International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 10 Issue 4 April - 2026, Pages: 69-86

Use Of Local Materials as an Inhibitor for Scale Formation in Oil Field Pipelines

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Abstract- *Scale formation and corrosion are major challenges in oilfield pipeline operations, adversely affecting flow assurance, production efficiency, and asset integrity. This study investigates the potential of locally sourced plant-based materials clove and cassava leaf extracts as eco-friendly and cost-effective scale inhibitors for oilfield applications. The extracts were prepared using solvent extraction and characterized using Fourier Transform Infrared (FTIR) spectroscopy to identify functional groups responsible for inhibition performance. Experimental evaluation was conducted on produced water, calcium carbonate ($CaCO_3$), barium sulfate ($BaSO_4$), and hybrid scale systems under controlled laboratory conditions. Inhibition efficiency was determined using gravimetric analysis, while corrosion behavior was assessed using mild steel coupon testing. Results showed that both extracts exhibited significant inhibition performance, with efficiencies comparable to conventional synthetic inhibitors, and improved effectiveness at higher concentrations. The inhibition mechanism is primarily attributed to adsorption, chelation, and interference with crystal nucleation and growth. Corrosion tests revealed reduced metal loss in treated systems compared to untreated samples. Economic analysis further demonstrated that the local inhibitors offer substantial cost advantages with favorable cost–benefit ratios. Overall, the findings establish clove and cassava leaf extracts as sustainable, environmentally friendly alternatives for mitigating scale formation and corrosion in oilfield pipelines.*

Keywords- Scale, Inhibition, Economic Analysis, Corrosion, Oil Field.

Introduction

Flow assurance remains a fundamental aspect of oil and gas production, ensuring the uninterrupted and efficient transport of hydrocarbons from the reservoir to processing facilities. Among the numerous challenges affecting flow assurance, mineral scale deposition and corrosion are two of the most persistent and detrimental issues encountered in oilfield pipeline systems [1]. These phenomena not only reduce production efficiency but also compromise pipeline integrity, leading to increased operational costs, equipment failure, and potential environmental hazards [2]. Scale formation occurs when dissolved inorganic salts precipitate from produced or injected fluids due to changes in thermodynamic conditions such as pressure, temperature, and chemical composition. Common oilfield scales include calcium carbonate ($CaCO_3$), barium sulfate ($BaSO_4$), and strontium sulfate ($SrSO_4$), which tend to deposit on the internal surfaces of pipelines, tubing, and production equipment [3; 4]. These deposits restrict fluid flow, increase pressure drop, and reduce the effective diameter of pipelines, thereby impairing production performance. In addition to flow restriction, scale deposition can accelerate corrosion processes by creating localized environments that promote electrochemical reactions on metal surfaces [5]. Corrosion, on the other hand, involves the gradual degradation of metallic materials due to chemical or electrochemical interactions with the surrounding environment. In oilfield systems, the presence of water, dissolved gases, salts, and microbial activity creates highly corrosive conditions [6; 7]. When combined with scale deposition, corrosion becomes more severe due to the formation of under-deposit corrosion sites, which are often difficult to detect and mitigate. The combined effects of scaling and corrosion present a major threat to the safety, reliability, and economic viability of oilfield operations [8; 9]. Traditionally, the control of scale formation has relied heavily on the use of synthetic chemical inhibitors such as phosphonates, polycarboxylates, and phosphate esters. These chemicals function by interfering with crystal nucleation, growth, and agglomeration processes, thereby preventing scale deposition [10; 11]. While effective, these conventional inhibitors are associated with several drawbacks, including high cost, limited biodegradability, and environmental toxicity. Their widespread use raises concerns regarding environmental sustainability, particularly in offshore and environmentally sensitive regions where strict discharge regulations are enforced [12; 13]. In response to these challenges, there has been a growing interest in the development of green scale inhibitors derived from natural and locally available materials. Plant-based extracts, agricultural by-products, and other biodegradable substances have emerged as promising alternatives due to their eco-friendly nature, low toxicity, and cost-effectiveness [14; 15]. These materials contain bioactive compounds such as tannins, flavonoids, and phenolic substances, which possess the ability to interact with metal ions and inhibit scale formation through mechanisms such as adsorption, chelation, and crystal growth modification [16; 14]. Despite the increasing attention given to green inhibitors, their application in oilfield operations remains limited. Many existing studies have focused primarily on laboratory-scale evaluations, with limited data on their performance under varying operational conditions or in comparison with conventional inhibitors. Furthermore, there is a need for more comprehensive investigations into the mechanisms of action, economic viability, and corrosion mitigation capabilities of these materials. This study addresses these gaps by evaluating the effectiveness of locally sourced plant materials specifically clove and cassava leaf extracts as scale inhibitors in oilfield pipeline systems. The research focuses on their performance against common oilfield scales, their interaction mechanisms, and their potential to serve as sustainable alternatives to conventional chemical inhibitors. By integrating experimental analysis with economic assessment, this work aims to contribute to the advancement of green chemistry solutions in petroleum engineering and promote the adoption of environmentally responsible practices in flow assurance management.

2.0 Materials and Method

2.1 Materials

Table 1: Materials and Functions

Compound	**Chemical Formula**	**Function in Scale Inhibition (Petroleum Engineering)**
Sodium Chloride	$NaCl$	Used in brine solutions; can influence scale formation in high-salinity environments.
Potassium Chloride	KCl	Component in completion fluids; affects scale precipitation in reservoir conditions.
Magnesium Chloride	$MgCl_2$	Contributes to scale formation (e.g., magnesiumbased scales) in production systems.
Barium Tetraoxosulphate (VI)	$BaSO_4$	Forms insoluble barite scale; targeted for inhibition in scale control experiments.
Sodium Lauryl Sulphate	SLS ($NaC_{12}H_{25}SO_4$)	Surfactant; may assist in dispersing scale inhibitors or reducing surface tension.
Aluminium Tetraoxosulphate (VI)	$Al_2(SO_4)_3$	Used in water treatment; influences scale control in produced water systems.
Calcium Trioxocarbonate (IV)	$CaCO_3$	Forms calcite scale; a primary target for scale inhibition in oilfield applications.
Sodium Trioxocarbonate (IV)	Na_2CO_3	Adjusts pH in scale inhibition tests; can precipitate carbonates to study scaling.
Crude Oil	Complex mixture	Source of hydrocarbons; affects scale deposition and inhibitor performance in tests.

Table 2: Apparatus and Functions

Apparatus	**Function**
Spatula	Used for transferring solid chemicals and samples during preparation.
Beakers	Used for mixing solutions, preparing brine solutions, and holding reaction mixtures.
Weighing balance	Precise measurement of chemical quantities for reproducible experiments.
Metal scraps	Surface for scale deposition studies and testing inhibitor effectiveness.
Sand paper	Surface preparation of metal coupons to ensure consistent scale adhesion studies.
Vacuum pump	Facilitates vacuum filtration for separating precipitates and scale particles.
Filter papers	Used in filtration processes to collect scale precipitates for analysis.

Soxhlet extractor	Extraction of organic components or inhibitors from scale deposits.
Measuring cylinder	Accurate volume measurement of liquids and solutions.
Syringe	Precise injection of inhibitors or sampling of solutions.
Buchner funnel	Vacuum-assisted filtration of scale precipitates and suspensions.
Magnetic stirrer	Ensures uniform mixing of solutions during scale formation and inhibition tests.
Hot plate	Provides controlled heating for reaction acceleration and temperature maintenance.

Figure 1: Spatula

Figure 2: Beakers

Figure 3: Weighing balance

Figure 4: Metal scraps

Figure 5: Sand papers

Figure 6: Vacuum pump

Figure 7: Filter papers

Figure 8: Soxhlet extractor

Figure 9: Graduated cylinder

Figure 10: Syringe

Figure 11: Buchner Funnel

Figure 12: Hot plate

2.2 Method

2.2.1 Material sourcing and preparation

This practical utilized three distinct green materials as local inhibitors, which are clove extract, cassava leaf extract and red onions skin. In the case of clove, it was purchased, while onion skins were collected in their discarded states from Ihiagwa market square, Obinze Owerri. For the case of cassava leaf it was sourced from a farm yard close to the laboratory where the practical was being performed.

1. Scale: The following steps were taken during the formulations of Hybrid and $BaSO_4$ Scales respectively:

Hybrid $BaSO_4/CaCO_3$ and $BaSO_4$:

a. The materials were carefully measured using a weighing balance.
b. 450 mL of Water was introduced into a beaker.
c. The measured materials for the Hybrid $BaSO_4/CaCO_3$ and $BaSO_4$ formulation were added into the beaker and stirred for 30 minutes @ 8 RPM.
d. 50 mL of crude oil was added into the mixture and stirred for another 30 minutes @ 8 RPM.
e. The mixture was poured into a separating funnel.
f. The mixture was left for a minimum of 2 days to age.

2. Scale inhibitors: The following steps were taken during the formulations of clove extract, red onions skin extract and cassava leaf extract respectively:

a. Clove extract: The cloves were carefully sorted and washed thoroughly with distilled water to remove any dirt or impurities. Afterward, they were air-dried at room temperature, ground into a fine powder using a locally made grinder, and stored in airtight plastic containers for later use. Extraction was carried out using a Soxhlet extractor with ethanol as the solvent, which efficiently removed about 99.5% of the active components. The extract obtained was then concentrated by evaporating the solvent at low temperature and stored in airtight containers for subsequent use.

b. Cassava leaf extract: The cassava leaves were carefully sorted and washed thoroughly with distilled water to remove any dirt or impurities. Afterward, they were air-dried, ground into a fine powder using a locally made grinder, and stored in airtight plastic containers for later use. The extraction was performed using a Soxhlet extractor with ethanol as the solvent, which efficiently extracted the active compounds from the cassava leaf powder. The solvent evaporated to concentrate the extract, and the final product was stored in airtight containers for subsequent use.was then evaporated to concentrate the extract, and the final product was stored in airtight containers for subsequent use.

Table 3: Scale Formulation concentration

Material	**Concentration (g)**	**Equivalent Mass in 450 mL of water (g)**
Sodium Chloride (NaCl)	0.028	12.6
Calcium Trioxocarbonate (IV) ($CaCO_3$)	0.005	2.25
Potassium Chloride (KCl)	0.005	2.25
Sodium Trioxocarbonate (IV) (Soda Ash) (Na_2CO_3)	0.002	0.9
Magnesium Chloride ($MgCl_2$)	0.002	0.9
Sodium Lauryl Sulphate (SLS) ($NaC_{12}H_{25}SO_4$)	0.001	0.45
Aluminium Tetraoxosulphate (VI) ($Al_2(SO_4)_3$)	0.0005	0.225
Barium Tetraoxosulphate (VI) ($BaSO_4$)	0.0005	0.225

2.2.2 Characterization

Fourier transform infrared spectroscopy, known as FTIR (Agilent Cary 630, US in transmission mode from 4000 to 600 cm−1), was employed to identify the existence of different functional groups in the suggested scale inhibitors.

2.2.3 Experimental Analysis

2.2.3.1 Scale Inhibition Test

1. Preparation of Test Solution: 10.0 mL of the prepared scale-forming solution (Hybrid $BaSO_4$/$CaCO_3$ and $BaSO_4$ solution) for each case of scale compound to be tested respectively were poured into a graduated cylinder.

2. Addition of Inhibitors

a. For Cassava Leaf Extract (CLE):
i. Low dose: 0.5 mL of CLE solution was added
ii. High dose: 1.0 mL of CLE solution was added

b. For Clove Extract (CE):
i. Low dose: 0.5 mL of CE solution was added
ii. High dose: 1.0 mL of CE solution was added

c. Control Setup: Same volume of solvent was added

3. Mixing and Incubation

a. The vials were tightly caped and place on a laboratory shaker operating at approximately 100 rpm.
b. The setup was maintained at ambient for 15 minutes exposure period to allow scale formation and inhibitor interaction.

4. Filtration (Vacuum Pump Process)

a. After incubation, the test sample were filtered through a pre-weighed, trimmed filter paper placed on a Büchner funnel under vacuum.

b. For the conclusion of each case the beaker and funnel were rinsed gently with small portions of deionized water to ensure that all deposited scale particles are collected on the filter paper.

5. Drying and Weighing

a. The filter paper were dried with the retained scale deposit in an oven set at 60–105 °C until constant mass is achieved.
b. The dried filter paper was cooled in a desiccator and weigh using an analytical balance.
c. Record the following readings:
  i. Mass of filter + deposit (m-sample)
  ii. Mass of blank filter (m-blank)
  iii. Deposit mass = (m-sample) − (m-blank)

Table 4: Produced Water (P.W) – Iron Carbonate ($FeCO_3$) Inhibition Test Sample Descriptions

Sample	**Description**
Sample A	(control)
Sample B	(P.W + CLE)
Sample C	(P.W + CLE)
Sample D	(P.W + Clove)
Sample E	(P.W + Clove)
Sample F	(P.W +Poly-Carboxylate)

Table 5: Hybrid $CaCO_3$/$BaSO_4$ Scale Inhibition Test Sample Descriptions

Sample	**Description**
Sample A	(control)
Sample B	(hybrid + CLE)
Sample C	(hybrid + CLE)
Sample D	(hybrid + Clove)
Sample E	(hybrid + Clove)
Sample F	(hybrid + Poly-Carboxylate)

Table 6: Barium sulphate ($BaSO_4$) Scale Inhibition Test Sample Descriptions

Sample	**Description**
Sample A	(control)
Sample B	(Barite+ CLE)
Sample C	(Barite + CLE)
Sample D	(Barite + Clove)
Sample E	(Barite+ Clove)
Sample F	(Barite + Poly-Carboxylate)

6. Inhibition efficiency calculation

Calcularion of the Inhibition Efficiency (IE%) for each inhibitor and dosage was facilitated using the formula below:
IE (%) = [(M-control − M-inhibitor) / M-control] × 100

where:

M-control = mass of deposit without inhibitor

M-inhibitor = mass of deposit with inhibitor

2.2.3.2 Corrosion Analysis Using the Static Jar Method

1**.** Preparation of Metal coupons

a. Cut mild steel or the chosen pipeline material into uniform pieces.
b. Polish, degrease with acetone or ethanol, rinse with distilled water, dry, and record the initial weights.

2. Prepare Scale-Forming Solutions

a. Prepare separate jars with scale-forming ions
b. Include one jar with produced water as the control (no scale ions).

3. Label and Fill Jars

a. Jars were labeled clearly
b. Equal volumes (3 mL) of each solution were poured into clean jars.

4. Coupons Immersion

a. One pre-weighed coupon were suspended in each jar, ensuring it is fully submerged and not touching the walls.
b. The jars were covered to prevent contamination.

5. Expose under Static Conditions

a. The setup was left for a period of 7 days at room temperature with a 2-day interval check routine.
b. Within the two days interval time, the samples were removed and weighed to ascertain their mass state.

6. Weigh and Record

a. Measure the final weight of each coupon.
b. Note any visible corrosion spots or deposits.

7. Compare Results: Compare weight loss and surface appearance between the control and scale-exposed samples to determine if scale promotes corrosion

2.2.4 ECONOMIC ANALYSIS

The economic analysis was performed to determine the cost-effectiveness of the locally prepared inhibitors in comparison with a commercial chemical inhibitor, following the procedures adopted by [17]. The analysis assessed both the production cost of the inhibitors and their performance efficiency, expressed as inhibition percentage, to establish an overall cost–benefit relationship.

All cost components were first identified and categorized into direct and indirect costs as recommended by [18]. Direct costs included raw materials, solvents, reagents, and energy used during extraction, while indirect costs covered labour and equipment usage. The cost of each item was determined using prevailing local market prices at the time of the study. The total production cost per litre of inhibitor (C_T) was obtained using Equation (1):

$$C\_T = C\_R + C\_S + C\_E + C\_L \quad (1)$$

where C_R = raw material cost, C_S = solvent/reagent cost, C_E = energy cost, and C_L = labour cost.

The inhibition performance data obtained experimentally were expressed as inhibition efficiency (%) and were used to determine the cost per percent inhibition (C_P), following the method described by [17]:

$$C\_P = C\_T / I\_E \quad (2)$$

where C_P = cost per percent inhibition (₦/%), and I_E = inhibition efficiency (%).

To evaluate the overall economic viability, a Cost–Benefit Ratio (CBR) was computed as shown in Equation (3):

$$CBR = I\_E / C\_T \quad (3)$$

A higher CBR value indicated a more economically efficient inhibitor. The comparative cost data for the local and synthetic inhibitors were analyzed, and their relative cost advantages were discussed based on their inhibition efficiencies.

Furthermore, a scale-up cost projection was conducted to estimate field-level economic performance. The projection considered a potential 30–50% reduction in cost due to bulk procurement and process optimization, consistent with the assumptions reported by [18]. The calculated results were organized into tables and graphical forms to enhance clarity and facilitate comparison between the laboratory and projected field costs.

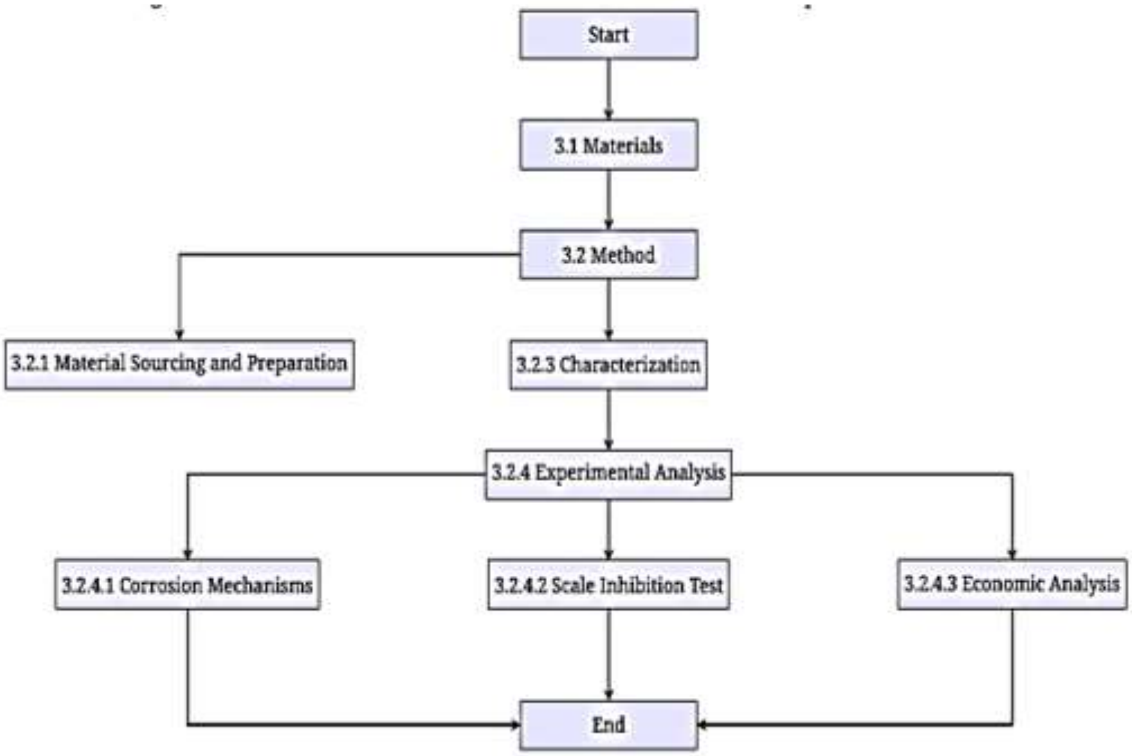

Figure 13: Flowchart of experimental procedure

3. Results and Discussion

3.1 Results

3.1.1 Characterization

Table 7: Clove Extract FTIR Absorption Bands and Functional Group Assignments

Absorption Band (cm^{-1})	**Functional Group / Chemical Assignment**	**Interpretation**
3380.6	Hydroxyl (–OH) groups	Broad O–H stretching vibration due to phenolic hydroxyl groups, primarily from eugenol, which is the major component of clove extract. Indicates strong hydrogen bonding among phenolic compounds.

2833	Aromatic C–H functional groups	C–H stretching vibrations associated with aromatic rings, confirming the presence of aromatic hydrocarbons typical of phenolic and lignin-type structures in clove oil.
1400–1600	Aromatic rings of phenolic compounds	C=C stretching in aromatic rings; confirms the presence of phenolic compounds, especially eugenol and other aromatic constituents responsible for antioxidant activity.
550–850	Bending of aromatic C–H (linked to eugenol)	Out-of-plane bending vibrations of aromatic C–H bonds associated with substituted benzene rings found in eugenol and eugenyl acetate.
1718	C=O bond (carbonyl stretching)	Carbonyl stretching vibration from esters or aldehydes, such as eugenyl acetate, indicating oxidation or esterification of eugenol derivatives in the extract.
1000	C–O stretching vibration	C–O stretching of ether or ester linkages typical of eugenol's methoxy group (–OCH_3) and other oxygenated phytochemicals in clove extract.

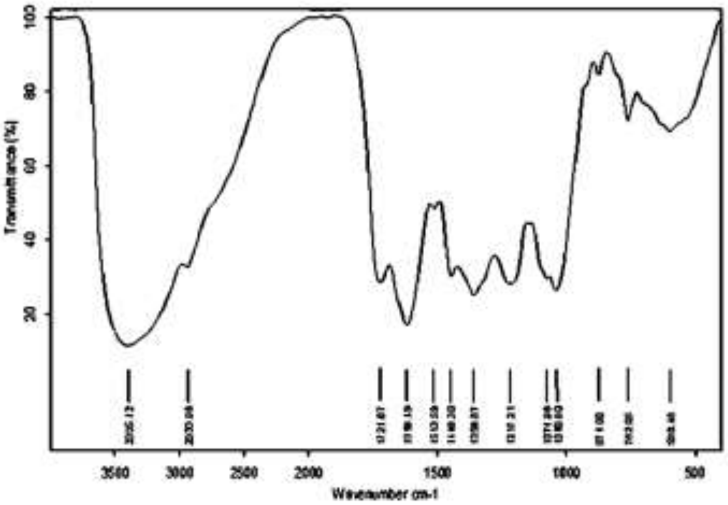

Figure 14: FT-IR spectra of clove extract.

Table 8: Cassava Leaf Extract FTIR Absorption Bands and Functional Group Assignments

Absorption Band (cm⁻¹)	**Functional Group / Chemical Assignment**	**Interpretation**
3385.35	O–H stretching vibrations (hydroxyl groups)	Broad O–H band indicates the presence of hydroxyl groups from phenolic compounds, alcohols, and carbohydrates common in cassava leaves; also reflects hydrogen bonding in polyphenols and water molecules.
1652.75	C=O stretching of carbonyl groups	Strong carbonyl absorption associated with aldehydes, ketones, or amide groups in proteins and flavonoids; confirms the presence of carbonyl-containing biomolecules in the extract.
1065.38	C–O–C stretching vibrations (ether or ester linkages)	Characteristic of C–O and C–O–C bonds found in polysaccharides, glycosides, and esters; indicative of carbohydrate and flavonoid components in cassava leaf extract.

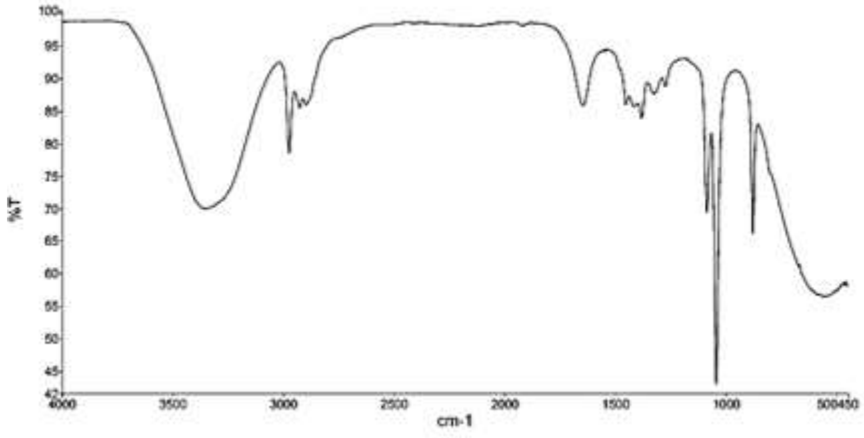

Figure 15: FT-IR spectrum of Cassava Leaf Extract

Table 9: FTIR Absorption Bands and Functional Group Assignments for Conventional Scale Inhibitor (Poly-Carboxylate)

Wavenumber (cm⁻¹)	**Observed Band**	**Functional Group Assignment**	**Interpretation**
3340	Broad absorption	O–H stretching vibration (hydrogen-bonded hydroxyl or carboxylic acid)	Indicates presence of –COOH / –COO⁻ groups and adsorbed moisture; typical of poly-carboxylate polymers.
2953 – 2868	Medium peaks	C–H stretching (sp³) of –CH_2 and –CH_3 groups	Represents aliphatic polymer backbone of the inhibitor.
1635	Strong band	Asymmetric stretching of carboxylate (COO⁻) or C=O stretch	Confirms carboxylate functionality responsible for scale inhibition through Ca^{2+} chelation.
1458	Medium band	Symmetric stretching of carboxylate (COO⁻); CH_2 bending	Characteristic of poly-carboxylate inhibitors such as polyacrylate or polymaleate.
1376	Weak–medium band	CH_3/CH_2 deformation and symmetric COO⁻ stretch	Supports presence of carboxylate groups along polymer chain.
<800	None significant	–	Absence of carbonate (710–875 cm⁻¹) or sulfate (1100, 670 cm⁻¹) peaks confirms non-mineral, organic character.

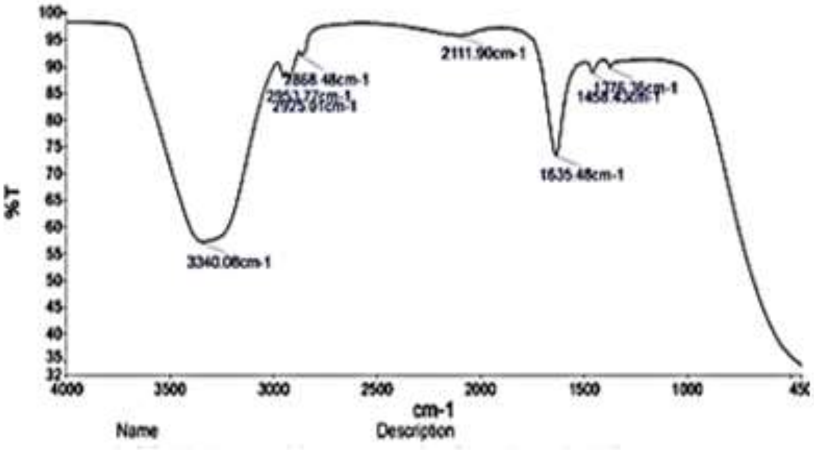

Figure 16: FT-IR spectrum of Conventional Scale Inhibitor

3.1.2 Inhibition Test

Table 10: Inhibition test for produced water

Sample	Volume inhibitor (mL)	Filter + deposit (g) (m_{total})	Filter blank (g) (m_{blank})	Deposit mass (g) (M)	Inhibition Efficiency IE (%)
A	0.0	0.485	0.155	0.330	0.00
B	0.5	0.315	0.155	0.160	51.52
C	1.0	0.295	0.155	0.140	57.58
D	0.5	0.305	0.155	0.150	54.55
E	1.0	0.285	0.155	0.130	60.61
F (Conventional)	1.0	0.280	0.155	0.125	62.12

Table 11: Inhibition test for Hybrid $BaSO_4/CaCO_3$ scale

Sample	Volume inhibitor (mL)	Filter + deposit (g) (m_{total})	Filter blank (g)	Deposit mass (g) (M)	Inhibition Efficiency IE (%)
A	0.0	0.493	0.155	0.338	0.00
B	0.5	0.320	0.155	0.165	51.18
C	1.0	0.305	0.155	0.150	55.62
D	0.5	0.315	0.155	0.160	52.66
E	1.0	0.290	0.155	0.135	60.06
F (Conventional)	1.0	0.283	0.155	0.128	61.78

Table 12: Inhibition test for $BaSO_4$ scale

Sample	Volume inhibitor (mL)	Filter + deposit (g) (m_{total})	Filter blank (g)	Deposit mass (g) (M)	Inhibition Efficiency IE (%)
A	0.0	0.373	0.155	0.218	0.00
B	0.5	0.262	0.155	0.107	50.92
C	1.0	0.255	0.155	0.100	54.13
D	0.5	0.260	0.155	0.105	51.83
E	1.0	0.245	0.155	0.090	58.72
F (Conventional)	1.0	0.240	0.155	0.085	60.46

3.1.3 Corrosion Test

Table 13: Corrosion test with metal coupons

Day	Initial Weight (g)	Final Weight (g)	Weight Loss (g)
0	12.400	—	—
2	12.400	12.392	0.008
4	12.392	12.376	0.016
6	12.376	12.350	0.026

3.1.4 Economic Analysis

Table 14: Economic analysis on local inhibitors used

Scale Type	Inhibitor	C_t (₦/L)	I_e (%)	C_p (₦/%)	CBR ($\times 10^{-2}$)
Produced Water	Clove Extract	3,500	60.61	57.75	1.73
Produced Water	Cassava Leaf	3,200	57.58	55.60	1.80
Produced Water	Conventional (Poly-Carboxylate)	7,000	62.12	112.74	1.20
Hybrid Scale	Clove Extract	3,500	60.06	58.27	1.72
Hybrid Scale	Cassava Leaf	3,200	55.62	57.52	1.74
Hybrid Scale	Conventional (Poly-Carboxylate)	7,000	61.78	113.33	1.18
$BaSO_4$ Scale	Clove Extract	3,500	58.72	59.61	1.68
$BaSO_4$ Scale	Cassava Leaf	3,200	54.13	59.13	1.69
$BaSO_4$ Scale	Conventional (Poly-Carboxylate)	7,000	60.46	115.76	1.15

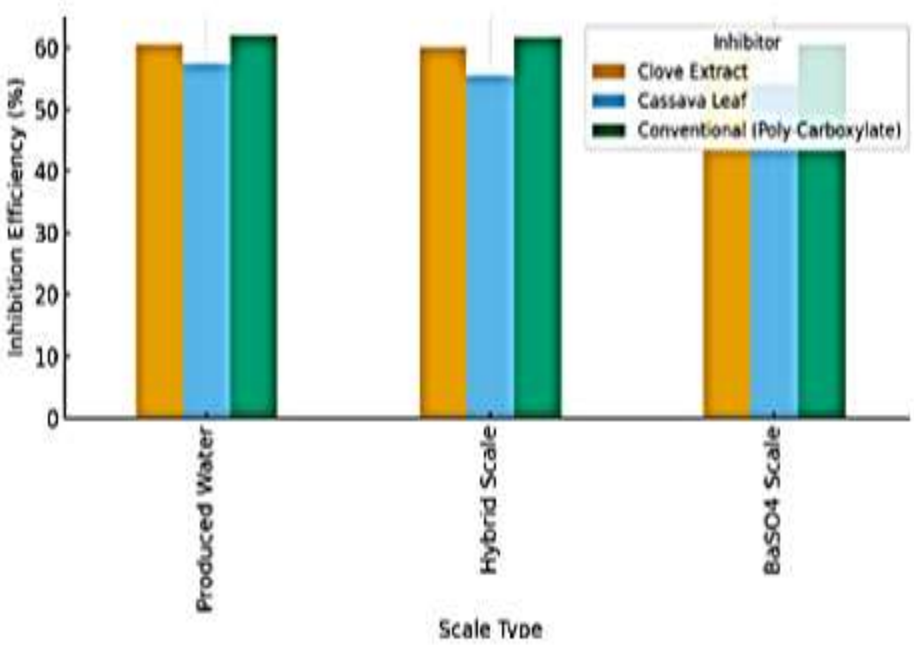

Figure 17: Inhibition Efficiency Comparison Across Scale Types

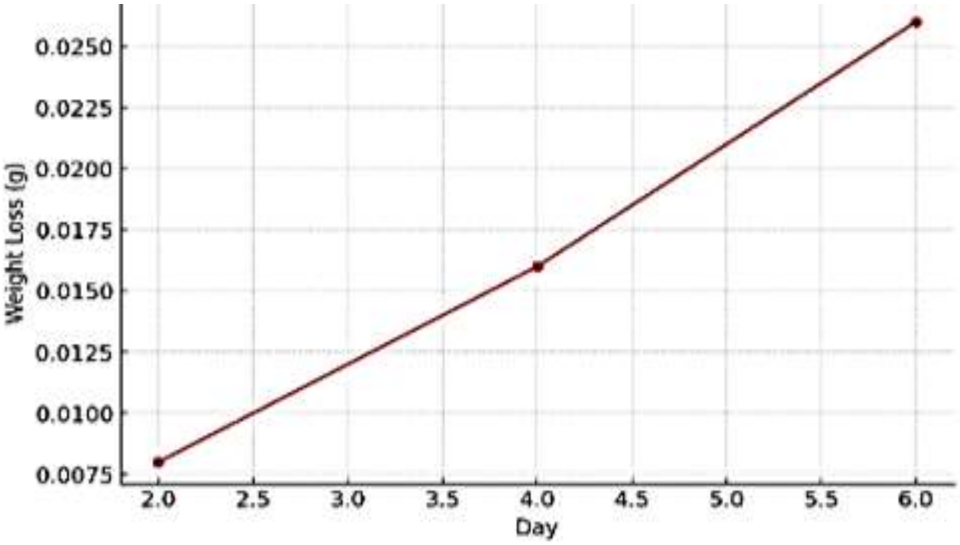

Figure 18: Weight Loss vs Corrosion Time

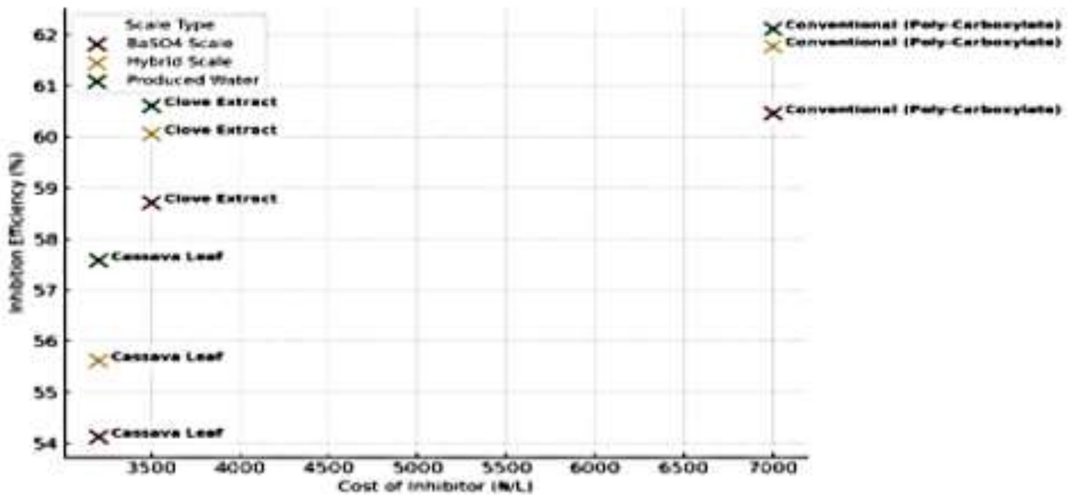

Figure 19: Scatter Plot Diagram of Inhibition Efficiency vs Cost of Inhibitor

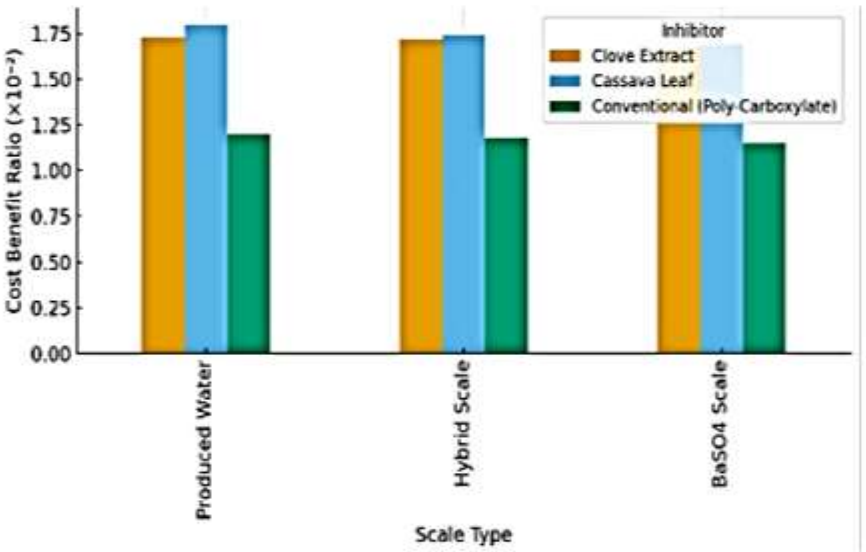

Figure 20: Cost Benefit Ratio (CBR) Comparison Chart

3.2 Discussion

The results obtained in this study confirm the significant potential of local plant materials specifically clove and cassava leaf extracts as effective green inhibitors for scale and corrosion control in oilfield pipelines. FTIR characterization in Tables 7 and 8 revealed the presence of hydroxyl (–OH), carbonyl (C=O), and aromatic functional groups, consistent with phenolic and flavonoid compounds. These findings align with reports by [19; 20], such functional groups interact with scale-forming ions (Ca^{2+}, Ba^{2+}, and SO_4^{2-}) through adsorption and complexation, thereby disrupting crystal nucleation and growth mechanisms.

The inhibition efficiencies obtained for the produced water, hybrid ($BaSO_4/CaCO_3$), and $BaSO_4$ (barite) scales (Tables 10–12) exhibited a clear concentration-dependent trend. For both extracts, increasing inhibitor dosage from 0.5 mL to 1.0 mL produced a corresponding rise in inhibition efficiency, confirming the adsorption-controlled mechanism typical of threshold inhibitors. Among the local inhibitors, clove extract consistently achieved the highest inhibition efficiencies of up to 60.61% for produced water and 60.06% for hybrid scale compared to cassava leaf extract, which achieved 57.58% and 55.62%, respectively. This superior performance is attributed to the higher eugenol and phenolic content in clove, enhancing its capacity for chelation and crystal modification.

The conventional poly-carboxylate inhibitor, although slightly more effective (up to 62.12%), showed only a marginal efficiency gain (≈4–6%) compared with the local extracts suggesting similar functional group interactions ($–COO^-$, –OH) between the synthetic polymer and the plant-based compounds.

The corrosion test (Table 13) further established that, in the absence of inhibitors, the metal coupons experienced progressive weight loss with exposure time. Over the 6-day period, the weight loss increased from 0.008 g (day 2) to 0.026 g (day 6). This observation agrees with the corrosion mechanisms, where the presence of scale deposits facilitates under-deposit corrosion by forming localized electrochemical cells. The results affirm that scale deposition significantly accelerates metal deterioration, emphasizing the importance of integrated scale and corrosion control strategies.

The economic evaluation (Table 14) highlighted the financial viability of using local green inhibitors over synthetic alternatives. Calculations of cost per percent inhibition (C_p) and cost–benefit ratio (CBR) were performed. The cassava leaf and clove extracts recorded C_p values of approximately ₦55–₦58 per % and CBR values ranging from 1.68×10^{-2} to 1.80×10^{-2}, indicating high efficiency at low cost. In contrast, the poly-carboxylate inhibitor, though slightly more efficient (up to 62.12%), incurred a substantially higher cost (₦7,000/L), resulting in an elevated C_p (≈₦110 per %) and a lower CBR ($\approx 1.15–1.20 \times 10^{-2}$). This confirms that the local extracts achieved comparable technical performance at nearly half the cost, thereby validating the hypothesis that green inhibitors are both economically and environmentally superior to conventional synthetic products.

Overall, the combined FTIR, inhibition, corrosion, and economic results strongly support the application of clove and cassava leaf extracts as sustainable and cost-effective alternatives to synthetic polymeric inhibitors for controlling barite and mixed scale formation in produced water systems.

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