OPTIMIZING HYDRATE MANAGEMENT: INTEGRATING MACHINE LEARNING AND FLOW ASSURANCE TECHNIQUES WITH A FOCUS ON NIGER DELTA FIELDS

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CERTIFICATION

This is to certify that this thesis titled “OPTIMIZING HYDRATE MANAGEMENT: INTEGRATING MACHINE LEARNING AND FLOW ASSURANCE TECHNIQUES WITH A FOCUS ON NIGER DELTA FIELDS” was carried out by INIBHUNU ELIORA ISIBHAKHOME with matriculation number ENG 1905779 of the Department of Petroleum Engineering, Faculty of Engineering, University of Benin in partial fulfilment of the requirements for the Award of the Degree, Bachelor of Engineering (B.ENG) under the guidance of Professor (Engr.) O.A OLAFUYI.

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DEDICATION

This work is dedicated God almighty, the source who has made my life beautiful. I dedicate this work to my parents, whose unwavering support, love, and encouragement have been the cornerstone to my academic achievements. Their sacrifices and belief in my abilities have shaped me into the person I am today.

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Firstly, I owe a debt of gratitude to the Almighty God for His manifold grace and mercy to me and for seeing me through from the very beginning up to this present stage of my life and career. I thank my parents Mr. and Mrs. INIBHUNU and my entire family(Reigns and Honour) for always being there for me. I'll also like to thank Mr UZOR Godwin for his support. Mr EGAH David, thank you so much for believing in me. I immensely appreciate you all for your support, love, care, advice, guidance and all before, during and after this period. I appreciate it all.

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Lastly, I want to thank the management and staff of the Department of Petroleum Engineering at the University of Benin, for providing me with opportunities and playing a significant role in preparing me to achieve this milestone.

ABSTRACT

This report explores the challenges associated with gas hydrates in the Niger Delta oil and gas fields, focusing on their formation, inhibition techniques, and effective management strategies. It begins with a review of the thermodynamic and kinetic conditions that favor hydrate formation, emphasizing the influence of pressure, temperature, and gas composition. Utilizing machine learning models, including linear regression and random forest, the study predicts hydrate volume fractions, with the random forest model demonstrating superior accuracy.

The effectiveness of traditional inhibitors such as methanol and monoethylene glycol (MEG) is evaluated, highlighting their roles in mitigating hydrate formation. The report identifies critical research gaps, including the need for field testing of inhibitors and comprehensive modeling of hydrate behavior in real-world conditions. Recommendations for future work include enhancing collaboration among industry stakeholders, conducting economic analyses of inhibition techniques, and investigating innovative materials like nanoparticles. By implementing these strategies, the oil and gas industry can improve operational efficiency and ensure sustainable production in the Niger Delta region.

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Gas hydrates are solid crystalline compounds that arise when water and gas molecules come together under specific temperature and pressure conditions. The water molecules create a cage-like crystal lattice structure through hydrogen bonding, and the gas molecules fill the empty spaces (cages) in the lattice without actually occupying a lattice position. In the realm of oil and gas production, gas hydrates can develop in pipelines, wells, and other equipment, resulting in blockages, flow assurance challenges, and potential safety hazards. (*Okereke, N.U.et al*). Various factors influence the formation of hydrates. Key elements include Pressure and Temperature, with the Niger Delta fields operating under conditions of high pressure and low temperature, both of which are favorable for gas hydrate formation.

Additionally, other components that influence gas hydrate formation consist of Water Content, where the presence of water in produced fluids increases the likelihood of gas hydrate development, as well as gas composition, which involves the presence of hydrate-forming gases such as methane, ethane, and propane, all contributing to gas hydrate formation.

Several methods and strategies can be utilized to control or inhibit the formation of gas hydrates. These techniques are referred to as Inhibition techniques. Some examples include Thermodynamic Inhibitors, which encompass chemicals like methanol, ethylene glycol, and triethylene glycol that are injected into the system to reduce the temperature at which hydrates form. Kinetic Inhibitors, which include chemicals like polyvinylcaprolactam and polyvinylpyrrolidone, that slow down the hydrate formation process. Anti-Agglomerants, such as alkylphenol ethoxylates and alkylpolyglycosides, aim to prevent hydrate particles from clumping together. Offshore production activities in the Niger Delta region of Nigeria have surged due to advances in technology enabling the extraction of petroleum fluids from reservoirs located thousands of feet beneath the seabed. However, offshore production in Nigeria continues to face flow assurance issues, including hydrate formation and CO_2 corrosion affecting the pipelines. (Dorstewitz, F. Mewes, D. (1995))

This presents significant hurdles in Niger Delta fields, such as elevated operating expenses, high costs associated with inhibitory chemicals, insulation, and heating systems, along with environmental concerns and several others. By comprehending the factors that drive gas hydrate formation and adopting effective mitigation strategies, operators can alleviate the impact of hydrates on production and cut down on operating costs.

Besides being a considerable challenge within the industry, it's noteworthy that hydrate formation can also play a crucial role in designing a tertiary recovery program for a reservoir utilizing hydrocarbon or carbon dioxide flooding. To prevent hydrate formation in the injection solvents, economic decisions must be made regarding whether to install a water removal unit or to inject a hydrate inhibitor. Enhanced hydrate predictive methods can assist in deciding which option is more beneficial.

1.2. BACKGROUND

The Niger Delta Basin, a highly productive hydrocarbon region located in Nigeria, is particularly important for gas hydrate research. Spanning around 300,000 square kilometers in the Gulf of Guinea, this basin has been a key area for oil and gas exploration since the late 1930s (Aniefiok et al., 2013). Its significant gas hydrate potential has increased its importance, with reserves of gas hydrates estimated to possibly exceed all known fossil fuel reserves combined. The basin's distinct geological features, such as thick sediment layers, active fault lines, and complex pressure-temperature conditions, make it an ideal environment for the formation and stability of gas hydrates (Babalola et al., 2019).

Gas hydrates in the Niger Delta Basin were first suspected in the late 1980s based on seismic data, marking a substantial potential energy source for Nigeria. Since the 1930s, hydrate formation has significantly impacted the growth of the oil and gas sector. This is due to the high likelihood of hydrates forming in transport and processing equipment, leading to blockages in pipelines, valves, distillation trays, and other related apparatuses. Recently, there has been a resurgence of interest in collecting data regarding the pressures and temperatures at which hydrates form from various gas mixtures, determining how dry the gas must be to avoid hydrate formation, and calculating the amount of inhibitors necessary to prevent hydrate formation under operating conditions. As new sources of natural gas or gas-condensates are discovered offshore in deep, cold waters or onshore in cooler climates, the need for hydrate inhibition will likely escalate.

Initial signs of gas hydrate presence in the Niger Delta Basin were revealed through seismic data analysis in the early 1990s, with follow-up geophysical surveys and limited drilling confirming their presence (Ajayi et al., 2020). The potential for gas hydrates to significantly enhance energy supplies in this region could have major economic consequences, both locally and globally. However, exploiting gas hydrates also brings environmental risks, including the possibility of seafloor instability and the release of methane into the water column, which could further aggravate global warming.

As of now, Nigeria boasts approximately 37.50 billion barrels of crude oil and over 209.26 trillion cubic feet of natural gas reserves, as reported by the Nigerian National Petroleum Investment Management Services (NUPRC, 2024). Operators conduct considerable oil exploration and production efforts throughout Nigeria due to the enormous reservoirs that are usually located inside marine areas and the frequent vandalism of onshore installations. The formation of hydrates is still a significant concern in offshore operations inside the Niger

Delta, despite the fact that technology is available to assist offshore production in Nigeria.

The oil and gas industry spends millions of dollars annually to keep gas hydrates from accumulating in pipelines and guarantee a constant supply of natural gas. One of the biggest obstacles to natural gas flowing via pipes is known to be gas hydrates. The formation of hydrates can result in major financial losses as well as major safety hazards. Depending on the environmental thermodynamic conditions, these hydrates may form in pipelines during the production, processing, or transportation of hydrocarbons. Consequently, preventing their creation is essential for a natural gas production process that is more effective.

According to recent studies, Nigeria's particular weather patterns allow petrol hydrates to form in the Niger Delta at temperatures higher than 0°C. The Hydrate Safety Margin (HSM) is also affected by the saline concentration in gas wells, which varies by area. The environment and generated gas may get contaminated if chemical inhibitors are used excessively due to a lack of knowledge about the Hydrate Safety Margin for a particular gas well. Dehydration techniques are sometimes used to lessen the problems associated with gas hydrate development. This strategy, however, is ineffective because it necessitates significant investment for regular maintenance of the molecular sieve unit and results in downtime.

In view of the problems posed by global climate change, developing solutions for responsible and sustainable resource utilisation requires an understanding of the geological and environmental processes that influence gas hydrate formation and stability.

1.3 STATEMENT OF THE PROBLEM

In the oil and gas industry, gas hydrates are a major problem, particularly in deepwater producing environments like the Niger Delta. Significant operational issues, including pipeline clogs, reduced flow efficiency, and rising maintenance costs, can arise from the formation of gas hydrates. Despite improvements in our knowledge of hydrate formation, there are still significant unanswered questions regarding the kinetics of hydrate formation, the effectiveness of different inhibitors, and the environmental effects of chemical treatments used to control hydrates. The complex relationships between gas components, inhibitors, and operating circumstances are often overlooked by current predictive models, which results in inadequate flow assurance measures. Additionally, the reliance on traditional thermodynamic hydrate inhibitors raises questions about their long-term efficacy and environmental impact. Extensive research that addresses these issues, develops novel inhibition techniques, and develops efficient flow assurance strategies suited to the particular conditions of the Niger Delta region is desperately needed as the industry works to increase production efficiency and sustainability. By providing a thorough analysis of gas hydrate behaviour and offering practical management solutions for them in oil and gas operations, this study aims to close these gaps.

1.4 AIMS AND OBJECTIVES.

In order to provide safe and effective operational standards and sustainable practices within the oil and gas industry, research is being conducted in the Niger Delta on gas hydrate formation and its suppression as well as flow assurance solutions. By fulfilling its set goals and objectives, which take into account the unique gas hydrate difficulties of the region, the oil and gas industry in the Niger Delta would be able to operate safely and dependably. These goals and objectives are broken down in detail in the section that follows.

1.4.1 AIMS

To ensure safe efficient and sustainable hydrocarbon production in the Niger Delta through effective gas hydrate management.

1.4.2 OBJECTIVES

1. Study Gas Hydrate Formation Conditions: Investigate the thermodynamic and kinetic factors that promote gas hydrate generation in high-pressure, low-temperature sub-sea environments of the Niger Delta.
2. Develop Inhibition Techniques: Test thermodynamic inhibitors like methanol and ethylene glycol along with low-dosage hydrate inhibitors to measure their ability to stop hydrate formation.
3. Model and Simulate Hydrate Behavior: Employ computational models to forecast the formation, expansion, and breakdown of hydrate volume fraction under site-specific conditions.
4. Implement Flow Assurance Solutions: The design of pipeline insulation systems alongside heating mechanisms and depressurization procedures helps reduce hydrate formation risks. Create comprehensive flow assurance strategies that merge chemical solutions with thermal treatments and mechanical methods.

1.5 SCOPE OF THE STUDY

This project will concentrate on flow assurance solutions and inhibitory strategies for gas hydrate development in the offshore Niger Delta areas.

The flow assurance in flow lines is currently the most important problem in oil and gas production wells because of the long distances, high pressure, and low temperature that are common in deep-water and onshore environments. These factors result in significant financial losses from production shutdowns and damage to pipelines or surface facilities caused by solid deposition in flowlines. Because of the significant financial expenses and challenging accessibility associated with solid deposition on flowlines, it is critical to minimise the dangers associated with the growing number of deep-water and even ultra-deep-water wells.

For a well to be completed successfully and operate smoothly, it is necessary to identify potential problems early on and use suitable remedial techniques. An effective sampling and analysis program that offers insight into tentative flow assurance issues could do this. The design and operation of multiphase production systems during start-up, shutdown, pigging, metering, leak detection, etc., are aided by a better understanding of the flow conditions, which in turn depends on theories of production and fluid characteristics, the spatial distribution of phases (oil, gas, water, and solids), and the multiphase flowing conditions (pressure, temperature, velocity).

The generation and deposition of natural gas hydrate, waxing, asphaltenes, slugging, naphthenates, scales, corrosion, erosion, and emulsions are the main flow assurance concerns in deepwater oil and gas production that require sufficient attention.

A number of methods have been put forth to prevent and lessen the generation of gas hydrates in pipelines. Physical procedures and chemical approaches are the two main groups into which these techniques fall. Depressurisation, heating, and dehydration are examples of physical techniques. Conversely, the chemical approaches involve the use of additives such anti-agglomerates (AA), kinetic inhibitors (KHI), and thermodynamic inhibitors (THI). Every technique has pros and cons of its own.

Depressurisation, which creates a pressure differential by lowering pressure on one side of the gas transport line, is typically used as a remedial procedure. The hydrates are able to migrate to the lower pressure end because of this pressure differential.

As we well know, hydrate formation is a complicated phenomenon that presents serious difficulties for a number of businesses, such as gas processing, desalination, and oil and gas. Hydrates can cause obstructions, harm to machinery, and even safety hazards. Thus, it is essential to accurately anticipate the volume percentage of hydrate formation in order to optimise operations and ensure process safety.

Simulations have developed into a potent tool for hydrate formation prediction in recent years. Thermodynamic, kinetic, and computational fluid dynamics (CFD) simulations are the three general categories into which these simulations fall.

In many different industries, simulations are essential for forecasting the production of hydrates. Hydrate formation conditions are frequently predicted using thermodynamic models, such as the Peng-Robinson equation of state. The volume fraction of gas hydrate formation is also simulated by numerical tools such as OLGA, Aspen HYSYS, CSMGem, and CFD models.

These models do have certain drawbacks, though, like ignoring kinetic impacts and presuming equilibrium circumstances. In order to overcome these constraints, hydrate formation rates and morphologies are increasingly being predicted using kinetic models and computational fluid dynamics (CFD) simulations.

CHAPTER TWO

LITERATURE REVIEW

2.1 GAS HYDRATE

Natural gas hydrates are solid, non-stoichiometric crystalline compounds that occur when water molecules attach themselves by hydrogen bonding and create cavities filled by either a gas or volatile liquid molecule (Wang *et al.,* 2022). Formation of hydrate requires like light ends of petroleum such as methane, ethane, propane, butane and adequate water in low temperature and high-pressure conditions (Seo *et al.,* 2021).

Crystalline structures known as "gas hydrates" are created when methane gas and water molecules coexist at the proper pressure and temperature. Under high pressure, methane hydrate is stable at temperatures just above or below 0˚C. Most ocean settings have the right pressure and temperature for methane hydrate stability, but the geothermal gradient causes significant volumes of hydrate to accumulate on the continental shelf. Because of the geothermal gradient, methane hydrate can be stable at depths where the temperature is higher than the equilibrium temperature at in situ pressure.

The interactions between the methane gas and the water molecules stabilise the cage-like structure that is created. A comparatively strong and stable lattice is produced by these interactions. Methane gas can be stored in large quantities as gas hydrates; at standard temperature and pressure, one cubic meter of a typical hydrate stores about 180 standard cubic meters of methane gas.

2.1.2 FORMATION OF GAS HYDRATES

In contrast to hexagonal ice, other geometric forms are created when gas molecules and water molecules come into contact at high pressure and low temperature. In addition to acting as host molecules, the water molecules form cage lattices that can accommodate gas molecules as guests. Due to the presence of the gas molecules, these cage-like crystalline formations are less dense than crystalline water structures. The water molecules' hydrogen bonds and the Vander Waals forces that keep the gas and water molecules together stabilise the gas hydrate that is created.

The gas hydrate's stability is due to the Vander Waals force, which also makes it more stable than regular ice created by water. Gas hydrates come in a variety of forms, each distinguished by the form of its cage. According to Equation (1.0), natural gas is mostly made up of methane gas, which when completely burned produces energy, carbon dioxide, and water.

$$CH_4 + O_2 \Rightarrow CO_2 + H_2O + \text{Energy} \uparrow \quad (1.0)$$

There are various uses for the energy released during this process. Because more energy is released and less CO2 is created, natural gas is therefore more environmentally benign than other fossil fuels. Figure 1 depicts the lattice structure of gas hydrate in visual form. In the centre, the guest is methane gas (green), while the host is a water molecule (pink). Figure 2 illustrates how gas hydrate can be delivered or stored at equilibrium circumstances using either its saturation temperature or pressure. Hydrates are typically stable at the saturation temperature and pressure. A few variables impact the hydrate's temperature and saturation pressure.

Factors including the environment of the sediments that contain the hydrate deposits and the weight and expense of the materials for the hydrate storage vessel. Generally speaking, hydrates are stable at modest pressures and temperatures, unlike the conditions needed for LNG and CNG.

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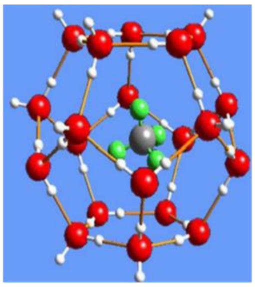

Figure 1: Cage-like structure of gas hydrate.

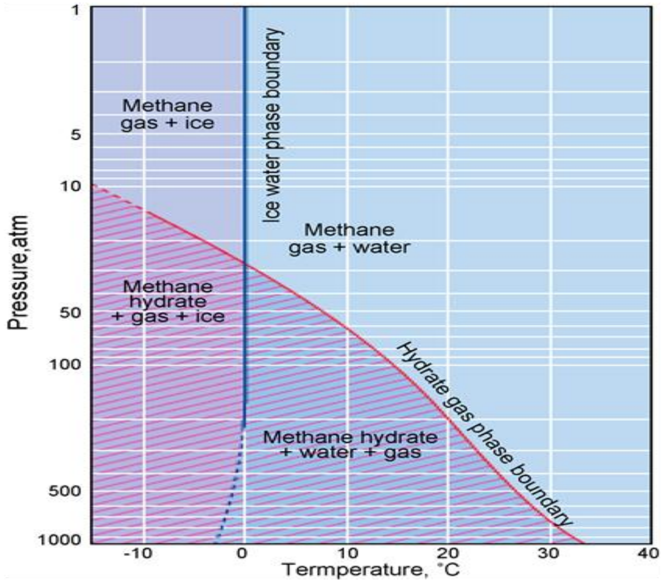

Figure 2: Phase diagram of gas hydrate stability.

2.2 PROPERTIES OF GAS HYDRATES

Figure 5 illustrates the three distinct crystal forms of gas hydrates: hexagonal structure (sH), cubic structure type I (sI), and cubic structure type II (sII). Methane, ethane, carbon dioxide, and hydrogen sulphide are examples of gas molecules with diameters between 4.2 and 6 that form type I (sI) gas hydrate. Type II (sII) gas hydrates are formed by other tiny molecules, such as nitrogen (d 4.2). Propane and iso-butane are examples of molecules with diameters of 6 d 7 that can also form sII gas hydrates. As indicated in Table 1, larger molecules with dimensions 7 d 9, such as iso-pentane and 2, 2-dimethylbutane, create sH gas hydrates when methane or nitrogen are present.

The slow cooling of gas and oil in pipelines or the quick cooling brought on by depressurising across the valves connected with the pipeline or distribution systems are the two main causes of flow assurance issues produced by gas hydrates. According to recent research on gas hydrate, hydrate formation in petrochemical operations and oil and gas pipelines is primarily influenced by three factors:

1) the presence of gas and water components

2) low temperatures, and

3) high pressures.

High fluid velocities, agitation, pressure, pulsations or any source of fluid turbulence, and the presence of CO2 and H2S are examples of secondary influencing factors that promote the development of hydrates.

Exploration and production of these massive methane gas reserves depend on an understanding of gas hydrate features. Some of the characteristics of the marine sediments are greatly influenced by the presence of hydrate. Field measurements and downhole records can be used to detect and capitalise on this.

S/N	Properties (Unit Cell)	Ice	Structure I (sI)	Structure II (sII)
1	Water molecules number	4	46	136
2	Lattice parameters at 273 K, nm	a = 0.452, c = 0.736	1.20	1.73
3	Dielectric constant at 273 K	94	~58	58
4	Water diffusion correlation time (µsec)	220	240	25
5	Water diffusion activation energy (kJ/m)	58.1	50	50
6	Shear Velocity (Vs), m/s	1949	1963.6	2001.1

7	Compressional Velocity (Vp), m/s	3870.1	3778.0	3821.8
8	Refractive index, 638 nm, −3˚C	1.3082	1.3460	1.350
9	Density, kg/m3	916	912	940
10	Poisson’s Ratio	0.33	~0.33	~0.33
11	Bulk Modulus (272 K)	8.8	5.6	-
12	Shear Modulus (272 K)	3.9	2.4	-
13	Velocity Ratio (comp./shear)	1.99	1.92	1.91
14	Linear thermal expn., K−1 (200 K)	56 × 10−6	77 × 10−6	52 × 10−6
15	Heat capacity, J/kg-K	3800	3300	3600
16	Thermal conductivity, W/m-K (263 K)	2.23	0.49 ± 0.02	0.51 ± 0.02

Table 1: Properties of Ice, structures I and II gas hydrates

2.3 CONDITIONS IN NIGER DELTA FIELDS THAT LEAD TO HYDRATE FORMATION.

The Niger Delta is vulnerable to hydrate formation for a number of reasons:
depth Production: Since many fields are located in depth (>1000m), where bottom temperatures are low (~4°C), the risks of hydrates are raised.

- High Pressure Pipelines: The high pressures at which gas pipelines operate—often surpassing 1000 psi—allow for the production of hydrate.
- High Water Content: The related gas generation and water condensation in pipes provide the free water needed for hydrates.
- Long Subsea Tiebacks: In certain fields, long-distance pipes (>50km) extend the cooling time for fluids, which raises the possibility of hydrates.

The following are the conditions that lead to hydrate formation in the Niger Delta

1. **Low temperature and high pressure**: The Niger Delta's seaward and deepwater environments have high seabed temperatures and tall weights, which promote hydrate organisation. While higher temperatures facilitate the arrangement of hydrate diamonds, high pressure forces water and gas particles into close proximity.

2. **Free Water and Natural Gas**: Two essential elements for hydrate organisation are water and distinctive gas. The likelihood of hydrate arrangement is increased when produced gas or water condensation in pipelines is not sufficiently dried.

3. **Pipeline Flow Restrictions and Dead Legs**: Areas of stagnant or slowly flowing liquids, such dead legs, can cool down faster and promote hydrate arrangement. Blockages are often caused by hydrates that tend to build up near valves, twists, and variations in pipeline distance across.

4. **Pressure Drops Across Valves and Chokes**: Joule-Thomson cooling, which lowers the temperature beneath the hydrate arrangement edge, is caused by gas development across choke valves and weight control devices.

5. **Seasonal and Environmental Factors**: The surrounding temperature decreases during stormy seasons, increasing the likelihood of hydrate arrangement, especially in surface and shallow subsurface offices. Because to the often, frigid water temperatures, subsea pipelines are particularly helpless.

6. **Inadequate Use of Hydrate Inhibitors**: Hydrate arrangement may arise from inadequate infusion of chemical inhibitors such as methanol, monoethylene glycol (MEG), or active hydrate inhibitors. The situation may be made worse by operational problems such as shameful dosing or the requirement for checking.

7. **Long Pipeline Transport Distance**: Enough cooling time for hydrate arrangement is provided by extended pipeline networks from seaward to coastal handling offices. Hydrate

hazards are increased by gas transfer over extended distances without warming or chemical restriction.

2.4 INHIBITION TECHNIQUES

Hammer Schmidt's 1934 paper on the production of hydrates in gas pipelines marked the beginning of mitigating measures for gas hydrate formation. As can be shown in Figure 3, numerous scientists and researchers worldwide have conducted in-depth studies on gas hydrate inhibition approaches over time.

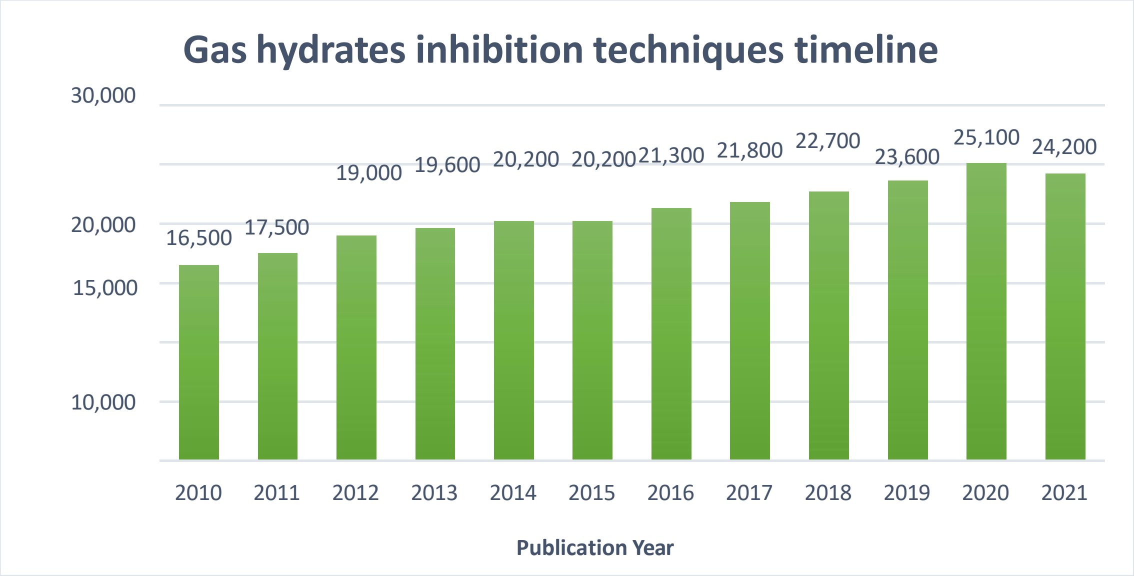

Figure 3: A short post-2010 gas hydrate inhibition techniques timeline representing the number of techniques proposed in hydrate inhibition-related academic publications (Source: Google Scholar).

Physical methods and chemical inhibitors are the two main groups into which gas hydrate inhibition approaches fall. Depressurisation and thermal heating are examples of the physical methods. Conversely, chemical inhibitor approaches use anti-agglomerates (AAs), kinetic hydrate inhibitors (KHI), and thermodynamic hydrate inhibitors (THI).

A number of methods have been put forth to prevent and lessen the generation of gas hydrates in pipelines. Physical procedures and chemical approaches are the two main groups into which these techniques fall.

Depressurisation, heating, and dehydration are examples of physical techniques. Conversely, the chemical approaches involve the use of additives such anti-agglomerates (AA), kinetic inhibitors (KHI), and thermodynamic inhibitors (THI). Every technique has pros and cons of its own.

Returning to the Niger Delta fields, Niger Delta operators employ a mix of mechanical, thermal, and chemical techniques to mitigate the dangers involved.

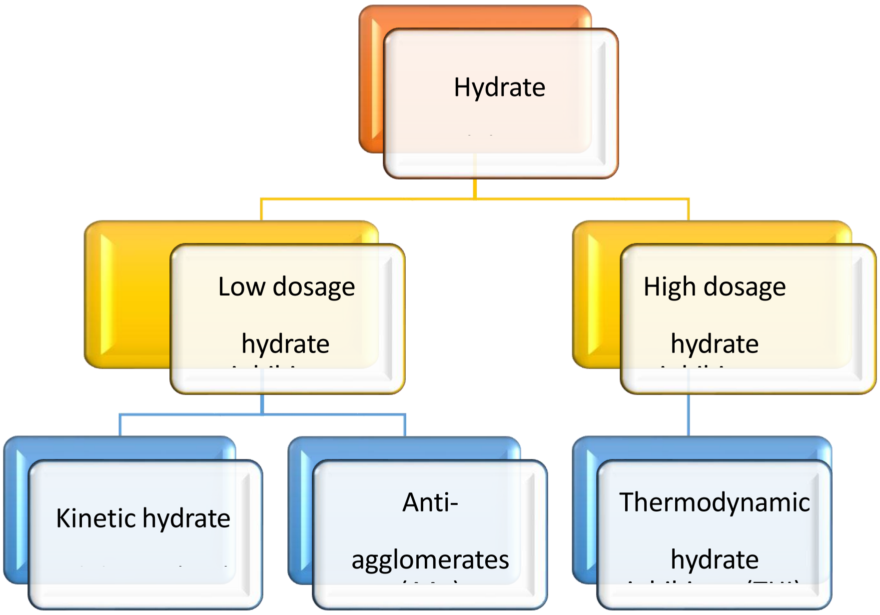

Figure 4: Hydrate inhibitors classification

2.4.1 THERMODYNAMIC HYDRATE INHIBITION IN THE NIGER DELTA

Thermodynamic inhibitors are commonly used by operators in the Niger Delta to change the hydrate equilibrium and avoid bottlenecks.

(A) Injection of Methanol

The injection of methanol is effective in preventing hydrate formation in both onshore and offshore gas pipelines, particularly in colder temperatures. This method is especially useful for short-term inhibition, such as during unforeseen shutdowns or startup procedures. Niger Delta fields face several challenges, including high prices due to the massive amounts needed, as well as environmental issues. Nigerian environmental restrictions limit the disposal of methanol, and additionally, methanol tends to vaporize in natural gas, which reduces its effectiveness.

- **(B) Injection of monoethylene glycol (MEG)**

Injection of monoethylene glycol (MEG) is the preferred method for long-distance and deepwater gas pipelines. MEG is more effective than methanol due to its lower volatility and simpler recovery. Its suitability for deepwater conditions makes it the preferred choice for fields such as Bonga, Agbami, and Egina.

MEG Regeneration Difficulties lead to increased chemical expenses in certain facilities due to the lack of MEG regeneration units. Additionally, scaling problems occur in MEG recovery systems, caused by formation water with high salt content, resulting in deposits.

Best Practices for the Industry

To effectively recover and reuse MEG, MEG Regeneration Units (MRUs) are currently integrated into sizable offshore FPSOs (Floating Production Storage and Offloading units).

2.4.2 KINETIC INHIBITION STRATEGIES IN THE NIGER DELTA

Some operators utilise Kinetic Hydrate Inhibitors (KHIs) and Anti-Agglomerants (AAs) to postpone hydrate development because thermodynamic inhibitors are expensive.

(a) Kinetic Hydrate Inhibitors (KHIs)

Kinetic Hydrate Inhibitors (KHIs) are used in areas with moderate subcooling, typically in temperatures between 4 and 6 degrees Celsius below the hydrate formation point. They are utilized at low concentrations, ranging from 0.1 to 2.0 weight percent, making them more economical than Methanol or MEG.

However, KHIs face challenges in Niger Delta Fields, where they are less effective in deepwater environments with strong subcooling exceeding 10°C. Furthermore, there are limited KHI formulations available that are suitable for the high salinity water found in the Niger Delta. Anti-Agglomerants (AAs) are commonly employed in oil-dominated areas, where they keep hydrates disseminated in the oil phase. This allows for continuous flow and prevents massive hydrate obstructions. AAs are often used in areas with an abundance of oil, such as Erha, Usan, and Bonga.

However, AAs are not suitable for gas-dominated pipelines, as hydrates cannot be suspended in gas. Additionally, AAs require specific oil-to-water ratios to function properly, which can be a challenge in certain field conditions.

2.4.3 PASSIVE & MECHANICAL HYDRATE PREVENTION IN THE NIGER DELTA

(a) Pipeline Insulation & Heating

Pipeline Insulation and Heating are used in deepwater fields to maintain fluid temperature above hydrate formation levels. Pipe-in-Pipe (PIP) insulation is a technique that minimizes heat loss during transportation, helping to prevent hydrate formation.

However, there are challenges associated with using pipeline insulation and heating in Niger Delta Fields. One major issue is that insulated pipes are expensive, making them inaccessible to smaller fields. Additionally, insulated pipes are ineffective during shutdowns, as the fluids gradually cool to seabed temperature, allowing hydrates to form.

Industry Best Practice: Industry Best Practice involves using innovative methods to prevent hydrate formation during shutdowns. Some operators maintain warm pipelines by utilizing Direct Electrical Heating (DEH), which helps to prevent hydrate formation. For example, the Egina FPSO features a heated flowline system specifically designed to prevent hydrate formation.

(b) Pressure Management Techniques

Pressure Management Techniques involve lowering pipeline pressure below hydrate stability thresholds to avoid clogs. This method is often applied in combination with chemical inhibition to improve flow conditions and prevent hydrate formation.

Challenges in Niger Delta Fields:

Challenges in Niger Delta Fields include the risk of hydrate formation if pressure drops are not properly controlled. Additionally, installing pressure management systems can be particularly challenging in long-distance underwater pipes that lack high-pressure boost stations.

(c) Pipeline Pigging & Water Removal

Pipeline Pigging and Water Removal involve frequent pigging operations to remove free water, which can promote hydrate formation. This method is mainly utilized in shallow-water and onshore fields where access to pig launchers is readily available.

Challenges in Niger Delta Fields:

Challenges in Niger Delta Fields include the difficulty of pigging deepwater pipelines due to long tiebacks. Additionally, if inhibitors are not used, hydrate production can still occur between pigging cycles, posing a significant risk.

5. Hybrid Approach for Niger Delta Flow Assurance

Operators combine multiple techniques for cost-effective hydrate prevention.

Example Hybrid Strategies in Niger Delta Fields:

Field	**Hydrate Inhibition Strategy**
Egina FPSO (TotalEnergies)	MEG injection + Insulated Pipelines + DEH
Bonga (Shell Nigeria)	MEG Injection + Regular Pigging
Erha (ExxonMobil)	Anti-Agglomerants + Pipeline Insulation
Agbami (Chevron)	Kinetic Hydrate Inhibitors + Pressure Control

Table 2: Hybrid Strategies in Niger Delta Fields

Best Practice: To cut chemical expenses, many operators employ MEG injection as the main technique and KHIs/AAs as secondary inhibitors.

2.5 FLOW ASSURANCE SOLUTIONS

A vital component of hydrocarbon production is flow assurance, which makes sure that gas and oil are transported from reservoirs to processing plants steadily and effectively. With an emphasis on the Niger Delta fields, this study assesses industry best practices for preserving continuous hydrocarbon flow. The study examines important issues such pipeline corrosion, hydrate formation, asphaltene precipitation, and wax deposition while evaluating successful mitigation techniques used locally.

One of the world's most productive areas for gas and oil production is the Niger Delta. However, there are major obstacles to flow assurance because of the complicated geological and environmental circumstances. With a focus on sustainable and economical tactics, this study looks at industry norms and solutions designed to the particular circumstances of the Niger Delta sectors.

2. 5.1 FLOW ASSURANCE CHALLENGES IN NIGER DELTA FIELDS

A. **Wax Deposition**

Wax Deposition is a significant issue in pipelines transporting crude oil with high paraffinic content. When the temperature drops, wax crystallization occurs, leading to wax buildup that restricts flow and increases pressure drop in pipelines.

Hydrate Formation

Hydrate Formation is a major concern in gas pipelines, as it can lead to hydrogen blockages and result in significant production shutdowns. The presence of water and cold temperatures creates an environment that encourages gas hydrate formation, posing a substantial risk to pipeline operations.

B. Asphaltene Precipitation : The dynamics of flow are impacted by asphaltene aggregation caused by unstable crude oil compositions.

C. Corrosion and Scale Deposition : Corrosion and Scale Deposition are significant concerns in pipeline operations. The presence of high CO2 and H2S levels accelerates pipeline corrosion, while the accumulation of mineral scales further decreases pipeline efficiency..

2.5.2 INDUSTRY BEST PRACTICES FOR FLOW ASSURANCE

Thermal Management Strategies

Thermal Management Strategies involve using various techniques to maintain optimal flow temperatures in pipelines. Insulated pipelines and electric heating methods are employed to keep the flow temperature above the Wax Appearance Temperature (WAT), preventing wax deposition. Additionally, both active and passive heating techniques are utilized to prevent hydrate formation.

Chemical Inhibition Techniques

Chemical Inhibition Techniques play a crucial role in maintaining pipeline flow efficiency and preventing various forms of deposition. Dispersants and wax inhibitors are used for efficient wax management, while thermodynamic and kinetic hydrate inhibitors are employed to prevent clogs caused by hydrate formation. Additionally, asphaltene inhibitors are used to preserve the stability of crude oil, and corrosion inhibitors are utilized to mitigate material deterioration.

echanical and Operational Strategies

Mechanical and Operational Strategies are essential for maintaining pipeline integrity and preventing flow assurance issues. Pigging procedures are employed to remove scale and wax deposits, while depressurization of the flowline is used to reduce hydrate hazards. Furthermore, intelligent pigging and routine monitoring are utilized for early corrosion detection, enabling proactive maintenance and minimizing potential damage.

Digital and Predictive Analytics in Flow Assurance

Digital and Predictive Analytics play a vital role in Flow Assurance by leveraging advanced technologies to optimize pipeline operations. The use of IoT technology and smart sensors enables real-time monitoring, providing valuable insights into pipeline conditions. Additionally, predictive maintenance powered by Artificial Intelligence (AI) allows for the early identification of potential flow assurance threats, enabling proactive measures to prevent disruptions and ensure uninterrupted flow.

2.6 OTHER WORKS DONE

1. Majeda Khraisheh et al (2022) conducted a study called “Towards Gas Hydrate-Free Pipelines: A Comprehensive Review of Gas Hydrate Inhibition Techniques” a concise conclusion which highlights the critical issue of gas hydrate formation in pipelines, which poses significant challenges to the oil and gas industry due to potential operational hazards and economic losses. It reviews various inhibition techniques, categorizing them into

physical methods, such as depressurization and heating, and chemical methods, including thermodynamic and kinetic inhibitors. The effectiveness of these methods varies, with some being more suitable for specific conditions than others. The research underscores the importance of continued innovation in hydrate management strategies to ensure safe and efficient gas transport, ultimately contributing to the sustainability of energy resources.

The research by Nurul Hasan et al (2014) titled "Gas Hydrate Formation Condition Review on Experimental and Modeling Approaches" provides an overview of research on gas hydrates, focusing on their formation conditions and the methodologies used to study them. It highlights the historical significance of gas hydrates in the oil and gas industry and notes a significant increase in related publications, indicating growing interest in their applications for energy recovery, gas separation, and storage. The review emphasizes the importance of understanding the thermodynamic conditions for hydrate formation, with a substantial amount of research dedicated to experimental investigations. It also discusses the development of predictive models, particularly the use of artificial neural networks (ANN) for estimating hydrate equilibrium conditions. The authors identify several areas needing further research, including the kinetics of methane hydrate formation, the effects of specific gas mixtures, and the impact of inhibitors. The document concludes by stressing the necessity for accurate experimental data to enhance predictive modeling and advance the practical applications of gas hydrates.

2.6 RESEARCH GAP

1. The following are the research gaps for the study "Towards Gas Hydrate-Free Pipelines" conducted by Majeda Khraisheh et al. in 2022.

Despite the effectiveness of chemical inhibitors, there are worries about their potential effects on the environment, especially when it comes to high dosage thermodynamic hydrate inhibitors (THIs) such alcohols. Research might concentrate on creating greener substitutes or strategies to lessen the environmental hazards connected to the inhibitors that are now in use.

Dual-Function Inhibitors' Effectiveness: Although dual-function hydrate inhibitors such amino acids and nanoparticles are mentioned in the paper, there isn't much information on how effective they are in comparison to conventional inhibitors. Their performance under different circumstances and possible benefits might be investigated in further detail.

Water Pollution from Kinetic Hydrate Inhibitors (KHIs): Because KHIs are soluble, its use raises issues regarding water pollution. Researching techniques for efficiently removing KHIs from water, including the application of nanofiltration membranes, may prove to be beneficial.

Long-Term Performance of Inhibitors: Studies on the stability and long-term efficacy of different hydrate inhibitors under various operating circumstances, such as pressures and temperatures, are necessary.

Cost-Effectiveness of Inhibition Techniques: Industry stakeholders may get information from examining the financial effects of various inhibition strategies, such as the cost-benefit comparison of modern inhibitors with conventional techniques.

Field Testing and Practical Uses: Although lab research yields useful information, new inhibitors and methods have not yet been thoroughly tested in the field.

The performance of inhibitors under real-world pipeline circumstances and practical applications could be the main topics of future research.

Comprehensive Modelling of Hydrate Formation: The comprehension and control of gas hydrates in pipelines may be improved by using increasingly complex models that precisely forecast hydrate formation and inhibition under diverse circumstances. These gaps offer chances for additional study that may result in better techniques for controlling the production of gas hydrates in the oil and gas sector.

2. The paper "Gas Hydrate Formation Condition Review on Experimental and Modelling Approaches" by Nurul Hasan et al. (2014) identifies a number of research gaps in the field of gas hydrates, which are essential for expanding our knowledge and useful applications of these materials. The following are the main research gaps identified:

Kinetics and Diffusion in Porous Media: Since kinetics and diffusion can have a major impact on the formation process, experimental research is required to determine the factors influencing methane hydrate formation in porous media.

The clathrate hydrate mechanism for pre-combustion carbon dioxide capture is not well understood, particularly with regard to experiments involving hydrate dissociation and production via thermal stimulation.

2. **Modelling Improvements**: To account for a wider range of factors influencing hydrate formation, current prediction models—including neural network approaches—need to be improved. This is especially important for samples that contain inhibitors, electrolytes, or contaminants, as well as heavier gas components.

Impact of Promoters and Inhibitors: Since current models might not sufficiently take these parameters into account, more research is required to precisely evaluate the effects of promoters and inhibitors on hydrate formation.

Comprehensive Reviews: To assist researchers in choosing the best methodology for their studies, there aren't many thorough reviews that summarise the large body of literature on hydrate formation circumstances. Filling up these gaps would improve knowledge of petrol hydrates and their uses, which would increase their usefulness across a range of sectors.

CHAPTER 3

METHODOLOGY

3.1 PREDICTING HYDRATE FORMATION.

3.1.1 RATE OF HYDRATE CALCULATION.

To create the most effective plan for handling hydrate formation, it is essential to have a thorough understanding of the circumstances that result in the initial hydrate development. Phase equilibria can be predicted by commercial software packages, but understanding the basics is required to evaluate the computer results. Nucleation and expansion are the two primary phases in the time-dependent process of hydrate formation. In addition to helping to understand the plug conditions in the gas pipeline and other equipment, the dynamics of gas hydrate production and gas hydrate crystal accumulation are crucial elements that direct the various parameters for mass production of gas hydrates (Mannel, D. and Puckett, D. (2008)). Equation (3.0) can be used to determine the rate at which hydrates form, and the first method is advantageous for storing natural gas as hydrate, while the latter is advantageous for avoiding hydrate blockages during the offshore processing, production, and transportation of oil and gas.

$$R = 4\pi K \mu_2 \left(f - f_{eq} \right)$$

where f is the gas's fugacity under the given conditions, f stands for the gas's fugacity at equilibrium conditions, R is the rate of hydrate formation, and K is the empirical kinetic parameter that Englezos established in 1987. K also represents the second moment of the particle size distribution for the hydrate crystals. The CNGA equation of state for natural gas mixtures, where the compressibility factor (Z) is provided in equation (3.1), can be used to determine the necessary fugacities.

$$Z = \frac{1}{1 + \frac{344400 \times P \times 10^{1.785SG}}{T^{3.825}}}$$

T stands for temperature (R), P for pressure (psig), and SG for the gas's specific gravity in relation to air. The following formulas can be used to calculate the particle size distribution's second moment (Englezos et al. 1987):

$$\mu_2 = 4r^2 \mu_o$$

$$\mu_o = \frac{3M\left(N - N_{eq}\right)}{4\pi V \rho r^3}$$

V is the volume of water that corresponds to the indicated number of moles of gas, is the density of the hydrate, r is the average particle radius of the hydrate crystals, M is the molecular mass of the hydrate, N is the number of moles of gas in solution under the specified conditions, and is the number of moles of gas present at equilibrium conditions.

Once determined, this rate can be used to determine the best inhibition and flow assurance techniques to use.

3.1.2 PREDICTING OF RATE VOLUME FRACTION OF GAS HYDRATE USING MACHINE LEARNING MODELS

As was previously indicated, rate fractions can also be found using computer software. Schlumberger's OLGA program will be used for the simulation in this study.

In this study, Schlumberger's Multiphase dynamic flow software, OLGA, was used to model an offshore natural gas production system consisting of a wellbore, wellhead, flowline, riser, and topside for an operational gas platform located in the offshore Niger Delta region (Schlumberger, 2022).

Multiphase fluids are transported by the system during offshore natural gas production. The offshore system includes a 160-meter wellhead pipe, a 3200-meter flowline that extends to a 400-meter vertical riser, a 120-meter horizontal topside pipe, and a well tubing pipeline with a 2800-meter true vertical depth.

The choke controls the entire production. The ambient temperatures at the well's entrance and exit are 52 °C and 4.5 °C, respectively. The flowline and riser both keep the temperature at 4.5 °C. The reservoir's temperature is 52 °C and its pressure is 210 bar. The temperature of the seawater is 4.5 °C. The internal and external walls have respective heat transmission coefficients of 10 W/m2K and 500 W/m2K. The pipeline's roughness is 0.000045 m and its internal diameter is 0.3048 m. There are 22 sections in the pipeline. In Figure 5, the model's schematic is shown.

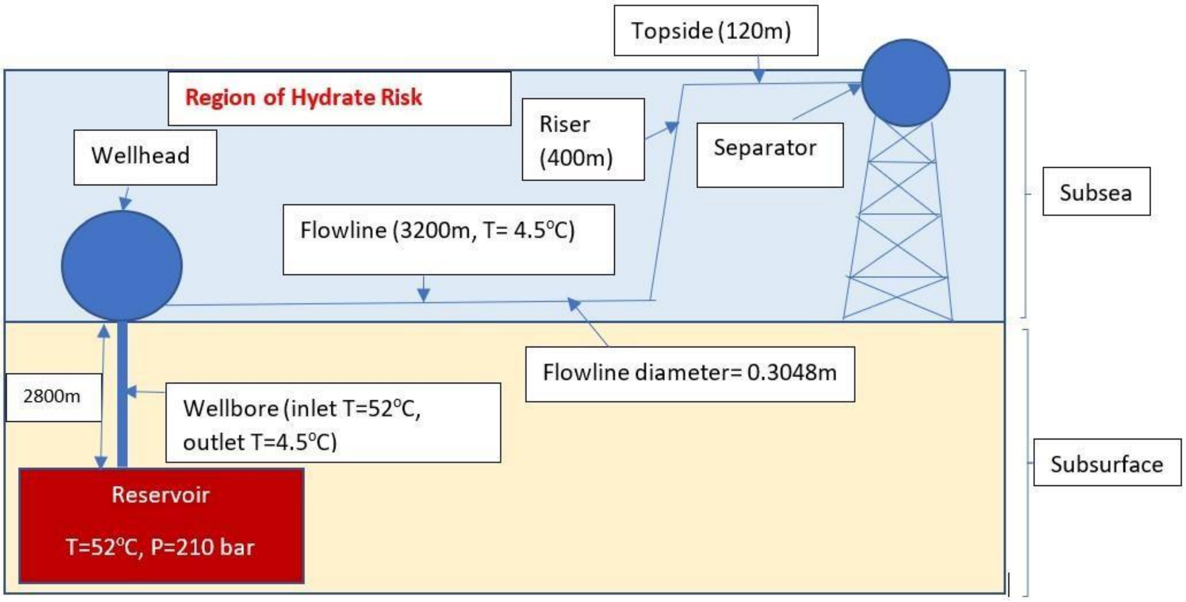

Figure 5: Schematic of the modelled offshore gas system

Constituents	**Amount (moles)**

Nitrogen	0.72
Carbon Dioxide	1.31
Methane	85.91
Ethane	6.74
Propane	3.12
N-Butane	0.90
I-Butane	0.71
N-Pentane	0.59
Water	10

Table 3: Constituents of fluid

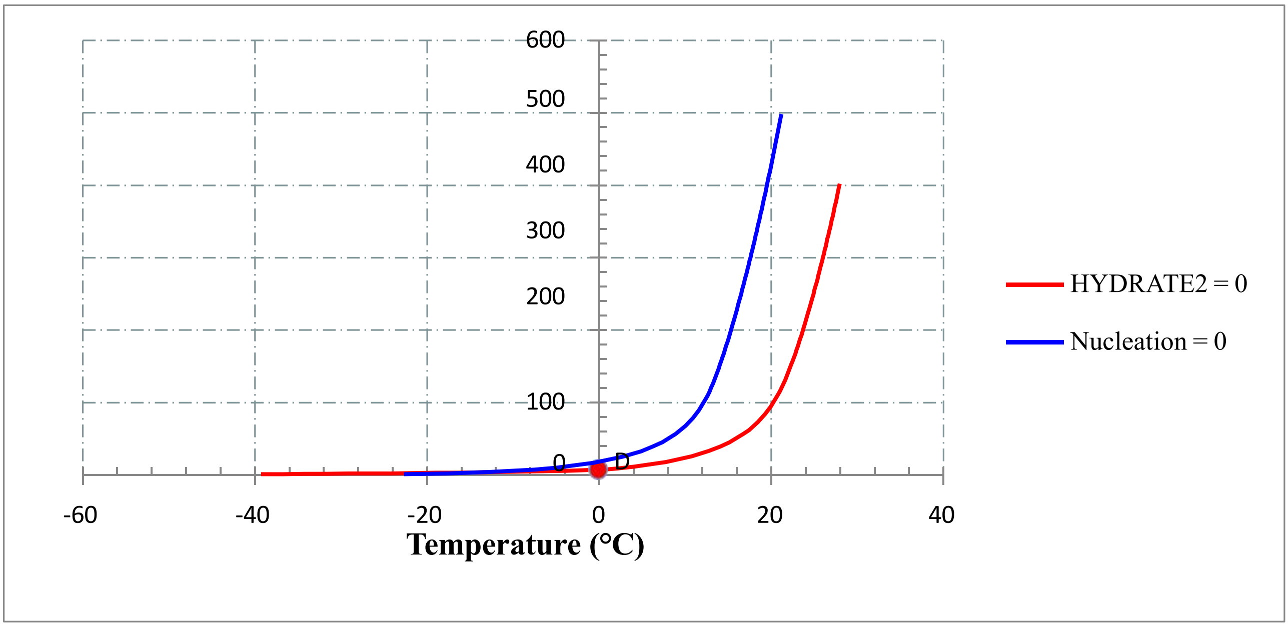

Figure 6: Equilibrium hydrate curves

The fluid descended to a subcooling temperature as it passed through the flowline, which was lower than the hydrate equilibrium temperature. The system's temperature quickly reached the hydrate formation temperature following the subcooling phase, and the flowline's heat dissipation prevented additional hydrate production.

The fluid temperature rises as a result of the heat emitted during the exothermic process of hydrate formation. At about 750 meters, the fluid temperature dropped below the threshold for hydrate formation, and hydrate started to develop.

The amount of hydrate in the pipeline increased dramatically at a distance of 2971 meters from the wellhead, reaching a maximum fraction of 0.54 at 3022 meters. This suggests that gas hydrates occupied 54% of the flow stream.

The pace of hydrate formation began to slow down about 3022 meters. The pressure kept dropping, but the temperature stayed constant. At about 3600 meters, the hydrate volume finally decreased to zero as the force that drove hydrate production diminished. Figure 6 shows that the simulation cycle lasted five hours in total.

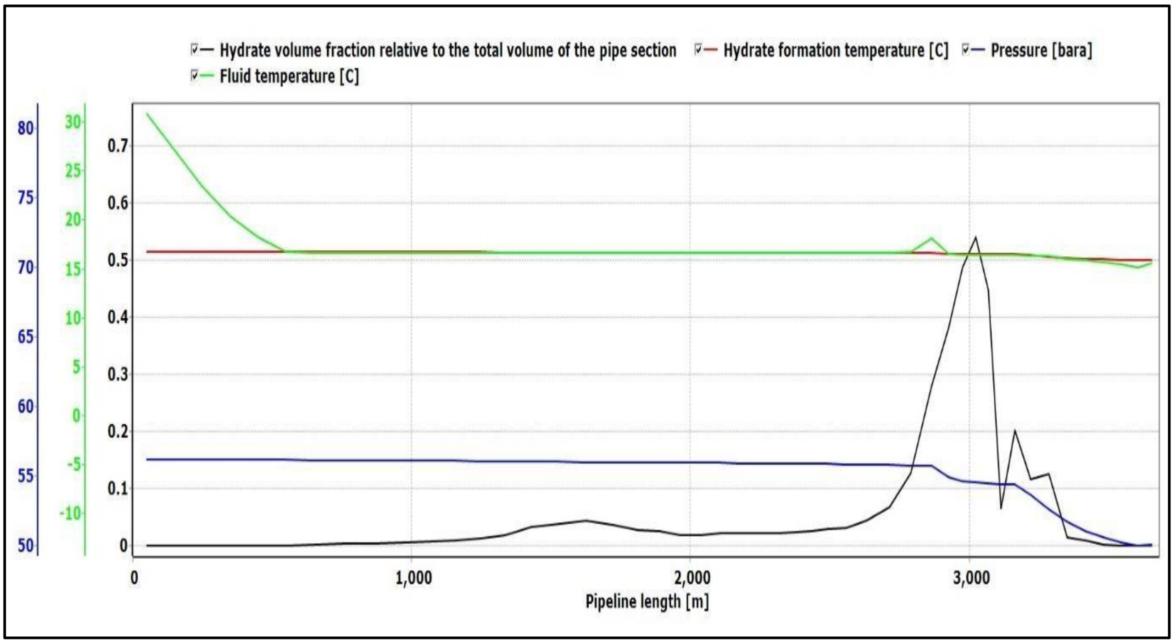

Figure 7: Simulation of the offshore gas system after 5 hours

The volume proportion of hydrate found in the simulation data was estimated using four models. The models contained input variables such pipeline length, pressure, pressure drop, hydrate formation temperature, hydrate formation rate, fluid temperature, hydrate formation pressure, water cut, mixture velocity, and hydrate formation temperature. The models' results showed the volume percentage of hydrate in the pipeline. Figures 8 and 9 show the parameters used to create the linear regression model and the other three models, respectively. Figure 7 shows the results of the cross-validation, which compared the actual volume fraction of hydrate derived from the simulation with the anticipated volume % of hydrate from the models.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 LINEAR REGRESSION MODEL

As stated earlier, 4 models were used for the prediction of rate fraction of hydrate formation. The first model used is the Linear Regression model. This model simulates a linear relationship in one response variable and an explanatory variable (Hackeling, 2014) that provides an interpretation of the nature of the dependence of the Volume fraction of hydrate on the independent variables.

A positive correlation between the Volume fraction of hydrate and pipeline length, hydrate formation rate, pressure, and fluid temperature is obtained, whereas a negative correlation is obtained between the Volume fraction of hydrate and Mixture velocity. The signs of the regression equation help in the interpretation of the type of relationship between the dependent and independent variables.

Certain parameters are employed by Linear regression model to predict volume fraction of hydrate and they are shown in figure 8:

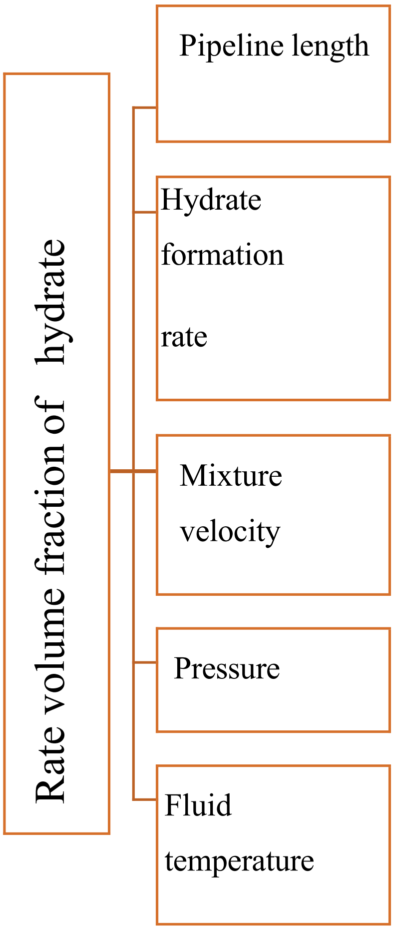

Figure 8: Parameters employed by Linear regression model to predict volume fraction of hydrate

Equation 4.1 makes it easier to comprehend how the volume percentage of hydrate can rise with increasing pipeline length, hydrate formation rate, pressure, and fluid temperature, while it can fall with decreasing mixture velocity. Additionally, with a correlation coefficient of 0.9307, the linear regression model's prediction accuracy was excellent.

Formula for calculating Linear progression is given as :

$$0.0001 * \mathit{Pipeline\ length} + 0.0442 * \mathit{Hydrate\ formation\ rate} - 0.5472$$

$$* \mathit{Mixture\ velocity} + 0.011 * \mathit{Pressure} + 0.0049 * \mathit{Fluid\ temperature} + 0.1375\ 9$$

(equation 4.1)

The regression results are presented in the Table 4 below :

Predictor	**Coefficients**	**Standard Errors**	**t**	**p-value (significance)**
Intercept	0.13745	0.32581	0.422	0.675
Pipeline length [m]	7.15E-05	1.01E-05	7.08	< .001
Hydrate formation rate per unit volume [kg/m^3-s]	0.04415	0.01782	2.477	0.017
Mixture velocity (m/s)	-0.54724	0.03187	-17.171	< .001
Pressure (bar)	0.01097	0.00501	2.191	0.034
Fluid temperature [°C]	0.0049	0.00275	1.781	0.082

Table 4: Results from the linear regression model to forecast volume fraction of hydrate

Due to the higher t-statistic and lower P-values used by Srivastava (2018), the regression results in Table 2 show that mixture velocity, pipeline length, hydrate formation rate, pressure, and fluid temperature are statistically significant.

4.2 MULTI LAYER PERCEPTRON NEUTRAL LAYER NETWORK

The multilayer perceptron is another model that is employed. Using its capacity to manage intricate nonlinear relationships between input variables such as pressure, temperature, and gas composition, this kind of artificial neutral network is utilised to forecast the volume percentage of gas hydrates, enabling a more precise prediction.

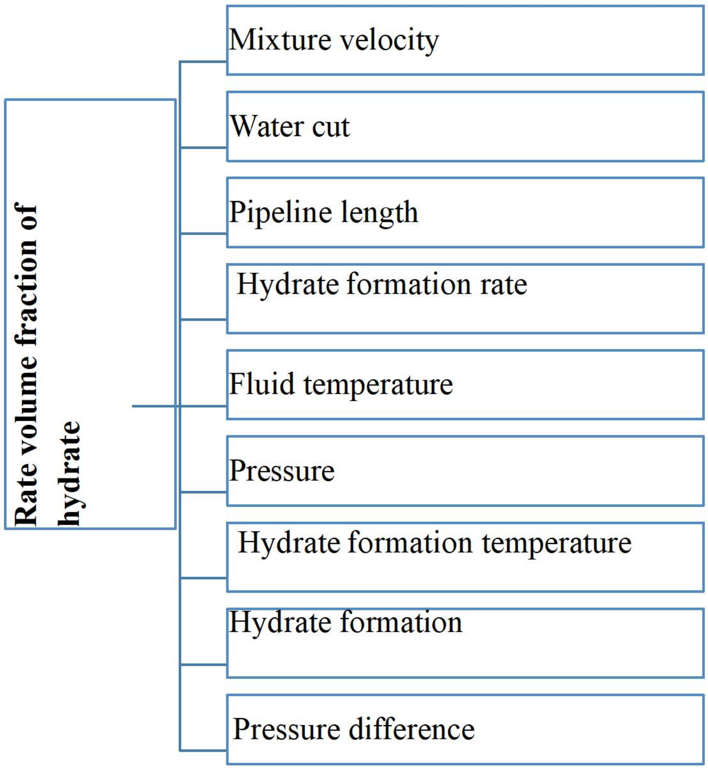

Figure 9: Parameters employed by the other three models to predict the volume fraction of hydrate

.3 RANDOM FOREST

Using random subsets of data and characteristics, Random Forest is an ensemble machine learning approach that mixes several decision trees to increase prediction accuracy for classification and regression problems.

4.4 DECISION TREE

A supervised learning method for classification and regression problems is decision tree learning. By dividing the data into subsets according to the most important characteristics, a model that forecasts the value of a target variable based on several input variables is created.

Actual	**Linear regression**	**Multi-Layer Perceptron**	**Random Forest**	**Decision Tree**
0	-0.016	-0.04	0.004	0.078
0.025	0.035	0.019	0.027	0.078
0	-0.013	-0.035	0.004	0.078
0.023	0.035	0.036	0.025	0.078
0.019	0.036	0.01	0.045	0.078
0.039	0.044	0.047	0.036	0.036
0.032	0.036	0.051	0.036	0.036
0.067	0.036	0.063	0.073	0.036
0.005	-0.002	0.002	0.003	0.036
0	-0.016	-0.008	0.003	0.036
0.019	0.037	0.01	0.042	0.066
0.014	0.021	0.005	0.015	0.066
0	-0.006	0.029	0.031	0.066
0.009	0.015	0.004	0.008	0.066
0.54	0.436	0.474	0.363	0.066
0.203	0.086	0.06	0.049	0.025
0.021	0.036	0.026	0.024	0.025
0.448	0.508	0.517	0.296	0.436
0.066	0.285	0.233	0.147	0.436
0.382	0.458	0.463	0.433	0.436
0.125	0.07	0.092	0.123	0.024
0.025	0.024	0.065	0.044	0.024
0.127	0.063	0.082	0.118	0.024
0	-0.013	0.016	0.002	0.024
0.029	0.025	0.067	0.041	0.024
0	-0.049	-0.002	0.003	0.03
0.036	0.046	0.008	0.026	0.03
0.043	0.049	0.006	0.028	0.03
0.022	0.034	0.026	0.025	0.03
0.002	0.001	-0.004	0.005	0.03

0.018	0.027	0.015	0.017	0.003
0.044	0.035	0.076	0.044	0.028
0.487	0.432	0.449	0.397	0.343
0.024	0.035	0.054	0.024	0.028
0.002	0.006	0.006	0.006	0.016
0	0.004	0.006	0.002	0.027
0.022	0.039	0.03	0.023	0.027
0.003	-0.007	0.001	0.002	0.027
0.007	0.01	0.002	0.007	0.027
0.028	0.037	0.028	0.03	0.027
0.002	0.007	-0.052	0.014	0.016
0.033	0.035	-0.013	0.029	0.039
0.116	0.141	0.276	0.114	0.152
0.014	0.053	0.04	0.059	0.152
0.28	0.175	0.203	0.129	0.19
0.001	0	-0.01	0.006	0.001
0.008	0.022	0.018	0.013	0.19
0.006	0.004	0.025	0.004	0.003

Table 5: Volume fraction of hydrate Predictions using four models

1. **Actual Values**: The true volume percentage of petrol hydrates is shown in this column and is used as the ground truth to assess how well the predictive models work.

2. **Model forecasts**: Each of the four models' forecasts are shown in the following columns:

- Linear Regression: A statistical technique that fits a linear equation to model the connection between a dependent variable and one or more independent variables.
- Multi-Layer Perceptron (MLP): One kind of artificial neural network that may capture intricate correlations in data is the MLP, which is made up of several layers of nodes (neurones).
- Random Forest: An ensemble learning technique that builds several decision trees during

training and returns the mean prediction for regression or the mode of the trees' categorisation predictions.

- Decision Tree: A model that makes use of a tree-like graph of choices and their potential outcomes, such as utility, resource costs, and chance event outcomes.

4.5 ANALYSIS OF PREDICTIONS

1. **Comparison of Predictions to Actual Values**:

The actual numbers are contrasted with the forecasts made by each model. We may evaluate each model's performance through this comparison.

If the projected value and the actual value were equal, the prediction would be perfect.

2. **Performance of Each Model:**

Linear Regression: There is a range of positive and negative values in the predictions made by this model, and some of the predictions differ greatly from the actual values. For example, the first prediction is -0.016, which is distant from the actual value of 0 and also negative. This suggests that the underlying relationship may not be adequately captured by the linear regression model.

Multi-Layer Perceptron (MLP): When compared to linear regression, the MLP predictions typically match the actual values. Significant deviations do still occur, though, as in the case of the predicted value of 0.474 and the actual value of 0.54. This implies that even though MLP is outperforming linear regression, it can still be improved.

Random Forest: Compared to the other models, the Random Forest model's predictions typically show a wider range of values and are more accurate. For instance, it makes a good guess of 0.363 for an actual value of 0.54. Compared to the first two models, this one appears to be better at capturing the data's variability.

Decision Tree: For a number of actual values, the Decision Tree model continuously forecasts the same value (0.078), demonstrating its lack of sensitivity to changes in the input data. This may indicate overfitting or a restriction in the model's capacity to extrapolate from the training set of data.

Summary of Findings

- **Overall Performance**: Out of the four models, the Random Forest model seems to perform the best because its forecasts are typically closer to the actual values. Although it is less reliable than Random Forest, the MLP likewise exhibits potential. While the Decision Tree model has predictions that are less variable, Linear Regression finds it difficult to adequately capture the link.
- **Model Selection**: Based on its results in this investigation, Random Forest would be the recommended model to use when estimating the volume fraction of petrol hydrates. To guarantee robustness and generalisability, more fine-tuning and validation would be required.
- **Future Considerations**: To enhance the models' performance, it could be helpful to investigate other models or hybrid approaches in addition to performing feature engineering or data pretreatment. Furthermore, a quantitative assessment of the models' performance could be obtained by utilising metrics like Mean Absolute Error (MAE) or Root Mean Squared Error (RMSE).

The table concludes by comparing various modelling techniques for gas hydrate volume fraction prediction and outlining the advantages and disadvantages of each.

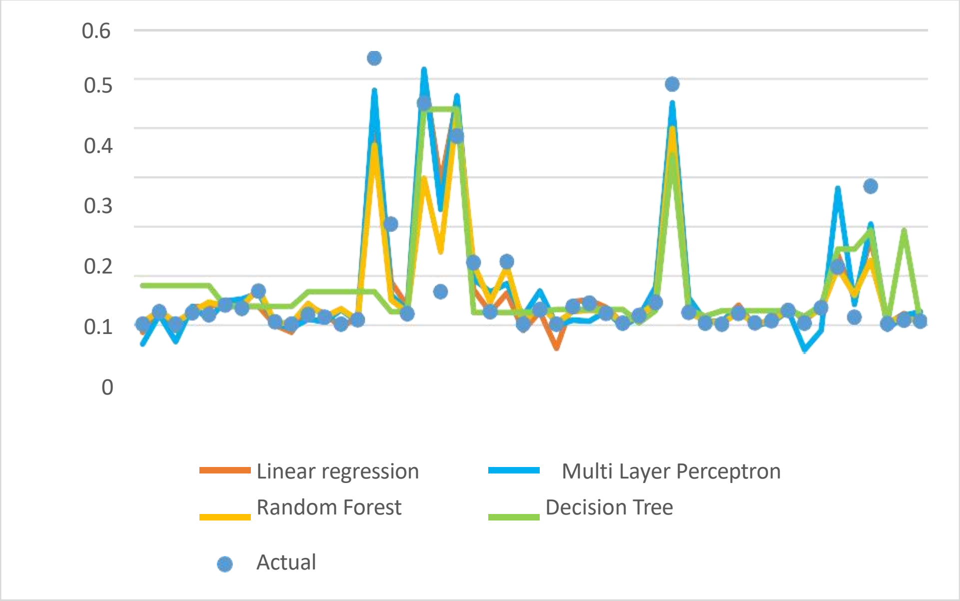

Figure 2: Predicted volume fraction of hydrate using the four model

Figure 11 presents a chart for the predicted and actual Volume fraction of hydrate values. It also implies that a linear model is capable of accurately forecasting the actual volume fraction of hydrate obtained in the simulation.

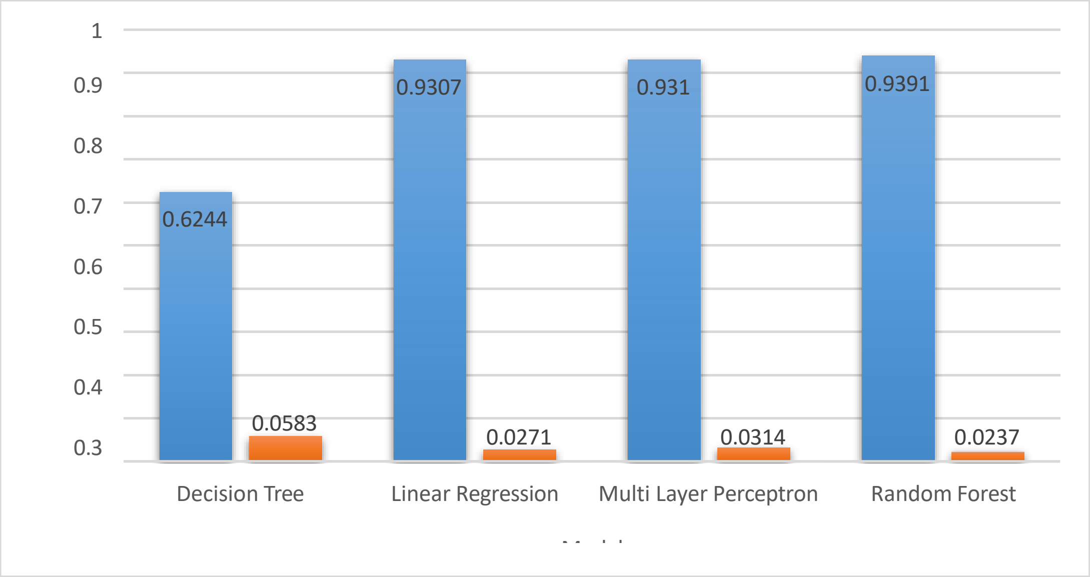

Figure 3: Accuracy of models' predictions

The aforementioned data indicates that while the Decision Tree model exhibits some predictive power, the other models under evaluation outperform it. Higher correlation coefficients and smaller mean absolute errors indicate that the Random Forest, Multi-Layer Perceptron, and Linear Regression models perform better in terms of prediction. The Random Forest model distinguishes itself from the others by obtaining the highest correlation coefficient and the lowest mean absolute error, indicating that it is better at identifying the underlying relationships in the data and producing precise predictions. Thus, the Random Forest model might be the best option for this specific regression problem of predicting the volume proportion of hydrates.

.This work used machine learning models and multiphase simulations to investigate the volume fraction of hydrates in an offshore gas system. With a peak volume percent of 0.54, simulations showed a significant danger of hydrate formation in the Niger Delta offshore gas flowlines, requiring management actions. With temperatures stable and pressures dropping, hydrate formation started at 750 m, peaked at 0.54 at 3022 m, and fell to zero by 3600 m. While Linear Regression provided superior interpretability, the Random Forest model had the highest accuracy (correlation coefficient of 0.9391, mean absolute error of 0.0271). Every ML model did well, but Random Forest came out on top. According to regression analysis, the hydrate volume percentage increases with longer pipeline lengths, greater hydrate formation rates, pressures, and fluid temperatures, but it decreases with higher mixture velocities.

Because of their precision and interpretability, Random Forest and Linear Regression are suggested for use in advanced hydration management strategies, enhancing operating efficiency and safety.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The use of machine learning algorithms to forecast the volume percentage of hydrate formation in offshore gas systems was well illustrated by this study. While Linear Regression offered important insights into the connections between input variables and hydrate production, the Random Forest model proved to be the most accurate and dependable. The results highlight how crucial it is to choose the right models depending on the particular needs of interpretability and accuracy. Operators can enhance operating safety and efficiency in offshore gas systems by utilising these models to apply sophisticated hydrate management strategies.

Important insights into the challenges of controlling hydrates in offshore gas systems, especially in the Niger Delta, are provided by the research on gas hydrate formation, inhibitory strategies, and flow assurance solutions. The Random Forest model was found to be the most accurate and dependable machine learning model used in the study to predict the volume fraction of hydrate formation. The importance of choosing the right prediction models based on operational settings' requirements for accuracy and interpretability is highlighted by this study.

One of the main conclusions is that hydrate formation starts at about 750 meters, peaks at 3022 meters, and stops at 3600 meters. To lessen the operational difficulties brought on by hydrate formation, this depth-related trend calls for focused management techniques in high-risk areas.

Additionally, it was discovered that hydrate amounts were greatly impacted by a number of operational factors, such as pipeline length, fluid temperature, pressure conditions, and the chemical environment. The risks of hydrate-related events in gas transport systems can be decreased by incorporating this knowledge into hydrate management strategies, which can improve operational safety and efficiency.

5.2 IMPLICATIONS FOR HYDRATE MANAGEMENT

The study's findings have significant implications for managing hydrate formation in offshore gas systems:

- **Hydrate Formation Trends**: The simulation results indicated that hydrate formation begins at **750 m**, peaks at **0.54** around **3022 m**, and drops to zero by **3600 m**. This trend highlights the need for targeted management measures in high-risk zones.
- **Key Influencing Factors**: Longer pipeline lengths, higher hydrate formation rates, increased pressures, and elevated fluid temperatures were found to increase hydrate volume fraction, while higher mixture velocities reduced it.
- **Model Recommendations**: The **Random Forest** model is recommended for its superior accuracy, while **Linear Regression** is recommended for its interpretability and ability to provide insights into variable relationships.

5.3 RECOMMENDATIONS FOR FUTURE WORK

The research on gas hydrate formation, inhibition strategies, and flow assurance solutions with an emphasis on Niger Delta fields yields a number of recommendations for the future. The following actions are advised in order to improve the models' accuracy and applicability even more:

1. **Use of sophisticated Modelling Techniques**: To improve hydrate formation forecasts, operators should use sophisticated modelling techniques including machine learning

algorithms. Making use of models such as Random Forest can yield precise insights that enable preemptive management actions.

2. **Dedicated hydration Management Strategies**: It is advised to create and put into practice customised hydration management plans that take into account individual operational and environmental circumstances, especially in regions that have been found to have a high risk of hydrate formation.
3. **Environmental Impact Assessments**: Perform in-depth analyses of how chemical inhibitors used to control hydrates affect the environment. Environmentally friendly substitutes that preserve efficacy while lowering ecological risks should be the main focus of research.
4. **Long-term Studies on Inhibitor Performance**: More research is required to determine the stability and long-term efficacy of different hydration inhibitors across a range of operational circumstances. To validate laboratory results, such research should incorporate field testing in the actual world.
5. **Economic Analysis of Inhibition Techniques**: It is advised to do a thorough cost-benefit analysis of the various hydration inhibition tactics. To guarantee cost-effective operations, industry stakeholders should compare the economic effects of advanced versus traditional approaches.
6. **Cooperation and Knowledge Sharing**: To stay up to date with developments in hydrate research and management techniques, stakeholders in the oil and gas sector, including as operators, researchers, and regulatory agencies, should promote cooperation and knowledge sharing.
7. **Future Research Directions**: It is necessary to do additional studies on the kinetics of hydrate formation and the effectiveness of dual-function inhibitors. Research on the

efficiency of more recent materials, like nanoparticles, in improving hydrate management may fall under this category.

The industry can enhance its approach to gas hydrate management by adopting these suggestions, guaranteeing increased operational effectiveness while reducing environmental effects and maintaining safety regulations.

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