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A Novel Gas Dispersible Foam Technology Can Improve the Efficiency Of Gas Injection Processes For IOR-EOR Operations In Unconventional Reservoirs

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- Artículo Técnico ☒
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Abstract

Gas injection has become one of the most investigated methods for enhanced oil recovery in unconventional reservoirs. Nonetheless, the presence of natural and induced fractures negatively impacts the gas injection efficiency due to its channeling towards nearby wells or poor coverage in the treated area due to lack of conformance. To overcome these difficulties and boost the oil recovery process by gas injection, this work presents a novel gas dispersible foam technology to improve the sweep efficiency of gas injection in unconventional IOR/EOR projects.

The development and evaluation of this technology has passed through a series of laboratory assurance stages that include fluids characterization, compatibility, and extensive coreflooding tests. A modelling approach is also presented, which was validated using lab and field data taken from the implementation of the technique in an extremely low porosity, tight and naturally fractured quartz-arenite gas condensate reservoir in Colombia. The workflow herein presented encompasses interdisciplinary components such as laboratory evaluation, reservoir modeling, treatment design, and wellsite setup and execution.

Laboratory testing and inter-well field applications results, along with the development and testing of a phenomenological modelling approach, demonstrate that the gas dispersible foam injection can be a high potential technique for oil and/or condensate recovery in unconventional reservoirs given its proven ability to improve the deep reservoir gas conformance and avoid the lack of gas containment during gas injection IOR/EOR in unconventional plays. Lab results in a tight naturally fractured sample, suggest that the estimated incremental oil recovery was ~36% and the effective gas mobility reduction was ~45%. This technique also exhibited less chemical adsorption losses, which contributes to better chemical emplacement and longer durability. The main results of the field application, including a progressive decrease in gas injectivity at the gas injector, a consistent reduction in GOR with an associated oil increase at the influenced producer well, and a reported treatment durability of ~ 6 months, were all properly represented by the model.

Each step of the workflow herein proposed not only assures the gas-based projects success, but also allows for smaller logistics footprint at the well location, along with less water consumption, which translates into cheaper and more efficient gas injection conformance operations.

1. Introduction

An economically viable production from unconventional reservoirs depends on the application of horizontal drilling and multi-stage hydraulic fracturing due to the extremely low permeability of the hydrocarbon bearing rock formations. Moreover, the relative high production rates during the primary production stage do not last long and the declination goes forward quickly. This phenomenon arises from the fact that a considerable amount of the hydrocarbons present does not achieve an effective flowing from the rock matrix to the well producers even after the application of extensive hydraulic fracturing jobs. In consequence, recovery factors are low sometimes compromising the return of the investment. Hence, the unconventional reservoirs production has been in need to develop more efficient technologies for IOR/EOR [1] [2].

Enhanced Oil Recovery methods often used in conventional reservoirs have been largely tested in unconventional reservoirs. Laboratory and simulation studies as well as some pilot field tests suggest predominantly the gas injection is the most feasible EOR method in unconventional reservoirs as compared with water injection, surfactants injections etc. [3], [4]. Consistent with this finding, gas injection has been widely studied in recent decades emphasizing the methodologies evaluation and the pros and cons of the possible injection schemes: Huff and Puff, and inter-well/pattern gas flooding. Also, different types of gases such as hydrocarbon and non-hydrocarbon gas (CO2, N2, Flue Gas, etc..) have been attempted [2] [4] [5].

In spite of the promising advances in gas injection for increasing the recovery factor in unconventional reservoirs, its effectiveness has been impaired by gas conformance control problems in reservoirs with natural fractures presence or heterogeneous permeability. Gas injection aims at guaranteeing an effective matrix sweep to recover additional oil. Nonetheless, this purpose is affected negatively by fractures or high permeability zones where the gas is channelized and deviated from this target [6] [7].

To optimize gas injection operations for IOR/EOR, foam technologies have been applied in conventional and unconventional reservoirs. While there have been many field pilots of foam implementations in conventional reservoirs, only few field pilots have been reported for unconventional ones [8], [9]. Foam Generation and their propagation into the reservoir promote the reduction of the injected gas mobility, and the diversion of gas flow to the matrix rock that surrounds the fractures, allowing new volumes oil production. Frequently, foam application is based on the Surfactant Alternating Gas (SAG) technique rendering positive results in term of incremental oil production [8] [9]. However, in search of improving technical aspects of foam application in fields operated under gas injection, such as reduction in water consumption, use of less surface equipment, and a more efficient use of the chemicals, a novel gas dispersible foam technology to improve the sweep efficiency of gas injection in IOR/EOR projects is presented.

In this paper, a conceptual model and workflow for gas dispersible foam technology design and field application in an unconventional reservoir is presented. The workflow encompasses interdisciplinary components such as laboratory evaluation, reservoir modeling, treatment design, and wellsite setup and execution.

2. Dispersed foam technology: design and application workflow

The successful implementation of a conformance technology such as the Dispersed Foam with hydrocarbon gas requires not only the existence of a strong technology concept, but also a rigorous and robust Front End Loading (FEL) process. The project presented herein included the screening of the specialized foamer, the experimental evaluation of its performance under different conditions (concentration, gas rates, rock types), selection of the candidate well to perform the Pilot, Operation design and planning, analytical modeling for benefits forecasting, field execution and surveillance plan to monitor results. This specific project included de acquisition of a base line Tracers program to properly track the gas injection conformance after the gas-dispersed foam treatment. The operation design and planning included both the subsurface aspects and the surface facilities and areal/regional infrastructure considerations, and rigorous risk analysis for both aspects of the project.

2.1 The injection of a chemical-in-gas stable dispersion: the concept. Taking a chemical agent into a reservoir using a gas as the carrying system is a novel technique that makes a difference as compared to chemical liquid-based injection operations, in terms of deeper and more effective contact of the chemical into the rock. This is because of gas diffusion effects promote better areal and vertical chemical distribution as well as enhanced adsorption of the chemicals favoring durability. Following this approach, a foam agent application through a gas stream towards the porous medium was tested at laboratory and field scales. Additionally, modeling approaches were also developed. This comprehensive analysis demonstrates that this novel technique to apply foam technology is an efficient mechanism to block temporarily high conductivity layers, control gas containment issues, rendering an improved gas injection conformance and incremental oil recovery.

2.2 Experimental assurance. A successful foam dispersed-in-gas technology application requires a holistic approach that considers both the reservoir characteristics, and the nature of the technology; and should include: chemical screening and selection, rock and fluids compatibility, emulsion formation risk, pores blocking etc. In order to design a suitable foam dispersed-in-gas solution for a specific target, standard tests are performed to characterize the chemicals and reservoir fluids properties as well as its interaction. Among these tests fluid-fluid and gas-fluid compatibilities are included, IFT and contact angle tests, and retention and desorption tests. Once, these preliminary tests are done, a coreflooding is performed to evaluate the solution performance in the rock system. This coreflooding test consists firstly of performing an oil recovery test injecting gas in a rock plug to determine base oil and gas relative permeabilities as well as recovery factor. After, the foam agent dispersed-in-gas is injected to induce a blockage mechanism into the fractures and thief zones. Gas conductivity is monitored during this process. Finally, the oil recovery test is done again to assess the foam technology effect in the rock system productivity.

Several corefloodings using the gas-dispersed foam technique have been done in naturally fractured, stress sensitive, core plug samples with low porosity and permeability (Figure 2). Figure 1 depicts the results obtained in one of those tests performed. A significant outcome is a reduction in gas conductivity around 45%. This gas flow blockage translates into an incremental recovery factor close to 36% (from 48% to 84%) after the third concentration of solution was injected (30 ppm). [10].

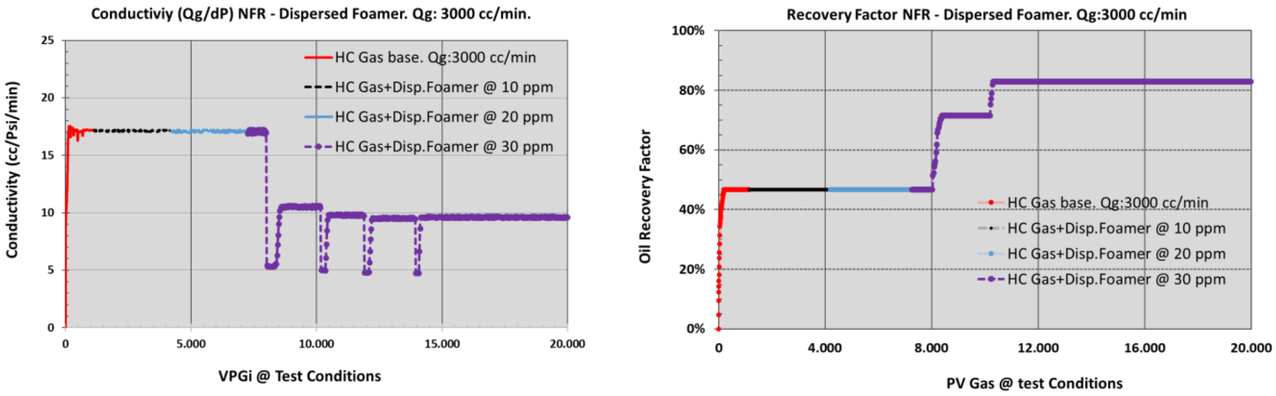

Figure 1. Results of coreflooding lab test at reservoir conditions. Left: Gas Conductivity, right: Recovery Factor. [10].

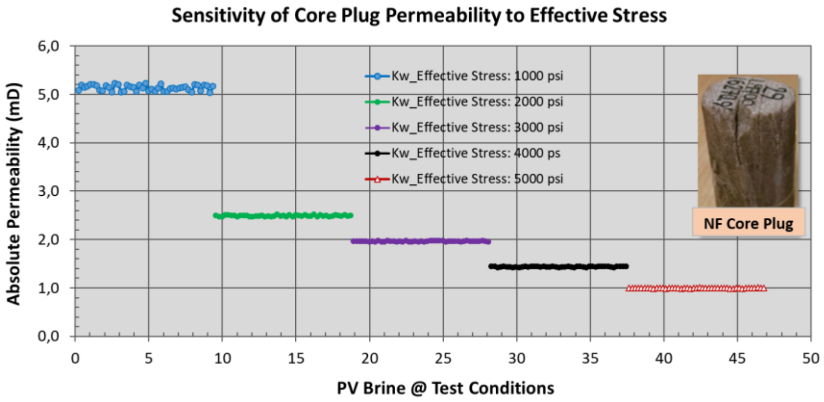

Figure 2. Absolute Permeability sensitivity of NF core plug to Stress state. Tests run at reservoir conditions, and five different hydrostatic confining pressures. Actual core plug photograph is inserted for visual illustration. [10].

2.3 Candidate Selection. As part of the FEL process, an identification and screening of candidates was performed to select an appropriate candidate well to perform the gas-dispersed foam intervention. It is worth to clarify that the gas condensate and volatile oil Piedemonte fields in Colombia have been developed under gas reinjection, but they do not have regular patterns. The gas injection is performed at the crestal areas of the structure whenever possible, and at the flanks.

The final selection of the candidate was done in a Gas Condensate reservoir with only one dedicated producer and two gas injectors located at approximately the same structural position than the producer, aligned approximately 180° opposite to the producer well (See Figure 3). The well selected for the foam treatment was the one notated as FRIf14, located NE from the producer, which was a mature gas injector with confirmed evidence of gas breakthrough and known injectivity performance, and where a successful liquid batch foam treatment had been performed two years before. There was enough subsurface data supporting the ultralow porosity (~4%) and permeability (< 0.1 mD) of the matrix system, and the naturally fractured characteristics of the reservoir.

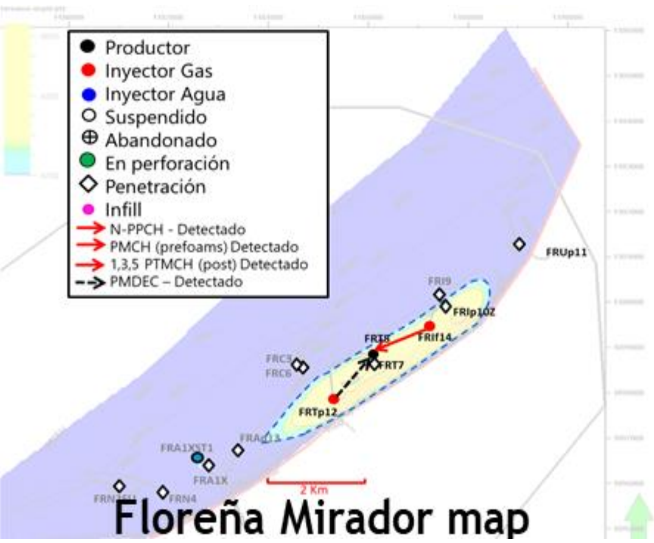

Figure 3. Location map for Dispersed Foam Pilot. [13].

2.4 Modeling. General success of injecting dispersed chemical treatments for formation damage remediation and in-situ foams has been demonstrated through laboratory tests and field applications. To harness this technique and design the most suitable solutions for a specific target, an analytical modeling tool has been developed for fine-tuning of treatment design parameters and the monitoring of operative variables at the wellsite. Predictions of expected chemical displacement and location into the reservoir after treatment and during the flowback can also be obtained (see Figure 4).

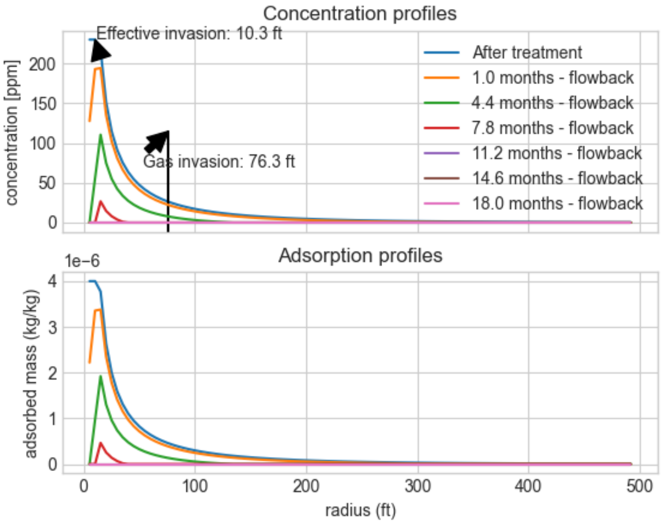

Figure 4. Chemical Profile in the reservoir after treatment and during flowback

The mathematical model behind the analytical tool consists of chemical sorption kinetics equations and a dynamic IPR analysis, all of this is fed by laboratory data. Numerical approaches for designing In Situ foam generation using dispersed chemical agents' injection have advanced through the development of a mechanistic model based on multi-component fluids flow, and transport and sorption equations for the foaming agent (surfactant). Foam is modeled using the lamella population balance method (LPBM). Foam texture is represented by a lamella concentration which is estimated using a population balance equation, and changes in foam texture are defined by lamella generation and coalescence dynamics. The model was calibrated using experimental data set from tight cores. During the test, dry gas was injected at a rate of 11.8 cc/min. Then, the foaming solution was dispersed on the injection gas stream at a concentration of 140 ppm, and the blocking foam was created after 369 pore volumes injected. The comparison of the core conductivity and recovery factor predicted by the model and experimental measurements are presented in Figures 5 and 6. Model results suggest a good agreement with experimental data where the recovery factor changes from 52.0% OOIP after the gas base injection to a recovery of 70.5% [11] [12].

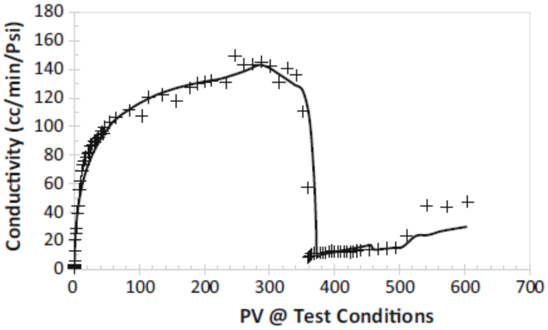

Figure 5. Validation mechanistic model: Gas conductivity along the core. [12].

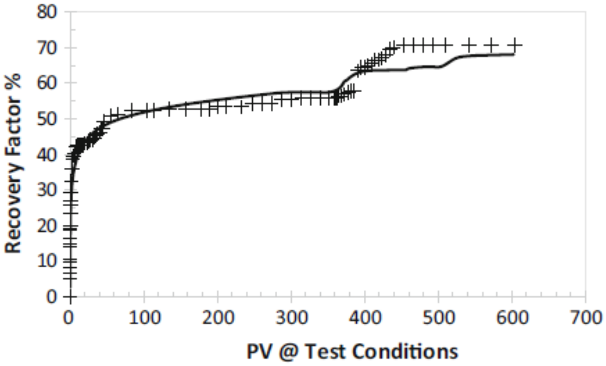

Figure 6. Validation mechanistic model: Oil recovery factor. [12].

2.5 Field pilot application. The effectiveness of dispersed foam technique in naturally fractured reservoir with low porosity and permeability was tested in a Colombian field [9]. Previously, a foam implementation using the SAG technique had been performed in the same well system. Around 1000 bbls of diluted foaming solution in a hydrocarbon gas stream was injected in an injector well at a rate injection varying between 30 and 40 MMSCF/d. The foam chemical dispersion rate in the gas stream started at 1 bbl/MMSCF, and was progressively increased, finishing at approximately 3 bbls/MMSCF. The treatment was performed using the same gas injection line of the well, and the chemical solution was injected utilizing a surface set up as illustrated in Figure 7.

Figure 7. Surface set up for Dispersed Foam Deployment at well location

The operation lasted for about three weeks during which a progressive reduction of gas injectivity was evidenced by the progressive increase of the WHP. Performance evaluation showed a strong blocking effect at the last stage of the dispersed foam injection, causing a gas injection reduction close to 50%. (See Figure 8). [9].

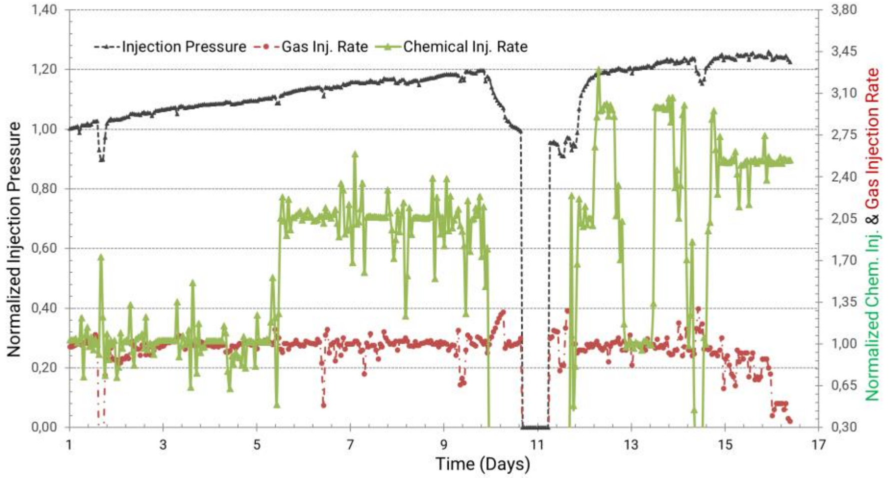

Figure 8. Dispersed foam injection performance.

In Figure 9, the production performance of the influenced well is depicted. The oil production clearly tends to increase over time, while GOR decreased. [9]

Production test performed at the producer well after the injection of the dispersed foamer showed a reduction in the GOR, and then it stayed closed to flat for several months. At the same time, the oil production continued to increase for about 6 to 7 months. After this period, the GOR started to raise again, while the oil rate started to decrease along with the increase on GOR, indicating the end of the intervention effect. The positive results of the gas-dispersible foam treatment were further confirmed by using a chemical tracer program that showed a time delay of two-fold to the gas injected after the dispersed foam job, Vs the gas injected before the job (63 days post job Vs 28 days as base line) (Figure 10) [9].

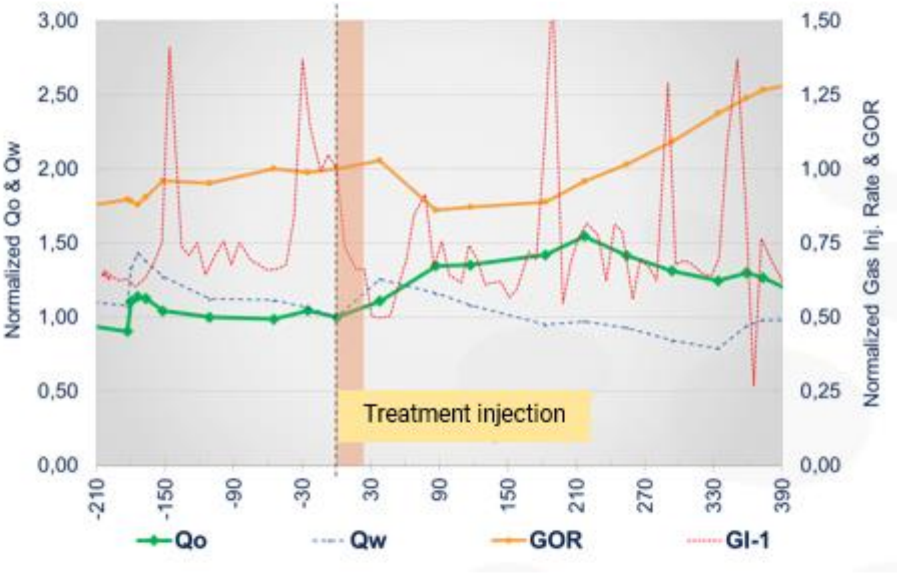

Figure 9. Production Performance – Well Influenced by Gas-Dispersed Foam Job.

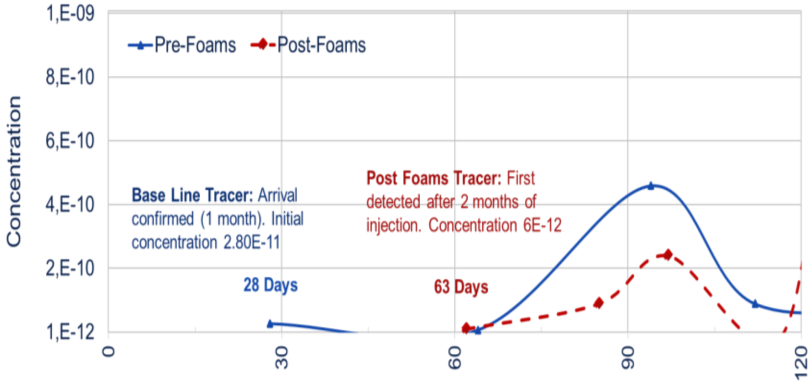

Figure 10. Chemical tracer program results at the well influenced by gas-dispersed foam job.

3. Conclusions

The following conclusions can be drawn from the material presented:

The investigations at lab scale, along with inter-well field application and the phenomenological modelling, demonstrate that the gas-dispersible foam injection can be a high potential technique for oil and/or condensate recovery in unconventional reservoirs, such as tight and naturally fractured sandstones. It can be applied to address the conformance difficulties associated with both the intra-reservoir heterogeneities and the lack of containment during gas flooding and Huff and Puff interventions.

A numerical multiphase and multicomponent model was developed to simulate the dispersed injection of a foaming agent. The model was validated using experimental coreflooding tests data at reservoir conditions, achieving successful reproduction of the conductivity of the gas and the incremental oil recovery after the dispersed foam treatment.

The duration of the gas-dispersed foam treatment is similar to the times observed for the Liquid Batch (SAG) technique, which was around six (6) months.

Experimental evaluation also confirms effectiveness of the gas-dispersible foam technology rendering gas conductivity reductions close to 45%, and Incremental oil recoveries close to 36% in naturally fractured, low poro/perm core plugs.

This new gas dispersible foam technique presents clear advantages over the more conventional SAG and Co-Injection techniques such as less operational footprint and water consumption, as well as deeper penetration treatments.

Due to the nature of this foam technique, its use can be extended to other type of Unconventional reservoirs such as Shale Gas or Shale Oil and could be performed using other non-condensable gases such as Nitrogen, and Flue Gas.

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