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A Texas MEOR Application Shows Outstanding Production Improvement Due To Oil Release Effects On Relative Permeability

Folami Akintunji, SPE, Atinum E&P, Inc.; Brian Marcotte, SPE, Alan Sheehy and Bradley Govreau, SPE, Titan Oil Recovery, Inc.

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Abstract

A Microbial Enhanced Oil Recovery (MEOR) application in the Big Wells Field located in Dimmit County, Texas has shown a significant improvement in production—both oil rate and water cut performance. As a result of a specific nutrient injection designed in the laboratory to stimulate in situ, naturally occurring microbes, for this San Miguel sandstone reservoir and its microbial ecology, a marked improvement was seen in the two producing wells to which the treatment was applied. The water cut in one well improved from fifty per cent to fifteen percent. The water cut in a second well improved from fifty-five to thirty-five percent.

Although previous field applications of this MEOR process had shown increases in oil production and decreases in water production, water production in this application was completely stopped for a brief time as a result of the treatment. This paper reviews the Big Wells producing well treatments and their results. A specific look at the oil release mechanism of this MEOR process offers an explanation as to how the oil released by these treatments impacts the relative permeability of fluids in the reservoir near the treated wellbores as demonstrated in the field producing well treatments. Similar benefits are seen during the treatment of water injection wells related to performance in adjacent producing wells.

The significance of this application is that field evidence supports that production improvements result from the release of oil in sufficient quantities to change the near wellbore relative permeability to both oil and water. Also, it demonstrates that this MEOR technology can be successfully applied to reservoirs in this geographical area and extends the lower threshold for formation permeability suitable for treatment. Having been successfully applied in other parts of North America, this is an important application of this MEOR technology in Texas.

Introduction

Between July 2007 and the end of 2011, there have been 183 applications of MEOR to enhance recovery of North American waterfloods in a programmatic approach of organic oil recovery. Organic oil recovery results from the management of the indigenous microbial ecology to facilitate the release of oil in the reservoir. The application of this process typically consists of five steps: 1) initial field screening, 2) well sampling and laboratory analysis, 3) application of the nutrient formula developed in the laboratory to a single producing well to assure the microbial response under actual field conditions replicates lab results, 4) pilot testing (if applicable) in a representative portion of the waterflood and 5) full-field application. Forty-four treatments have been applied to forty-one producing wells and one hundred and twenty-three treatments have been applied to forty-one injection wells. From the results available to date, on average the wells and their adjacent producers have seen an oil production increase eighty-eight per cent of the time. On average, these applications have resulted in a 102% increase from pre-treatment rates to post-treatment maximum rates. Table 1 shows the results available as of January

1, 2012. The two treated producers were in the Big Wells field and were considered as step #3 in the above five-step approach to field treatment.

Table 1. Over one hundred and eighty applications were performed in 98 wells through 2011.

Summary	# of Wells	# of TMTs	# of Increases	Success Rate	% Oil Increase
PRODUCERS					
ISRMA	28	30	20	71%	192%
Producers	13	14	12	92%	176%
Total	**41**	**44**	**32**	**78%**	**186%**
Pending	1	1			
INJECTORS					
Injectors	**41**	**123**	**40**	**98%**	**35%**
Pending	15	15			
ALL WELLS					
Wells Treated-Confirmed Results	**82**	**167**	**72**	**88%**	**102%**
Wells Treated - Pending	16	16			
TOTAL	**98**	**183**			
* Pending: waiting results.					

Field Background

The Big Wells Field is located in south Texas about 149 miles (240 km) southwest of San Antonio. The field was discovered in 1969 and waterflood operations were initiated in 1971 on an inverted five spot pattern. In 1974 infill drilling was started because of very poor waterflood response on 80 acre (32.4 ha) well spacing.

The main producing zone of the Big Wells Field is the San Miguel/Olmos formation. This formation is a very silty and shaley (calcareous) sandstone with very fine grain sand and mica. This reservoir is 5,500 feet (1,676 meters) deep. Gross pay is estimated to average 200' with net pay of 50'. The porosity is 20% and the permeability 40 md. Bottom hole temperature is 178^{o}F (81^{o}C). The oil gravity is 33^{o}API and the oil viscosity is 2.5 cp at reservoir temperature.

Produced water has total dissolved solids (TDS) of 34,000 ppm with sodium, calcium and magnesium the dominant cations. The dominant anion is chloride at 23,400 ppm. The water composition would tend towards a positive scaling potential. From a microbial perspective, the San Miguel formation is moderate to high in temperature and low to moderate in TDS.

Current production is 90 BOPD, 96 BWPD and 26 MCFPD from the Atinum properties. Prior to treatment, oil production was noted to create an emulsion, which occurs during production and is somewhat difficult to break. On the Atinum leases there are 14 producing wells, 68 idle wells and 1 water disposal well. The waterflood has been inactive for twenty years, although the operator is considering the reactivation of the waterflood. Cumulative production is 5 million BO, 1.4 million BW and 4 BCF of gas from the Atinum properties. In 1986 cumulative production from the entire field was reported to be 6 million BO. With 31.5 million barrels OOIP, 19% of the OOIP had been recovered from the Big Wells Field when well spacing was on 80 acres. (Reviere, R. H. 1986).

Oil Release Mechanism

Unlike many previous attempts at MEOR, this organic oil recovery process does not attempt to introduce microbes into the oil-producing reservoir (Sheehy, A. 1990). Instead, indigenous microbes are stimulated to grow and reproduce due to the introduction of a reservoir-specific mixture of environmentally benign nutrients. The approach needs to be customized to accommodate the different microbial ecologies in each reservoir. In the ideal application, the water injection system becomes the transport medium for the nutrients, distributing the nutrients throughout the reservoir. By activating certain species of microbes, changes in the flow characteristics of the oil are affected and induce the reservoir system to release additional oil to the active flow channels (Town, K. 2010). Stimulated microbes act at the interface of reservoir oil and water altering the flow potential in the producing formation. In the higher permeability portions of the reservoir, newly released oil, water and microbes may interact to form a transient (temporary) micro-emulsion that may alter the sweep efficiency of the injected water as it moves through the reservoir but this is not seen in all cases based on surface indicators. Based on laboratory data, it is believed that in a waterflood, this process can recover up to an additional 10% of the original-oil-in-place. (Davis C. P. 2009)

Reservoir Screening and Lab Work

The application of this organic oil process typically consists of five steps: 1) Initial field screening, 2) Well sampling and laboratory analysis, 3) Apply the nutrient formula developed in the lab to a producing well to determine the microbial response is maximized, 4) Pilot testing (if applicable) and 5) Full-field application. Because the waterflood has been inactive for a number of years, the normal five steps could not be followed. For Step 3, Atinum planned to treat two producers after the completion of the lab work to check the field response to the laboratory-developed nutrient mixture.

Although most of the parameters of the Big Wells Field were well within the range of past successful application, some specific characteristics of the Big Wells Field placed the field at the margins for successful treatment. There were two primary concerns. One concern was the ability of an organic oil recovery process to work in reservoirs of permeability of less than 50 md, previously believed to be the lower limit of MEOR applications. A second concern was the low energy level of the reservoir. Even if the process worked, would the reservoir have enough energy to move the released oil to the producing wellbore? Reservoir temperature was also on the high-end of normal treatment parameters.

In January 2010, produced fluid samples from both wells A-8 and B-17 were taken and shipped to the laboratory for detailed analysis. Based on the lab work, it was determined that the targeted microbes were present and that they responded well to nutrient stimulation. See Table 2 for an example of the increase in number of microbes and the number of oil interactive forms.

Table 2. Targeted Microbes Respond Well to Nutrients.

Well	Number of microbes*	Microbial biodiversity*	Oil-interative microbes*
B-17 January 21, 2010 Low nutrient levels	Greatly Increased	Increased	Greatly Increased
B-17 January 21, 2010 High nutrient levels	Greatly Increased	Increased	Greatly Increased

*Comparison to untreated produced fluids

Producer Treatment Summary

Preliminary screening of the field and microbial assessment of produced fluid samples led to the injection of nutrients into Big Wells A-8 and B-17 on November 3, 2010. Produced water was stored in temporary tanks near the wellheads prior to treating the wells. A chemical tote of specially blended nutrients developed from the lab work was delivered to each of the wells to be treated. The nutrients in each tote were blended with 100 barrels of produced water and displaced with produced water into the producing formation. The treatments were injected down the casing-tubing annulus and no rig was required to pull either the rods or the tubing. The nutrient treatments were injected at very low pressure and there was no difficulty in pumping the treatments in spite of the reservoir's low permeability. See Table 3 for injection rates and pressures.

Table 3. Treatment and Displacement Parameters

	Treatment			Displacement		
Well	Volume (Barrels)	Average Rate	Maximum pressure	Volume (Barrels)	Average Rate	Maximum pressure
A-8	105	1.7 BPM	30 psi	125	1.6 BPM	480 psi
B-17	111	1.8 BPM	30 psi	120	0.8 BPM	170 psi

It is unknown why the injection pressure increased during displacement. Annular volume is about sixty barrels so it is not fill up. There are several possibilities of why pressure might increase including fines and particulates. Injection fluids were not filtered. So, it is likely to be particulates in the tank, where produced water was accumulated and stored for the treatment. After pumping Titan nutrients into the reservoir, the wells were shut-in for nine days to allow the microbial stimulation processes to proceed. The wells were returned to production on November 10, 2010.

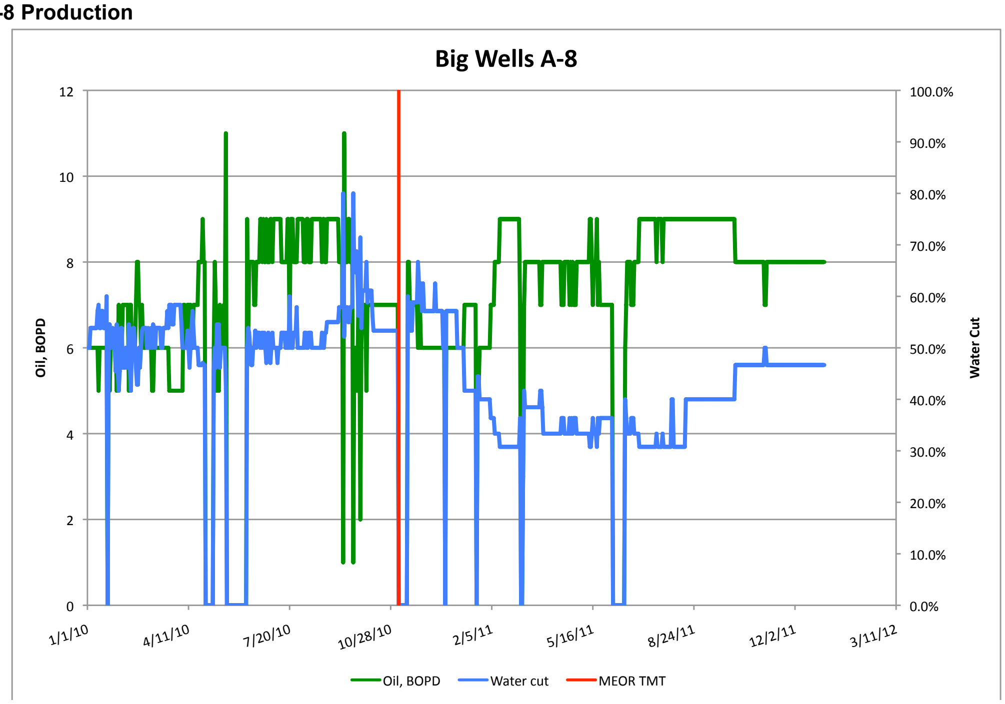
Microbial Response

Wellhead samples were collected from November 10, 2010 once the wells were put back on production. Samples were taken over four weeks of production. As production recommenced, reservoir and annulus fluids, nutrients and microbes move and mix. Early samples are representative of microbial activity in the wellbore, tubing and casing. Later samples are increasingly representative of the microbial interaction effects further from the wellbore. Overall, the number of microbes grown was greater than expected as the numbers exceeded those experienced in the lab. From a microbial perspective, the treatments were very successful. Duplication of lab results is the ultimate goal of this step in the process but precise replication is rarely obtained because conditions are far from ideal in the reservoir. Given the technical difficulty involved, the microbial response in these wells was outstanding. However, there remained the concern as to whether significant amounts of nutrients were able to penetrate the formation. There was also a concern in that there may not have been enough energy in the reservoir to move oil released by microbial stimulation caused by the injection of the nutrient mixture.

Production Results

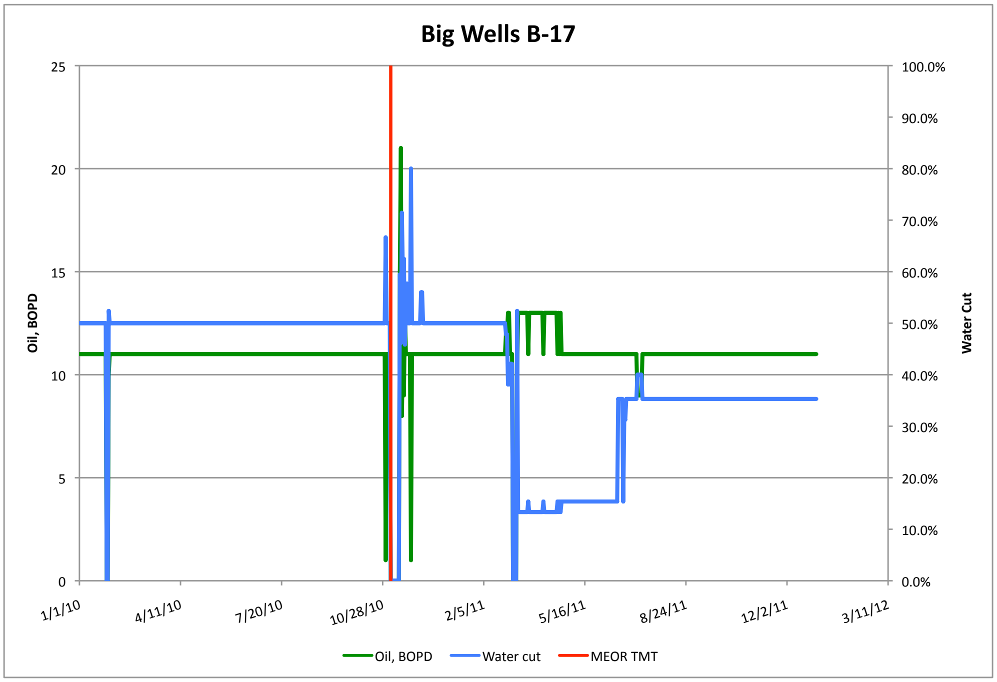
During the month prior to treating, Well A-8 produced an average of 7 BOPD + 8 BWPD, 53% water cut. Following the treatment, Well A-8 started to exhibit changing water cut performance in early January 2010. On January 9, it produced 7 BOPD + 5 BWPD, 42% water cut. Production slowly improved to 9 BOPD and 4 BWPD, 31% water cut in July. See Figure 1 for A-8 production. Because of this production response at A-8 additional produced fluid samples were requested from both wells. This is when the field reported that well B-17 was not making any water and a water sample could not be taken.

Figure 1. A-8 Production



Prior to treatment, Well B-17 was producing 11 BOPD and 11 BWPD, 50% water cut. Two days after being returned to production, Well B-17 showed a quick production peak of 21 BOPD + 18 BWPD, 46% water cut on November 15, 2010. This was a little surprising since a two-day shut in during January 2010 did not show any production increase. Within a week production settled down at 11 BOPD + 11 BOPD, 50% water cut until March when it was verbally reported not to be making any water. On March 11, 2011, B-17 was making 13 BOPD + 2 BWPD, 13% water cut. Its water cut has slowly risen since then.

Figure 2. B-17 Production

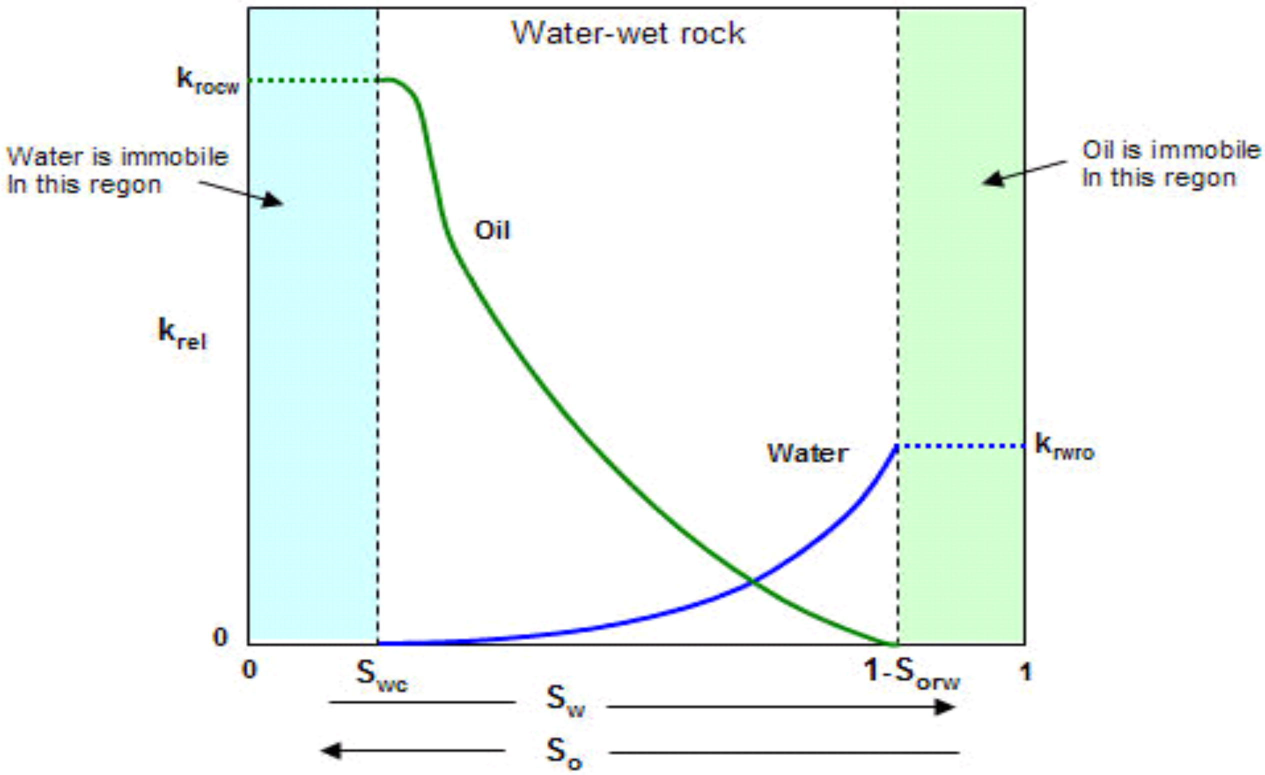


Discussion

Typically in a mature waterflood, oil occurs as isolated trapped immovable droplets that have little or no relative permeability to oil due to high in situ water saturation. Residue hydrocarbons tend to bond and coat the reservoir grains and act as pore-filling material. In a very mature waterflood, generally only water can flow toward the well bore (Schowalter 1999). The little bits of oil that are produced tend to be dragged to the producers as water moves through the pore channels.

As previously discussed, this organic oil recovery process releases oil that would normally be trapped within the reservoir. Although water cut changes have been reported previously in applications in California (Zahner 2010) and Saskatchewan (Town 2009), water cut in this application dropped to zero, albeit briefly. Despite the relatively low rate of production in this field (both oil and water), the authors believe that substantial oil was released near wellbore as a result of the nutrient treatment and this release of oil resaturated the producing channels in the reservoir rock. This resaturation of the reservoir changed the relative permeability of both the oil and water and resulted in lower water flow and improved oil flow. To increase the relative permeability to oil and decrease the relative permeability to water, the oil saturation would have to increase and the water saturation would have to decrease. See Figure 3, Relative Permeability Curve. To increase the relative permeability to oil enough to eliminate all water flow, the oil saturation would have to increase significantly. The very low reservoir energy prevented a more dramatic increase in oil production in this instance despite the apparent saturation changes. However, the oil release and change in relative permeability is significant in terms of the observed flow character as it might occur in other, higher-energy fields.

Figure 3. Typical Relative Permeability Curve[6]



Conclusion

The nutrient application targeting specific microbes was proven for this field in the successful application in two producing wells. These producer treatments confirmed the effectiveness of using nutrients in creating an effective biological response. The addition of nutrients was effective in creating long-term growth of desired microbial species and the creation of large numbers of hydrocarbon interacting forms of microbes. There is no doubt that the production response was a direct result of the nutrient stimulation even though the absolute volume of production was low. This is the first successful application of MEOR or organic oil recovery in a reservoir with permeability as low as 40 md.

Acknowledgements

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