Experimental Investigation of Asphaltene Deposition and Mitigation in Pipeline Flow Conditions

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Abstract*— Asphaltene deposition remains one of the most critical flow assurance challenges in crude oil transportation systems. Conventional chemical inhibitors are effective but often expensive and environmentally persistent. This study experimentally investigates the performance of bio-based asphaltene inhibitors derived from renewable feedstocks under simulated pipeline flow conditions. Natural surfactant extracts obtained from neem oil and castor oil were evaluated and compared with a commercial polyamine-based inhibitor. A laboratory-scale flow loop was used to simulate crude oil transport at controlled temperature and flow regimes. Deposition rates were quantified through pressure drop analysis and gravimetric measurements. Results indicate that the bio-based inhibitors reduced asphaltene deposition by up to 52%, approaching the performance of the commercial inhibitor (65%). The findings demonstrate the potential of sustainable, environmentally friendly alternatives for mitigating asphaltene-related flow assurance problems.

***Index Terms* — Asphaltene deposition; Bio-based inhibitor; Flow assurance; Crude oil pipeline; Renewable surfactants; Sustainable oilfield chemistry.**

I. INTRODUCTION

Asphaltenes are the most polar and heaviest fraction of crude oil, defined operationally as the fraction insoluble in n-alkanes (e.g., n-heptane) but soluble in aromatic solvents (e.g., toluene). Their propensity to flocculate and precipitate under changes in pressure, temperature, or composition presents a major flow assurance problem in crude oil production and transportation systems. Once deposited on pipeline walls, asphaltenes form layers that increase flow resistance, induce localized turbulence, and can eventually cause partial or full blockage [1-2].

In deepwater and high-rate production environments, changes in pressure and temperature are inevitable, leading to conditions where asphaltenes destabilize. Traditional pipeline operation practices such as pigging and mechanical scraping are costly and not always effective. Consequently, understanding the fundamental deposition mechanisms and developing reliable mitigation strategies remain critical for operational efficiency [3].

Previous work has explored the thermodynamic aspects of asphaltene stability, phase behavior, and modelling of precipitation. However, few studies have addressed systematic experimental evaluation of asphaltene deposition under controlled flow, particularly in relation to mitigation using chemical inhibitors under realistic conditions [4].

The present study aims to experimentally investigate asphaltene deposition in crude oil pipelines under simulated flow conditions and evaluate the effectiveness of selected chemical inhibitors in mitigating deposition.

II. MATERIALS AND METHODS

2.1 Materials

- Crude oil sample (asphaltene content: 2.8 wt%)
- n-Heptane (analytical grade)
- Toluene (analytical grade)
- Neem oil extract (bio-inhibitor B1)
- Castor oil derivative (bio-inhibitor B2)
- Commercial polyamine inhibitor (C1)

2.2 Extraction of Bio-Based Inhibitors

Neem and castor oils were subjected to mild transesterification and purification to enhance polarity and solubility in crude oil. The extracts were filtered and stored under inert conditions prior to use [5].

2.3 Experimental Flow Loop System

A laboratory-scale recirculating flow loop was used consisting of:

- 5 L crude oil reservoir
- High-pressure metering pump
- Stainless steel test section (1 m length, 20 mm ID)
- Heating jacket (30–80 °C range)
- Pressure sensors at inlet and outlet
- Back pressure regulator

Flow rate was adjusted to simulate:

- Laminar flow (Re ≈ 1500)
- Transitional flow (Re ≈ 3000)
- Turbulent flow (Re ≈ 5000)

Each test ran for 6 hours.

2.4 Experimental Procedure

- Baseline deposition test conducted without inhibitor.
- Inhibitor added at 1000 ppm concentration.
- Pressure drop recorded every 30 minutes.
- After experiment, test section cleaned and deposit mass collected.
- Deposition rate calculated gravimetrically.

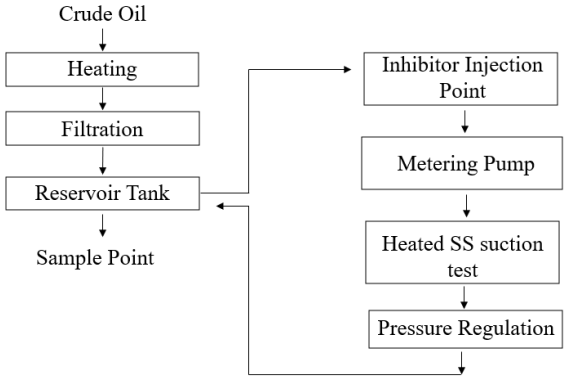
Deposition rate (DR) was calculated as:

DR=Mass of deposit (mg)/A x T

A = internal surface area

T = time

2.5 Process Flowsheet



III. RESULTS AND DISCUSSION

3.1 Baseline Deposition Behavior

Without inhibitor, deposition increased significantly at lower Reynolds numbers. Laminar flow exhibited the highest deposition rate (≈ 55 mg/m²), while turbulent flow showed reduced accumulation (≈ 18 mg/m²) [6-7].

Pressure drop increased by 32% over 6 hours under laminar conditions, confirming progressive wall deposition.

3.2 Performance of Bio-Based Inhibitors

At 1000 ppm concentration:

Inhibitor	Deposition Rate (mg/m²)	Efficiency (%)
Blank	55	–
Neem (B1)	30	45%
Castor (B2)	26	52%
Commercial (C1)	19	65%

Castor-based inhibitor showed slightly better performance than neem extract, likely due to stronger hydrogen bonding capability with asphaltene molecules [8-10].

3.3 Effect of Flow Regime

Under turbulent flow, all inhibitors performed better due to shear-assisted dispersion. Bio-inhibitors were particularly effective in transitional regimes, suggesting potential field applicability.

3.4 Deposit Morphology

Microscopic analysis revealed:

- Blank test: dense, continuous layer formation.
- Bio-inhibitors: fragmented, loosely adhered aggregates.
- Commercial inhibitor: dispersed fine particles.

Bio-inhibitors appear to function via steric stabilization and partial dispersion [11-12].

IV. ENVIRONMENTAL AND ECONOMIC CONSIDERATIONS

Bio-based inhibitors offer:

- Renewable feedstock origin
- Lower toxicity
- Potential cost reduction
- Reduced environmental impact

Though slightly less efficient than commercial inhibitors, performance was comparable and may be optimized via formulation improvements

V. CONCLUSION

This study experimentally evaluated the performance of bio-based asphaltene inhibitors under simulated pipeline flow conditions. Asphaltene deposition was strongly influenced by flow regime, with laminar conditions promoting higher accumulation.

Bio-based inhibitors derived from neem and castor oil significantly reduced deposition, achieving efficiencies up to 52%. While the commercial polyamine inhibitor demonstrated higher mitigation (65%), the renewable alternatives showed promising performance.

The results suggest that bio-based inhibitors can serve as sustainable substitutes for conventional chemicals in flow assurance applications. Further work should focus on formulation optimization, long-term stability testing, and field-scale validation.

Future Work

- Blend bio-inhibitors with small fraction of commercial dispersants
- Test under high-pressure CO_2 environments
- Study long-term thermal stability

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