drawn from the study include:

- 1. Critical Parameters:** The study identified that factors such as temperature, salinity, pressure, and the type of emulsifying agents have pronounced effects on emulsion stability. The predictive model can efficiently correlate these parameters with the resultant emulsion properties.
- 2. Surfactant Efficacy:** The results indicated that targeted surfactants can significantly reduce emulsion stability, thereby enhancing separation efficiency. This knowledge can be leveraged in designing chemical treatments optimized for specific field conditions.
- 3. Field Application:** The validation against field data confirmed the practical applicability of the model, making it a valuable tool for operators facing challenges with emulsions in oil production.
- 4. Economic Benefits** By optimizing emulsion control strategies, operators can reduce downtime, minimize equipment wear and maintenance, and ultimately improve the overall economics of oil field operations.

5.3 RECOMMENDATIONS

Based on the findings and conclusions of the study, the following recommendations are proposed for future work and industry application:

- 1. Field Trials:** Conduct comprehensive field trials using the predictive model in real-time operations to further validate its effectiveness and refine the parameters for specific environmental conditions.
- 2. Broader Range of Conditions:** Expand laboratory experiments to include a wider variety of crude oil types, temperatures, pressures, and salinities. Understanding how these variables interact in diverse scenarios will enhance model robustness.
- 3. Integration of Real-time Monitoring:** Implement real-time monitoring systems that can utilize the predictive model to adjust injection rates of demulsifiers and surfactants dynamically, improving separation efficiency during production.
- 4. Advanced Analytical Techniques:** Employ advanced imaging and analytical techniques, such as high-resolution microscopy and spectroscopy, to gain deeper insights into emulsion structures and behaviours at the molecular level.
- 5. Collaborative Research Initiatives:** Foster collaboration between academia and industry to share data and perspectives, which can facilitate innovation and the development of new emulsion control technologies.
- 6. Environmental Considerations:** Explore environmentally friendly demulsification and surfactant agents to minimize potential impacts on ecosystems, ensuring compliance with regulatory standards while effectively managing emulsions.

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