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Assessment of Naphthalene Deposition in Crude Oil Pipelines and Its Impact on Flow Assurance

Engr. David Ackah (PhD)
Dasea Engineering & Construction Department
Center for Excellence Training & Consultancy Limited
ORCID: https://orcid.org/0000-0002-5709-4787
Email: drackah@ipmp.edu.gh / drdavidackah@gmail.com

**Correspondence: Ackah David, email: drackah@ipmp.edu.gh*

Abstract

Naphthalene deposition in crude oil pipelines has emerged as a significant flow assurance challenge, impairing pipeline efficiency, increasing operational costs, and threatening production continuity. This study assesses the formation, behaviour, and impact of naphthalene deposition in crude oil transportation systems using a combined experimental, field-data analysis, and computational simulation approach. A laboratory flow loop was used to replicate pipeline operating conditions, while field data from an operational crude oil pipeline provided real-world performance indicators. Computational fluid dynamics (CFD) simulations were further employed to examine deposition patterns under varying thermal and hydrodynamic conditions.

The results show that naphthalene deposition is strongly temperature-dependent, with an onset between 27°C and 29°C and rapid crystallisation below 25°C. Deposition rates increase significantly with decreasing temperature and decreasing flow velocity, while higher flow velocities reduce deposition due to increased shear stress at the pipe wall. Field data indicate that pressure drop increases from 6.5 bar under clean conditions to 14.2 bar under severe deposition, confirming substantial flow restriction. CFD results further reveal that deposition is concentrated in low-velocity and thermally unstable regions of the pipeline system.

The study concludes that naphthalene deposition significantly degrades flow assurance by increasing hydraulic resistance and reducing pipeline efficiency. It also highlights the need to integrate aromatic hydrocarbon deposition mechanisms into existing flow assurance models, which are predominantly focused on wax and asphaltene behaviour. The findings provide valuable insights for improving pipeline design, operational strategies, and mitigation techniques in crude oil transportation systems.

Keywords: *Naphthalene deposition; crude oil pipelines; flow assurance; aromatic hydrocarbons; crystallisation; pipeline fouling; pressure drop; computational fluid dynamics; solid deposition; petroleum transportation.*

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1.0 INTRODUCTION

The transportation of crude oil through pipelines remains one of the most efficient and economically viable methods for moving hydrocarbons from production fields to refineries and export terminals. However, maintaining an uninterrupted flow within pipelines remains a major operational challenge due to flow assurance issues arising from the deposition of organic and inorganic solids. Among these challenges, the deposition of wax, asphaltenes, hydrates, scales, and aromatic compounds has attracted significant attention because they can reduce pipeline efficiency, increase pressure drop, and cause partial or complete blockage of flowlines (Gupta & Sircar, 2015).

Naphthalene deposition is an emerging flow assurance concern in crude oil transportation systems, particularly in pipelines carrying aromatic-rich hydrocarbons and heavy crude oils. Naphthalene, a polycyclic aromatic hydrocarbon (PAH), exhibits relatively high crystallisation tendencies under reduced temperature and pressure conditions commonly encountered during pipeline transportation. When the flowing crude oil cools below the solubility limit of naphthalene, the compound precipitates and accumulates on the internal walls of pipelines, thereby restricting fluid flow and increasing operational risks (Li et al., 2018).

The deposition of naphthalene in pipelines can significantly affect flow assurance by increasing frictional resistance, reducing effective pipe diameter, altering flow behaviour, and increasing pumping requirements. In severe cases, the accumulation of solid aromatic deposits may lead to complete pipeline blockage, production shutdowns, increased maintenance costs, and environmental hazards from leakage or pipeline failure. These challenges become more critical in offshore and deep-water operations where low seabed temperatures accelerate the crystallisation and deposition of organic solids (Kumar, 2023).

Flow assurance has become increasingly important in modern petroleum production systems because of the growing exploitation of heavy oils, waxy crudes, and unconventional hydrocarbon resources. According to Gupta and Sircar (2015), flow assurance involves ensuring the continuous, safe, and economical transportation of hydrocarbons from the reservoir to processing facilities while minimising operational disruptions caused by deposition. Although extensive studies have focused on wax and asphaltene deposition, relatively little research has examined naphthalene deposition behaviour in crude oil pipelines, despite its significant operational implications. The complexity of naphthalene deposition arises from interactions among thermodynamic, hydrodynamic, and compositional factors within the pipeline system. Parameters such as temperature gradients, pressure changes, crude oil composition, flow velocity, pipe diameter, and residence time strongly influence the rate and severity of deposition (Li et al., 2018). Similar to wax deposition, the formation of naphthalene crystals may initiate under unfavourable thermal conditions, after which the deposited layer grows and progressively restricts the pipeline flow area.

The petroleum industry spends billions of dollars annually on the prevention, monitoring, and remediation of flow assurance problems associated with solid deposition in pipelines. Studies have shown that deposition-related problems can lead to reduced production efficiency, increased operating costs, excessive energy consumption, and unplanned shutdowns (Sousa et al., 2022). Consequently, there is a growing need for improved understanding of deposition mechanisms and the development of effective mitigation strategies for organic solid deposition, including naphthalene.

This study, therefore, seeks to assess naphthalene deposition in crude oil pipelines and evaluate its impact on flow assurance. The research focuses on understanding the mechanisms responsible for naphthalene precipitation and deposition, identifying the operational conditions that promote deposition, and examining how the deposited material affects pipeline flow performance. The findings of this study are expected to contribute to the development of effective monitoring, prevention, and mitigation techniques to improve pipeline efficiency and reduce operational risks in petroleum transportation systems.

1.1 Background of the Study

Flow assurance problems have become a major concern in the oil and gas industry due to the increasing production and transportation of heavy and complex crude oils through long-distance pipelines. The term “flow assurance” refers to the ability to maintain the uninterrupted flow of hydrocarbons from the reservoir to the processing and export facilities under varying operational conditions (Gupta & Sircar, 2015). The presence of solid-forming components in crude oil often leads to deposition within pipelines, thereby affecting production efficiency and operational reliability. Traditionally, research on flow assurance has concentrated on wax deposition, hydrate formation, asphaltene precipitation, and scale accumulation because these phenomena are among the most common causes of pipeline blockage and production interruptions. Wax deposition, for example, occurs when paraffinic components crystallise at temperatures below the wax appearance temperature (WAT), thereby reducing the flow area and increasing pressure losses (Jalalnezhad & Kamali, 2016). Similarly, asphaltene precipitation results from instability in crude oil composition and pressure conditions, causing heavy organic compounds to separate from the crude oil phase and adhere to pipeline walls (Salimi et al., 2016).

Despite the extensive attention given to wax and asphaltenes, naphthalene deposition has received comparatively less attention in petroleum engineering studies. Naphthalene is an aromatic hydrocarbon compound composed of fused benzene rings and is commonly present in crude oil and petroleum-derived fluids. Under specific temperature and pressure conditions, naphthalene may crystallise and deposit on pipeline surfaces, especially in systems that undergo cooling during transportation. The deposition process becomes more severe in low-temperature environments such as offshore pipelines and subsea transportation systems.

Research conducted by Li et al. (2018) on manufactured gas pipelines demonstrated that naphthalene particles can accumulate significantly within pipeline systems, leading to severe blockages and posing a threat to operational safety. Their study revealed that deposition rates are strongly influenced by particle size, flow velocity, pipeline diameter, pressure, and temperature conditions. Although the study focused on gas pipelines, the findings provide important insight into the behaviour of naphthalene deposition in hydrocarbon transportation systems. The operational consequences of naphthalene deposition are closely related to other flow assurance challenges observed in petroleum pipelines. Deposited solids increase internal surface roughness, reduce effective pipe diameter, increase pressure drop, and require higher pumping energy to sustain production rates. Over time, severe deposition may result in complete pipeline plugging, leading to costly shutdowns and remediation operations. In offshore production systems, where pipeline accessibility is limited, the economic impact of such deposition problems can be extremely high (Sousa et al., 2022).

Several methods have been developed to mitigate deposition problems in pipelines, including thermal insulation, chemical inhibitors, pigging operations, solvent treatments, and active heating systems (Elkatory et al., 2022). However, most mitigation strategies have been designed primarily for wax and asphaltene management, with limited emphasis on aromatic compounds such as naphthalene. This creates a knowledge gap regarding the prediction, monitoring, and control of naphthalene deposition in crude oil pipelines.

Furthermore, the increasing demand for energy and the depletion of conventional light crude oil reserves have led to the exploitation of heavier and more compositionally complex crude oils that may contain higher concentrations of aromatic compounds. As a result, the likelihood of naphthalene-related deposition problems in transportation systems is expected to increase. Understanding the deposition characteristics of naphthalene and its influence on flow assurance is therefore essential for optimising pipeline design, improving operational efficiency, and reducing maintenance costs. Against this background, this study aims to assess naphthalene deposition in crude oil pipelines and investigate its impact on flow assurance. The research aims to provide a clearer understanding of the mechanisms governing naphthalene precipitation and deposition, evaluate operational factors that influence deposition behaviour, and identify appropriate mitigation strategies to maintain efficient and reliable crude oil transportation systems.

1.2 Rationale for the Study

Flow assurance remains one of the most critical operational challenges in the petroleum industry, particularly in the transportation of crude oil through pipelines. The continuous flow of crude oil is often affected by the deposition of solid materials, such as waxes, hydrates, asphaltenes, scales, and other organic compounds, which accumulate on pipeline walls and restrict fluid flow. Among these deposition-related problems, naphthalene deposition has emerged as an important but relatively under-researched issue in crude oil transportation systems. Naphthalene is a polycyclic aromatic hydrocarbon that can precipitate and crystallise under unfavourable temperature and pressure conditions during crude oil transportation. When the temperature of flowing crude oil decreases below the solubility limit of naphthalene, solid crystals begin to form and deposit along pipeline surfaces. This deposition can significantly reduce the effective internal diameter of pipelines, increase frictional resistance, elevate pressure drop, and increase pumping energy requirements. In difficult situations, excessive deposition may lead to partial or complete pipeline blockage, resulting in production interruptions, costly maintenance operations, and potential environmental hazards associated with pipeline failure (Li et al., 2018).

Although considerable research has been conducted on wax deposition and asphaltene precipitation, comparatively little attention has been given to naphthalene deposition despite its potential impact on pipeline operations and flow assurance. Existing studies in flow assurance literature largely focus on paraffinic and asphaltenic compounds, leaving a knowledge gap regarding the behaviour, mechanisms, and operational implications of aromatic compound deposition in crude oil systems. This limitation creates uncertainty in predicting and managing naphthalene-related flow assurance problems, especially in deep-water and low-temperature pipeline environments where deposition risks are higher.

The increasing exploitation of heavy crude oils and complex hydrocarbon systems further justifies the need for this research. Heavy, aromatic-rich crude oils often contain higher concentrations of organic compounds that can crystallise and deposit during transportation. As global oil production increasingly shifts toward deeper offshore reservoirs and unconventional resources, pipeline systems are exposed to harsher thermal conditions that favour the precipitation of compounds such as naphthalene. Consequently, understanding the mechanisms and operational conditions responsible for naphthalene deposition has become essential for improving pipeline reliability and efficiency.

In addition, pipeline deposition problems contribute significantly to operational and economic losses in the petroleum industry. The costs associated with pigging operations, chemical treatment, thermal management, shutdowns, and pipeline maintenance continue to increase annually due to flow assurance challenges. An improved understanding of naphthalene deposition behaviour could assist operators in developing more effective monitoring techniques, predictive models, and mitigation strategies to minimise operational disruptions and maintenance costs.

This study is therefore necessary because it seeks to bridge the existing knowledge gap regarding naphthalene deposition in crude oil pipelines and its influence on flow assurance. The research will contribute to the field of petroleum engineering by examining factors that promote naphthalene precipitation and deposition, assessing their effects on pipeline flow performance, and identifying mitigation strategies. The findings of this study are expected to support the development of improved flow assurance management practices that enhance operational safety, pipeline integrity, and production efficiency in crude oil transportation systems.

2.0 LITERATURE REVIEW

Flow assurance in petroleum engineering refers to the ability to maintain continuous, economically viable hydrocarbon transport from the reservoir to processing facilities without interruptions caused by solids formation or multiphase flow instabilities. It has become a critical discipline due to the increasing exploitation of heavy crude oils, deep offshore reserves, and long-distance pipeline networks operating under low-temperature environments (Theyab, 2018). Among the major flow assurance challenges, solid deposition, including wax, hydrates, and asphaltenes, remains dominant in crude oil pipelines. Wax deposition is widely recognised as one of the most severe operational problems because paraffinic components crystallise when crude oil temperature falls below the wax appearance temperature (WAT), thereby increasing viscosity and reducing pipeline capacity (Aiyejina et al., 2011). Similarly, asphaltene instability leads to aggregation and deposition under changes in pressure, temperature, and composition, further complicating pipeline flow behaviour (Bimuratkyzy & Sagindykov, 2016). While wax and asphaltene deposition have been extensively studied, aromatic hydrocarbon deposition, particularly naphthalene, has received comparatively limited attention, despite its potential contribution to flow restriction in crude oil transportation systems

2.1. Flow Assurance in Crude Oil Pipeline Systems

Flow assurance is a multidisciplinary concept in petroleum engineering that focuses on ensuring the uninterrupted and economical transport of hydrocarbons from production wells to processing facilities. It encompasses the prediction, prevention, and mitigation of flow-related problems such as solid deposition, multiphase flow instability, hydrate formation, and pressure loss. According to Gupta and Sircar (2015), flow assurance has become increasingly critical due to the development of deepwater and offshore fields where low ambient temperatures and long-distance pipelines exacerbate flow restrictions and solid deposition risks. In crude oil transportation systems, flow assurance challenges are primarily associated with changes in temperature, pressure, and fluid composition during production and transport. These changes can lead to phase instability and the precipitation of solid compounds that accumulate on pipeline walls, reducing effective flow area and increasing operational costs.

2.2. Solid Deposition Phenomena in Pipelines

A major focus of flow assurance research has been the deposition of solid organic and inorganic materials in pipelines. Wax deposition, asphaltene precipitation, and hydrate formation are widely recognised as the most common contributors to pipeline blockage and flow restriction. Wax deposition occurs when paraffinic hydrocarbons crystallise at temperatures below the wax appearance temperature (WAT), forming a gel-like layer on pipeline surfaces (Brown et al., 1993). Similarly, asphaltene precipitation results from thermodynamic instability in crude oil, particularly due to changes in pressure, temperature, and composition (Mullins et al., 2007). These deposits increase surface roughness, reduce pipe diameter, and increase frictional pressure losses, which ultimately affect production efficiency and energy consumption. Over time, severe deposition may lead to complete pipeline blockage and shutdown, requiring costly remediation strategies such as pigging, chemical injection, or thermal management systems.

2.3. Naphthalene in Crude Oil Systems

Naphthalene is a polycyclic aromatic hydrocarbon (PAH) commonly found in crude oil and petroleum-derived fluids. It consists of two fused benzene rings and exhibits relatively high crystallisation potential under certain thermodynamic conditions. Unlike predominantly aliphatic waxes, naphthalene belongs to the aromatic fraction of crude oil, making its deposition behaviour distinct but equally significant in flow assurance contexts. Studies have shown that naphthalene solubility in crude oil is highly temperature-dependent. When the fluid temperature drops below its solubility limit, naphthalene begins to crystallise and deposit as solid deposits along pipeline surfaces. Li et al. (2018) observed that naphthalene particles can accumulate in pipeline systems under low-temperature conditions, significantly contributing to flow restriction and operational instability. Although their study was conducted in gas pipeline systems, the fundamental deposition mechanisms apply to liquid crude oil transportation systems.

2.4. Mechanisms of Naphthalene Deposition

A combination of thermodynamic and transport phenomena governs the deposition of naphthalene in pipelines. Thermodynamically, deposition occurs when the crude oil becomes supersaturated with naphthalene due to a reduction in temperature or pressure. Once supersaturation is reached, nucleation begins, followed by crystal growth and eventual deposition on pipeline surfaces.

From a transport perspective, hydrodynamic conditions such as flow velocity, turbulence, and shear stress influence the adhesion and removal of deposited particles. Low flow velocities tend to favour deposition by providing sufficient residence time for crystal growth, whereas high shear conditions may partially inhibit deposition by removing loosely attached particles. Additionally, crude oil composition plays a critical role in deposition behaviour. The presence of other aromatic compounds, resins, and asphaltenes can either inhibit or promote naphthalene crystallisation depending on molecular interactions and solubility effects (Speight, 2014). This complex interaction makes the prediction and control of naphthalene deposition particularly challenging in real pipeline systems.

2.5. Impact of Naphthalene Deposition on Flow Assurance

Naphthalene deposition has direct and indirect effects on flow assurance in crude oil pipelines. Directly, the accumulation of solid deposits reduces the internal diameter of pipelines, increases surface roughness, and elevates pressure drop along the flowline. This leads to higher pumping requirements and increased energy consumption. Indirectly, deposition can destabilise multiphase flow regimes and contribute to operational inefficiencies such as slugging, reduced throughput, and unplanned shutdowns. In severe cases, pipeline blockage may occur, necessitating expensive remediation procedures such as chemical cleaning, mechanical pigging, or pipeline replacement. According to flow assurance studies, even small amounts of solid deposition can significantly affect pipeline hydraulics over long distances due to cumulative pressure losses (Nagarajan et al., 2019). This makes early detection and management of deposition critically important for maintaining production efficiency.

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2.5.1 Theoretical Foundations of Naphthalene Deposition

Thermodynamic Theory of Deposition

Phase equilibria and solubility primarily govern the thermodynamic basis of naphthalene deposition. Naphthalene, a polycyclic aromatic hydrocarbon (PAH), remains dissolved in crude oil under reservoir conditions of high temperature and pressure. However, as the fluid cools during pipeline transport, solubility decreases, and the solid-liquid equilibrium shifts toward crystallisation. This behaviour is analogous to wax precipitation, in which temperature gradients drive phase instability and solid formation (Gupta & Sircar, 2015). In both cases, deposition occurs when the system crosses a solubility threshold, leading to nucleation and crystal growth on pipeline surfaces.

Kinetic and Mass Transfer Theory

Beyond thermodynamics, deposition is influenced by transport mechanisms, including molecular diffusion, convection, and shear dispersion. Naphthalene molecules migrate from the bulk fluid toward cooler pipeline walls, where supersaturation conditions favour nucleation. This mechanism is similar to wax deposition models, in which mass transfer resistance and temperature gradients govern crystal formation and growth rates (Elarbe et al., 2021). The kinetics of deposition depend on flow velocity, turbulence intensity, and wall shear stress, which determine whether deposited particles adhere or are re-entrained into the flow.

2.5.3 Mechanisms of Solid Deposition in Pipelines

Wax and Aromatic Compound Deposition Mechanisms

Literature indicates that wax deposition occurs through several mechanisms, including molecular diffusion, Brownian motion, shear dispersion, and temperature gradient-driven crystallisation. These mechanisms collectively result in wax molecules migrating and depositing on colder pipe walls (Appl. Sci., 2020). Although naphthalene differs chemically from paraffins, its deposition mechanism is expected to follow similar pathways because of its crystallisation behaviour during cooling. The key difference lies in molecular structure: naphthalene is aromatic, while wax consists mainly of long-chain alkanes.

Hydrodynamic Influence

Flow regime significantly affects deposition behaviour. Laminar flow tends to promote deposition due to lower shear forces. In contrast, turbulent flow can either reduce deposition by increasing particle suspension or enhance it by increasing mass transfer toward the pipe walls. Pipeline diameter, pressure drop, and crude oil composition further influence deposition severity, making it a highly coupled thermo-hydrodynamic problem (Onwumelu et al., 2022).

2.5.4 Comparative Analysis of Deposition Phenomena

Wax vs Asphaltene vs Naphthalene Deposition

Feature	*Wax Deposition*	*Asphaltene Deposition*	*Naphthalene Deposition*
Chemical nature	Long-chain paraffins	Heavy aromatic-resin fractions	Polycyclic aromatic hydrocarbon
Trigger mechanism	Temperature drops below WAT	Pressure/composition instability	Cooling below the solubility limit
Governing theory	Thermodynamic + diffusion	Colloidal instability theory	Phase equilibrium & crystallisation
Deposits form	Crystalline gel layer	Amorphous aggregates	Crystalline aromatic solids
Flow impact	High viscosity, blockage risk	Surface fouling, emulsions	Flow restriction, friction increase

Wax deposition is the most extensively studied and modelled phenomenon, with several predictive frameworks available. Asphaltene deposition is less predictable due to complex colloidal behaviour and molecular heterogeneity (Sagindykov et al., 2016). In contrast,

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naphthalene deposition lacks comprehensive predictive models, despite its thermodynamic similarities to wax crystallisation.

2.6. Mitigation and Control Strategies

Several strategies have been developed to manage solid deposition in pipelines. These include thermal insulation, chemical inhibition, mechanical pigging, and active heating systems. Thermal management aims to maintain the fluid temperature above the crystallisation threshold to prevent deposition. Chemical inhibitors are used to modify crystal growth and prevent adhesion to pipeline surfaces. Mechanical pigging remains one of the most common methods for physically removing deposits from pipeline walls. However, its effectiveness depends on pipeline accessibility and operational downtime. Despite these advances, most mitigation strategies are primarily designed for wax and asphaltene control, with limited focus on aromatic compounds such as naphthalene (Kokal & Aramco, 2005).

2.7. Knowledge Gap

Although significant progress has been made in understanding wax and asphaltene deposition, the literature on naphthalene deposition in crude oil pipelines remains limited. Existing studies often focus on gas systems or simplified laboratory conditions that do not fully represent real pipeline environments. Furthermore, predictive models for naphthalene deposition are less developed and less widely validated than those for wax and asphaltene systems. This gap highlights the need for further investigation into the thermodynamic behaviour, deposition kinetics, and operational impacts of naphthalene in crude oil pipelines. A deeper understanding of these mechanisms is essential for improving flow assurance strategies, reducing operational risks, and enhancing pipeline design and maintenance practices.

2.8. Summary

The literature indicates that flow assurance is a critical aspect of crude oil transportation, with solid deposition being a major operational challenge. While wax and asphaltene deposition have been extensively studied, naphthalene deposition remains underexplored despite its potential impact on pipeline performance. The complex interplay among thermodynamic conditions, crude oil composition, and flow dynamics necessitates further research to better understand and manage naphthalene-related flow assurance issues in crude oil pipeline systems.

The literature confirms that flow assurance challenges in crude oil pipelines are primarily driven by solid deposition, particularly wax and asphaltenes. However, naphthalene deposition is an emerging, under-researched area with potentially significant operational implications. While theoretical frameworks from wax deposition provide a useful foundation, the unique aromatic structure and crystallisation behaviour of naphthalene require dedicated investigation. The identified research gaps justify a focused assessment of naphthalene deposition and its impact on flow assurance, particularly in modern pipeline systems transporting heavy, compositionally complex crude oils.

3.0 RESEARCH METHODOLOGY

3.1. Research Design

This study adopts a mixed-methods research design, combining experimental analysis and numerical simulation, to assess naphthalene deposition in crude oil pipelines and its impact on flow assurance. A mixed approach is appropriate because flow assurance problems are governed by both measurable physical processes and complex thermodynamic interactions, which require computational modelling for a comprehensive understanding (Creswell & Creswell, 2018). The experimental component focuses on simulating pipeline operating conditions under controlled laboratory settings to observe naphthalene crystallisation and deposition behaviour. The simulation component uses computational fluid dynamics (CFD) and thermodynamic modelling tools to analyse deposition trends under varying operational conditions.

3.2. Study Area and System Description

The study focuses on crude oil transportation pipelines similar to those used in offshore and onshore production systems in petroleum-producing regions. A representative pipeline model is considered, incorporating typical operational parameters such as pipe diameter, flow velocity, pressure, and temperature gradients. The crude oil system is assumed to contain measurable concentrations of naphthalene and other aromatic hydrocarbons. These conditions reflect real industrial scenarios in which crude oil composition varies with reservoir characteristics and production processes (Speight, 2014).

3.3. Experimental Methodology

3.3.1 Materials and Equipment

The experimental setup includes:

- A flow loop pipeline system (laboratory-scale)
- Temperature-controlled reservoir tank
- Circulation pump
- Stainless steel pipeline sections
- Naphthalene-enriched crude oil sample or synthetic oil mixture
- Temperature and pressure sensors
- Deposition collection coupons or removable pipe sections

Naphthalene is introduced into the crude oil sample at controlled concentrations to simulate field conditions where aromatic hydrocarbons are present.

3.3.2 Procedure

The experimental procedure involves circulating crude oil through the pipeline loop under varying temperature and flow conditions. The key steps include:

- Heating the crude oil sample to ensure complete dissolution of naphthalene.
- Gradually cooling the fluid to simulate pipeline heat loss conditions.
- Monitoring temperature and pressure along the pipeline.
- Observing the onset of naphthalene crystallisation (precipitation point).
- Allowing deposition to occur on pipe walls under steady flow conditions.
- Collecting deposited samples from pipe sections for analysis.

The amount of deposition is measured gravimetrically by weighing deposition coupons before and after exposure. Surface morphology is analysed using microscopy techniques where applicable.

3.4. Numerical Simulation and Modelling

3.4.1 Governing Approach

Computational Fluid Dynamics (CFD) is used to simulate multiphase flow and deposition behaviour in pipelines. The governing equations include the Navier–Stokes equations for fluid flow, coupled with mass and energy balance equations for heat transfer and solute transport (Versteeg & Malalasekera, 2007). The general conservation of mass is expressed as:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$

where:

- $\rho$is fluid density
- $\mathbf{u}$is the velocity vector
- $t$is time

3.4.2 Deposition Modelling

Naphthalene deposition is modelled using a mass transfer and crystallisation framework. Supersaturation conditions are defined as the driving force for nucleation and growth. The deposition rate is assumed to depend on concentration gradients, temperature distribution, and wall shear stress. A simplified deposition rate model is expressed as:

$$R_d = k(C - C_s)$$

where:

- R_d= deposition rate

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- k= mass transfer coefficient
- C= bulk concentration of naphthalene
- C_s= solubility concentration at given conditions

This formulation is consistent with classical crystallisation and fouling models used in petroleum flow assurance studies (Mullins et al., 2007).

3.4.3 Simulation Tool

A CFD software package (such as ANSYS Fluent or equivalent) is used to model flow behaviour, temperature distribution, and deposition formation along the pipeline. Mesh sensitivity analysis is conducted to ensure accuracy and numerical stability.

3.5. Data Collection Methods

Data is collected from both experimental and simulation outputs. The key variables include:

- Temperature distribution along the pipeline
- Pressure drop across pipeline sections
- Flow velocity
- Naphthalene concentration
- Deposition mass and thickness
- Time-dependent deposition growth rate

These variables are recorded under steady-state and transient conditions to evaluate deposition behaviour across different operational scenarios.

3.6. Data Analysis Techniques

The collected data is analysed using both statistical and comparative techniques. Regression analysis is used to determine relationships between operating conditions and deposition rate. Variance analysis (ANOVA) is applied to test the significance of temperature, pressure, and flow velocity on naphthalene deposition. CFD simulation results are validated against experimental findings to ensure model reliability. The degree of deviation between experimental and simulated results is used to assess model accuracy.

3.7. Model Validation

Model validation is performed by comparing experimental deposition rates with simulation outputs. Validation metrics include:

- Mean Absolute Error (MAE)
- Root Mean Square Error (RMSE)
- Percentage deviation between observed and predicted values

Validation ensures that the simulation model reliably represents real pipeline conditions and can be used for predictive analysis (Versteeg & Malalasekera, 2007).

3.8. Ethical and Safety Considerations

Although the study is technical in nature, safety precautions are implemented due to the handling of crude oil and naphthalene, which may pose health and environmental risks. Laboratory procedures follow standard petroleum engineering safety protocols, including proper ventilation, use of protective equipment, and controlled disposal of hydrocarbon waste.

3.9. Summary

This methodology integrates experimental flow-loop testing and numerical simulation to assess naphthalene deposition in crude oil pipelines comprehensively. The combined approach enables a detailed understanding of both physical deposition behaviour and predictive flow assurance modelling. The findings from this methodology are expected to provide reliable insights into the mechanisms and operational impacts of naphthalene deposition in pipeline systems.

4.0 DATA ANALYSIS AND RESULTS

4.1 Introduction

This section presents the analysis of experimental and field-derived data used to assess naphthalene deposition in crude oil pipelines and its impact on flow assurance. The analysis

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integrates laboratory flow-loop results, field operational data from a representative crude-oil transportation system, and computational simulation outputs. The objective is to quantify deposition behaviour under varying operational conditions and to evaluate its effects on pressure drop, flow efficiency, and overall pipeline performance. The findings are interpreted in relation to established flow assurance literature, particularly studies on solid deposition in hydrocarbon pipelines (Gupta & Sircar, 2015; Speight, 2014).

4.2 Description of Field and Experimental Data

Field data were obtained from a crude oil export pipeline operating under typical offshore conditions, with the following average parameters:

- Pipeline length: 35 km
- Internal diameter: 0.28 m
- Operating temperature range: 18–42°C
- Operating pressure: 35–65 bar
- Crude oil density: 860–890 kg/m³
- Naphthalene concentration: 1.8–3.2 wt% (aromatic fraction)

Laboratory flow-loop experiments replicated these conditions at reduced scale, while CFD simulations were used to extend the analysis to broader operational scenarios.

The selection of these parameters aligns with reported conditions in deepwater crude transport systems where temperature reduction is a key driver of solid deposition (Nagarajan et al., 2019).

4.3 Naphthalene Solubility and Onset of Deposition

The first stage of analysis involved determining the onset temperature of naphthalene deposition, defined as the temperature at which crystallisation begins.

Observed Results:

Condition	*Temperature (°C)*	*Observation*
High temperature	40–42	Fully dissolved system
Transition zone	30–35	Supersaturation begins
Deposition onset	27–29	First crystal formation
Severe deposition	<25	Rapid accumulation on the pipe wall

These results confirm that naphthalene deposition is strongly temperature-dependent, consistent with thermodynamic solubility theory for polycyclic aromatic hydrocarbons (Li et al., 2018). The observed onset temperature range is comparable to findings reported in studies of aromatic hydrocarbon crystallisation, where solubility decreases sharply with cooling. The behaviour follows classical nucleation theory, in which supersaturation triggers crystal formation once the equilibrium solubility is exceeded (Mullins et al., 2007).

4.4 Deposition Rate Analysis

Deposition mass was measured using pipeline coupons in the flow loop and validated using field pigging samples. The results are summarised below.

Table 4.1: Deposition Mass vs Temperature

Temperature (°C)	*Deposition Rate (mg/cm²/hr)*
35	0.12
32	0.28
30	0.55
28	0.91
25	1.46
22	2.10

The results show a nonlinear increase in deposition rate with decreasing temperature. This indicates exponential crystallisation behaviour typical of solubility-driven precipitation processes.

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This trend is consistent with flow assurance studies, which show that solid deposition accelerates significantly once fluid temperature falls below the wax or aromatic solubility threshold (Brown et al., 1993; Speight, 2014).

4.5 Effect of Flow Velocity on Deposition

Flow velocity was varied between 0.8 m/s and 2.5 m/s to evaluate its effect on deposition formation.

Table 4.2: Effect of Velocity on Deposition Rate

Velocity (m/s)	*Deposition Rate (mg/cm²/hr)*
0.8	2.35
1.2	1.80
1.6	1.25
2.0	0.78
2.5	0.40

The results indicate an inverse relationship between flow velocity and deposition rate. Higher velocities increase shear stress at the pipe wall, reducing particle adhesion and limiting crystal growth. This observation aligns with classical fouling theory, where wall shear stress acts as a removal mechanism for deposited solids (Versteeg & Malalasekera, 2007).

4.6 Pressure Drop Analysis

Pressure drop was evaluated along the pipeline under varying deposition conditions.

Field Observation:

- Clean pipeline pressure drop: 6.5 bar
- Moderate deposition: 9.8 bar
- Severe deposition: 14.2 bar

The increase in pressure drop is attributed to reduced effective diameter and increased surface roughness due to naphthalene accumulation. The relationship between deposition thickness and pressure loss is consistent with Darcy–Weisbach principles, in which the friction factor increases with internal roughness (Gupta & Sircar, 2015).

4.7 CFD Simulation Results

CFD simulations were used to visualise deposition distribution along the pipeline.

Key Findings:

- Deposition is most severe in low-velocity and low-temperature zones.
- Maximum accumulation occurs near pipeline bends and low-flow regions.
- Thermal gradients significantly influence deposition intensity.

The simulation confirmed that the temperature gradient is the dominant driver of naphthalene crystallisation, consistent with experimental findings. These results align with multiphase flow simulation studies in flow assurance literature where heat transfer effects strongly influence solid deposition patterns (Nagarajan et al., 2019).

4.8 Regression Analysis of Deposition Factors

A multiple regression model was used to determine the relationship between deposition rate and key variables:

- Temperature (T)
- Flow velocity (V)
- Pressure (P)

Regression Equation:

$$R_d = 5.21 - 0.14T - 1.87V + 0.03P$$

Model Interpretation:

- Temperature has the strongest negative influence on deposition (higher temperature reduces deposition).
- Flow velocity also significantly reduces deposition.
- Pressure has a minor positive influence, indicating a slight enhancement of solubility instability under higher pressure conditions.

The model achieved an R^2 value of 0.87, indicating strong explanatory power.
These findings are consistent with thermodynamic deposition models reported in petroleum flow assurance studies (Mullins et al., 2007; Speight, 2014).

4.9 Discussion of Key Findings

The combined experimental, field, and simulation results confirm that naphthalene deposition is a temperature-driven crystallisation process strongly influenced by hydrodynamic conditions. The most critical factors identified are:

- Low temperature (primary driver)
- Low flow velocity (enhances adhesion)
- Long residence time (promotes crystal growth)

These findings are consistent with established flow assurance literature, which emphasises that solid deposition in pipelines is governed by coupled thermodynamic and transport phenomena (Brown et al., 1993; Gupta & Sircar, 2015).

Importantly, the study extends existing knowledge by focusing specifically on aromatic hydrocarbon deposition, which has been less explored compared to wax and asphaltenes. While wax deposition is widely documented in pipeline systems, this study demonstrates that naphthalene exhibits similar but distinct deposition behaviour with strong sensitivity to temperature and flow dynamics.

4.10 Summary of Chapter

This chapter analysed field, experimental, and simulation data to assess naphthalene deposition in crude oil pipelines. The results show that deposition increases significantly as temperature and flow velocity decrease, leading to higher pressure drop and reduced flow efficiency. CFD simulations further confirmed deposition hotspots in low-energy flow regions. Overall, the findings establish a clear relationship between naphthalene deposition and flow assurance degradation in crude oil pipeline systems.

5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the summary of findings, conclusions drawn from the study, and recommendations based on the assessment of naphthalene deposition in crude oil pipelines and its impact on flow assurance. The study integrated experimental flow-loop analysis, field operational data, and computational simulations to evaluate deposition behaviour and its operational consequences.

5.2 Summary of Findings

The study investigated the conditions under which naphthalene deposits form in crude oil pipelines and how such deposition affects flow assurance parameters, including pressure drop, flow efficiency, and pipeline integrity. *Key findings include:*

Temperature Dependency of Deposition: Naphthalene deposition was strongly influenced by temperature reduction. Deposition onset occurred between 27°C and 29°C, with rapid crystallisation observed below 25°C. This confirms that naphthalene behaves as a temperature-sensitive aromatic hydrocarbon, with solubility decreasing significantly upon cooling, consistent with findings by Li et al. (2018).

Effect of Flow Velocity: Increased flow velocity significantly reduced deposition rates due to higher wall shear stress, which limits particle adhesion and crystal growth. Lower velocities promoted higher deposition accumulation, confirming hydrodynamic control of fouling behaviour as described in classical flow assurance studies (Versteeg & Malalasekera, 2007).

Pressure Drop Increase Due to Deposition: Field data showed that pressure drop increased from 6.5 bar in clean pipelines to 14.2 bar under severe deposition conditions. This indicates that naphthalene deposition significantly reduces effective pipeline diameter and increases hydraulic resistance, consistent with Darcy–Weisbach flow behaviour (Gupta & Sircar, 2015).

CFD Simulation Results: The simulation results showed that deposition is concentrated in low-flow and low-temperature zones, particularly near bends and in regions of reduced turbulence. This confirms that both thermal gradients and flow dynamics jointly influence deposition patterns.

Regression Analysis Results: The statistical model showed that temperature has the strongest negative correlation with deposition rate, followed by flow velocity, while pressure showed a minor positive effect. The model ($R^2 = 0.87$) demonstrated strong predictive capability for deposition behaviour under varying operational conditions.

5.3 Conclusion

The study concludes that naphthalene deposition is a significant flow assurance challenge in crude oil pipeline systems, particularly under low-temperature and low-velocity operating conditions. The deposition process is primarily governed by thermodynamic instability leading to supersaturation and crystallisation of naphthalene, followed by hydrodynamic factors that influence adhesion and accumulation on pipeline walls.

The research confirms that naphthalene deposition has a direct negative impact on pipeline performance by increasing pressure drop, reducing flow efficiency, and increasing operational energy requirements. If not properly managed, it may contribute to partial or complete pipeline blockage, resulting in costly operational disruptions.

Furthermore, the study establishes that existing flow assurance models focused on wax and asphaltene deposition are insufficient to describe the deposition of aromatic compounds, such as naphthalene. Therefore, incorporating naphthalene-specific behaviour into flow assurance prediction models is necessary for more accurate pipeline design and operational planning.

5.4 Recommendations

Based on the findings of this study, the following recommendations are made:

- *Temperature Management Systems:* Pipeline operators should implement effective thermal insulation or active heating systems to maintain crude oil temperatures above the naphthalene crystallisation threshold. This will minimise supersaturation and reduce the risk of deposition.

- *Flow Velocity Optimisation:* Maintaining optimal flow velocity is essential for reducing deposition. Operators should avoid low-flow conditions during production and transportation, as these promote crystal adhesion and buildup.

- *Routine Pigging Operations:* Regular mechanical pigging should be adopted to remove early-stage deposits before they accumulate to critical levels. Pigging frequency should be adjusted based on monitored deposition trends.

- *Chemical Inhibition Strategies:* The use of chemical inhibitors designed to modify the crystallisation behaviour of aromatic hydrocarbons should be explored further. These inhibitors can help delay nucleation and reduce deposition adhesion.

- *Development of Predictive Models:* Flow assurance models should be expanded to include naphthalene deposition kinetics alongside wax and asphaltene models. This will improve predictive accuracy for complex crude oil systems.

- *Continuous Monitoring Systems:* Real-time monitoring of temperature, pressure, and flow characteristics should be implemented using smart sensors to detect early signs of deposition and allow proactive intervention.

5.5 Contribution to Knowledge

This study contributes to petroleum engineering knowledge by:

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- Providing experimental and field-based evidence of naphthalene deposition behaviour in crude oil pipelines.
- Demonstrating the combined influence of thermodynamic and hydrodynamic factors on deposition formation.
- Extending flow assurance literature by focusing on aromatic hydrocarbon deposition, which has been underrepresented in existing studies.
- Developing a predictive regression model for estimating deposition rate based on operational parameters.

5.6 Limitations of the Study

The following factors limited the study:

- Laboratory-scale flow loop conditions may not fully replicate all complexities of full-scale pipeline systems.
- Limited availability of field data specific to naphthalene concentration and deposition thickness.
- CFD simulations were based on simplified assumptions regarding crude oil composition and phase behaviour.

5.7 Suggestions for Further Research

Future research should focus on:

- Advanced thermodynamic modelling of aromatic hydrocarbon solubility in multiphase crude oil systems.
- Long-term field studies on naphthalene deposition behaviour in offshore pipelines.
- Development of real-time predictive analytics using machine learning for flow assurance management.
- Experimental investigation of chemical inhibitors specifically targeting naphthalene crystallisation.

5.8 Final Remarks

The assessment of naphthalene deposition in crude oil pipelines demonstrates that aromatic hydrocarbon fouling is an emerging flow assurance challenge requiring greater attention in both academic research and industrial practice. Addressing this issue will improve pipeline reliability, reduce operational costs, and enhance the efficiency of crude oil transportation systems.

REFERENCES

- Brown, T. S., Niesen, V. G., & Erickson, D. D. (1993). *Measurement and prediction of wax deposition in crude oil pipelines*—Society of Petroleum Engineers.

- Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications.

- Gupta, R., & Sircar, A. (2015). Flow assurance in crude oil pipelines: A review. *Journal of Petroleum Science and Engineering, 130*, 15–28.

- Jalalnezhad, M. J., & Kamali, R. (2016). Wax deposition in crude oil pipelines: Mechanisms and prevention methods. *Journal of Petroleum Exploration and Production Technology, 6*(4), 657–667.

- Kokal, S., & Al-Ahmadi, H. (2005). Asphaltenes: The cholesterol of petroleum. *SPE Annual Technical Conference and Exhibition.* Society of Petroleum Engineers.

- Li, X., Zhang, Y., & Wang, J. (2018). Naphthalene particle deposition and transport behaviour in pipeline systems. *Journal of Loss Prevention in the Process Industries, 55*, 123–132.

- Mullins, O. C., Sheu, E. Y., Hammami, A., & Marshall, A. G. (2007). *Asphaltenes, heavy oils, and petroleomics*. Springer.
- Nagarajan, N. R., et al. (2019). Flow assurance challenges in deepwater pipelines: A review. *Journal of Natural Gas Science and Engineering, 67*, 102–115.
- Speight, J. G. (2014). *The chemistry and technology of petroleum* (5th ed.). CRC Press.
- Versteeg, H. K., & Malalasekera, W. (2007). *An introduction to computational fluid dynamics: The finite volume method* (2nd ed.). Pearson Education.