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Comparative Evaluation of Polyacrylic–Polyaspartic Acid Blends as Eco-Friendly Scale Inhibitors in Oilfield Produced Water

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Abstract
Scale formation remains a major flow assurance problem in oilfield production systems, particularly where produced water with complex chemical composition is handled. This study evaluates the performance of blended polyacrylic acid (PAA) and polyaspartic acid (PASA) as phosphorus-free scale inhibitors using produced water samples obtained from two oilfields located in the South-South (PWSS) and South-East (PWSE) regions of Nigeria.

An Optimal (Mixture) Design approach was used to investigate the effects of inhibitor dosage (0.01–0.1 ppm), temperature (50–70 °C), and pH (6–8) on scale inhibition efficiency through static jar test experiments. Quadratic response surface models were developed for both produced water systems and showed good agreement with experimental results, with coefficients of determination (R^2) greater than 0.93. Maximum inhibition efficiencies of 97.42% for PWSS and 94.82% for PWSE were obtained under optimized conditions.

The results indicate that PAA–PASA blends are effective at low dosages and exhibited high inhibition performance across produced waters with different chemical characteristics. This suggests that the blends can be considered suitable candidates for environmentally friendly scale control in oilfield operations.

Keywords: *Scale inhibition; Produced water; Polyacrylic acid; Polyaspartic acid; Flow assurance*

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I. INTRODUCTION

In oil and gas production systems, inorganic scale deposition is a common operational problem that can result in flow restriction, reduced heat transfer efficiency, equipment damage, and increased maintenance costs [1]. Scale formation is closely linked to changes in pressure, temperature, and produced water chemistry, which may cause precipitation of sparingly soluble salts such as calcium carbonate and calcium sulfate [2]. Produced water is an inevitable by-product of crude oil production and typically contains dissolved salts, divalent ions, and other constituents that promote scaling. In flowstations and other surface facilities, pressure reduction, fluid mixing, and residence time, further increases the likelihood of scale formation. As a result, effective scale control remains an important aspect of flow assurance management. Chemical scale inhibition is widely applied due to its effectiveness and operational simplicity. However, conventional phosphonate-based inhibitors raise environmental concerns because of their poor biodegradability and phosphorus content. In response, recent research has focused on environmentally acceptable polymeric inhibitors [3]. Polyacrylic acid (PAA) has been reported to exhibit good dispersing properties and tolerance to high calcium concentrations, while polyaspartic acid (PASA) is biodegradable and capable of complexing scale-forming ions. Recent studies suggest that blending polymeric inhibitors can improve inhibition efficiency through synergistic effects [4].

In a previous study, the present authors investigated the performance of PAA–PASA blends using a single oilfield produced water system [5]. Therefore, the present study extends that work by incorporating an additional produced water system with distinct physicochemical characteristics, thereby enabling comparative assessment of inhibitor performance and robustness. Figure 1, is a schematic illustration of the mechanism of the PAA-PASA blend in inhibiting produce water scale formation, showing threshold inhibition, crystal growth modification, and dispersion effects arising from the synergistic polymer interaction, based on experimental observations.

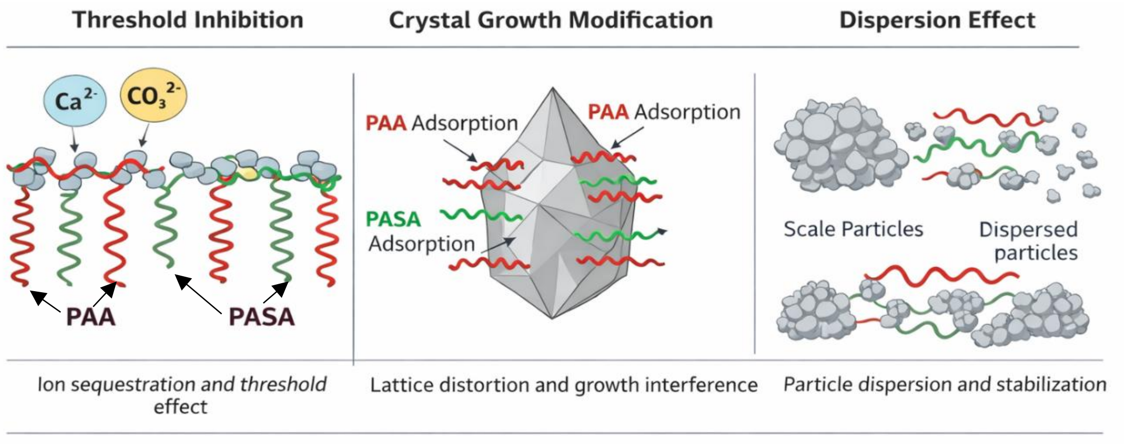


Figure 1. Schematic representation of the scale inhibition mechanism of the PAA_PASA blend.

The objective of this study is to comparatively assess the scale inhibition performance of PAA–PASA blends in two oilfield produced water systems with different chemical characteristics, in order to evaluate the robustness and practical applicability of the blends for oilfield scale control.

II. METHODOLOGY

Two produced water samples were collected from oilfield facilities located in the South-South (PWSS) and South-East (PWSE) regions of Nigeria. Sampling, preservation, and handling were carried out in accordance with ISO 5667-3 guidelines [6]. Physicochemical parameters relevant to scale formation were determined using standard analytical procedures [7].

An Optimal (Mixture) Design methodology was applied using Design-Expert software to study the effects of inhibitor dosage (0.01–0.1 ppm), temperature (50–70 °C), and pH (6–8) on scale inhibition efficiency [8]. The experimental design enabled the evaluation of individual and interaction effects of the selected variables.

Scale inhibition performance was evaluated using static jar tests in accordance with the GB/T 16632-2008 standard. Treated and untreated produced water samples were maintained at the specified temperature for 24 h. After cooling, samples were filtered and analyzed by complexometric titration using disodium dihydrate salt of Ethylene Diamine Tetraacetic Acid (EDTA) to determine residual concentrations of scale-forming ions. The physicochemical properties of the produced water samples are presented in Table 1.

Table 1: Physicochemical properties of PWSS and PWSE.

S/NO.	PARAMETERS	RESULTS		ANALYSIS METHOD
1	Produced Water Sample	PWSS	PWSE	
2	pH	9.2 at 34.3°C	7.8 at 31.5°C	SM-4500-B
3	Turbidity (NTU)	100	24	SM-2130B
4	Conductivity (µs/cm)	1659	2430	SM-2520B
5	Total Dissolved Solids (mg/L)	832	1378	SM-2540C
6	Total Suspended Solids (mg/L)	2460	1156.2	SM-2540D
7	Total Alkalinity (mg/L)	1212.8	1805.6	SM-2320B
8	Total Hardness (mg/L)	2.40	9.60	SM-2340C
9	Chloride (mg/L)	750	1270	SM-4500C
10	Sulphate (mg/L)	1.00	5.49	ASTM D 515-16
11	Carbonate as CO_3^{2-} (mg/L)	0.01	0.081	SM-2320B
12	Bicarbonate as HCO_3^- (mg/L)	<0.01	0.73	SM-2320B
13	Calcium as Ca^{2+} (mg/L)	<0.001	0.24	SM-3500-Ca-B
14	Sodium as Na^+ (mg/L)	0.016	3.97	SM-3500-Na-B
15	Potassium as K^+ (mg/L)	11.8	23.52	SM-3500-K-B
16	Total iron (mg/L)	0.548	0.028	SM-3500-Fe-B
17	Density (kg/m^3)	0.982	1.032	ASTM D1429-A

The experimental design matrix and corresponding inhibition efficiencies are presented in Table 2.

Table 2: Experimental design matrix, factor levels, and output responses.

Experimental Runs	Component 1	Component 2	Factor 3	Factor 4	Responses: In.Eff. (%)	
	PAA (ppm)	PASA (ppm)	Temp. (deg.C)	pH	PWSS	PWSE
1	0.01	0.1	50	6	-5.13	30.54

2	0.01	0.1	60	6	-20.00	10.46
3	0.01	0.1	70	6	-84.93	-17.28
4	0.1	0.01	70	8	18.14	59.15
5	0.1	0.01	60	8	84.47	54.9
6	0.1	0.01	50	8	55.35	94.82
7	0.055	0.055	50	8	97.42	89.25
8	0.055	0.055	70	8	56.70	75.87
9	0.055	0.055	60	8	69.28	88.53
10	0.055	0.055	60	6	-40.70	24.14
11	0.055	0.055	70	6	-55.45	-2.69
12	0.055	0.055	50	6	-9.43	30.65
13	0.01	0.1	70	7	2.34	29.47
14	0.01	0.1	60	7	5.56	16.88
15	0.01	0.1	60	7	5.61	16.92
16	0.1	0.01	50	7	12.61	78.33
17	0.1	0.01	60	7	10.3	21.88
18	0.1	0.01	60	7	10.17	21.65
19	0.055	0.055	60	7	5.05	11.67
20	0.055	0.055	70	7	45.16	7.39
21	0.055	0.055	60	7	5.00	11.57
22	0.1	0.01	60	6	-24.32	12.66
23	0.1	0.01	70	6	-75.81	-6.25
24	0.1	0.01	50	6	-8.16	35.63
25	0.01	0.1	60	8	87.26	40.52
26	0.01	0.1	70	8	16.59	30.21
27	0.01	0.1	50	8	45.39	80.93

III. RESULTS AND DISCUSSION

The physicochemical characteristics of the produced water samples indicate that both PWSS and PWSE possess conditions are favorable for inorganic scale formation, although noticeable differences exist in ionic composition, hardness, and total dissolved solids. Such variations are known to influence scale precipitation behavior and may affect inhibitor adsorption efficiency and overall performance. The presence of divalent ions and elevated salinity levels in both systems suggests a high propensity for scale formation under changing operational conditions [9].

The performance evaluation of the PAA–PASA blends shows that effective scale inhibition was achieved in both produced water systems across the investigated operating ranges. High inhibition efficiencies were obtained at relatively low inhibitor dosages, indicating favorable threshold inhibition behavior. Under optimized conditions, maximum inhibition efficiencies of 97.42% and 94.82% were achieved for PWSS and PWSE, respectively. These results demonstrate that the blended inhibitor formulation remains effective despite differences in produced water chemistry.

Response surface analysis revealed that inhibitor dosage exerted a significant influence on scale inhibition efficiency in both systems, while temperature and pH exhibited both individual and interaction effects. An increase in temperature generally resulted in a reduction in inhibition efficiency, particularly at lower inhibitor dosages. This trend is consistent with reported behavior of polymeric scale inhibitors, where elevated temperatures may reduce adsorption efficiency and polymer stability [10]. Variations in pH were also observed to affect inhibition performance, likely due to changes in polymer ionization state and interaction with scale-forming ions.

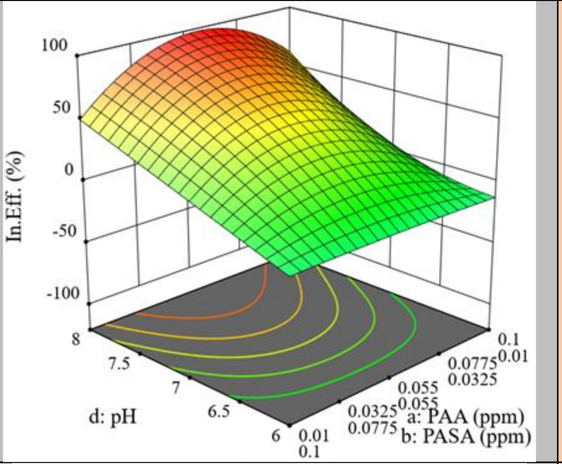
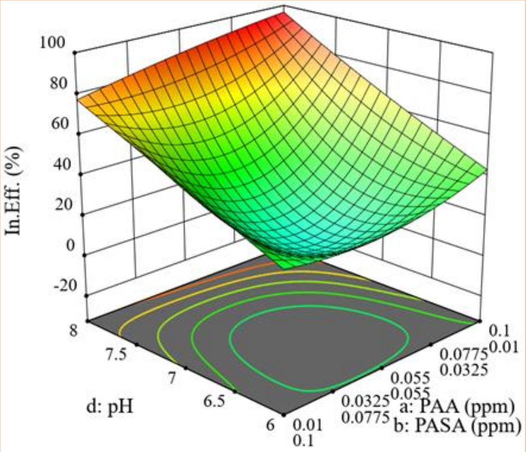
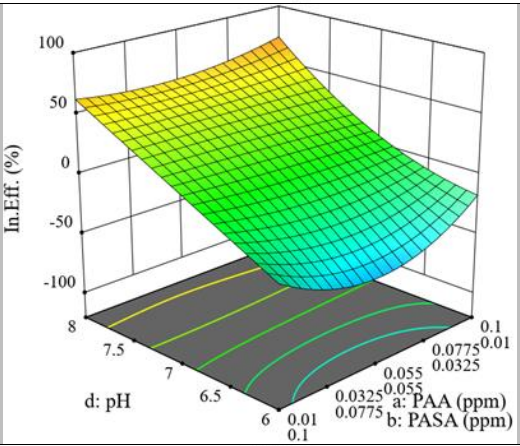
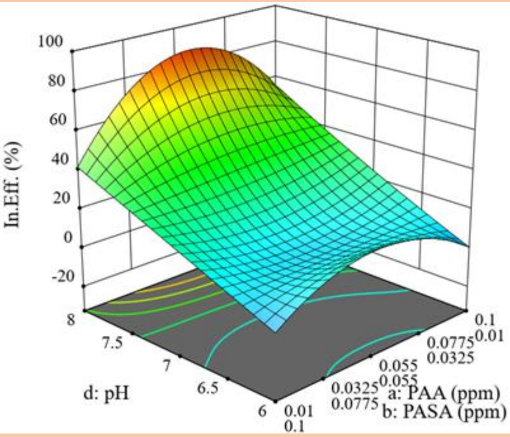
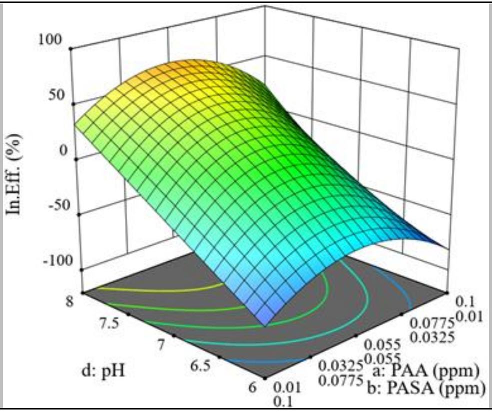
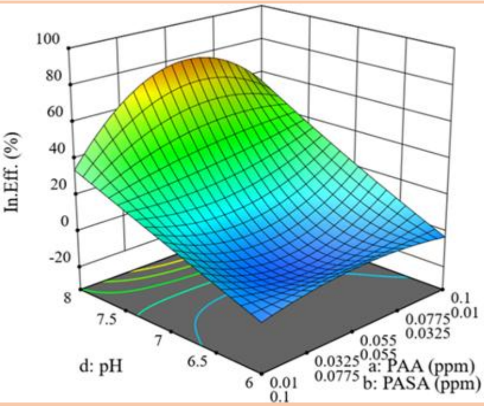
The occurrence of negative inhibition efficiency values observed under certain experimental conditions, notably pH 6 (acidic condition), as presented in Table 2, has been previously examined and discussed by the present authors. In that earlier work, the underlying causes of scale promotion at unfavorable operating conditions, as well as the scale inhibition mechanism of the PAA–PASA blend, were explained in detail [5]. The present study builds on those findings by extending the evaluation to an additional produced water system, thereby enabling comparative validation of inhibitor performance across differing physicochemical environments.

Negative inhibition efficiency values indicate higher solubility of scale micro-crystals originally present in the produced water samples, and also scale promotion rather than inhibition and are typically associated with poor creation of active sites, non-optimal combinations of inhibitor dosage, temperature, and pH. At insufficient dosage levels, the PAA–PASA blend may be unable to effectively adsorb onto active crystal growth sites, while elevated temperatures can reduce polymer adsorption efficiency and stability, acidic pH results in poor deprotonation of the PAA, and PASA molecules producing few active sites. Under such conditions, partial interaction between polymer molecules and scale-forming ions may facilitate nucleation rather than suppress it, resulting in increased scale formation relative to untreated systems.

The scale inhibition mechanism of the PAA–PASA blend is primarily attributed to a combination of threshold inhibition, crystal growth modification, and dispersion effects. The synergistic interaction between polyacrylic acid and polyaspartic acid enhances adsorption onto developing crystal surfaces, interferes with lattice growth, and limits agglomeration of precipitated particles. These mechanisms restrict the formation of adherent and compact scale deposits, thereby improving inhibition efficiency at low dosage levels.

The combined effects of operating variables on scale inhibition efficiency are illustrated in the response surface plots shown in Table 3 for a better visualization and comparison for both produced water samples.

Table 3: Response surface plots of scale inhibition efficiency (In.Eff.), at 50ºC, 60ºC, and 70ºC for PWSS and PWSE.

TEMP.	**PRODUCED WATER SAMPLES**	
	PWSS **In.Eff. (%)** -84.93 ▆ 97.42	**PWSE** **In.Eff. (%)** -17.28 ▆ 94.82
50^{O}C		
60^{O}C		
70^{O}C		

Comparative evaluation of PWSS and PWSE indicates that although produced water chemistry influences the magnitude of inhibition efficiency and the optimal operating conditions, the overall performance trends of the PAA–PASA blends remain consistent across both systems. This suggests that the blended inhibitor formulation exhibits a degree of robustness and adaptability when applied to produced waters with differing chemical characteristics. However, the observed variations also highlight the importance of site-specific optimization to achieve maximum inhibition efficiency.

Overall, the results confirm that blending PAA and PASA provides effective scale control across multiple produced water systems while maintaining environmentally acceptable characteristics. The consistency of the inhibition trends across both samples supports the applicability of the PAA–PASA blend for oilfield scale control, provided that operational parameters are appropriately optimized for specific field conditions.

IV. CONCLUSION

This study comparatively evaluated the performance of blended polyacrylic acid and polyaspartic acid (PAA–PASA) scale inhibitors using produced water samples obtained from two oilfields with differing physicochemical characteristics. The results confirm that both produced water systems exhibit significant scaling potential and that effective scale control can be achieved through the application of PAA–PASA blends at low inhibitor dosages.

Experimental findings show that the blended inhibitor formulation provides high scale inhibition efficiency in both produced water systems, with maximum efficiencies of 97.42% and 94.82% obtained for PWSS and PWSE, respectively. Although variations in produced water chemistry influenced inhibition magnitude and optimal operating conditions, the overall performance trends remained consistent across both systems.

The observed reduction in inhibition efficiency at elevated temperatures and the occurrence of negative inhibition responses under certain conditions were attributed to non-optimal combinations of dosage, temperature, and pH. These behaviors are consistent with the adsorption- and stability-dependent nature of polymeric scale inhibitors and highlight the importance of appropriate parameter optimization for effective scale control.

The scale inhibition mechanism of the PAA–PASA blend is primarily governed by threshold inhibition, crystal growth modification, and dispersion effects arising from the synergistic interaction between polyacrylic acid and polyaspartic acid. The consistency of these mechanisms across both produced water systems supports the robustness of the blended formulation.

Overall, the findings demonstrate that PAA–PASA blends offer a viable and environmentally acceptable alternative to conventional phosphonate-based scale inhibitors for oilfield produced water systems. While laboratory-scale results indicate strong inhibition performance across different water chemistries, further studies involving long-term testing and field-scale validation are recommended to confirm practical applicability under operating conditions.

REFERENCES

[1]. Zhang, Y., Liu, T., Zhao, J., Sun, W. (2020). Performance and mechanism of green polymer inhibitors for scale control in oilfield produced water. Journal of Petroleum Science and Engineering, 189, 106957. https://doi.org/10.1016/j.petrol.2020.106957

[2]. Neff, J. M., Lee, K., DeBlois, E. M. (2017). Produced water: Overview of composition, fates, and environmental effects. Produced Water, 3–54.

[3]. Kelland, M. A., Smith, D. E., Yang, M. (2017). Environmentally acceptable polymeric scale inhibitors for oilfield applications. Energy Fuels, 31(10), 10525–10534. https://doi.org/10.1021/acs.energyfuels.7b01892

[4]. Liu, Y., Zhang, H., Wang, L., Chen, X. (2022). Synergistic inhibition of calcium carbonate scale by environmentally friendly polymer blends. Journal of Molecular Liquids, 356, 119003. https://doi.org/10.1016/j.molliq.2022.119003

[5]. Ohimor, E. O., Aghoghophia, E. A., (2025). Evaluation of Polyacrylic–Polyaspartic Acid Blends as Eco-Friendly Scale Inhibitors in Oilfield Produced Water. International Journal of Built Environment and Earth Science. VOL. 9 NO. 4 (196 - 215). https://doi.org/10.70382/tijbees.v09i4.044

[6]. ISO. (2018). ISO 5667-3: Water quality—Sampling—Part 3: Preservation and handling of water samples.

[7]. APHA. (2017). Standard methods for the examination of water and wastewater (23rd ed.). American Public Health Association.

[8]. Montgomery, D. C. (2017). Design and analysis of experiments (9th ed.). Wiley.

[9]. Kelland, M. A. (2016). Production chemicals for the oil and gas industry (2nd ed.). CRC Press.

[10]. Wang, Z., Xu, D., Neville, A. (2019). Investigation of polymer scale inhibitor performance under high-temperature oilfield conditions. Corrosion Science, 159, 108133. https://doi.org/10.1016/j.corsci.2019.108133