

GREEN RESERVOIR CONFORMANCE TREATMENT IN OIL FIELDS: FOCUS ON SILICATE-BASED TECHNOLOGIES

István Lakatos, Gabriella Szentes

*Applied Research Institute of Earth Sciences, University of Miskolc, Hungary
MTA-ME Geoengineering Research Group, University of Miskolc, Hungary*

Slawomir Falkowicz, Renata Cicha-Szot

Oil and Gas Institute – National Research Institute

ABSTRACT: Reservoir conformance control (RCC) is a general term comprising several well stimulation technologies including hydraulic fracturing, matrix acidizing, bottomhole clean-up, leak-off remediation, selective fluid flow improvement. Philosophy of profile correction and particularly water shutoff methods is conscious and directed initiation of formation damage in the target reservoir space and the proper production stage through drastic reduction of mobility. The scientific and engineering results discussed in the paper cover description of philosophy of profile correction and options to exclude water encroachment, application of silicate based technologies and well performance which clearly indicated advantages of the technology.

General aspects

The appropriate application of reservoir conformance control, particularly in depleted fields, can significantly lead to improved and enhanced oil and gas recovery (IOR/EOR), and hence the profitability of operations. The term “conformance” in its original form is defined as the measure of the volumetric sweep efficiency during the recovery and the forced intervention into the reservoir. The term also refers to a measure of and the treatment of excess water (rarely gas) production. Excess water production usually imparts indirectly a negative influence on volumetric sweep efficiency, and as a result deteriorates the profitability of production operations. The technical options of IOR and EOR technologies focusing on these problems are flooding technologies addressing the whole reservoir space and well treatments addressing the near wellbore regions. It should be emphasized that there is no sharp boundary between these two options. However, the reservoir conformance control (RCC), particularly the water shutoff treatments are much cheaper methods, their response time is short, risk is lower, and therefore they are highly appreciated by the operators.

Main goals of RCC methods and water shutoff treatments

The formation damage, decreasing productivity/injectivity and deterioration of flow profile are expensive and permanent headache of oil and gas production. However, mitigation of formation damage and fluid flow control including water shutoff are intervention in such phenomena, which is usually invisible, hard to influence and quantify and often out of our control. Despite

that fact, the water shutoff technologies are indispensable elements of production scenario because currently the global oil production is about 4 Gt accompanied with 12 Gt water production. The cost of water lift-up may represent 70% of total fluid production and 55% in total maintenance expenditure of an active production well. The high water production can be traced back to different reasons. As shown here in Figure 1 using 3D illustration, usually the viscous fingering, matrix channeling, conning, cusping, fracture network, vugular channeling, casing leaks are in the background of high water cut in oil fields.

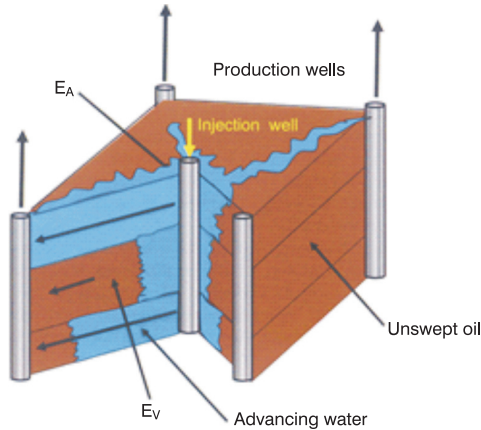


Fig. 1. Viscous fingering is the most frequent problem having high water cut in oil producers

Philosophy of profile correction and options to exclude water encroachment

Conscious and directed initiation of formation damage in the target reservoir space and the proper production stage through drastic reduction of mobility. The drastic mobility alteration can be accomplished *in situ* by:

- Extreme modification of rheological properties,
- Effective modification of pore structure,
- Simultaneous modification of both the rheological properties and the pore structure.

Although several hundreds of different methods have been developed in the past decades, the most frequently used water shutoff technologies and chemicals can be classified as follows:

- Inorganic based gels (pH controlled),
- Organic based gels (ionic X-linking),
- Monomer based gels (covalent bonding),
- Mixed inorganic and organic gels (multifunctional bonding barriers),
- Microgels (covalent X-linked solid microgels).

Application of silicate-based technologies

Earlier, the organic gel technologies were preferentially used, however their field applications were highly limited by restricted thermal stability and environmental regulation. Although the silicates as RCC and EOR application was claimed as a patent already a hundred years ago (1918 and 1922), their wide-range application got to the forefront of field operations only

from the mid-80s of the last century. It has been approved that permeability modification with silicates is a viable and successfully tested alternative of methods developed for selective flow control in porous and fractured formation rocks, soils, etc. This can be attributed to the fact that the silicate technology is a multifunctional method, which has high flexibility to meet various field conditions tailoring the treatment protocol to individual producing and injection wells. The internal and external catalyzed gelation methods attracted great attention today due to their outstanding features, among others:

- Low viscosity of treating solutions, viz. good placement selectivity,
- Short to moderate pumping time before onset of gelation,
- Flexible chemical mechanism,
- Good chemical and chemical stability,
- Excellent thermal and mechanical resistivity,
- Easy gel breaking in case of technical failures,
- Simple and cost-effective surface technology,
- The silicates are environmentally friendly materials,
- Silicates are prone to form precipitates instead of gel.

Unfortunately, the pure silicate gels had some disadvantageous properties too. Therefore extensive R&D activity was initiated mainly in Hungary and Norway. The pioneering efforts, in the Applied Research Institute of Earth Sciences, University of Miskolc, started already decades ago and their directions were the following:

- Addition of anionic polymers to silicates with the aim at simultaneous cross-linking of polymers and gelation of silicates;
- Cross-linking of silicates by cationic polymers in a bulk phase resulting in a semi-flexible, single network in gel;
- Gelation of silicates in the presence of additives, mostly humates, resulting in a rigid, but clustered network in gel;
- Addition of in situ decomposing pH lowering compounds (e.g. urea) to polymer/silicate solutions to control gelation time in bulk injection technology;
- Joint application of silicate solutions and nanosilica particles.

Until now, more than 100 jobs were carried out to restrict water production in oil wells (Hungary and Oman), restriction of gas migration in a collapsed well drilled into an overpressurized CO₂ reservoir (Serbia) and remediation of casing leakoff in an underground gas storage facility (Germany). The statistical data clearly prove that the job success rate is over 70% while the 55% is sufficient to attain the economical success. Despite some unsuccessful treatments, the overall revenue is definitely 3–5 times of the OPEX+CAPEX, and the positive response of well treatments is extending sometimes for years.

Recent application of the green and advanced silicate technology in Hungary

The laboratory and field studies made possible to accumulate enormous amount of experiences, knowledge, and know-how. These are summarized in numerous papers presented at different forums of the Society of Petroleum Engineers organized worldwide. The scientific and engineering results discussed in these papers have been cited more than 300 times in the international literature, dissertations, and patents. Hereby, only two papers are cited demonstrating the historical background and the recent technical achievements. The first one is summarizing the results of water shutoff and profile control treatments in three different oilfields operated by

the PDO (Oman). In time of the project, that was the most successful one compared to efforts by other invited service companies being active in Oman. The second paper is dealing with the most advanced silicate water shutoff treatment applied in Hungarian oil field. Unique feature of this technology was that a combined silicate/polymer/nanosilica system was first applied in practice not only in Hungary, but the world. As an example, the production history, period of the treatment and the positive response of the well is illustrated in Figure 2.

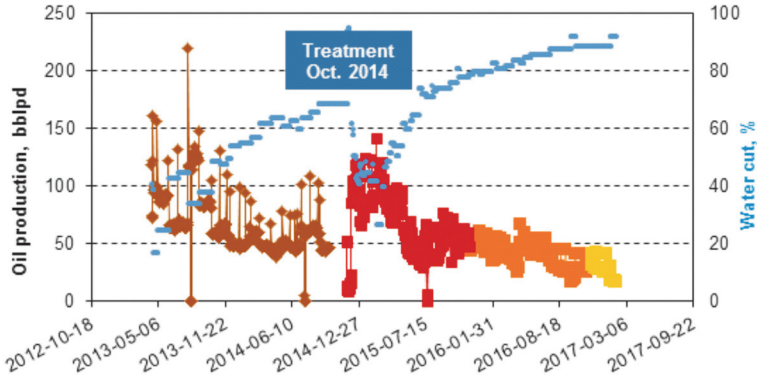


Fig. 2. Production characteristic before and after the treatment

Table 1. Characterization of treatment

Average water cut (before)	> 70%
Oil production rate (before)	~ 50 bbl/d
Average water cut (after)	< 40%
Oil production rate (after)	> 120 bbl
Total incremental oil production	21,000 bbl
Total reduced water production	32,000 bbl
Lifetime of positive response	3 years
OPEX/CAPEX (two treatments)	238 thousand USD
Net profit	653 thousand USD

The well performance clearly indicated the following advantages:

- Combining the silicates with polymers, particularly “liquid” or suspension polymers, some fundamental deficiencies of the single silicate gel could be eliminated through forming double network in gel;
- Combining the silicate and silicate/polymer gels with nanomaterial, the advanced nucleation of gel formation provided faster, reliable and controllable chemical reactions under both laboratory and field conditions;
- The polymer is a retardant, while the nanosilica is an accelerator of gelation. The combined method proved too superior to organic gel RCC methods providing wider controlling options to comply the requirements in and around the reservoirs and wells;
- Inevitable advantage of the composite silicate/polymer/nanosilica methods are that it is based on cheap, easily available chemicals and all components of the technology are absolutely environmentally friendly;

- The composite silicate gel has long-term thermal stability up to 150°C, decreases the permeability down the less than 0.1 mD by 4–5 orders of magnitude, and alternates the driving force of flow from hydrodynamic – to diffusion-based;
- Application of silicate/polymer/nanosilica gel to control the detrimental water production resulted in outstanding technical and economic results treating two oil producers operating in an oil field, Hungary;
- Since the profitability of treatments was above the expectation, the operator plan to continue the advanced RCC method to control water production in brown, partially depleted oil fields.

The author are looking forward a fruitful and perspective cooperation with the professionals of the Polish Oil and Gas Co. with the aim at improving the well performance at both oil and gas fields.

Acknowledgements

The authors wish to express their appreciation to the National Research Program, (GINOP-2.3.2-15-2016-00010), and the European Regional Development Fund also supported this presentation.

Literature

- [1] Lakatos I., Lakatos-Szabó J., Kosztin B., Al-Sharji H.H., Ali E., Al-Mujaini A.A. R., Al-Alawi N.: Application of Silicate/Polymer Water Shutoff Treatment in Faulted Reservoirs with Extreme High Permeability. SPE European Formation Damage Conference, Proceedings SPE 144112, ISBN 978-1-61399-121-3, 7–10 June 2011, Noordwijk, The Netherlands 2011,
- [2] Lakatos I., Lakatos-Szabó J., Szentes G.: Revival of Green Conformance and IOR/EOR Technologies: Nanosilica Aided Silicate Systems. A Review SPE Pet. Eng. (USA) Paper 189534, DOI: org/10.2118/198534-MS. Presented at the SPE International Conference and Exhibition on Formation Damage Control held in Lafayette, LA, USA 2018.

Przyjazne dla środowiska technologie stymulacji złóż ropy naftowej na bazie krzemianów

STRESZCZENIE: Technologia RCC (*Reservoir Conformance Control*) to ogólny termin obejmujący kilka technologii stymulacji odwiertu, w tym: szczelinowanie hydrauliczne, kwasowanie matrycy, czyszczenie odwiertów, remediację wycieków, selektywne usprawnianie przepływu płynu. Idea korekty profilu, a w szczególności metod odcinania dopływu wody, jest świadomą i ukierunkowaną inicjacją uszkodzenia formacji w docelowej przestrzeni złoża, która przeprowadzona podczas odpowiedniego etapu produkcji prowadzi do drastycznego ograniczenia mobilności wody w analizowanym ośrodku. Wyniki badań naukowych i inżynierskich omówione w artykule obejmują opis filozofii korekty profilu, zastosowanie technologii opartych na krzemianach oraz analizę produkcji otworów poddanych takiej korekcie, która potwierdziła zalety stosowania technologii RCC.