Electromagnetic Prevention of Scaling in Oil Production

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Abstract This paper presents research into how electromagnetic and ultrasonic fields affect the inhibition of calcium carbonate crystallization. It shows that resonant-wave electromagnetic exposure effectively prevents scaling in wells equipped with electric centrifugal pumps, resulting in >6x mean time between repairs. This technology can help significantly reduce the usage of oilfield reagents to prevent or address scaling, which means lesser environmental burden.

1. Introduction
Scaling of oil and gas wells and equipment makes the oil formation less permeable, reducing the flow rate, and increases the operating costs [1-3]. Scaling is mainly composed of calcium carbonate, calcium and barium sulfates, corrosion products, and heavy oil sediments.

The well space and the oil-yielding formation can be controlled by various physical and chemical methods to improve the yield and prevent/address scaling [1]. Chemicals remain the industry standard; although they have some certain advantages, they are also environmentally hazardous. Electrophysical and electromagnetic methods are becoming increasingly relevant, as they can be used in the process of oil production [4-12]. This approach to handling scaling is clearly proven promising by the ongoing studies of how physical fields (magnetic, electromagnetic, or acoustic fields) affect the structuring of dispersed systems and the phase formation of water and water-oil systems [4-7, 12, 13]. Besides, these methods help use less reagents for lesser environmental burden.

The paper presents research into how electromagnetic and ultrasonic fields generated by a resonant-wave emitter affect the deposition of sodium and calcium salts; the research uses mineral water models and operating data on the developed resonant-wave unit RVU-1 (RVU) as used to prevent scaling in wells operating electric centrifugal pumps (ECP).

2. Experimentation
How electromagnetic and ultrasonic field could affect the inhibition of calcium salt crystallization was researched on a mineral water model of the following ionic composition:

Ca²⁺ 250.8, Mg²⁺ 85.3, Na⁺ 3120.2, Cl⁻ 4492.1, HCO₃⁻ 1720.5, mg/l; this was essentially a processed-water model, PWM, of the Vyangapurovskoye field; the solution was made from AR-graded CaCl₂, MgCl₂·6H₂O, NaCl, NaHCO₃, Na₂SO₄ salts.

Laboratory tests used a bench designed by Pilot Process System Research Institute.
The team studied the effects of the electromagnetic field generated by the bench, in which the axial winding of the electromagnetic emitter core generated electromotive force, the resultant vector of which followed the axis of well equipment, while the orthogonal winding generated magnetomotive force, the resultant vector of which followed the motion of the oversaturated water solution in a CaCl2 - MgCl2 - NaHCO3 - NaCl model at 75ºC, see Figure 1. The magnetic induction the PWM was exposed to reached 1.5 to 1.8 T.

![Figure 1. Distribution of magnetic induction vectors when generating an electromagnetic field by an emitter.](image)

Size of the emerging CaCO3 crystals was measured by an Analysette 22 NanoTec plus laser diffraction particle-size analyzer. The morphology of CaCO3 particles created by the electromagnetic field was analyzed by a Rigaku Ultima IV X-ray diffractometer. Analysis used Cu-Kα radiation at 20 kV and 2 mA with wavelength λ = 1.5405 Å. Scanning was done with a 0.02° increment in a range of 2θ = 15-115°. Match! was used for diffractogram processing and phase analysis.

The morphology of NaCl and CaCO3 generated by electromagnetic and acoustic fields was analyzed by a Bruker D8 ADVANCE diffractometer that used the Bragg-Brentano method. Analysis used Cu-Kα radiation at 40 kV and 40 mA. Scanning was done from 10° to 145°C with 0.01°C increment; exposure per point was 10 s. Qualitative phase analysis used PDF-2 X-ray database in PDXL v. 1.8.1.0. For more accurate quantitative phase analysis, the vol.% of f-extractions was calculated by the Rietveld method using a pseudo-Voigt function to describe the peak profiles; given its asymmetry, the background radiation was subtracted by the Sonneveld-Wisser method.

3. Discussion
Exposure of water solutions to electromagnetic fields is known to affect the water structure, hydrated ions, and solubility of inorganic salts [4,5,12].

Ufa State Aviation Technical University has cooperated with the Pilot Group to develop a scaling prevention method that uses electromagnetic fields; testing this method did not identify any significant effects or acute toxicity in daphnia exposed to the generated electromagnetic field [6]. The technology uses little energy, as the generator only needs about 100 W.

A ultrasonic field is known to prevent or significantly inhibit scaling. 1 to 16 kHz is deemed the most optimal range for acoustic exposure, which is below the ultrasonic threshold of 40 kHz [7].
This is why further research into calcium carbonate crystallization under the influence of physical fields covered the co-effects of electromagnetic and ultrasonic fields on the interaction of CaCl₂ and NaHCO₃. X-ray testing revealed that when CaCO₃ emerges from an oversaturated water solution in a CaCl₂ - NaHCO₃ - NaCl model at 75°C as exposed to an electromagnetic field, aragonite was the predominant newly emerging compound, see Figure 2. As the electromagnetic field primarily generated aragonite, which is a low-adhesion mineral, the calcium carbonate crystals could be easily removed from the well by the water-oil emulsion rather than being deposited on the equipment inside the well. Calcium carbonate in the form of aragonite has far lower free surface energy than calcite, hence lower surface adhesion and lower agglomeration of aragonite crystals. This data was confirmed by pilot testing.

Ultrasonic exposure at 22 kHz resulted in the deposition of halite, calcite, aragonite, and vaterite in a 51:72:1:1 ratio, see Figure 3. The predominance of emerging calcite in the presence of sodium chloride was assumingly due to the ionic strength of the solution, as the (NH₄)₂CO₃·CaCl₂ model generated CaCO₃ in the form of vaterite predominantly with the crystal size being reduce from 20 to 2 µm when exposed to an ultrasonic field at 20 and 40 kHz [7].

![Figure 2. Diffractogram of CaCO₃ crystals generated by an electromagnetic field. Calcite (C). Aragonite (A).](image-url)
As shown in diffractograms, exposure to a ultrasonic field at 22 kHz and an electromagnetic field at 150 kHz produced sediments that were 93% calcite, 2.7% aragonite, and 3.8% vaterite (Fig. 4). Laser diffraction testing of CaCO$_3$ crystals showed that simultaneous exposure to a 22-kHz ultrasonic field and a 150-kHz electromagnetic field resulted in the emergence of two calcium carbonate particle groups sized ~2.5 and ~15 µm; the ratio of these two groups remained constant over 55 minutes, a sign of low adhesion and agglomeration. The 2.5-µm group could be a mixture of aragonite and vaterite, as the ratio of these two groups matched that of aragonite plus vaterite to calcite as found by X-ray analysis, see Figure 6. CaCO$_3$ crystal-size distribution was wider when exposed to the Earth’s magnetic field, a sign of agglomeration.
Figure 5. CaCO3 crystal-size distribution when exposed to the Earth’s magnetic field.

Figure 6. CaCO3 crystal-size distribution under simultaneous exposure to a 22-kHz ultrasonic field and a 150-kHz electromagnetic field.

Pilot testing thus proved this technology efficient against scaling in ECP-equipped pumps. Figure 7 presents the results of RVU application at oil-and-gas fields in 2018 and 2019. At the Listvenskoye field, one that features calcium carbonate and iron sulfides, using the RVU reduced the calcium carbonate concentration in sediments from 51.0 to 14.4 percent, whereas the mineralization of the water solution dropped from 200 to 18.6 g/dm$^3$. ECP time to failure rose to 321 days.

Figure 7. RVU operation at Listvenskoye, Mishkinskoye, and Yem-Yeganskoye fields.
Mishkinskoye and Yem-Yeganskoye fields had barium sulfate deposits and NaCl, CaSO₄·2H₂O, and other inorganic compounds, see Table 1. Modified RVUs more than doubled the mean time to failure. With a 99% watercut, ECP time to failure reached 636 days with no complications arising, see Figure 7. RVU performance was proven by the ECP running stably at the Verkhneochenskoye field throughout its operation: no complications arose due to halite deposition.

Table 1. Water minerals and ECP failure causes at the Yem-Yeganskoye field, no RVU.

| Well, Field                  | Complication | Water chemistry | Cause of failure                      |
|-----------------------------|--------------|-----------------|---------------------------------------|
| Well 1, Yem-Yeganskoye field | barites      | CaCO₃, 1.15%    | Lower throughput, impurities           |
|                             |              | Al₂O₃, 0.92%    | (solids damaging the ECP actuators)    |
|                             |              | SiO₂, 0.69%     |                                        |
|                             |              | BaSO₄, 81.83%   |                                        |
|                             |              | SrCl₂, 1.18%    |                                        |
|                             |              | Fe₃O₄, 4.95%    |                                        |
|                             |              | ZnCO₃·ZnOH₂, 0.34% |                                |
|                             |              | KCl, 6.83%      |                                        |
|                             |              | NaCl, 2.11%     |                                        |
| Well 2, Yem-Yeganskoye field | barites      | FeS, Fe₃O₄,    | Scaling, solid deposits on the         |
|                             |              | Ca₂Fe₂O₅, 7.8%  | actuators, 100%                        |
|                             |              | Fe₂ZnO₄, 85.7%  | clogging of the lower                  |
|                             |              | BaSO₄, 85.7%    | flow-through canals.                   |
|                             |              | SiO₂, 6.5%      |                                        |

Figure 8. Condition of equipment actuators: RVU in use.

At a well in the Urshakovskoye field, one abundant in calcites, halites, and plasters, time to failure was risen to 332 days; no scaling was found on the actuators, see Figure 8. At the Yarino-Kamennolozhskoye field, one rich in calcites and plasters, ECP time to failure became 1.5 times longer.

Use of RVUs in wells prone to scaling effectively resulted in a >6x longer mean time between repairs. This technology can help significantly reduce the usage of oilfield reagents to prevent or address scaling, which means lesser environmental burden.

4. Conclusion
Electromagnetic and ultrasonic fields can efficiently prevent scaling and perform well in a variety of industrial settings. RVU pilot tests prove electromagnetic fields efficient against scaling of ECP-equipped wells; the solution works well against calcites, barites, and halites alike. It can help prevent
mineral deposition on the equipment inside a well. Importantly, it can be used in production without affecting it.

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