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Inoculation Key To MEOR Technique

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WILMINGTON, DE.–An advanced microbial enhanced oil recovery (MEOR) technology has been piloted successfully in the field, and now is expanding its application across North America and the rest of the world. With its unique inoculation step and proprietary injection protocol, this technology stands apart from other MEOR approaches in that it offers a recovery mechanism that is dynamic, reversible and reliable.

This breakthrough solution provides a viable, organic and "no-capital" option for improved oil recovery that is proving to be profitable for many mature waterfloods. It joins more traditional EOR methods, such as gas flooding and chemical treatments, but is differentiated by price and reversibility. It utilizes a customized combination of microbes and nutrients selected for the reservoir to maximize the effectiveness of the treatment and to assure the greatest efficacy across a wide range of reservoir conditions.

There are two methods by which this MEOR treatment can provide a substantial increase in crude oil recovery factor. The first is improved sweep efficiency through flow conformance. By modifying (or "bio-plugging") high-permeability zones in the reservoir, this MEOR treatment forces water to target oil from previously unswept parts of the reservoir to improve overall sweep efficiency.

A second, differentiated mechanism, allows for reduced oil/rock surface tension, resulting in a change in the wettability of the rock and lower residual oil saturation. With this method, the microbes produce a surface-wetting agent that reduces residual oil saturation to generate additional oil production. No oil-in-water emulsions are created, since there is no impact on the oil-water interfacial tension.

MEOR Inoculation

While most MEOR treatments consist solely of injecting a nutrient solution down hole, this new technology offers improved response and reliability through an additional, critical step: inoculation.

Using this innovative inoculation approach, water samples are collected from an oil reservoir and naturally occurring microbes are screened for functional activity that will deliver the desired results. The microbe demonstrating the greatest functionality is then selected, propagated and fermented in a live broth. The broth, along with a customized aqueous nutrient solution, is injected into the reservoir, and the microbes begin their work.

In contrast to a nutrient-only approach, MEOR inoculation:

- Improves the odds that the desired microbial strain is being nourished by the targeted nutrients;
- Penetrates deep into the reservoir; and
- Ultimately results in higher recovery rates.

Inoculation has been shown in laboratory tests to be critical to the success of MEOR. The improved flow conformance MEOR mechanism was measured in a specially designed slim tube apparatus with a nutrient-only treatment, and was compared with a second slim tube using the new MEOR methodology that included nutrients and inoculum. Authentic fluids (live injection water and dead oil) were used for the test. After feeding, the pressure drop across the inoculated slim tube was significantly higher than the slim tube treated only with nutrients, indicating it was working better and faster than a nutrient-only treatment.

Based on promising lab results such as this, in which the mechanism showed a 15 percent increase in recovery factor, the technology was brought to a limited field pilot on part of a waterflooded unit. The pilot used a microbe that improved sweep efficiency through permeability modification and flow conformance. The pilot was performed on three injectors in an inverted nine-spot pattern.

This was the first field test of the MEOR technology for flow conformance using the inoculation method. In the pilot, the observed increase in production rate was 15-20 percent. The field test results demonstrate the efficacy of combining inoculating microbes with optimum nutrients to temporarily alter reservoir ecology in favor of functional microbes. The

TABLE 1

Minimum Criteria for Considering Microbial EOR Treatment

Production Mode	Waterflood
Formation Type	Sandstone
Permeability	>50 mD
Temperature	70°C/150°F
Salinity	<9% TDS
Oil Viscosity	>16 API
Well Pressure	<3,000 psi
pH	5-9

FIGURE 1

Permeability as a Function of Depth

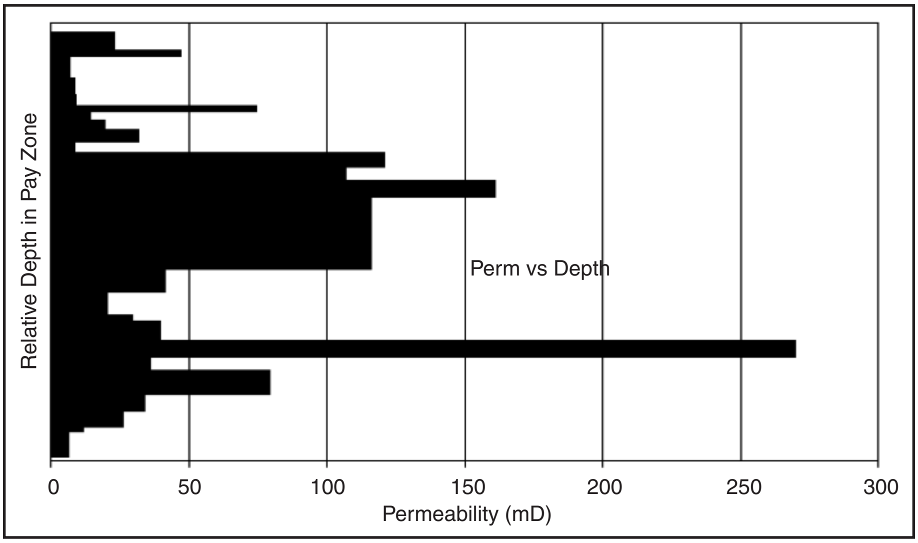
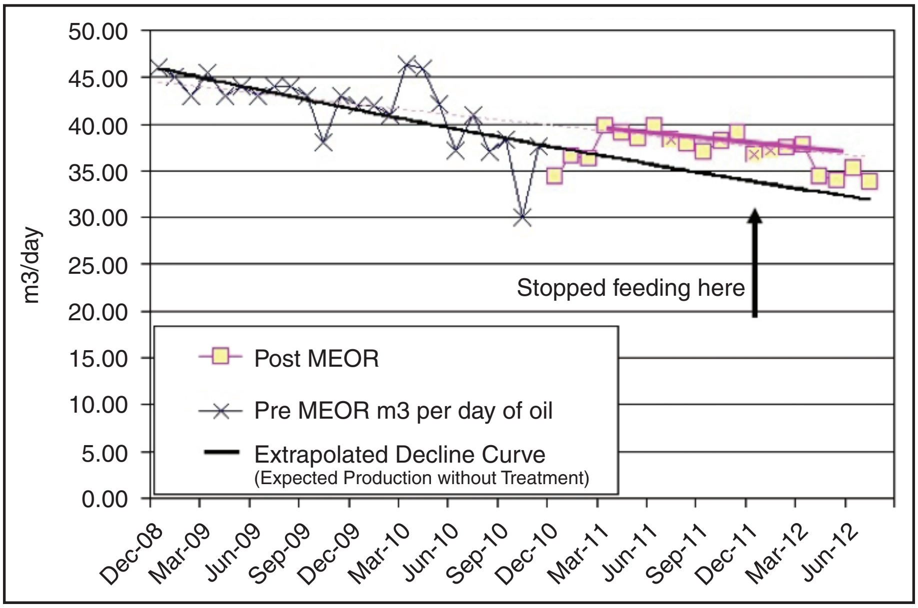


FIGURE 2

Battery Level m3/day Oil Production (Actual)



permeability modification action of the functional microbes allowed water to reach previously unswept areas and recover more oil.

Lab To Field

Many factors had to be addressed in adapting the scale of the technology from the laboratory to first-time field implementation. These included:

- Assuring the treatments did not bypass the reservoir;
- Assuring the reservoir was not blinded by the inoculation; and
- Understanding the effects of biocides and corrosion inhibitors commonly used in the oil field.

The unique aspects of each production area, the nature of the oil and water, the formation matrix, and the background microbial population and their complex interactions were assessed also. Understanding and integrating this valuable information into field implementation is another key to the success of the new MEOR technology.

The advances made in the field indicate the technology can improve oil recovery in many fields with very low capital investment and with a much smaller environmental footprint, compared with other EOR techniques. By some estimates, up to 25 percent of the oil fields in the United States are potentially suitable for MEOR.

Selecting A Field

The technology works very well under a specific range of field conditions, including one critical feature: The field must be under a waterflood. The waterflood is the mechanical means for transporting the microbes and nutrients into the reservoir. The maturity of the waterflood is of less concern, since the technology is successful in fields with moderate to low oil cuts. It also is designed to

FIGURE 3A

Change in Water Cut

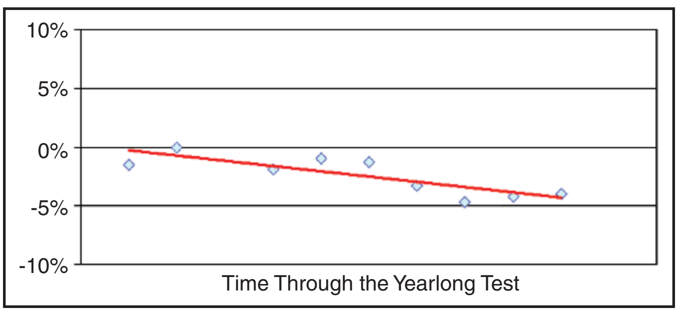


FIGURE 3B

Relative Increase In Oil Production

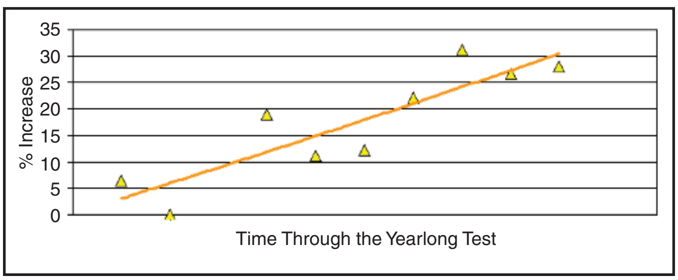
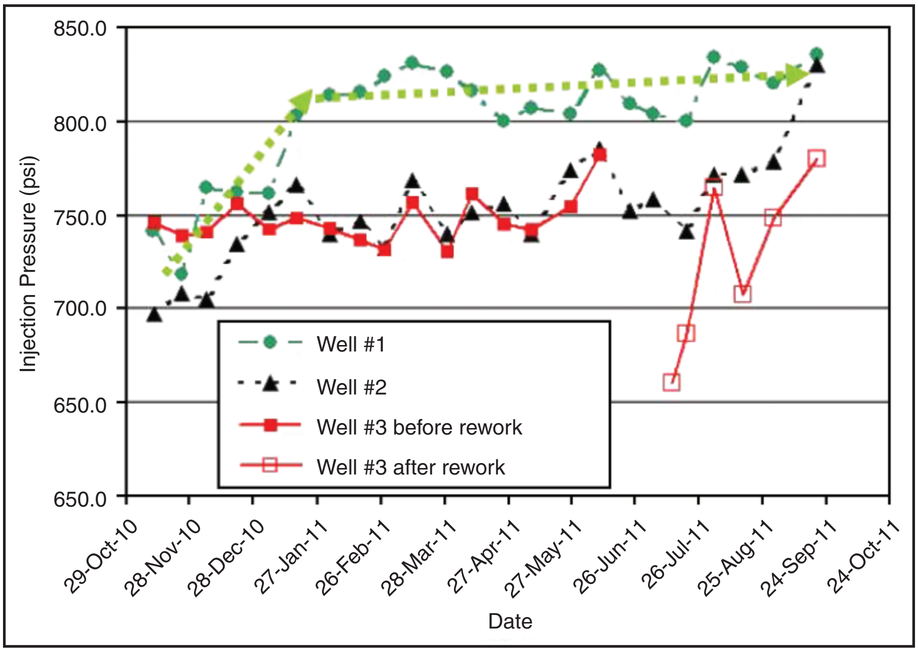


FIGURE 4

Injection Pressure for Treated Wells



work in reservoirs with Darcy flow through the formation matrix. Slim tube testing demonstrates permeability can be modified in excess of 40 D.

Other considerations are summarized in Table 1. The pore throat diameter of the rock must be wide enough to allow the microbes to pass, thus the permeability needs to be at least 50 mD. Temperature, salinity and pH are also key considerations in that these parameters determine the type and diversity of life seen in the reservoir.

In general, MEOR works well with light to heavy oils. However, reservoirs with very high-viscosity oil are difficult to evaluate in sand-pack experiments.

Downhole pressure is also a consideration, given that at very high pressures, only pressure tolerant microbes (piezophiles) will operate efficiently.

Four other factors are considered in new fields:

- Mobility ratio;
- Permeability variation;
- Directionality of the permeability; and
- Streaks of severe bypassing in the reservoir.

High oil viscosity will lead to an oil/water mobility ratio that is not favorable (greater than one) and may potentially result in water fingering through the formation. High permeability variation or high contrast, as well as directionality of the permeability, will result in watered-out channels in the oil reservoir and poor vertical and/or poor areal sweep efficiency.

Dye tests are used to check for severe fractures in the reservoir. Inoculation and feeding protocols must be adjusted when transit times are less than 24-48 hours between injectors.

In the limited field pilot, the oil had an API gravity of 19 and a viscosity of 90 centipoise. Consequently, the mobility ratio was unfavorable and would result in water fingering in the formation, even for a homogenous reservoir.

The formation graded from shale to very fine-grained sand, and permeability varied considerably with depth. Figure 1 shows the permeability plotted as a function of depth through the pay zone. This profile is based on core analysis for one of the producer wells used in this field test.

High permeability streaks are apparent in this profile, and the permeability variation indicated poor vertical sweep efficiency, even if the oil/water mobility ratio was favorable. Finally, there was some directionality to the permeability in the target field.

Field Design

The characteristics of this field made it an ideal candidate for advanced MEOR technology using the flow conformance mechanism to improve sweep efficiency. The MEOR pilot treatment was applied to three injectors that communicated with 17 producers in the pattern. This represented about a third of the production from the central fluid processing unit or battery that serviced this field.

To prevent other factors from confounding the interpretation of test results at the battery level, it was important to minimize operational changes throughout the duration of the pilot. This was achieved by working closely with the operator.

Besides an impact on production, an increase in the injection pressure is a necessary indicator for success. A drop in water cut in the affected producers should be observed as well.

The injection pressures of the treated injectors and the water cuts from the producers in the pilot were measured during the test. While this pilot covered part of a field, testing at the full-field level provides more accurate data and lowers costs through more efficient delivery of the inoculum and nutrients.

To prevent well-blinding and assure the effects are propagated deep in the reservoir, the inoculation and regular feedings relied on a proprietary injection process to ensure the microbes did not blind the well and that nutrient effects were propagated far beyond the well bore, thus preventing fouling.

Microbe Selection

Much research effort has focused on developing functional screens to find the best microbes for the job. Searching for a useful microbe is a lot like looking for a needle in a haystack.

There is great diversity in live reservoir water; thousands of species have been observed in an oil reservoir. To sort through this diversity, researchers begin by looking for anaerobic microbes. In the anaerobic environment of a reservoir, adding oxygen is not considered a viable option because of corrosion issues and limited carrying capacity in the injected water.

A second consideration is that adding sulfate could cause oil well souring by encouraging the growth of sulfate-reducing organisms. Therefore, researchers restricted theirselves to a limited set of electron acceptors, concentrating mostly on nitrate.

The anaerobic, nitrate-reducing microbe selected for this particular trial showed excellent plugging characteristics as well as reversibility. If feeding is stopped, biomass and adhesion are lost and the functional microbial colonies get washed away by the pressurized fluids moving through the field. The reservoir ecology returns to its former equilibrium.

Field Data

The pilot test was run for 12 months. Results were measured by incremental oil production and a change in water cut. The team also used leading indicators such as increased injection-well back pressure measured at a constant injection rate.

Figure 2 presents oil production data at the unit level before and after the MEOR test. One-third of production was affected by the MEOR treatment, and within four months of starting the MEOR test, there was an obvious increase in production above the decline curve. This increased production became significant when a new production trend was established. The production from this unit followed a new trend curve that is shifted higher and has a shallower slope than the pre-MEOR decline curve.

The jump in decline curve also appears about three months after the pilot began, as would be expected because of transit times. It disappeared about three months after feeding stopped, thus confirming the reversibility of the treatment.

The water cuts for the affected producer wells were measured for the duration of the test and the composite water cut for this group of wells was calculated. Fifteen of the 17 producer wells showed a significant decline in water cut. The change in the composite water cut and corresponding increase in oil production for the affected wells is shown in Figures 3A and 3B.

Negative deviations in water cut indicate reduced water cuts, which result in more oil being produced while the pump rates on producers are held constant. The increased oil production calculated from the water cut data is consistent with actual production.

Researchers have developed a way to measure leading indicators such as injection pressure at a constant injection flow in a consistent manner in the field. Figure 4 shows the injection pressure data for the three injectors using that method.

There is clearly an increase in the back pressure for two of the wells. The third well only showed a pressure response after being reworked because of mechanical difficulties. The increase in injection pressure happened within a few months and was sustained for the duration of the MEOR test. This clearly demonstrates that significant permeability modification was developed in this reservoir, as this MEOR test was designed to do.

The results from this test have led to an expanded field pilot. Many other fields are under evaluation, including carbonate reservoirs as well as relatively sour fields. Researchers are sampling actively in the United States and Canada, since the treatment meets the improvement needs of many waterfloods at no capital expense.

It appears that MEOR treatment with inoculation is particularly successful because it improves sweep efficiency in a dynamic and reversible manner. The method works naturally with the reservoir hydrology, lithology, and ecology to recover previously unswept areas in the formation. Nutrients follow the flow of injection water, and microbes follow the nutrients.

When new areas of the reservoir become watered out, microbe colonies will establish themselves there (dynamic). When the nutrients are withheld, the targeted microbes will die, and the reservoir ecology will re-establish itself to its steady state (reversible).

MEOR is still trying to prove itself among more established EOR methods, but researchers are hopeful this new MEOR technology has its place in the EOR tool kit.

With demonstrated successes and a strong team of scientists and engineers dedicated to this technology, it can be the solution for affordably increasing oil recovery. ❒

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