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Squeeze Inhibition in Buzios with optimization of Chemical Treatment using phosphonate in acid form

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Abstract
This paper describes the first squeeze inhibitor operation in Buzios field using a patented phosphonate in acid form. A short description of inorganic scale well formation, laboratory tests and technical operational aspects are cited in the paper. The acidizing problems and positive squeeze results are detailed to promote a better problem understanding and provide optimizations in futures treatments.

Keywords
scale; squeeze; treatment

Introduction
Buzios field reservoir is located between 5.000 and 6.000m below sea level, in a seawater depth of approximately 1.900 m. It is a carbonate reservoir formed by the Barra Velha and Itapema formations. The first module started in April 2018 and nowadays four production stationary unit (PSU) are in operation.
Several PVT sampling aqueous bottles recovered during oil well drilling campaign showed high ions concentration, as calcium, strontium, and bicarbonate, for example.
The characteristics of the formation water, high pressures, temperatures, and carbonate reactivity results in a medium-high scaling potential or saturation ratio for calcium carbonate in production tubing, intelligent completion valves and subsea production system.
Since the production beginning in 2018, scaling events have been observed in production wells, despite very low water cut (<0.5%).
As a result of the scale formation, producing zones were closed, intelligent valves were cycled, and other actions were taken to minimize the problem.
In the present, due the high costs involved and operational limitations to scale removal and inhibition, process and products optimizations are essential to reduce costs and risks.
Scale removal and inhibition operations were carried out in the Well-A. The first took place in September 2020 using 10% (v/v) acetic acid and then the well returned to production for three months. In December 2020 squeeze inhibition 10%(v/v) it was conducted.
The chemical properties of the contracted inhibitor allowed the opportunity to evaluate the use of the patent filed in 2019 of squeeze treatment optimization with an organophosphonate, in acid form, for simultaneous removal and inhibition of scale in the same operation [1].
The results obtained showed removal of the damage, increase and stability of the productivity index (PI)

Methodology
A set of laboratory experiments [2] is a prerequisite for the design of a conventional squeeze treatment. The scale inhibitor must be compatible with a representative water composition, efficient in scale inhibition, compatible with the carbonate reservoir and have an adequate adsorption isotherm.
To reach the goal of the simultaneous removal and inhibition, a carbonate dissolution experiment with scale inhibitor had to be included in the workflow.

Experimental Procedure

Three different brines, shown in the Table 1, were used in the laboratory experiments.

Table 1. Brine compositions in mg/l

	Compatibility	Efficiency	Coreflood
Na	39 070	59 646	53 630
K	2 315	0	3 260
Ca	2 081	9 338	7 470
Mg	744	1 218	737
Ba	8	23	25
Sr	557	1 342	2 700
Br^-	0	0	460
HCO_3^-	0	2 465	0
pH	7.1	6.2	6.0

Compatibility

This was accessed through a severe experiment in which the inhibitor, as supplied, has been mixed with the corresponding brine and the same doped with $CaCl_2$ until a final Ca concentration of: 5,000, 10,000, 20,000, 30,000 and 40,000 mg/l. The mixture proportions evaluated were: 100(Brine)/0(Inhibitor), 90/10, 50/50, 10/90 and 0/100 (%v/v).

Efficiency

The inhibitor efficiency was attested through the Tube Blocking Test – TBT (Table 2) with the corresponding brine.

Table 2. TBT parameters

Flowrate	10 ml/min
Coil ID	0.5 mm
Coil Length	1 m
Pressure	1,000 psi
Temperature	100°C

Coreflood – Compatibility

A core plug of each reservoir formation was subjected to the flow of oil @Swi and of water @Sor, before and after the injection of the squeeze treatment. A maximum deviation of 10% between permeabilities was tolerated at these saturation endpoints.

Coreflood – Isotherm

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

Dissolution

An excess of calcium carbonate is mixed with the inhibitor solution at reservoir temperature. The dissolved mass was calculated based on the determination of Ca with an ICP-OES equipment.

Results and Discussion

As previously stated, Well-A well has a history of saline scaling since 2018 despite the low water cut values (< 0.5%).
Multiscale thermodynamic simulator [3] showed a medium-high scale potential of calcium carbonate in the well [4] as shown in the Figure 1.
The range of pressure, temperature and the flowrate and water cut considerate in the simulations are shown in Table 3.
Results obtained in the Multiscale simulator are shown in Figure 1 at different points of the production system.

Table 3. Pressure, temperature and flowrate used in Multiscale simulation.

Properties	Value
Pressure (kgf/cm^2)	562-616
Temperature (^{0}C)	94.5 -97.0
Flowrate (m^3/d)	5189
Water Cut (%)	0.35

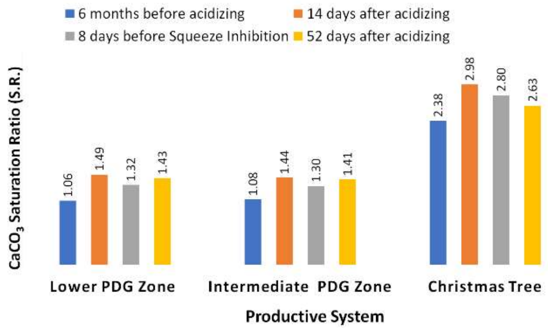

Figure 1. Calcium carbonate saturation ratio (S.R.) before and after acidizing and squeeze inhibition.

Well-A has intelligent completion valves (ICV) in three production zones. In addiction the well has pressure downhole gauge (PDG) in the annulus in three zones as well as a PDG sensor in the tubing near the upper producing zone.
In order to eliminate scaling saline problems in tubing, two chemical injection mandrels (CIM) for scale inhibitor continuous dosage in annulus of the lower and intermediate production zones were installed. Unfortunately, the two chemical injections mandrels are unavailable.

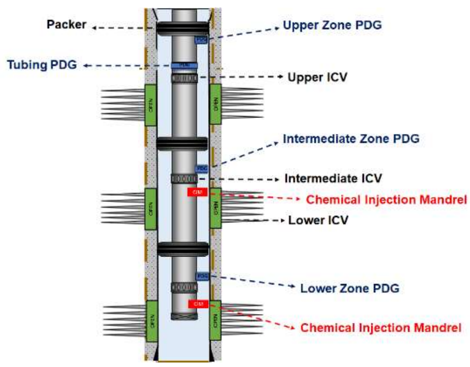

Figure 2. Well-A schematic completion drawing.

In May 2018, severe scale formation was verified in the upper well zone with periodic ICV cycling to minimize salt formation effect. Due the scale process aggressiveness, the upper ICV was closed.
A new scaling process between the lower and intermediate well zone in June 2018 it was observed, and periodic ICV cycling were performed to minimize salt formation.
Figure 3 shows the pressure and temperature behavior in the tubing PDG. The temperature increases and pressure decrease is an indication of below salt deposition tubing PDG sensor.

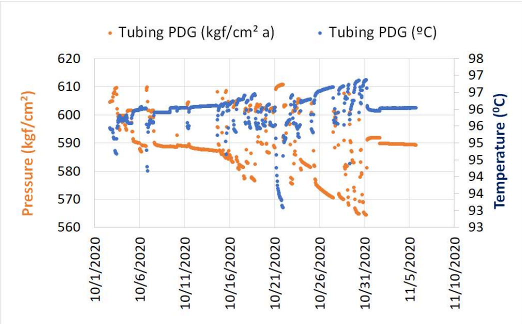

Figure 3. Pressure and temperature in the tubing PDG.

Focused on cost reduction and remote Petrobras experience, a well service stimulation vessels (WSSV) were conducted in September 2020.
It was used 10% acetic acid due equipment limitations in the stationary production unit (SPU).
The WSSV e a SPU are shown in Figure 4.

Figure 4. WSSV approaching SPU to perform the acetic acid 10% treatment.
The acidizing operation was performed to optimize the removal of inorganic Scale. The acidizing and well return sequence to production is shown in Figure 5.

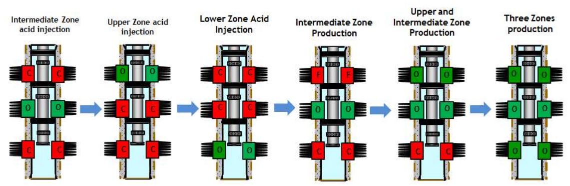

Figure 5. Acidizing and well return sequence to production.

The operation was a success, as shown in Table 4 and 5, with significant increase in well productivity index (PI).

Table 4. Damage removal in all zones production

Date	Note	PI (m³/d/kgf/cm²)
Apr. 2018	Beginning of production	300
May 2018	Upper zone scale formation	140
Sept. 2020	After WSSV acidizing	290

Table 5. Damage removal in lower and intermediate zones production

Date	Note	PI (m³/d/kgf/cm²)
May 2018	Beginning of production	130
April 2020	Before acidizing	88
Sept. 2020	After WSSV acidizing	173

The well returned to production and after fifteen days the upper zone was closed to preserve integrity due the fast-scaling formation.
In October 2020 it was observed a scale process between intermediate and lower zone.
The rapid return of scaling process after acidizing made squeeze inhibitor operation mandatory.
The scale inhibitor had already been qualified in all laboratory tests and was therefore ready for field application.

Laboratory tests using scale Inhibitor 10% (v/v) solution showed a dissolution of 3kg calcite per cubic meter of solution in normal conditions of temperature and pressure. Similar values of calcium carbonate dissolution were observed in ARXIM [5] simulations using industrial water in reservoir conditions due to high carbon dioxide concentration (18% molar).
Squeeze 11[6] simulations showed a well inhibition duration longer than 10 months for 5189 m^3/d production (0.5% water cut) in Well-A.
Based on laboratory tests, remotes operations were carried out using WSSV.
The Squeeze operation it was optimized as shown in Figure 6.

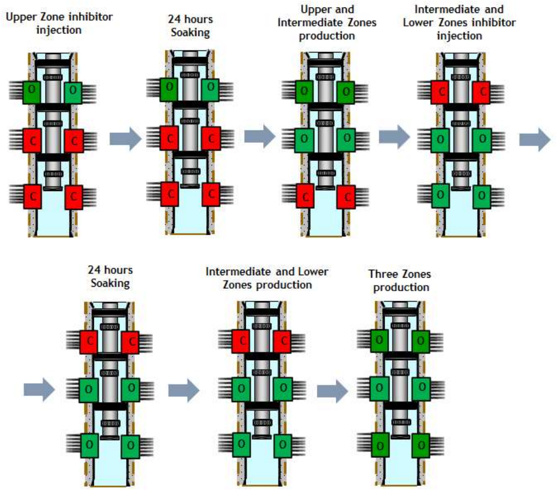

Figure 6. Scale inhibitor squeeze and well return sequence to production.

It was observed the removal of significant part of the damage and productivity index stabilization. This is the first time where a damage removal was observed in a squeeze treatment in a presalt field operated by Petrobras.
The Table 6 shows the results obtained in lower and intermediate zones production.
Figure 7 shows the productivity index before and after the acidizing and inhibitor squeeze operation.

Table 6. Damage removal in lower and intermediate zones production after squeeze inhibitor operation

Date	**Note**	**PI (m³/d/kgf/cm²)**
May 2018	Beginning of production	130
April 2020	Before acidizing	88
Sept. 2020	After WSSV acidizing	173
Dec. 2020	Damage after WSSV acidizing and scale formation	114
Dec 2020	After inhibition (Drums Sampling)	210

After inhibition and all zones opened the PI was 230 m³/d/kgf/cm² and stays very stable since then. The graphic below illustrates the highlights behaviors in terms of PI throughout time.

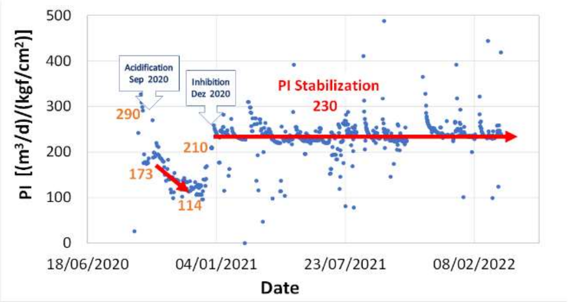

Figure 7. Productivity index values before and after acidizing and squeeze inhibition operations

Conclusions

Calcium carbonate saturation ratio is close to that observed after acidizing.
Fifteen days after the well acidizing, the damage process returned.
Inhibition removed the damage and stabilized well PI since December 2020.
Scale inhibition must be done after acidizing to avoid damage evolution.

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