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Development of Magnetic Anti-Scale Accessories for O&G wells – Lab and Field scale Tests

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Abstract
This paper details the development of a magnetic accessory designed to mitigate scale build-up in onshore and offshore wells. First, we experimentally studied the effects of magnetic fields on scale deposition in turbulent pipe flow, using an oil-in-brine emulsion. Our findings indicate that the application of a magnetic field can significantly reduce scale deposition in hydraulic valves. These insights led to the subsequent development of the magnetic accessory. The first manufactured accessory has been qualified in laboratory to withstand high temperatures, pressures and highly corrosive environments, generating a high-intensity magnetic field by only using high energy magnets of NdBFe in an innovative arrangement developed by the authors especially for this application. After all qualification steps being successful to demonstrate accessory robustness, it has been installed in a Brazilian offshore well where its performance has been monitored since then.

Keywords
Scale; Magnetic Treatment, Anti-Scale Solution, Accessories, Oil and Gas, Well.

Introduction
The traditional strategy to prevent the problem of scale build-up in O&G wells is the continuous injection of chemical inhibitors. However, for some configurations of wells, there are portions that are not assisted by chemical injection. There is also an impressive number of downhole injection failures reported by operators (Aldeia et al. 2022). Failures due to scale formation induce high costs related to workover jobs for scale removal, which include the operational costs as well as production-loss costs due to the necessity of interrupting the oil production to run squeeze jobs.

The magnetic treatment, on the other hand, is a physical solution based on the application of magnetic field on the produced fluid. By applying this treatment, there is a tendency to generate solids with minor adherence characteristics. For instance, in the scenarios where $CaCO_3$ scale is the major concern, the magnetic field tends to prioritize less cohesive polymorphs such as vaterite, instead of the more stable calcite form (Figure 1).

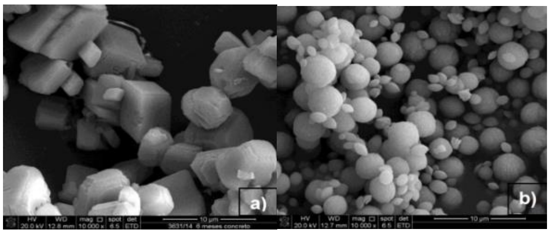


Figure 1 - a) Calcium Carbonate without the presence of magnetic field: Calcite; b) with the presence of magnetic field: $CaCO_3$ Vaterite)- Souza Junior, JR.

A possible mechanism points towards the manipulation of turbulent flow structures by the magnetic field (Jäckel et al. 2023). The effect of magnetic fields on flow characteristics of conductive fluids is given by the Lorentz equation (Eq. (1)), which describes the force [F_L] that is felt by a fluid parcel with charge q and velocity [v] moving through a magnetic field:

$$[F_L] = q\,([E] + [v] \times [B]) \quad (1)$$

where [E] and [B] are the electric and magnetic field vectors, respectively.

The theory of scale mitigation through magnetic flow field modulation is based on the observation that near-wall vortices are driving particles, such as inorganic nuclei, in the near-wall regions of pipes. Particles caught in a vortex are "slung" towards the viscous sublayer by strong centrifugal forces, a result of their inertial mass. Once a particle reaches the viscous sublayer, its likelihood of returning to the turbulent region is significantly reduced due to the dampening effect of viscous forces in the near-wall region. This process, known as turbophoresis, likely contributes to increased concentrations of salt particles in the near-wall regions, thereby potentially accelerating the rate of inorganic deposits on the walls. Previous research has shown that strong magnetic fields can significantly alter these near-wall vortices, up to completely dissipating turbulence. (Moriconi 2020).

Given these findings, it is reasonable to assume that the magnetic dissipation of vortex structures could play a crucial role in mitigating turbophoresis and the subsequent buildup of saline scale through magnetic intervention.

This study describes the laboratory tests performed to verify the efficiency of magnetic treatment on scale mitigation and based on obtained results, it also describes the development of a robust anti-scale equipment using high energy permanent magnets of neodymium-boron-iron (NdBFe) as the source of the magnetic field capable to withstand the harsh conditions of oil and gas wells.

Laboratory Tests

Prior to the design of a novel magnetic accessory intended for scale mitigation, an experimental study was conducted to better understand the impact of magnetic fields on scale deposition. This research specifically focused on turbulent pipe flow, analyzing the behavior of an oil-in-brine emulsion under magnetic influence.

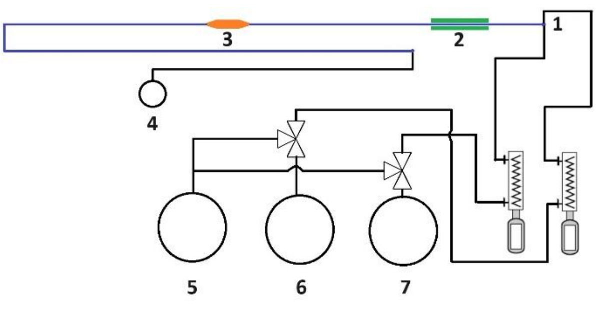


Figure 2 – Experimental loop for investigation of calcium carbonate scaling in saline oil emulsions under applied magnetic fields. Labels: (1)- mixture point, (2)- magnetic device, (3)- valve, (4)- waste tank, (5)- water tank. (6)- brine tank, (7)- emulsion tank.

The purpose of these experiments was to gain insights into how magnetic fields could potentially reduce scale build-up in such environments.

The experiments were conducted on a test bench consisting of an acrylic tube with an inner diameter of 11 mm and a length of 70 meters (see Fig. 2). A mixture of two solutions was studied: a saline solution and an oil-in-brine emulsion, which are mixed at the beginning of the pipeline and flow through 70 meters of a pipe, and being eventually discharged into a designated tank.

The emulsion was prepared by stirring a solution composed of 80% v/v saline solution of calcium chloride at a concentration of 7.35 g/L, and 20% v/v mineral oil (Lubrax Turbina X 10) with a kinematic viscosity of 10 cSt at 40 ºC and a relative density of 0.85. Additionally, 0.04% of the surfactants Span 60 and Tween 80 (50%/50%) were added to the emulsion for stabilization. The other pumped solution consisted of sodium bicarbonate in an aqueous base at a concentration of 12.6 g/L. For the tests, a sliding-sleeve valve was installed 28 meters downstream from the mixing point of the solutions. Tests were conducted with a 0.55 Tesla magnetic device installed and without the device for comparison of results. The magnetic device was installed 38 centimeters upstream of the valve to analyze its effect. All tests were conducted maintaining a flow rate of 150 L/h of saline solution and 187.5 L/h of emulsion. For test control, a differential pressure meter was installed on the valve to monitor the increase in pressure due to scaling. The differential pressure defined as the limit for ending the test was 2.5 bar.

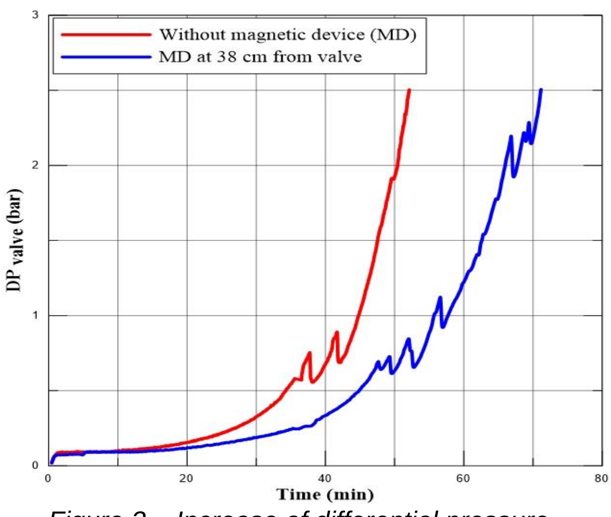


Figure 3 – Increase of differential pressure between the valve inlet and outlet due to scale formation with and without magnetic device.

Figure 3 effectively demonstrates the impact of a magnetic field on operational longevity. The graph showcases that installing a magnetic device 38 cm from the valve markedly slows down the scale deposition process. This reduction in scale buildup consequently postpones valve blockage, resulting in improved and sustained system performance over a longer period.

Prototype Manufacturing

Building on the insights gained from our experimental campaign, we proceeded with the design of a novel magnetic accessory. It is a seamless tubular element that can be installed as an integral part of the production string – Figure 4. It is composed by five (5) main elements: two crossovers - that connects the equipment to the tubing string, one internal pipe – that conducts the produced fluid, one magnetic arrangement – positioned around the internal pipe to treat the fluid, and one external pipe – placed around the magnetic arrangement for protection. The design is better described in the patent **BR 10 2021 0256958**.

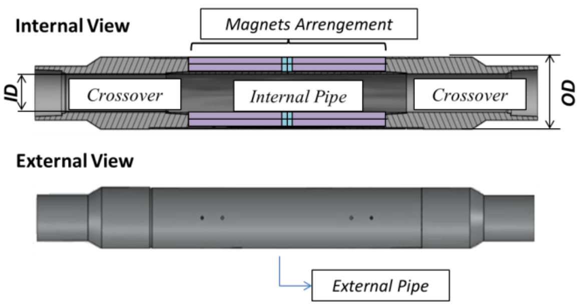


Figure 4 – 5 ½" Magnetic Accessory as-fabricated

It is important to highlight that there is no welding in the design. The crossovers can be adapted for any tubing string by simply changing the connections at the crossovers dimensions - in this paper, the manufacturing of a 5 ½" accessory is described. Figure 5a shows an internal view of the accessory with the arrangement of magnets around an internal pipe – the magnetic arrangement is composed of more than 200 magnets of NdBFe. Figure 5b shows an external view of the equipment as manufactured, with the magnetic arrangement covered by an external pipe and two crossovers at its extremities for connection with the tubing sting.

Figure 5 – Magnetic Arrangement (a) and 5 ½" Accessory as manufactured (b).

In order to ensure the accessories were robust to be installed in field, they passed through several qualification tests in laboratory simulating the forces which they could suffer during handling, transportation, installation and operation in well. This qualification steps consisted of:

- Vibration tests in an electrodynamic shaker, applying a 6.0 g (RMS) random vibration spectrum of 10-2000 Hz (+3dB/octave of 10-100 Hz, constant of 100-500 Hz and -3dB/octave of 500-2000 Hz) in the three axes (X, Y and Z) during 15 minutes each;
- Shock test in a bench test consisting of a tower that drops the accessory from a specific height with the objective to obtain a half sine pulse with an acceleration of 200 g in 11 ms. Three pulses were performed on each of the X, Y and Z axes;
- Hydrostatic test performed following the API 14L standard (American Petroleum Institute, 2020) with a test time of 15 minutes after pressure stabilization at room temperature. The tested internal pressure was 11,000 psi;
- The measurement of magnetic field was performed on accessory cross-section using a gaussimeter and a hall probe as shown in Fig. 5.

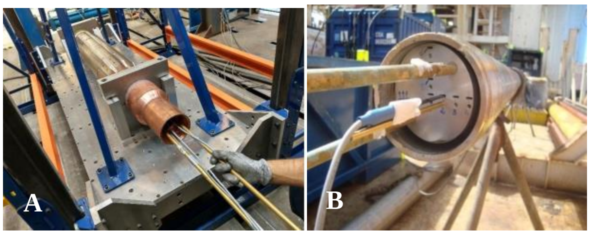
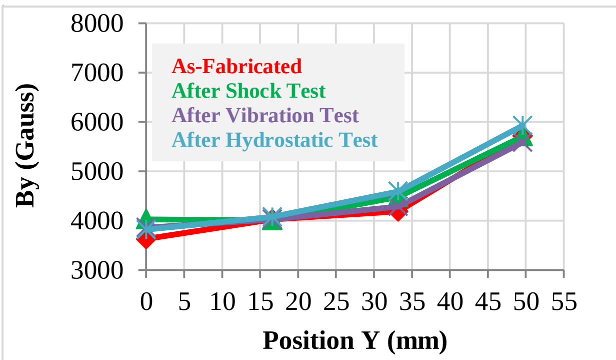


Figure 5 –Measurement of magnetic field just after the shock test (a), the metallic support (b) highlighting the seven positions that can be measured, and the three gaussimeters.

After each qualification test, the magnetic field (B) was measured again on the accessory to check the variations promoted by the tests. The average B measured for the 5 ½" Magnetic Accessory after qualification tests compared to the values obtained just after manufacturing can be checked on Figure 6. The graphs show the measured values in four different positions along X-axis and Y-axis. It can be seen that no more than 5% of variation was verified between each measurement (which is mostly due to uncertainties of the measurement itself). Therefore, these results demonstrate the good robustness of the design for installation in field.



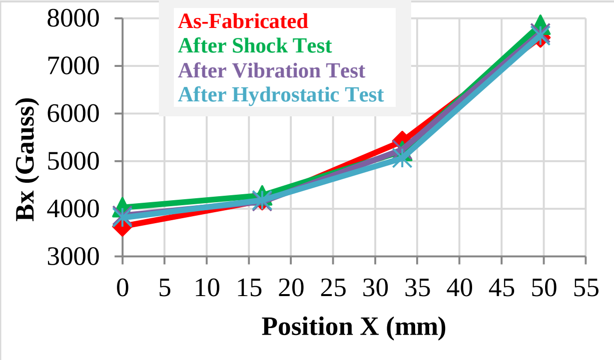


Figure 6 - Magnetic Field Density variation as-fabricated and after Shock, Vibration and Hydrostatic tests for the 5.5" Magnetic Device.

Field Deployment

Finally, the first equipment was installed in an Offshore Well in Brazil in August 2021. In order to facilitate the handling of the equipment and also mitigate the risks of impact in the region of the magnets during its installation, the device was made-up to two Pup Joints – Figure 7. Magnetic measurements were conducted again to confirm the device was functional up to the moment of installation - no deviation higher than 5% was observed from previous measurements. The magnetic accessory was hoisted from the riser deck to the catwalk. After installation, the device didn't interfere in any further step typical for well production. Since the installation in field, no scale issue has been reported by the operator.

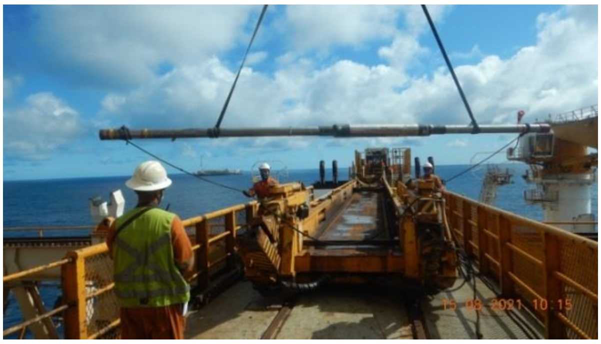


Figure 7 - Magnetic Device during installation in field.

Conclusions

Building on our experimental campaign and findings, which demonstrated that the application of a magnetic field can significantly reduce scale deposition in pipes, this technical paper detailed the development of a magnetic anti-scale accessory to be tested in offshore wells.

For qualification purposes, the accessory passed through a series of tests (vibration, shock, hydrostatic) to simulate the forces they would be submitted to during handling, transport, installation, and field utilization. Magnetic field was measured before and after each test to ensure the accessories functionality. Based on the results, both devices were approved for installation in offshore wells.

The first Magnetic Anti-Scale Accessory has been successfully installed in a Brazilian offshore well in 2021 and now a comprehensive installation program shall be performed over the next years to assess the real impact of the technology on delaying scale formation. Besides that, other potential effects of magnetic field on rheological properties of the oil (e.g. reduction of oil viscosity) are under study.

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Responsibility Notice

The authors are the only responsible for the paper content.

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