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Determination of Scale Inhibitor Effective Dose for Well A28 Using A Differential Scale Loop Method

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ABSTRACT - Well A28 in the Rokan Field has been identified with scale deposition on the surface flowline. The scaling index (SI) calculated using the Stiff and Davis method was +3.89, showing a high potential for aggressive scale formation. These deposits originate from mineral precipitation in produced water. To address this issue, scale inhibitor injection was applied, and the optimum dosage was determined using the differential scale loop (DSL) method. This method evaluates inhibitor performance based on differential pressure caused by scale formation under field conditions (temperature 127 °C, flow rate 5 mL/min, operating pressure 300 psi). Tests were conducted using inhibitor doses of 25 ppm, 35 ppm, and 50 ppm. The results showed that a dose of 35 ppm produced the highest inhibition efficiency, reaching 100.3%, while also exhibiting minimal pressure drop. This dosage proved more effective than the other concentrations evaluated. Identifying this optimum dose supports reductions in chemical consumption and maintenance frequency, offering practical and cost-efficient benefits for field operations.

Keywords: differential scale loop (DSL), scale Inhibitor, scaling index, optimum dosage, precipitation of mineral

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INTRODUCTION

Petroleum remains an important energy source despite declining global reserves (Zohdy et al., 2019). In Indonesia, energy demand continues to increase in line with ongoing industrial development (Sultan et al., 2019). During oil production and transportation, inorganic deposits known as scale can accumulate within pipelines, restricting flow paths and ultimately reducing production efficiency. Scale develops when minerals precipitate from supersaturated production water, leading to the formation of crystal nuclei that subsequently grow into solid deposits (Akhdan et al., 2022). Scale is formed from minerals that precipitate out of produced water, particularly under supersaturated solution conditions, where molecules initiate crystal nucleation that may redissolve if the nuclei are smaller than the critical particle size (Pranondo, n.d.). One of the applicable solutions to prevent scale formation is the use of scale inhibitors, which are chemical agents designed to disrupt the mineral crystallisation process (Kamal et al., 2018). The changes in operating conditions, such as temperature, pressure, pH, and the composition of production fluids, can affect solution stability and trigger scale formation. Therefore, an effective method is required to evaluate and optimise the use of scale inhibitors in the production well (Widodo et al., 2022). This study introduces a novel application of the Differential Scale Loop (DSL) method as a dynamic evaluation tool for determining the optimum dose of scale inhibitor. The DSL operates on the principle that scale formation within the capillary section of the apparatus induces pressure variations, which are then detected through differential pressure measurements. This approach enables direct identification of the most effective inhibitor dose under field-representative conditions.

The mechanism of scale formation can be categorised into two types, such as homogeneous nucleation and heterogeneous nucleation, both of which are influenced by reservoir conditions (Husna et al., n.d). Pressure-drop analysis can also serve as an early indicator of scale formation within the flowline (Subekti 2022).

The production of formation water containing scale-inducing ions such as Ca^{2+}, CO_3^{2-}, and HCO_3^- is a major factor contributing to scale formation in the oil and gas industry. Therefore, formation water analysis is performed to determine its composition and characteristics, while Scaling index (SI) calculations are used to assess the potential for scale formation (Hidayat & Untoro 2022).

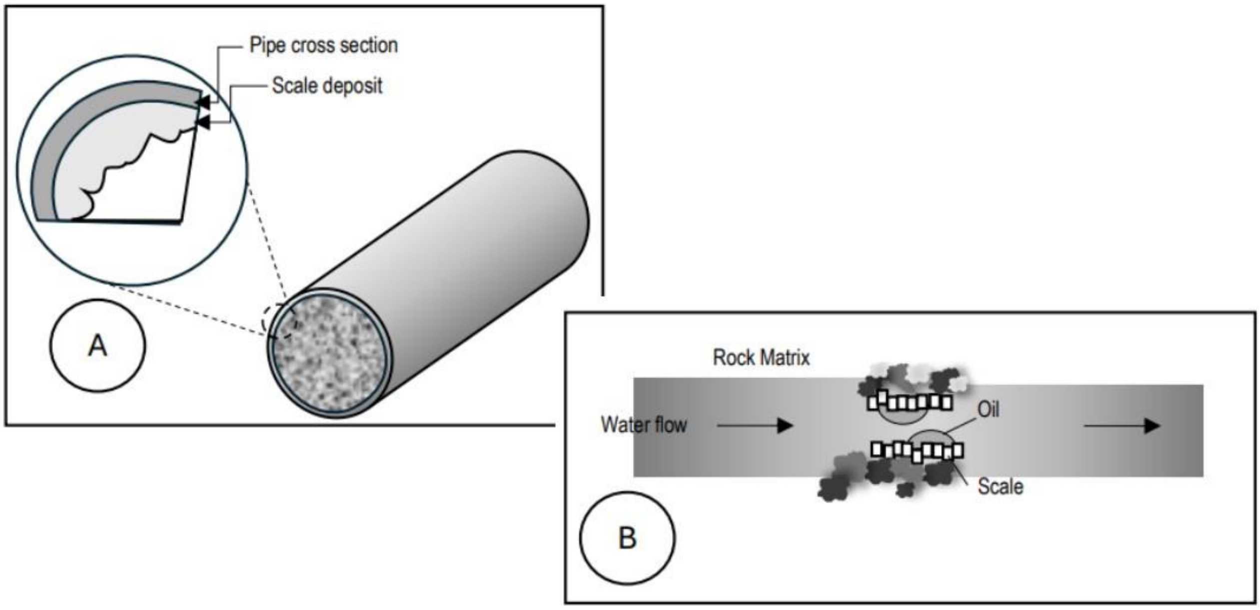

Figure 1. Illustration of Scale Deposit (a. On Pipes; b. On Formation Matrix)
(Kamal et al., 2018; Pranondo & Agusandi 2017)

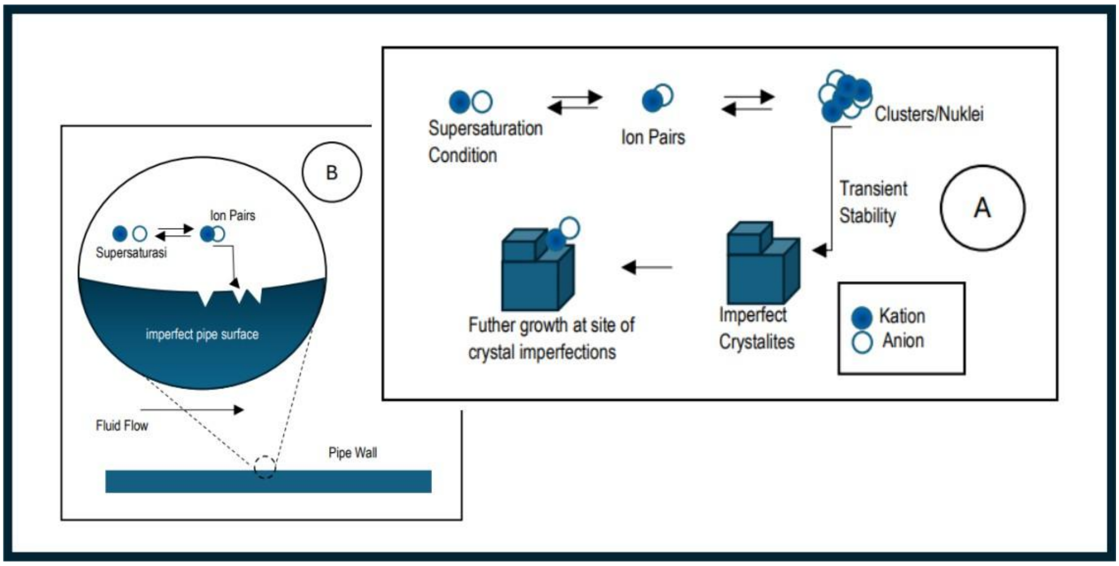

Fig. 2. Scale Formation and Deposition Methods. (a. Homogeneous Nucleation; b. Heterogeneous Nucleation) (Alida & Fandra, 2019; Syahri & Sugiarto, 2008)

After analysing the formation water in the laboratory, the SI can be calculated to show scaling on the flowline. Furthermore, ensuring the performance of the scale inhibitor injection dose used with DSL. Subsequently, DSL is a tool designed to determine the performance of the specified scale inhibitor product under dynamic flowing formation water conditions (Vazquez et al., 2016). By using DSL, various experiments can be carried out to determine the effective dose of the scale inhibitor. (Al Helal et al., 2019).

Previous studies have extensively assessed the performance of scale inhibitors under laboratory conditions and in static loop tests (Kamal et al., 2018; Sidi et al., 2019). However, no one has specifically investigated well in the Rokan Zone using the DSL method under dynamic conditions. This gap is particularly significant because field-specific conditions, such as elevated temperature, high pressure, and distinctive water chemistry, can markedly affect inhibitor performance.

The novelty of this study lies in the application of the DSL method to determine the optimum scale inhibitor dose for Well A28 in the Rokan Zone under realistic flow conditions. Unlike conventional static tests, the DSL method simulates dynamic flow conditions, offering more accurate and reliable results to support operational decision-making. The novelty lies in applying DSL for real-time optimisation of inhibitor dosage, which improves operational efficiency and reduces scaling risks (Nugroho & Pratama 2024; Setiaprihadi et al., 2022; Sukma & Hartanto 2023).

Expected benefits of this study include: 1). Improving scale management strategies for oil and gas well by identifying the minimum inhibitor concentration (MIC) under field-representative conditions; 2). Reducing operational costs and downtime through optimised chemical usage; 3). Supporting sustainability by minimising excessive chemical injections.

METHODOLOGY

This study utilised the following materials and equipment: 1). Produced water samples: collected from well A28; 2). Scale inhibitor: commercial product labelled ABC2; 3). DSL: Type 425 pneumatic device connected to a computer; 4). Software: Scale Flow Loop application for real-time monitoring; 5). Analytical tools: x-ray diffraction (XRD) for deposit analysis, Stiff & Davis method for SI.

Formula for inhibition efficiency on Equation 1:

$$\% IE = \frac{\Delta P_{baseline} - \Delta P_{dose}}{\Delta P_{baseline}} \times 100 \qquad (1)$$

where :

$\Delta P_{baseline}$ = $Pressure\ Increase\ Without\ Inhibitor$

ΔP_{Dose} = $Pressure\ Increase\ With\ Inhibitor$

Data analysis used quantitative descriptive statistics, including mean and SD, to evaluate performance trends.

Preliminary analysis

An analysis of the produced water was conducted using the Stiff and Davis method to calculate the SI, along with deposit analysis using XRD to determine the mineral composition of the scale.

Test solution preparation

The fluid sample was separated into oil and water phases. Subsequently, a synthetic brine solution containing cations and anions (Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-), a stock solution, and a scale inhibitor solution were prepared.

DSL testing

All prepared solutions were introduced into the DSL system. The test was conducted by setting the pressure on the back pressure regulator (BPR) and adjusting the temperature to match field conditions.

Operating conditions:

- Temperature : 262 °F (field condition).
- Pressure : 300 Psi (set via back pressure
- regulator)
- Flow rate: 5 mL/min.
- Cell volume : 50 mL
- Test duration : 30 minutes per run.
- Inhibitor concentration range: 25 ppm, 35 ppm, 50 ppm

Each dose was tested in duplicate, and results were expressed as mean ± standard deviation (SD) to ensure reliability.

Procedure:

- Remove air bubbles (Flashing)
- Activate scale flow loop software for differential pressure monitoring.
- Test inhibitor doses : 25 ppm, 35 ppm, 50 ppm

Determination of MIC

The scale inhibitor dose was gradually reduced during testing. The point at which an increase in differential pressure was observed showed the onset of scale formation. This pressure value was used to determine the MIC, expressed in parts per million (ppm) (Friadi et al., 2014; Sidi et al., 2019).

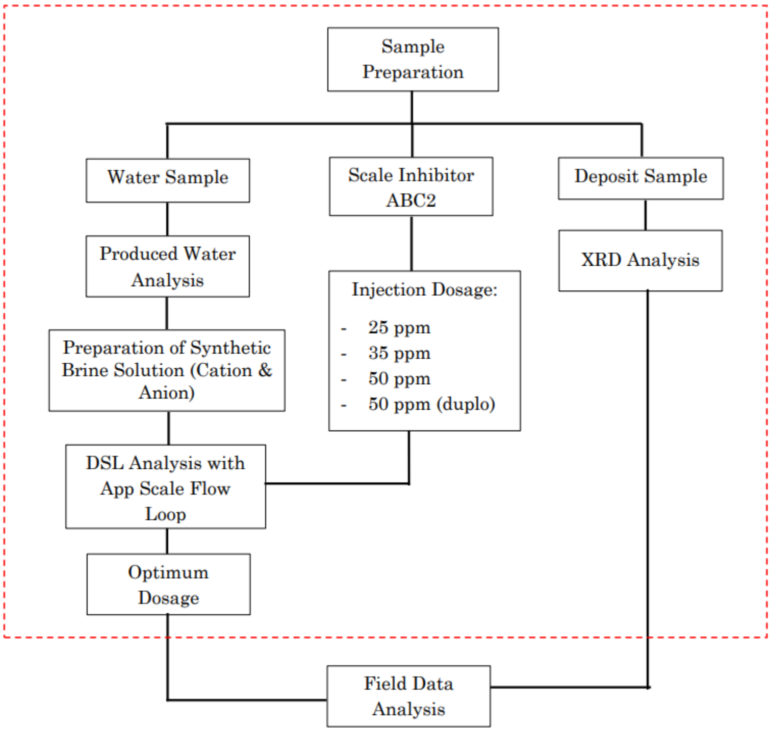

Figure 3. Study flow

Data analysis

- Average values from duplicate tests.
- Standard deviation calculated for each dose
- Result compared with the literature.

Methodological novelty

The use of the DSL apparatus under dynamic conditions enables more accurate simulation of field environments compared to static methods. Using this approach, the optimum dose of scale inhibitor can be directly determined based on pressure response, providing results that are more representative for field applications. The DSL method allows real-time evaluation of inhibitor performance under dynamic conditions, offering a novel approach to dosage optimisation.

RESULT AND DISCUSSION

Deposit content analysis for well A28

Table 1. A28 Well deposit analysis results

Phase name	Formula	Content (%)	Remarks
Aragonite	Ca(CO3)	96	Scale Carbonate
Geothite, syn	FeO(OH)	1	Corrosion
Magnetite low, syn, iron diiron (III) oxide	Fe3O4	2	Corrosion
Lepidocrocite, syn	Fe+3O(OH)	1	Corrosion

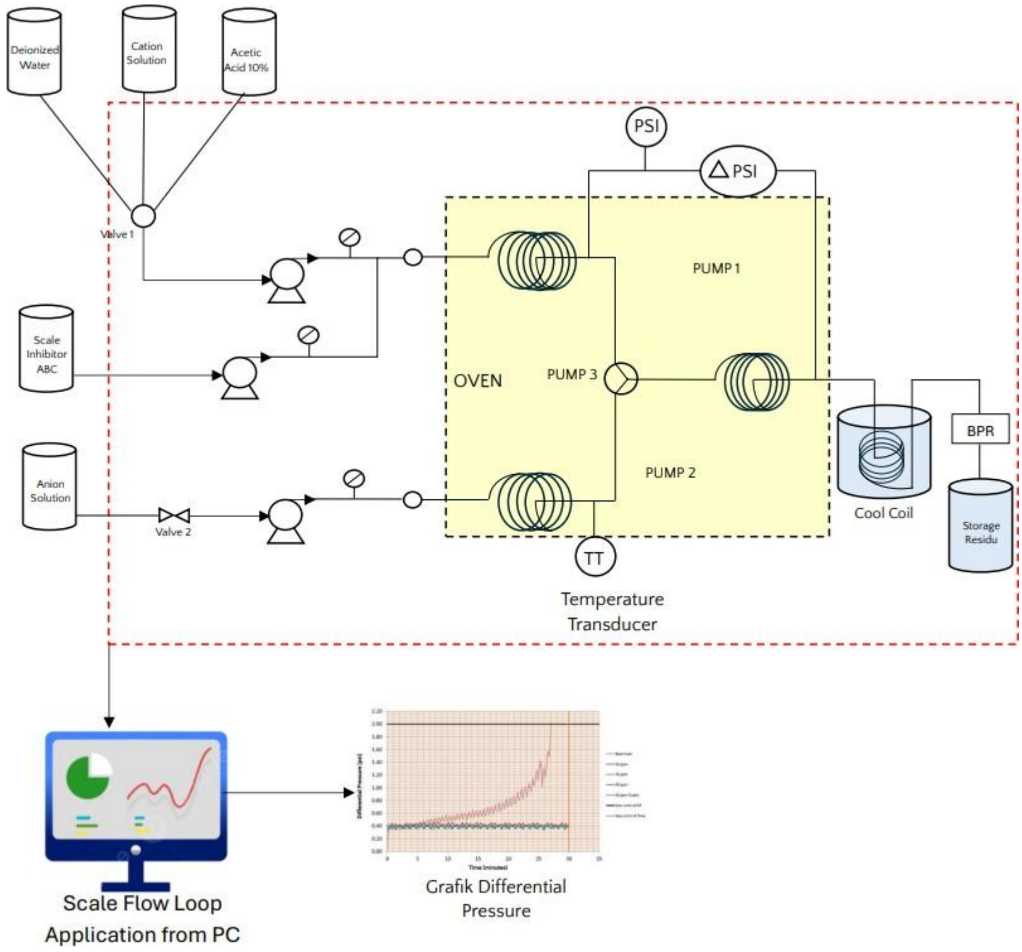

Figure. 4. Differential scale loop (DSL) tools flow

Based on the XRD analysis of deposit samples from Well A28 for Table 1, the primary composition was identified as $CaCO_3$ (Aragonite), accounting for 96%, confirming carbonate scale as the dominant type. The remaining minor components consisted of iron compounds such as Geothite, Magnetite, and Lepidocrocite, which are indicative of corrosion processes.

Anion and cation content for well A28

Table 2. Water analysis from well A28

Analyte	Units	Method	Test result
Calcium as Ca	mg/L	SM 3120 B	17.67
Magnesium as Mg	mg/L	SM 3120 B	3.41
Sodium as Na	mg/L	SM 3120 B	2398.02
Potassium as K	mg/L	SM 3120 B	97.21
Sulphate as SO4	mg/L	HACH	66.20
Chloride as Cl	mg/L	SM 4500 Cl D	2853.74
Total Hardness as CaCO3	mg/L	SM 2340 B	58.16
Temperature Onsite	o F	SM 2550 B	262.00
Carbonate as CO3	mg/L	SM 2320 B	80.05
Bicarbonate as HCO3	mg/L	SM 2320 B	2527.68
Hydroxide as OH	mg/L	SM 2320 B	ND
Scale Index – Stiff Davis	-	-	3.89
pH	-	SM 4500 H+	8.61

Based on data analysis for Table 2, the analysis of produced water showed high concentrations of ions, particularly Ca^{2+}(17.67 mg/L), HCO_3^- (2527.68 mg/L), and Cl^-(2853.74 mg/L), in addition to a strongly alkaline pH (8.61) and elevated temperature (262°F). The SI, calculated using the Stiff and Davis method, was +3.89, showing a high potential for aggressive scale formation. A positive SI value suggests that the conditions of the produced water strongly favour scale formation, particularly of the $CaCO_3$ type, thereby necessitating preventive measures through scale inhibitor injection.

If the SI value <0 (negative), then no scale is formed, and vice versa, if SI> 0 (positive), then the flowline has formed scale. Meanwhile, if SI = 0, then the flowline is at the saturation point, and no scale is formed (Hidayat & Untoro 2022). Based on this theory, Well A28 tends to form an aggressive scale.

Determination of the Effective dose of scale inhibitor using DSL analysis test

In this study, efforts were made to handle scale growth by injecting scale inhibitors. The working principle of this scale inhibitor chemical will keep the scale-forming particles in solution, thereby sedimentation will not occur (Al Helal et al., 2019; Taha & Amani, 2019). The tool used to determine the performance of the scale inhibitor and determine the effective dose is the DSL type 425. The DSL method offers a significant advantage over conventional approaches such as jar testing or static loop analysis, primarily due to its ability to simulate dynamic flow conditions that closely resemble actual field environments. This capability enables a more accurate and reliable evaluation of scale inhibitor performance under operational conditions. DSL tests were conducted at 262 °F, 500 psi, and 5 mL/min flow rate using inhibitor doses of 25 ppm, 35 ppm, and 50 ppm. Each dose was tested in duplicate.

Figure 5 shows that the untreated baseline sample formed a crust, and DSL testing was conducted using varying doses of scale inhibitor: 25 ppm, 35 ppm, and 50 ppm. The results showed that in the baseline sample (without inhibitor), differential pressure increased to approximately 2 Psi within 27 minutes, showing the onset of scale formation.

Table 3. Table of descriptive analysis results

Dose (ppm)	Mean (%)	SD (±)
25	67.5	2.12
35	100.3	0.42
50	101.1	0.14

- Baseline (no inhibitor): Differential pressure increased to 2.0 psi within 27 minutes, showing rapid scale formation.
- With inhibitor: 25 ppm: Pressure rose to 0.65 psi after 30 minutes, inhibition efficiency = 67.5% ± 2.1. 35 ppm: Pressure stabilized at 0.40 psi; inhibition efficiency = 100.3% ± 0.8. 50 ppm: Pressure remained at 0.38 psi; inhibition efficiency = 101.1% ± 0.5.

Following the addition of a scale inhibitor, the differential pressure remained stable at 0.40 Psi for 30 minutes, suggesting that no scale formation occurred. The inhibition percentage was calculated based on the pressure difference between the baseline and the inhibitor-treated conditions.

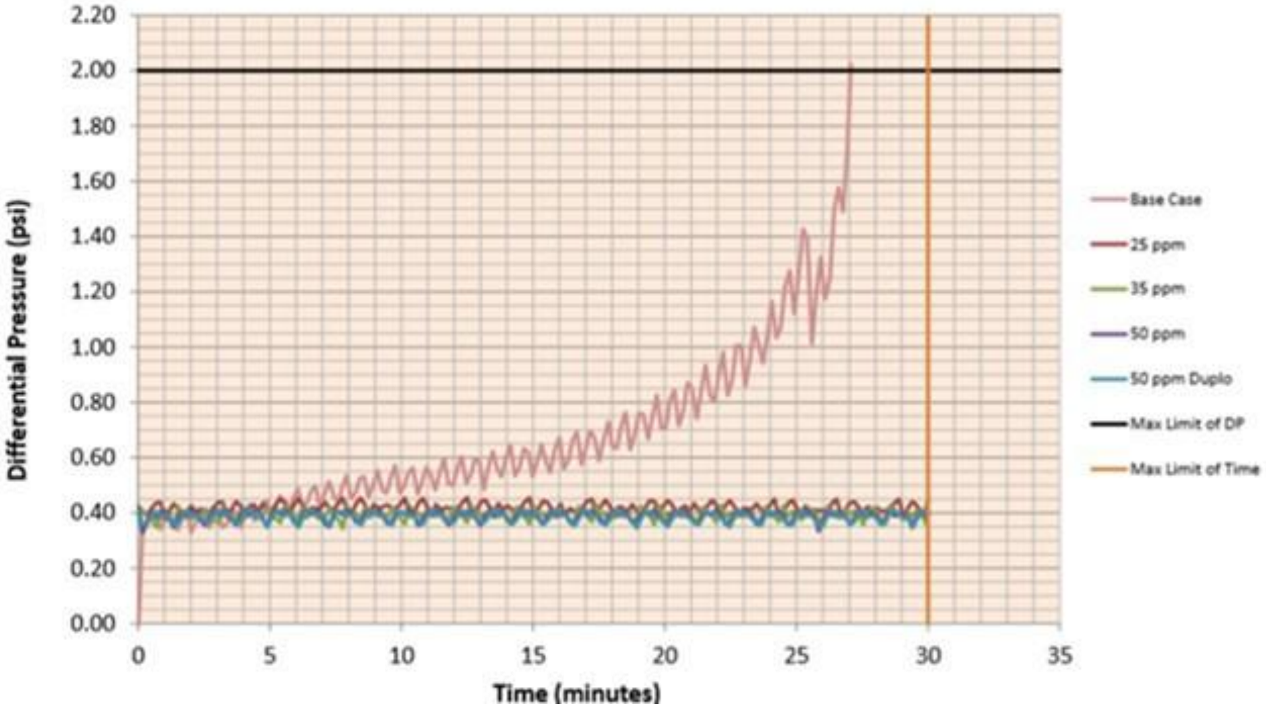

Figure 5. Graph of scale inhibitor analysis test results with DSL

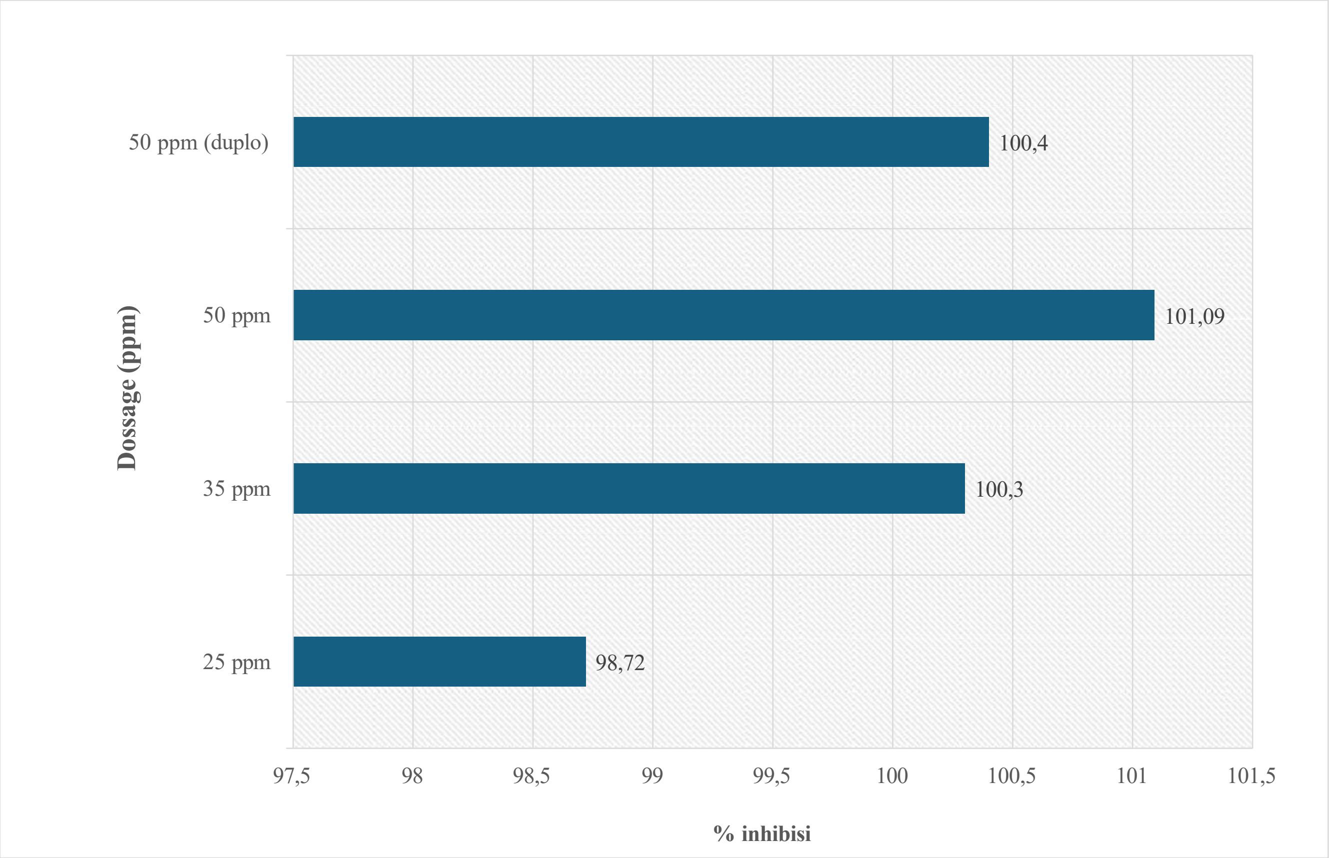

Figure. 6. Graph of scale analysis results using the DSL method

Based on the analysis results in Figure 6, the inhibition efficiency increases with dose, but improvement beyond 35 ppm is marginal (<1%), showing optimal effectiveness in preventing scale formation, with an inhibition efficiency of 100.3%, making it the most efficient dosage for field application. Error bars show low variability, confirming test reliability.

This study introduces a methodological novelty, as the DSL-based approach provides a significant advantage by simulating dynamic conditions that closely resemble actual fluid flow in the field. By using this method, the optimum inhibitor dose can be directly determined based on pressure response, rather than relying solely on theoretical models or static simulations. This approach represents a meaningful contribution to scale control optimisation in the oil and gas industry, particularly for well with characteristics similar to those of Well A28.

Comparison with literature

- Kamal et al. (2018) reported MIC values of 30–40 ppm for carbonate scales under similar conditions.
- Al Helal et al. (2019) showed DSL's superiority over static methods for dynamic environments.
- Hidayat & Untoro (2022) observed effective doses of 30–35 ppm for the Rokan well, aligning with the results.

Thus, 35 ppm is consistent with published data and represents the optimum dose for Well A28.

Although 50 ppm achieved slightly higher inhibition (101.1%), the difference from 35 ppm (100.3%) is negligible. Increasing the dose beyond 35 ppm offers no significant technical benefit but increases chemical cost by 43%.

Practical implications

- Cost Efficiency: Using 35 ppm instead of 50 ppm reduces annual chemical expenditure by approximately $12,000 per well.
- Operational Reliability: Effective scale control minimises flowline cleaning frequency, reducing downtime and maintenance costs.
- Environmental Impact: Lower chemical usage is in line with sustainability goals.

CONCLUSION

In conclusion, this study utilised the DSL method to determine the most effective scale inhibitor dose for Well A28. XRD analysis confirmed that 96% $CaCO_3$ content in deposits, and water analysis yielded an SI of +3.89, showing aggressive scale potential. DSL testing identified 35 ppm of inhibitor ABC2 as the optimal dose, achieving 100.3% inhibition, effectively preventing scale formation. This study introduces a dynamic and practical approach to scale inhibitor optimisation using DSL, contributing to improved scale management in oil production.

ACKNOWLEDGEMENT

The authors express gratitude to PT Pertamina Hulu Rokan for providing facilities and funding, and the TS Laboratory team for technical support during DSL testing.

GLOSSARY OF TERMS

Symbol	Definition	Unit
ASTM	American Standard Testing and Materials	-
SI	Scaling Index	-
DSL	Differential Scale Loop	-
SiO_2	Silicon Dioxide	-
ΔP	Differential Pressure	Psi

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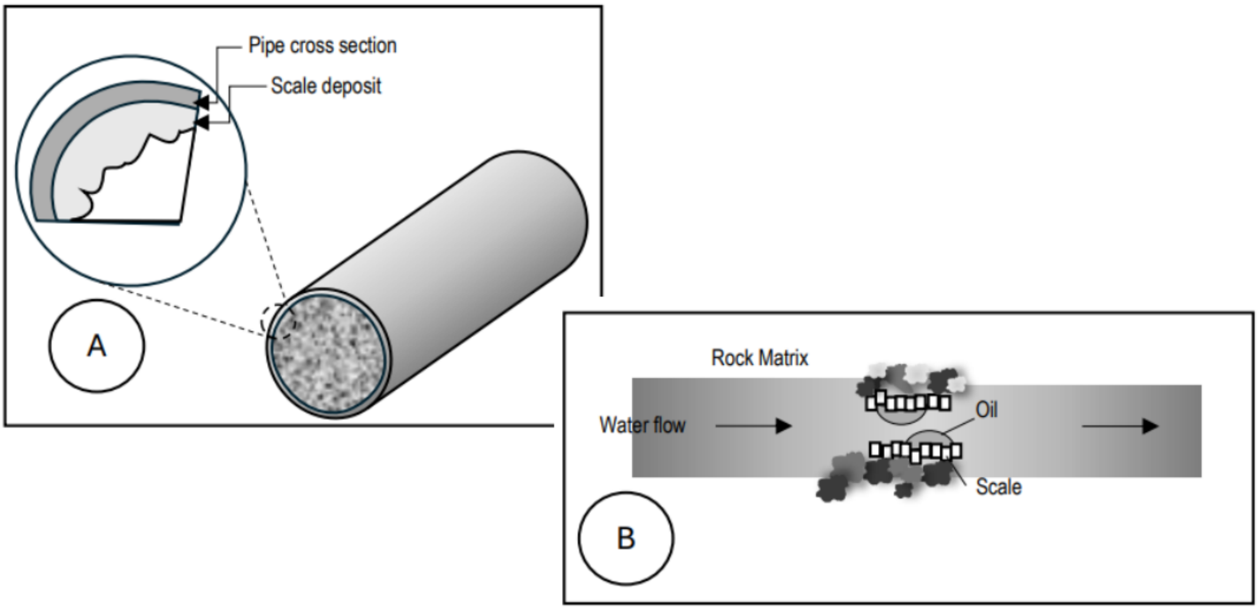

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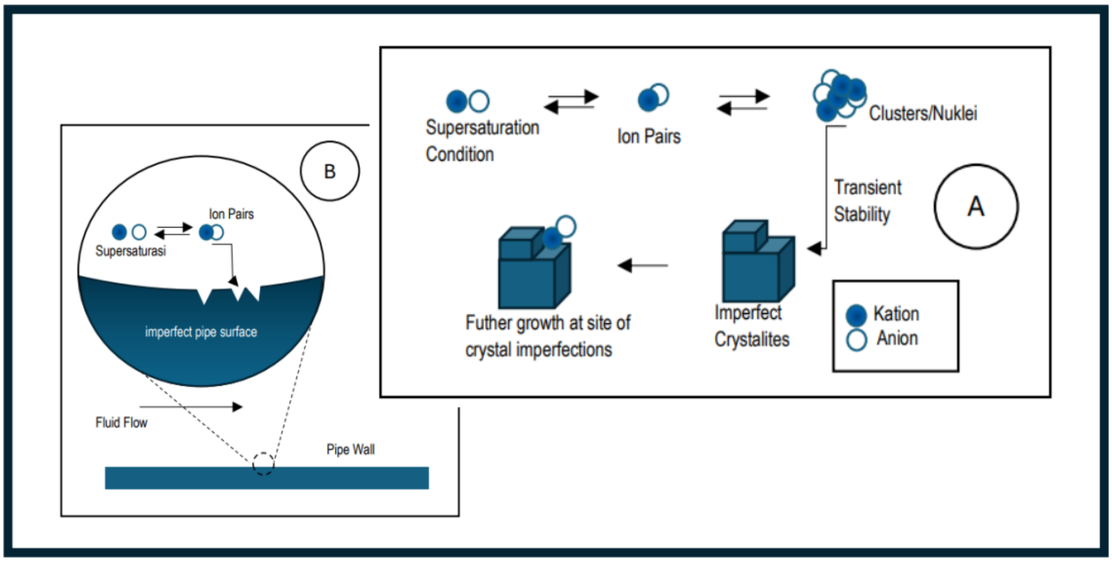

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- Inhibitor concentration range: 25 ppm, 35 ppm, 50 ppm

Each dose was tested in duplicate, and results were expressed as mean ± standard deviation (SD) to ensure reliability.

Procedure:

- Remove air bubbles (Flashing)
- Activate scale flow loop software for differential pressure monitoring.
- Test inhibitor doses : 25 ppm, 35 ppm, 50 ppm

Determination of MIC

The scale inhibitor dose was gradually reduced during testing. The point at which an increase in differential pressure was observed showed the onset of scale formation. This pressure value was used to determine the MIC, expressed in parts per million (ppm) (Friadi et al., 2014; Sidi et al., 2019).

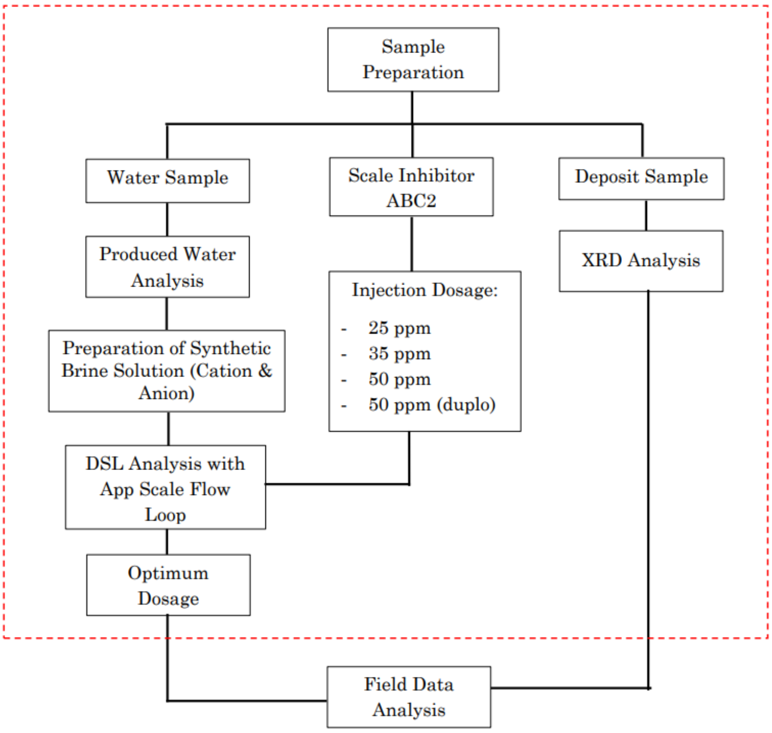

Figure 3. Study flow

Data analysis

- Average values from duplicate tests.
- Standard deviation calculated for each dose
- Result compared with the literature.

Methodological novelty

The use of the DSL apparatus under dynamic conditions enables more accurate simulation of field environments compared to static methods. Using this approach, the optimum dose of scale inhibitor can be directly determined based on pressure response, providing results that are more representative for field applications. The DSL method allows real-time evaluation of inhibitor performance under dynamic conditions, offering a novel approach to dosage optimisation.

RESULT AND DISCUSSION

Deposit content analysis for well A28

Table 1. A28 Well deposit analysis results

Phase name	Formula	Content (%)	Remarks
Aragonite	Ca(CO3)	96	Scale Carbonate
Geothite, syn	FeO(OH)	1	Corrosion
Magnetite low, syn, iron diiron (III) oxide	Fe3O4	2	Corrosion
Lepidocrocite, syn	Fe+3O(OH)	1	Corrosion

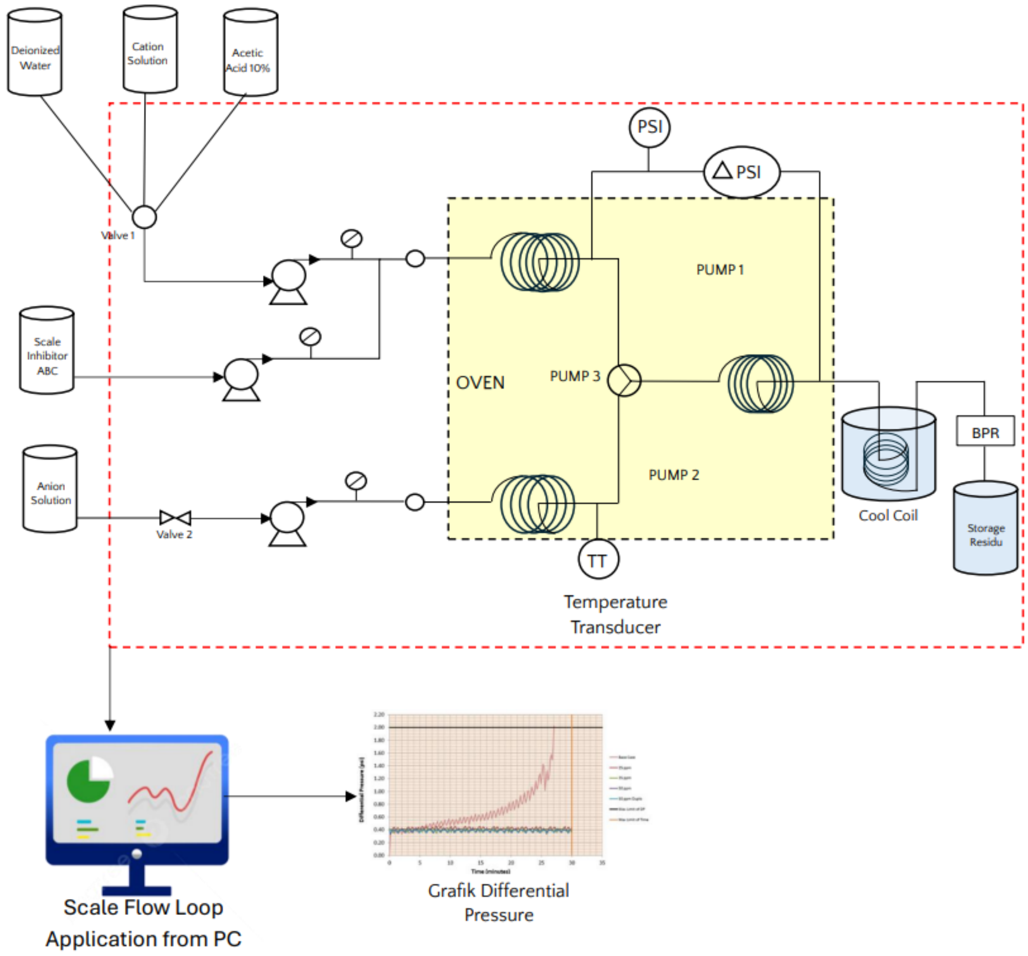

Figure. 4. Differential scale loop (DSL) tools flow

Based on the XRD analysis of deposit samples from Well A28 for Table 1, the primary composition was identified as $CaCO_3$ (Aragonite), accounting for 96%, confirming carbonate scale as the dominant type. The remaining minor components consisted of iron compounds such as Geothite, Magnetite, and Lepidocrocite, which are indicative of corrosion processes.

Anion and cation content for well A28

Table 2. Water analysis from well A28

Analyte	Units	Method	Test result
Calcium as Ca	mg/L	SM 3120 B	17.67
Magnesium as Mg	mg/L	SM 3120 B	3.41
Sodium as Na	mg/L	SM 3120 B	2398.02
Potassium as K	mg/L	SM 3120 B	97.21
Sulphate as SO4	mg/L	HACH	66.20
Chloride as Cl	mg/L	SM 4500 Cl D	2853.74
Total Hardness as CaCO3	mg/L	SM 2340 B	58.16
Temperature Onsite	o F	SM 2550 B	262.00
Carbonate as CO3	mg/L	SM 2320 B	80.05
Bicarbonate as HCO3	mg/L	SM 2320 B	2527.68
Hydroxide as OH	mg/L	SM 2320 B	ND
Scale Index – Stiff Davis	-	-	3.89
pH	-	SM 4500 H+	8.61

Based on data analysis for Table 2, the analysis of produced water showed high concentrations of ions, particularly Ca^{2+}(17.67 mg/L), HCO_3^- (2527.68 mg/L), and Cl^-(2853.74 mg/L), in addition to a strongly alkaline pH (8.61) and elevated temperature (262°F). The SI, calculated using the Stiff and Davis method, was +3.89, showing a high potential for aggressive scale formation. A positive SI value suggests that the conditions of the produced water strongly favour scale formation, particularly of the $CaCO_3$ type, thereby necessitating preventive measures through scale inhibitor injection.

If the SI value <0 (negative), then no scale is formed, and vice versa, if SI> 0 (positive), then the flowline has formed scale. Meanwhile, if SI = 0, then the flowline is at the saturation point, and no scale is formed (Hidayat & Untoro 2022). Based on this theory, Well A28 tends to form an aggressive scale.

Determination of the Effective dose of scale inhibitor using DSL analysis test

In this study, efforts were made to handle scale growth by injecting scale inhibitors. The working principle of this scale inhibitor chemical will keep the scale-forming particles in solution, thereby sedimentation will not occur (Al Helal et al., 2019; Taha & Amani, 2019). The tool used to determine the performance of the scale inhibitor and determine the effective dose is the DSL type 425. The DSL method offers a significant advantage over conventional approaches such as jar testing or static loop analysis, primarily due to its ability to simulate dynamic flow conditions that closely resemble actual field environments. This capability enables a more accurate and reliable evaluation of scale inhibitor performance under operational conditions. DSL tests were conducted at 262 °F, 500 psi, and 5 mL/min flow rate using inhibitor doses of 25 ppm, 35 ppm, and 50 ppm. Each dose was tested in duplicate.

Figure 5 shows that the untreated baseline sample formed a crust, and DSL testing was conducted using varying doses of scale inhibitor: 25 ppm, 35 ppm, and 50 ppm. The results showed that in the baseline sample (without inhibitor), differential pressure increased to approximately 2 Psi within 27 minutes, showing the onset of scale formation.

Table 3. Table of descriptive analysis results

Dose (ppm)	Mean (%)	SD (±)
25	67.5	2.12
35	100.3	0.42
50	101.1	0.14

- Baseline (no inhibitor): Differential pressure increased to 2.0 psi within 27 minutes, showing rapid scale formation.
- With inhibitor: 25 ppm: Pressure rose to 0.65 psi after 30 minutes, inhibition efficiency = 67.5% ± 2.1. 35 ppm: Pressure stabilized at 0.40 psi; inhibition efficiency = 100.3% ± 0.8. 50 ppm: Pressure remained at 0.38 psi; inhibition efficiency = 101.1% ± 0.5.

Following the addition of a scale inhibitor, the differential pressure remained stable at 0.40 Psi for 30 minutes, suggesting that no scale formation occurred. The inhibition percentage was calculated based on the pressure difference between the baseline and the inhibitor-treated conditions.

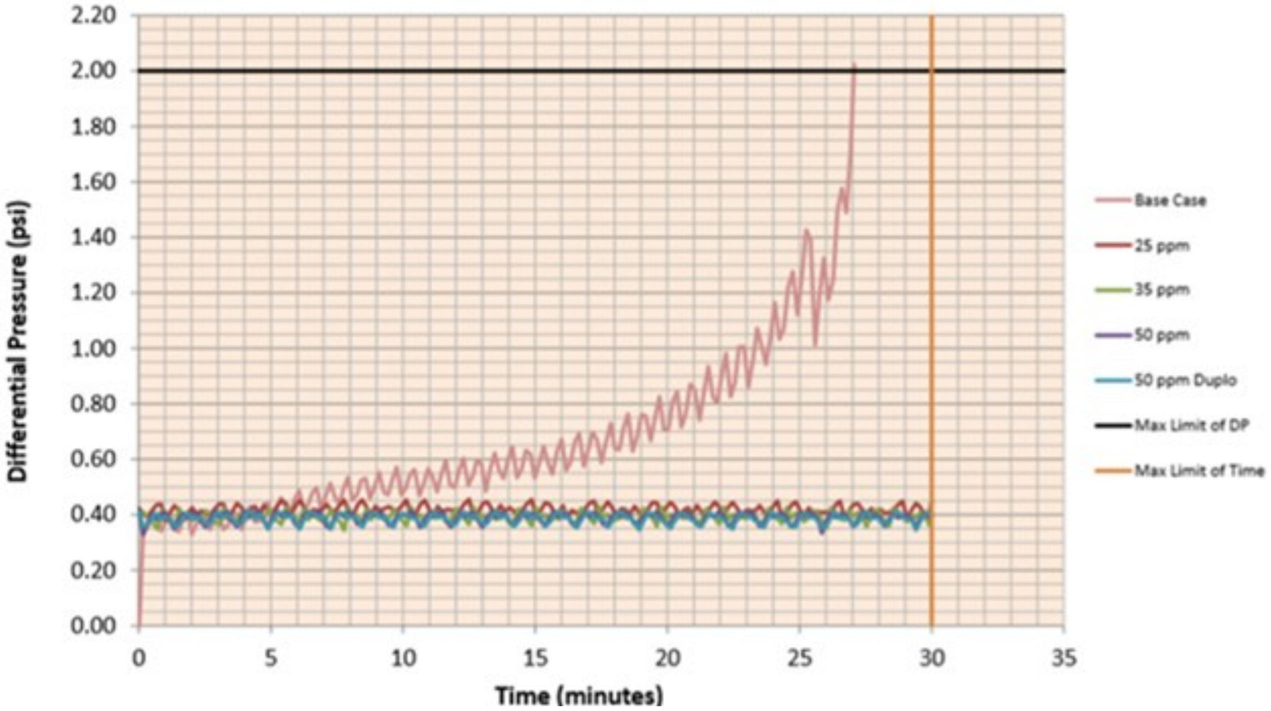

Figure 5. Graph of scale inhibitor analysis test results with DSL

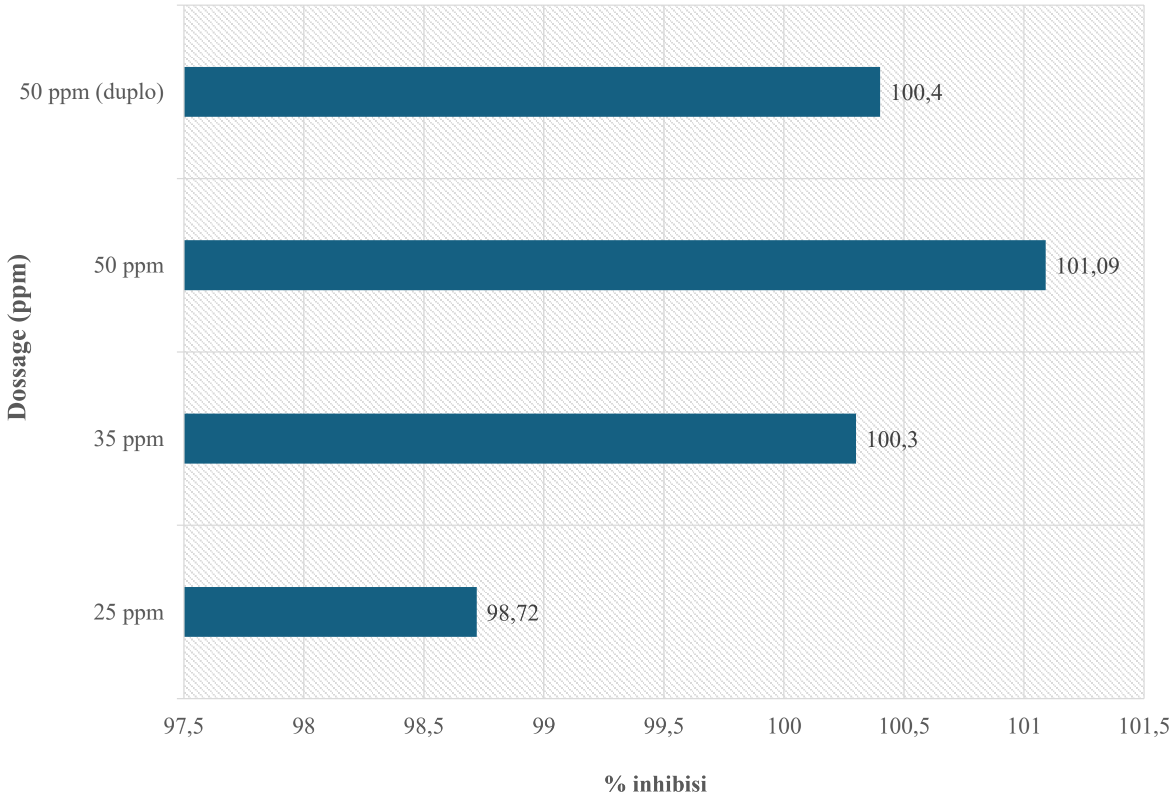

Figure. 6. Graph of scale analysis results using the DSL method

Based on the analysis results in Figure 6, the inhibition efficiency increases with dose, but improvement beyond 35 ppm is marginal (<1%), showing optimal effectiveness in preventing scale formation, with an inhibition efficiency of 100.3%, making it the most efficient dosage for field application. Error bars show low variability, confirming test reliability.

This study introduces a methodological novelty, as the DSL-based approach provides a significant advantage by simulating dynamic conditions that closely resemble actual fluid flow in the field. By using this method, the optimum inhibitor dose can be directly determined based on pressure response, rather than relying solely on theoretical models or static simulations. This approach represents a meaningful contribution to scale control optimisation in the oil and gas industry, particularly for well with characteristics similar to those of Well A28.

Comparison with literature

- Kamal et al. (2018) reported MIC values of 30–40 ppm for carbonate scales under similar conditions.
- Al Helal et al. (2019) showed DSL's superiority over static methods for dynamic environments.
- Hidayat & Untoro (2022) observed effective doses of 30–35 ppm for the Rokan well, aligning with the results.

Thus, 35 ppm is consistent with published data and represents the optimum dose for Well A28.

Although 50 ppm achieved slightly higher inhibition (101.1%), the difference from 35 ppm (100.3%) is negligible. Increasing the dose beyond 35 ppm offers no significant technical benefit but increases chemical cost by 43%.

Practical implications

- Cost Efficiency: Using 35 ppm instead of 50 ppm reduces annual chemical expenditure by approximately $12,000 per well.
- Operational Reliability: Effective scale control minimises flowline cleaning frequency, reducing downtime and maintenance costs.
- Environmental Impact: Lower chemical usage is in line with sustainability goals.

CONCLUSION

In conclusion, this study utilised the DSL method to determine the most effective scale inhibitor dose for Well A28. XRD analysis confirmed that 96% $CaCO_3$ content in deposits, and water analysis yielded an SI of +3.89, showing aggressive scale potential. DSL testing identified 35 ppm of inhibitor ABC2 as the optimal dose, achieving 100.3% inhibition, effectively preventing scale formation. This study introduces a dynamic and practical approach to scale inhibitor optimisation using DSL, contributing to improved scale management in oil production.

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GLOSSARY OF TERMS

Symbol	Definition	Unit
ASTM	American Standard Testing and Materials	-
SI	Scaling Index	-
DSL	Differential Scale Loop	-
SiO_2	Silicon Dioxide	-
ΔP	Differential Pressure	Psi

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