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A Workflow to Address Compatibility Issues Between Acid Jobs and Scale Inhibitor Squeeze Treatments – Sapinhoá Field Case

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Abstract
Multiple scale inhibitor chemistries have been developed for scenarios with a high calcium content, such as carbonate reservoirs. Although many options succeed in providing short-term tolerance, some inhibitors tend to fail over prolonged exposure, particularly at typical concentrations used in squeeze treatments. This study presents a workflow that enables the design of field treatments with these less tolerant chemistries in the challenging scenario of an injection following an acid job. A case study in the Sapinhoá field demonstrates the success of this methodology in determining an optimal volume for the buffer pill between treatments, based on a metric sensitive to this design aspect.

Keywords
flow assurance; scale remediation; scale inhibitor squeeze

Introduction
The Sapinhoá field, located in Block BM-S-9 in the central portion of the Santos Basin, is situated approximately 310 km offshore from the Brazilian coast. With a water depth of around 2,140 m and reservoir depths ranging from 5,000 to 6,000 m, the field is characterized by salt layers that can be as thick as 2,000 m [1].
Production in the field commenced in 2013, initially utilizing the Floating Production Storage and Offloading (FPSO) *Cidade de São Paulo* and later expanding to include the FPSO *Cidade de Ilha Bela* in 2014. The combined production capacity of these floating vessels reaches 270,000 barrels of oil and 11,000,000 m³/d of gas.
To address oilfield scale issues, it was recommended that all wells be stimulated to their full capacity, as smaller drawdowns have been shown to reduce precipitation. Additionally, downhole scale inhibitor injection was advised, along with the provision of a scale inhibitor option for potential squeeze treatments as a safeguard.
Since 2022 production losses resulting from scale issues have been observed in a specific well, and they were attributed to severe intermittence in the downhole scale inhibitor injection. However, given the imminent heavy workover scheduled to address the well's integrity concerns, it was decided to incorporate a scale removal/inhibition scope into this intervention.
This work aims to tackle the challenges associated with recommending a scale inhibitor squeeze treatment design, considering an extended shut-in period and the inhibition as an added scope to an acid job [2].

Methodology
Laboratory experiments are crucial for designing squeeze treatments. The scale inhibitor must be compatible with the other aqueous fluids involved, efficient [3], compatible with the reservoir and have an adequate adsorption isotherm.

Experimental Procedure
Previous testing led to the selection of a scale inhibitor with a high calcium (Ca) tolerance. The properties of the three samples employed are shown in Tab. 1.

Table 1. Scale inhibitor properties.

Sample #	pH	Density, g/cm³
1	4.36	1.2763
2	3.43	1.2309
3	3.76	1.2377

Three different brines, shown in Tab. 2, were used in the laboratory experiments.

Table 2. Brine compositions in mg/l.

	Coreflood	Efficiency	Compatibility
Na	76,720	60,121	60,121
K	4,352	3,067	3,067
Mg	2,186	1,107	1,107
Ca	8,051	6,772	6,772
Ba	70	70	70
Sr	2,900	2,719	2,719
Br	862	0	0
SO_4	0	107	0
HCO_3	0	1,665	0
pH	6.4	*	Not adjusted

*cationic brine pH = 7.60±0.20 and anionic brine pH = 7.60±0.05

Coreflood – Compatibility

A formation core plug sample was subjected to the flow of oil at irreducible water saturation (S_{Wi}) and of water at residual oil saturation (S_{Or}), before and after the reverse injection of approximately 6 PVs (Pore Volumes) of a 10% scale inhibitor solution containing 2% potassium chloride (pH 4.5). A limited deviation between the permeabilities, K_O @S_{Wi} and K_W @S_{Or}, was tolerated.

Coreflood – Isotherm

The isotherms were obtained during the injection and subsequent post flush of the inhibitor. The effluent was collected, and the inhibitor profile was determined with an ICP-OES equipment. With this, an isotherm could be derived.

Efficiency

The inhibitor efficiency was attested with a Tube Blocking Test – TBT (Tab. 3). Figure 1 shows it's schematic.

Table 3. TBT parameters.

Flowrate	10 ml/min
Coil ID	0.5 mm
Coil Length	1 m
Pressure	1,000 psi
Temperature	67℃

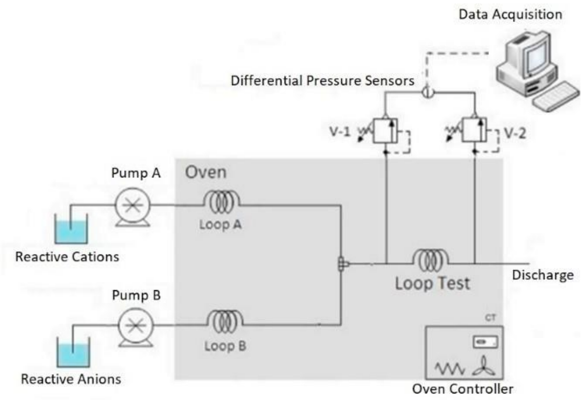

Figure 1. Tube Blocking Test

Compatibility

To represent the eventual mixing zone between the spearhead acid job and the posterior scale inhibitor squeeze, two solutions were mixed. The first one consisted of the field brine doped with calcium chloride until a final Ca concentration of 20,000 mg/l. For the second one four different solutions were used consisting of 2, 10, 15 and 20% scale inhibitor solutions. The mixture proportions evaluated were: 10(brine) : 90(inhibitor solution), 30 : 70, 50 : 50, 70 : 30 and 90 : 10 in %vol.

Every mixture pH was adjusted to 4,0 using sodium hydroxide to mimic the equilibrium pH at the formation after the total expenditure of the acid/inhibitor acidity. This value of 4,0 was obtained via thermodynamic simulation in Multiscale 8.3 [4] considering the total expenditure of a chloridric acid 15%.

Results and Discussion

Coreflood test

The scale inhibitor was considered appropriate for application in this field due to the relatively small change in permeability considering the water saturation (S_W) obtained in the testing, as seen in Tab 4, and an appropriate release curve as seen in Fig. (2).

Table 4. Permeabilities at endpoint saturation

Stage	Permeability
Ko @Sw = 60%	135 mD
Kw @Sro	19 mD
6 PVs squeeze treatment pill	
Kw @Sro	31 mD
Ko @Sw = 89%	96 mD

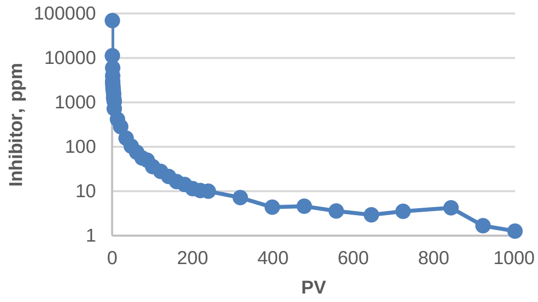

Figure 2. Inhibitor release curve

Efficiency

Figure 3 shows the scale inhibitor efficiency test results. A Minimum Inhibitory Concentration (MIC) of 40 mg/l was considered, as it is the lowest concentration evaluated for which there was no increase in pressure differential during the TBT.

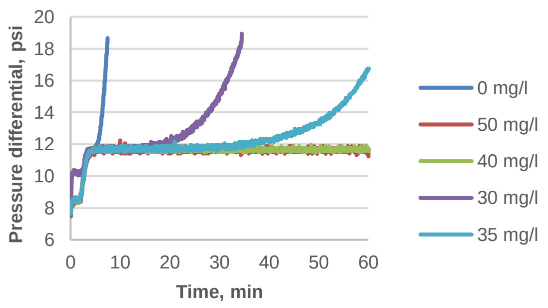

Figure 3. TBT results

Compatibility

Table 3 shows the compatibility results. The inhibitor's tolerance to calcium is highly dependent on time.

Table 3 – Scale inhibitor tolerance to calcium

Compatibility – Doped Brine (20,000 mg/l Ca) : Scale Inhibitor Solution						
	Time	10:90	30:70	50:50	70:30	90:10
20% Scale Inhibitor	48h	Clean	--	Cloudy	--	Cloudy
	5d	Clean	--	Cloudy	--	Cloudy
	7d	Clean	--	Cloudy	--	Cloudy
	1m	Clean	--	Cloudy	--	Cloudy
	Time	10:90	30:70	50:50	70:30	90:10
15% Scale Inhibitor	48h	Clean	Slightly Cloudy	Clean	Clean	Clean
	5d	Clean	Cloudy	Cloudy	Cloudy	Clean
	7d	Clean	Cloudy	Cloudy	Cloudy	Cloudy
	1m	Clean	Cloudy	Cloudy	Cloudy	Cloudy

	Time	10:90	30:70	50:50	70:30	90:10
10% Scale Inhibitor	48h	Clean	Clean	Clean	Clean	Clean
	5d	Clean	Clean	Clean	Cloudy	Clean
	7d	Clean	Cloudy	Cloudy	Cloudy	Clean
	1m	Clean	Cloudy	Cloudy	Slightly Cloudy	Clean
	Time	10:90	30:70	50:50	70:30	90:10
2% Scale Inhibitor	48h	Clean	--	Clean	--	Clean
	5d	Clean	--	Clean	--	Clean
	7d	Clean	--	Clean	--	Clean
	1m	Clean	--	Clean	--	Clean

Field Design

To address the compatibility issue, a novel workflow is proposed. First, we need to establish a boundary between the compatible/incompatible domain. This is illustrated in Fig. 3.

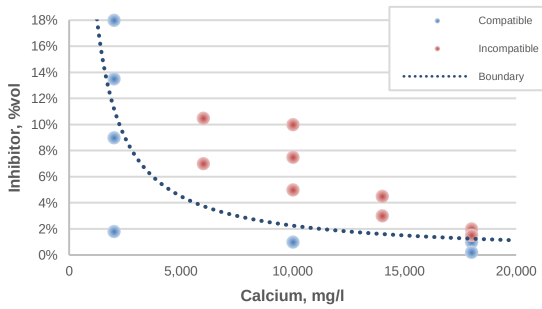

Figure 3. Compatible domain boundary

The arrangement of the data suggested a boundary shape of the type $x \times y = const$. This equation is very similar to the solubility product of a salt, $K_{sp} = [A]^p[B]^q$, which describes the equilibrium $A_pB_q \rightleftharpoons pA + qB$. The dotted curve was obtained considering a modelling like this and using the mean value between the adjacent compatible/incompatible points for a calcium concentration of 18,000 mg/l.

Now we need to obtain the mixing zone composition to plot against the boundary. This can be approximated by performing two conventional placement simulations, one for the acid job spearhead and another for the scale inhibitor (Fig. 4) [5]. For the acid we are interested in the calcium content and can model it as a tracer. For the inhibitor we consider an adsorption model with the best fit isotherm considering the data obtained in the coreflood test.

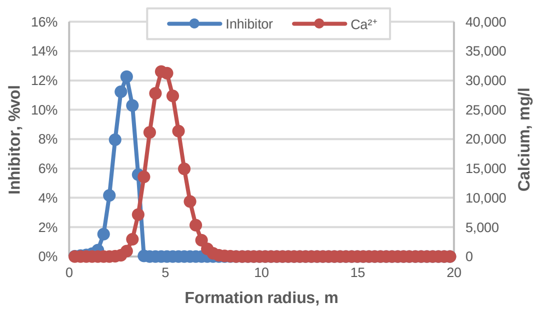

Figure 4. Concentration profile

Based on a concentration profile like that shown in Fig. 4, it is possible to identify the highest concentration of scale inhibitor for each calcium concentration value. Using the twenty-layer model that's been proposed for this well, the search is performed on all layers to determine the maximum scale inhibitor concentration for each calcium concentration value. This analysis allows you to generate a curve that represents the most critical situation in terms of compatibility.

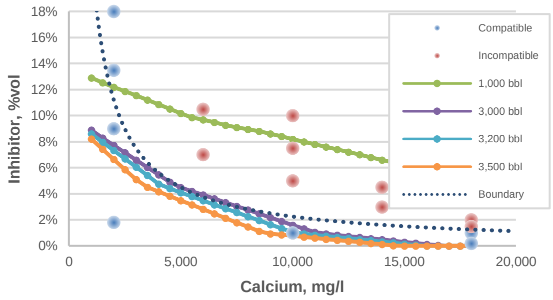

Figure 5. Sensitivity analysis for a buffer pill

This workflow allowed us to adjust the buffer pill volume between the acid job and the scale inhibitor squeeze treatment to perform a placement within a compatible domain.

Conclusions

This study establishes a workflow to give best recommendations for the design of scale inhibitor squeeze treatments following an acid job, in a sequence.

For this Sapinhoá field case, due to the long shut-in periods required to meet operational constraints, a large buffer pill volume of at least 3,000 bbl was recommended. Given the necessity for these long shut-in periods in the field it is recommended to search for other chemistries to better encompass these requirements.

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References

[1] Naveiro, J. T., Haimson, D., *Offshore Technology Conference Brasil*, OTC-26320, 2015

[2] Silva, M. G. F. da, Camargo Jr., S. T. de, Freitas, T. C., Silva, G. M. L. L. da, Rosario, F. F. do, Costa, F. G. da, Rosa, K. R. S. A. da, Fontes, R. A., Patent US11952534B2

[3] Rosa, K. R. S. A. da, Fontes, R. A., Rosário, F.F. do, Freitas, T. C., Penna, M. O., Castro, B. B., Silva, M. G. F. da, Silva, G. M. L. L. da, Silva,

J. M., Figueiredo, M. R., *Offshore Technology Conference Brasil*. OTC-29683, 2019.
[4] Kaasa, B., et al., Multiscale 8.3©. Expro Petrotech, Haugesund, Rogaland, Norway.
[5] Squeeze 12, Inst. of Petroleum Engineering, Heriot-Watt University, Edinburgh, UK