

MEOR Success in Southern Saskatchewan

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Summary

A microbial enhanced-oil-recovery (MEOR) process was successfully applied in a mature waterflooded reservoir in Saskatchewan, Canada. A nutrient solution, which was designed specifically for this reservoir to stimulate indigenous microbes to grow, multiply, and help to release oil, was tested and piloted. A significant decrease in water cut and increase in oil production have been realized through the selective stimulation of bacteria using nutrient injection.

The field is a mature waterflood averaging more than 95% water cut. To combat the increasing water-cut issue, an in-situ microbial response analysis (ISMRA) was performed on a typical high-water-cut producer in the area. The test well was treated with a nutrient solution and then was shut in for a number of days to allow indigenous microbes to grow and multiply. Upon return to production, the well produced at an average of 200% more oil with a 10% decrease in water cut for a year. Pretreatment rates averaged 1.2 m³/d of oil (8 BOPD) and post-ISMRA treatment daily production peaked at 4.1 m³/d of oil (26 BOPD). The ISMRA provides a direct support of laboratory studies and frequently increases oil production.

As a result of the successful ISMRA, a pilot project was initiated and the nutrients were applied in three batch treatments on an injector with three offset production wells. Three weeks after the first batch treatment, a water-cut decrease was seen at one of the offset producers. This well's oil production gradually increased from 1.4 to more than 8 m³/d (9 to 50 B/D). Oil production in another producer doubled from 1.5 to more than 3.0 m³/d (9 to 19 B/D). Subsequent treatments were tried on marginally economic wells and on a reactivated idle producer. The average decrease in water cut in these wells was more than 10%. On the idle well, oil production increased from 0.5 m³/d (3 B/D) pretreatment to an average of 3.0 m³/d (19 B/D) post-treatment.

Throughout the world, there remains a huge target for enhanced-oil-recovery (EOR) processes to target (Bryant 1991). This successful MEOR application will have a tremendous impact on ultimate recovery in many of these reservoirs not only through an increase in production, but a decrease in operating costs through associated reduction in lifting costs with less water production.

Introduction

Trial Field. The trial field is located in the southwest corner of the province of Saskatchewan, Canada, southwest of Swift Current. The trial field produces from the Upper Shaunavon sand. The field was discovered in 1952, and the waterflood was started in approximately 1967, initially set up as an inverted-five-spot pattern on 80-acre spacing.

The Upper Shaunavon sits on a structural high and has three members. The upper member is very high quality sand and an excellent reservoir. The middle member, a poorer quality sand than the upper member, is isolated from the upper member. The lower member is a tight mixture of sands and shales. The average porosity ranges from 21.5% in the upper member to 15.2% in the lower member. The average permeability ranges from 567 md in the upper member to 53 md in the lower member. The average net pay is 2.6 m (8.5 ft) in the upper member, 1.8 m (5.9 ft) in the

middle member, and 1.4 m (4.6 ft) in the lower member. Reservoir temperature is 47°C (117°F). Reservoir depth is 1200 m (3,927 ft). Total dissolved solids of the produced water are 10025 mg/L.

Cumulative oil production is 3.3 million m³ (21 million bbl), with average recovery of approximately 29% of the original oil in place. Like most waterflooded reservoirs, low recovery makes the Upper Shaunavon an ideal EOR candidate. Oil gravity is 22–24°API. Current oil production is 62 m³/d (391 B/D), with 1300 m³/d of water (8,190 BWPD) and 4250 m³/d of gas. Current injection is 1700 m³/d (10,700 BWPD).

The MEOR Process. MEOR is a group of processes based on increasing oil recovery by use of bacteria. In general, the mechanisms can be grouped into those which alter oil, water, reservoir, or interfacial properties, usually through mimicry of chemical EOR processes and those that use the biological mass (biomass) for flow diversion (Gao 2009). MEOR traditionally has involved the injection of particulate bacteria and the food they need to generate the EOR chemical or biomass.

There are very few documented applications of successful MEOR projects in waterfloods. Most successful MEOR applications are single-well treatments that would be better described as wellbore cleanup. Although the first evaluation of this process was on a production well in the Alton field in Australia (Sheehy 1990), this process targets mature oil fields currently using conventional water-injection (waterflood) operations as a means of secondary recovery. Unlike previous attempts at MEOR, this process does not attempt to introduce microbes into the oil-producing reservoir. Instead, through a sophisticated analysis of field-specific crude oil and water, microbes that are naturally indigenous to the oil reservoir are identified and quantified (Davis 2009). On the basis of laboratory techniques, analysis, and specific field-test procedures, a “designer mixture” of naturally occurring nutrients is formulated and released into the reservoir by means of the water-injection system. Although the nutrient additives are proprietary, the nutrient mixture is made up of a solution of salts, ammonium nitrate, and organic compounds. The water-injection system becomes the transport medium for the designed nutrient formulations. The reservoir is treated with a targeted and unique nutrient formula. The process is designed for crude-oil production and is not currently suitable for either natural-gas or condensate fields, nor is poorly mobile oil currently a target of this process. Certain species of resident microbes have a cellular change resulting in an affinity for oil instead of water. Attracted to oil, these resident microbes move to and insert themselves into the oil/water interface around any trapped oil in the reservoir. The flow characteristics of the trapped oil are affected by the presence of microbes at the oil/water interface. The changes in the oil/water/rock/bacteria interfaces result in the deforming of the residual oil, allowing small droplets to form and be released into the active flow channels of the reservoir. Fig. 1 shows how microbes work at the oil/water interface to help release oil. In very highly permeable portions of the reservoir (“thief zones”), newly released oil, water, and microbes can interact to form a transient (temporary) microemulsion, which effectively alters the sweep efficiency of the injected water as it moves through the reservoir to improve current production and ultimate recovery.

Reservoir Screening and Laboratory Work

The reservoir parameters were reviewed to determine if this reservoir is a good candidate for MEOR. There are two main criteria for a good candidate reservoir: mobile oil and the presence of specific species of microbes. In spite of relatively low oil gravity in the target field, the reservoir had good waterflood response, indicating

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Oil Microdroplet Formation

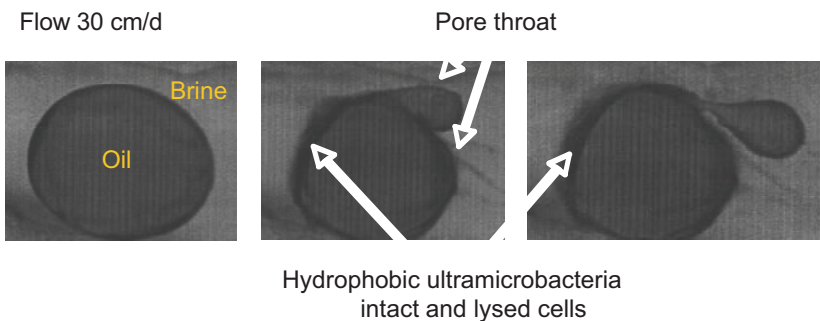


Fig. 1—Oil-release process: Microbes migrate to the oil/water interface to help break up the oil.

that the oil is mobile. With the reservoir's moderate temperature of 47°C (117°F) and with produced water with only 9500 mg/L of chlorides, it was very likely that microbes were present in the reservoir. Laboratory analyses of bacterial growth were conducted on the samples of produced water. Incubations were established with a range of nutrients and concentration of nutrients. The samples were examined by microscopy for evidence of cellular changes. Bacterial-growth patterns and replication rates consistent with the nutrients used as supplements were observed. Equally important, the nutrient manipulation resulted in the growth of a subpopulation of bacteria capable of interaction with the oil/water interface. Specific nutrient combinations resulted in optimal potential for oil recovery and were recommended for use in this reservoir.

Field Application

The application of MEOR to the field has been performed in stages. First, the nutrients developed in the laboratory were used in treating a producing well. When the appropriate microbial response was observed, the second step was to treat an injection well. Since these were both successful, additional applications are being administered in both producers and injectors. A description of each step and the result of each step follow.

ISMRA. Once laboratory work is complete, the formula devised specifically for this reservoir is applied to a producing well in a cyclic treatment. This is called ISMRA and is done mainly to confirm that the appropriate microbes are stimulated. **Table 1** gives details of the number of bacteria, bacterial biodiversity, and the proportion of hydrophobic bacteria present. Results are semi-quantitative for presentation purposes.

Pretreatment samples showed a low number but diverse range of resident bacteria. Very few of these were hydrophobic oil-interactive forms. After nutrient treatment, the number of bacteria and number of oil-interactive forms increased dramatically. However, the biodiversity decreased because of the selective nature of the nutrients used.

The post-treatment samples showed the emergence in the field of hydrophobic oil-interactive forms. There was a substantial similarity between the bacterial-growth patterns observed in the laboratory and from post-ISMRA produced-water samples. Overall, post-treatment samples may produce different population sizes

compared to the laboratory, but the ratio of hydrophobic to total bacteria remains constant.

Often this treatment also results in an increase oil production. On 6 December 2007, ISMRA was performed on Well A in Trial. A 1.3-m³ (8-bbl) tote of chemical nutrients solution was mixed with 13 m³ (82 bbl) of injection water. The nutrient solution was injected into Well A through the tubing-casing annulus and displaced with 27 m³ (170 B) of injection water. Well A was then shut-in for 7 days to allow specific indigenous microbes to grow and multiply as a result of the nutrient stimulation. On 13 December, Well A was returned to production. Results were encouraging. The targeted species of microbes grew and reproduced exceptionally well. Also, oil production increased, with an associated decrease in water cut. Pretreatment daily production average for Well A was 1.2 m³ of oil (8 BOPD) and 20.8 m³ of water (131 BWPD), a 94% water cut. Post-ISMRA-treatment daily production peaked at 4.1 m³ oil (26 BOPD) and 19.0 m³ of water (120 BWPD), an 80% water cut. Well A is still seeing incremental production with current daily production of 2.2 m³ oil (14 BBL) and 21.0 m³ water (132 BWPD), a 91% water cut. There was no change in the character of the produced fluid reported, and no treating problems were noted. This single-producing-well application result exceeded expectations by delivering approximately 500 m³ (3,150 bbl) of incremental oil. The water cut, percent water produced,) also decreased significantly, which was another positive result of the treatment from an operating perspective. See the production graph in **Fig. 2**.

Pilot. Now that the nutrients had been proved to be appropriate for this reservoir, a pilot project was initiated. Injection Well B was chosen for the pilot. It has three offset producers, Wells C, D, and E. The pilot area is depicted in **Fig. 3**. The intent of this pilot test is to document the production response from the application of the MEOR process. In addition to a production increase, a micro-emulsion may form in the reservoir, which will manifest itself at surface with lower injectivity in the pilot injector. The injection rate has been maintained on Injector B, and there has been no change in injectivity, which implies that no emulsion has formed. Also, there has been no indication of a microemulsion forming in the produced fluids (**Fig. 4**).

The injector was batch treated with the nutrient solution, which was pumped down the injector and displaced into the reservoir

TABLE 1—WELL A COMPARISON OF BACTERIA RESULTS

| Well | Number of Bacteria | Bacterial Biodiversity | Hydrophobic Bacteria |
|--------------------------|--------------------|------------------------|----------------------|
| Pre-ISMRA no nutrients | + | ++ to +++ | +/- |
| Pre-ISMRA with nutrients | ++++ | ++ | ++++ |
| Post-ISMRA 30 minutes | ++++ | + | ++++ |
| Post-ISMRA 3 days | ++ to +++ | ++ | +++ |
| Post-ISMRA 5 days | ++ to +++ | +++ | +++ |

+/- Sparse; + few; ++ moderate; +++ many; and ++++ numerous.

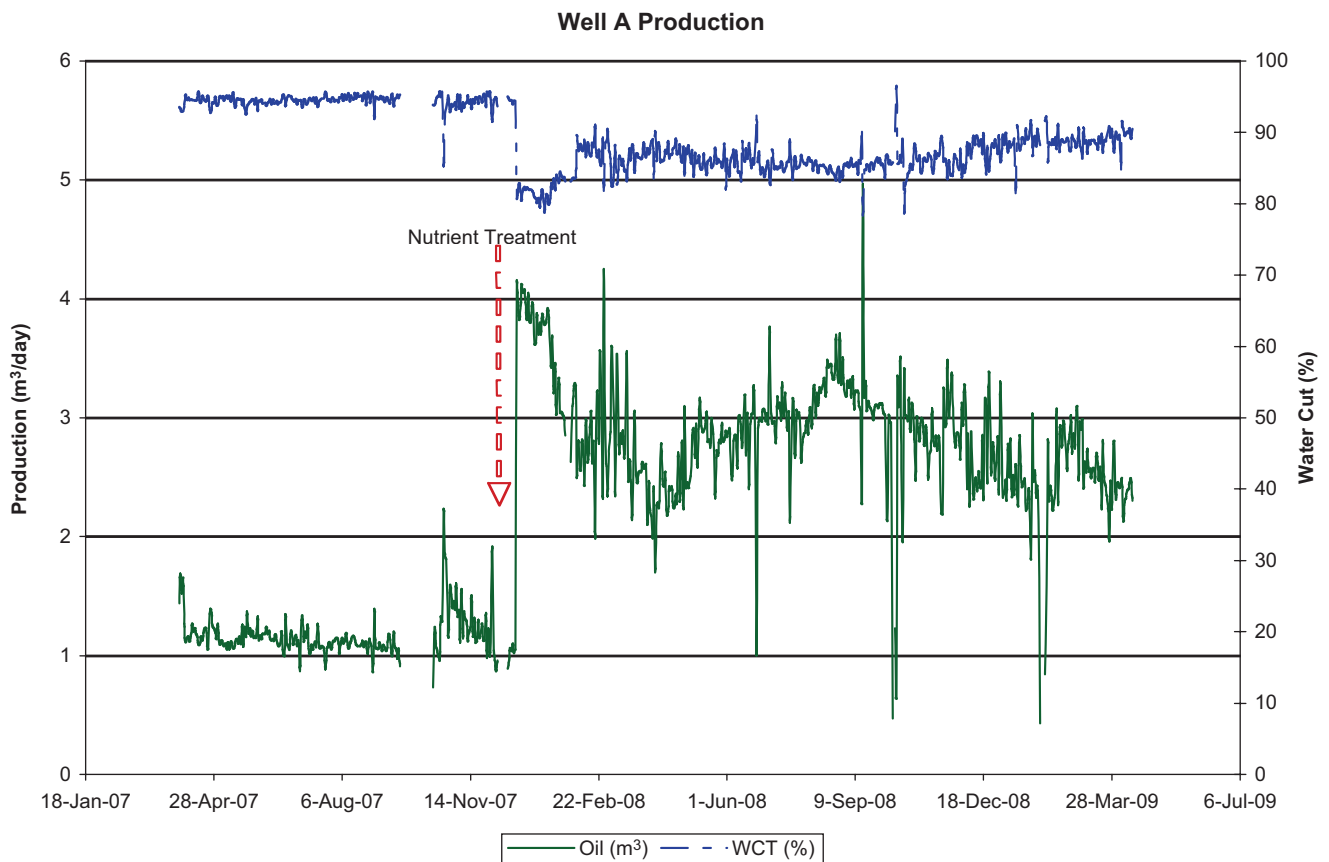


Fig. 2—Producing Well A responds to cyclic treatment of nutrients.

with an additional 200% of the tubing volume of injection water. On 24 April 2008, Injector B was treated with a 1.3-m³ (8-bbl) tote of chemical-nutrient solution, which was mixed with 16 m³ of injection water. After being injected, the nutrient solution was displaced with 32 m³ (200 bbl) of water. Allowing the microbes time to incubate and populate, injection into Well B was limited for the next 8 days. Injected volumes were 10, 20, 50, and 75% of normal injection across the 8-day period.

After the nutrient injection, wellhead samples from the first offset production wells of the treated injector were taken and analyzed in the laboratory. Samples were tested by culturing and analyzing to determine changes in microbial composition and growth. The producers were monitored continually for rates, fluid levels, and produced-water chemistry. From this information, the coordination and scheduling of additional treatments were determined. Subsequent batch treatments were conducted on 29 July and 3 December 2008.

On 10 May Well C increased from daily production of 1.5 m³ of oil (9 BOPD) and 50.2 m³ of water (316 BWPD), a 97% water cut, to 4.6 m³ of oil (29 BOPD) and 51.8 m³ of water (326 BWPD), a 92% water cut. Production continued to improve and the well peaked at 10.0 m³/d of oil (63 bbl) and 68.0 m³ water (428 BWPD), an 87% water cut. First response was expected in Well C because it is the nearest adjacent producer and it produces the most fluid. Current production shows a 350% increase in oil production and an 8% decrease in average water cut. Laboratory analysis shows that the targeted species of microbes grew and reproduced exceptionally well in Well C. Many microbes were in their hydrophobic state, in which they move to the oil/water interface and help to release additional oil (Fig. 5).

Gradually, positive response has been seen in the E offset producer. Starting at daily production of 1.5 m³ oil (9 BOPD) and 25 m³ of water (158 BWPD), a 94% water cut, daily production peaked at 3.0 m³ of oil (19 BOPD) and 38.3 m³ of water (241 BWPD), a 93% water cut. Current production is 1.9 m³/d of oil (12 BOPD) and 36.8 m³ water (232 BWPD), a 93% water cut (Fig. 6).

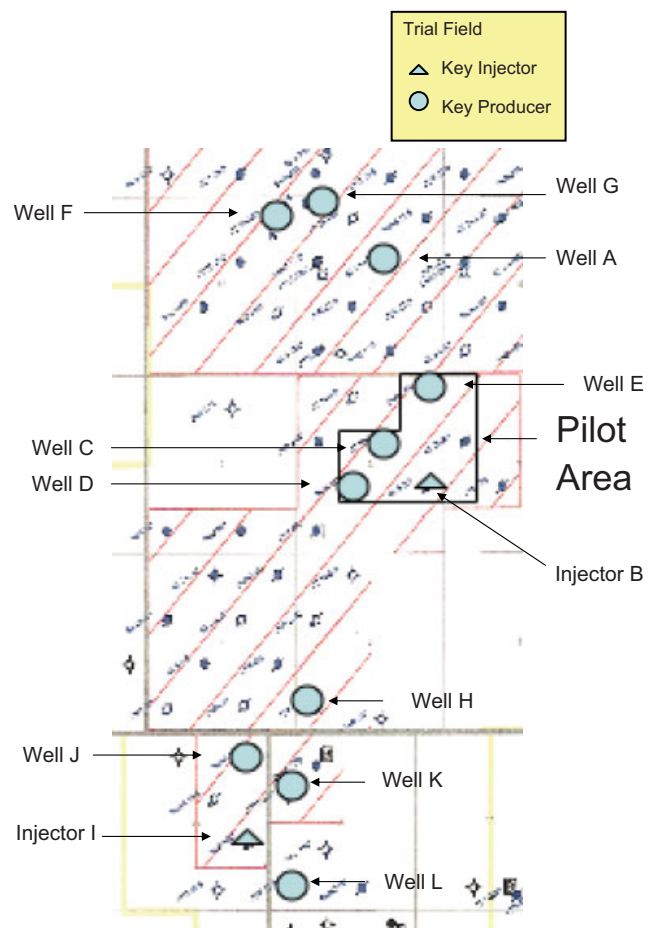


Fig. 3—Partial field map.

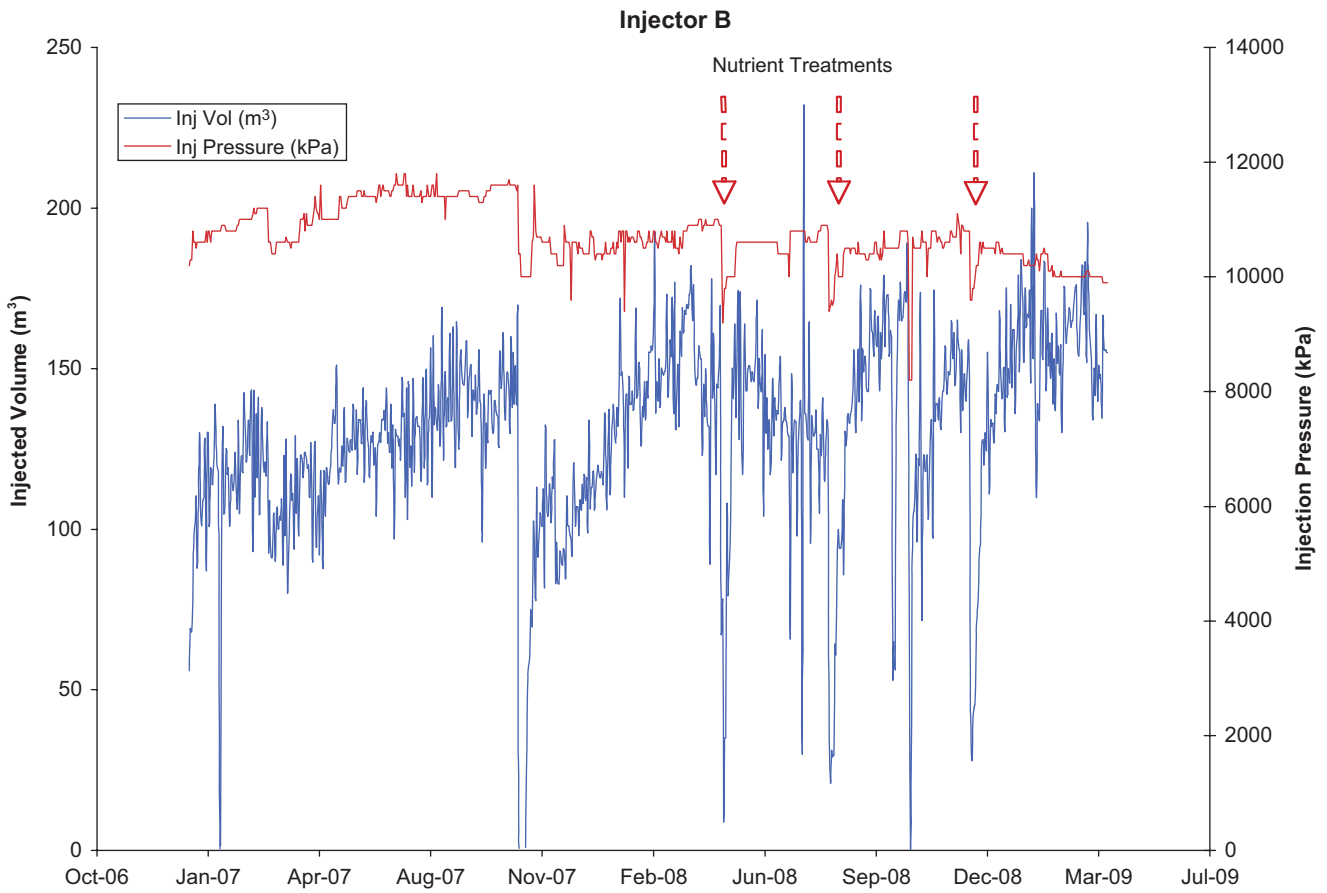


Fig. 4—Injection rate at Well B, the pilot injector, is maintained.

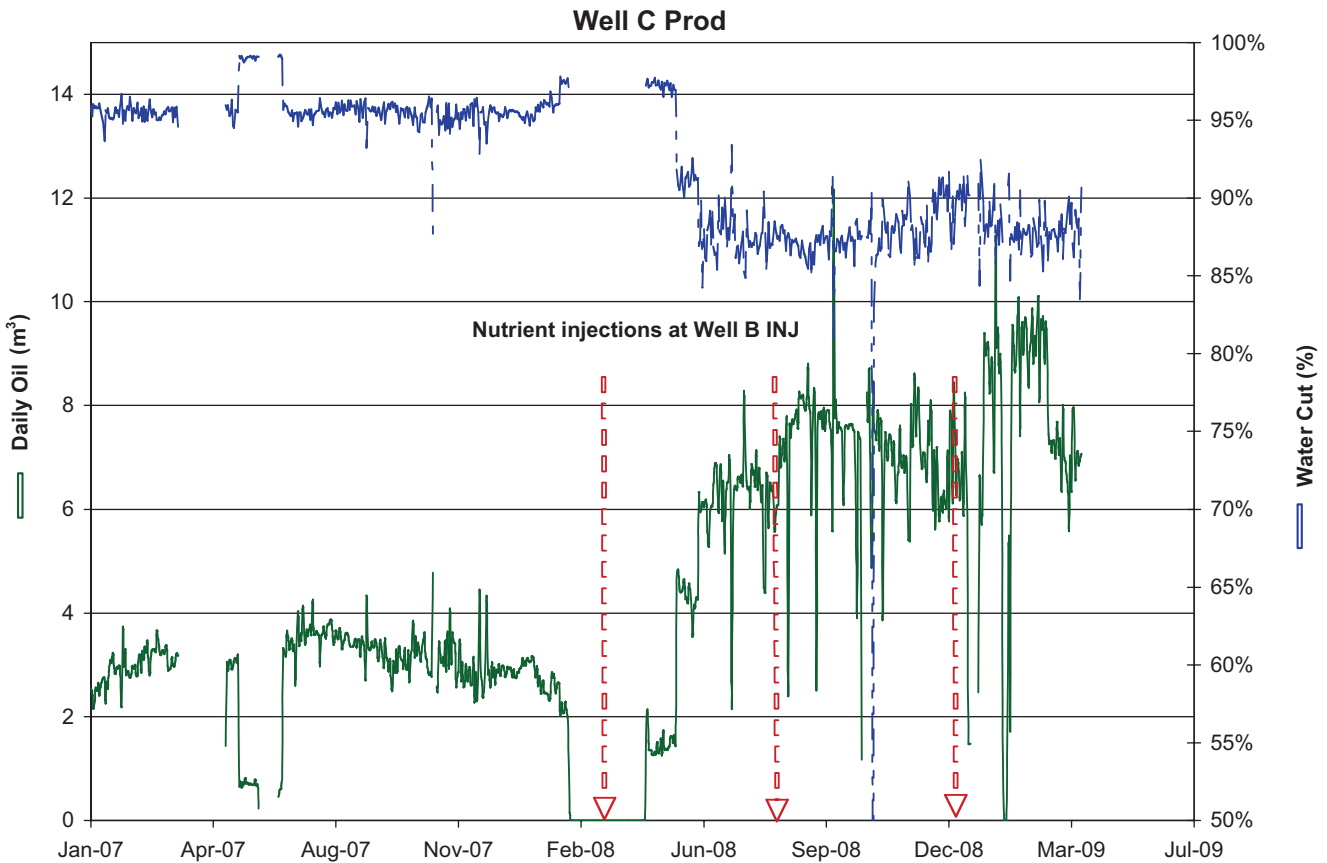


Fig. 5—Producing Well C responds to treatments in offset Injector B.

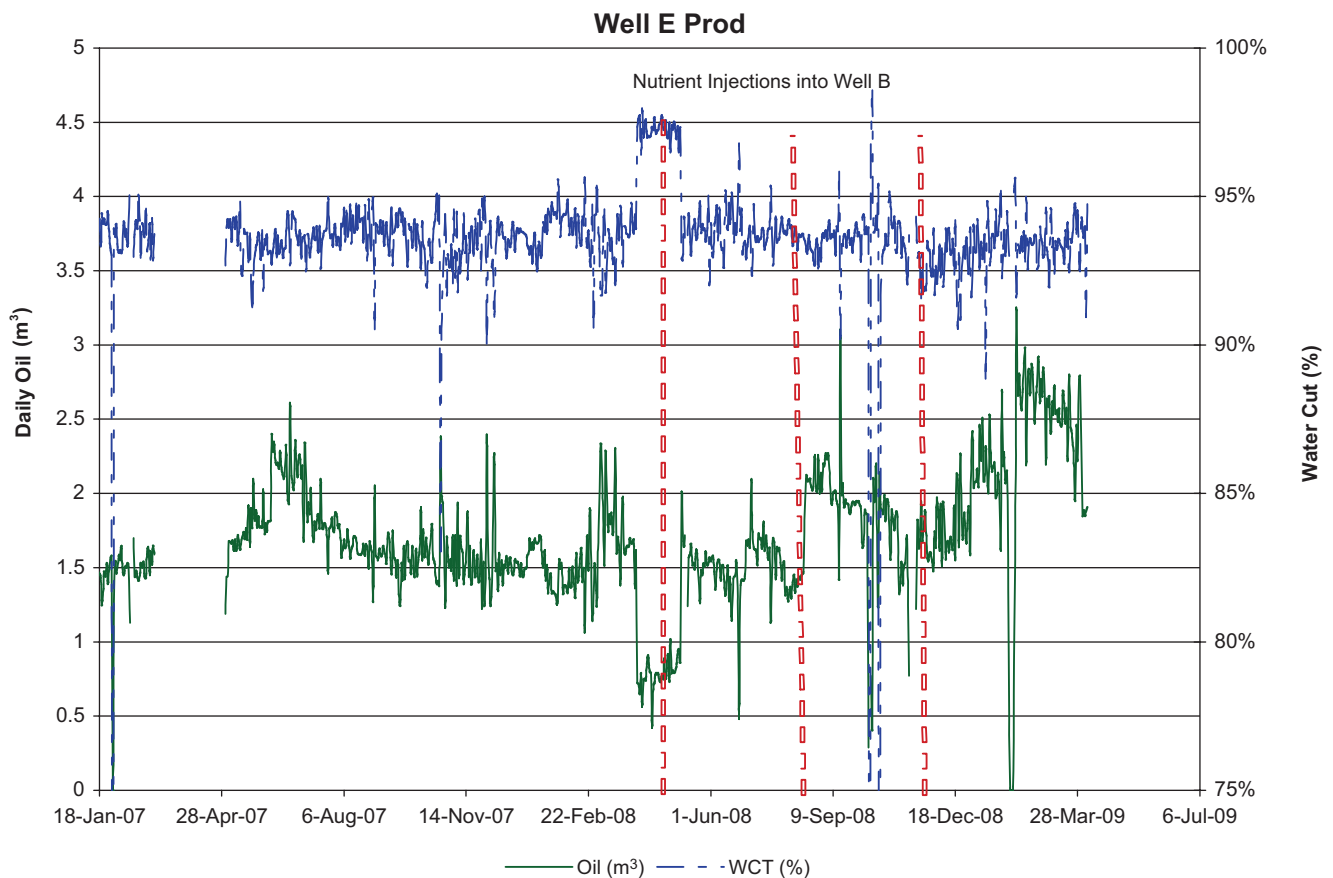


Fig. 6—Producing Well E responds to treatments in offset Injector B.

To date, no response has been seen in the other offset well, Producer D. This is not a surprise because transit time from Injector B is very likely to be longer, on the basis of well location, reservoir volume, and injection conformance. Well D daily oil production remains at 0.5 m³/d of oil (3 BOPD) and 1.5 m³/d of water (9 BWPD). Laboratory analysis of produced fluids from Well D indicates that only a small number of microbes are present. The low microbe concentrations in Well D indicate that the nutrient effect has not yet reached this producing well.

Additional Producer Applications. As a result of the magnitude of oil response seen in the ISMRA treatment on Well A, subsequent producer treatments were performed. On 25 April 2008 MEOR treatments were performed on Wells F and G. Well F had been idle since 2005 and was reactivated to see what effect a nutrient treatment would have on a reactivated well. Because the microbes did not respond with the first treatment, Well F was retreated on 27 July. Then on 4 December 2008, a treatment was performed on Well H. In each case, a 1.3-m³ (8-bbl) tote of chemical-nutrient solution was mixed with 13 m³ (82 bbl) of injection water through the tubing/casing annulus and displaced with injection water. The test well was then shut in for 7 to 10 days to allow specific indigenous microbes to grow and multiply as a result of the nutrient stimulation.

Of the three production wells treated, Wells F and G have shown exceptional response. Well F increased from 0.6 m³/d of oil (4 BOPD) and 3.2 m³/d of water (20 BWPD), an 84% water cut to 4.1 m³/d of oil (26 BOPD) and 4.6 m³/d of water (29 BWPD), a 53% water cut. Well G averaged 0.5 m³/d of oil (3 BOPD) and 30 m³/d of water (189 BWPD), a 98% water cut, before the second treatment, which was very similar to the 0.5 m³/d of oil (3 BOPD) and 25 m³/d of water (158 BWPD), a 95% water cut that it was yielding in July 2005 when it last produced. After the second treatment, the well peaked at 3.0 m³/d of oil (19 BOPD) and 20.8 m³/d of water (131 BWPD), an 87% water cut.

Even though initial oil production was disappointing, there was an excellent microbial response in Well H. It is believed that

the lack of increased oil production is a result of other reservoir conditions. See Figs. 7 through 9 for production curves of all three production wells, respectively.

Expanding the Pilot. After seeing the response in the pilot area, it was decided to apply the MEOR process to a second injector. A batch treatment was pumped into Injector I on 4 December 2008. As in the pilot, an oil-production increase was seen approximately 3 weeks after the first injection of nutrients. The three offset producers, Wells J, K, and L, responded. In total, they have increased production from 10.2 m³/d of oil (64 BOPD) and 157 m³/d of water (989 BWPD), a 94% water cut to a peak of 16.7 m³/d of oil (105 bbl) and 151 m³/d of water (951 BWPD), a 90% water cut. See Figs. 10 through 12 for the individual production curves.

Discussion

The trial field is experiencing several economic improvements. Not only is there an increase in oil production, but also there is an increase in oil recovery. With the increasing oil production and decreasing water cut, lifting costs are reduced. All these factors contribute to extending the life of the field. As in this application, a reduction in water production is often seen with these nutrient treatments. For instance, on ISMRA Well A, water production dropped from 20.8 m³/d (131 BWPD) to 19 m³/d (120 BWPD). It is believed that the changes to the oil/water/bacteria interface in the wellbore region change the relative permeability of water and oil. Because the MEOR nutrients stimulate microbes that compete with sulfate-reducing bacteria, a reduction of sulfide may be experienced. Some governments have programs in place to encourage EOR projects. This project is benefiting from provincial-government support to apply a new process.

There are several advantages of this process over other EOR processes, and even over other MEOR processes. It is low cost to implement. Average incremental cost per barrel in the trial MEOR application has been USD 6.00 (USD 37.73/m³). There is

Well H

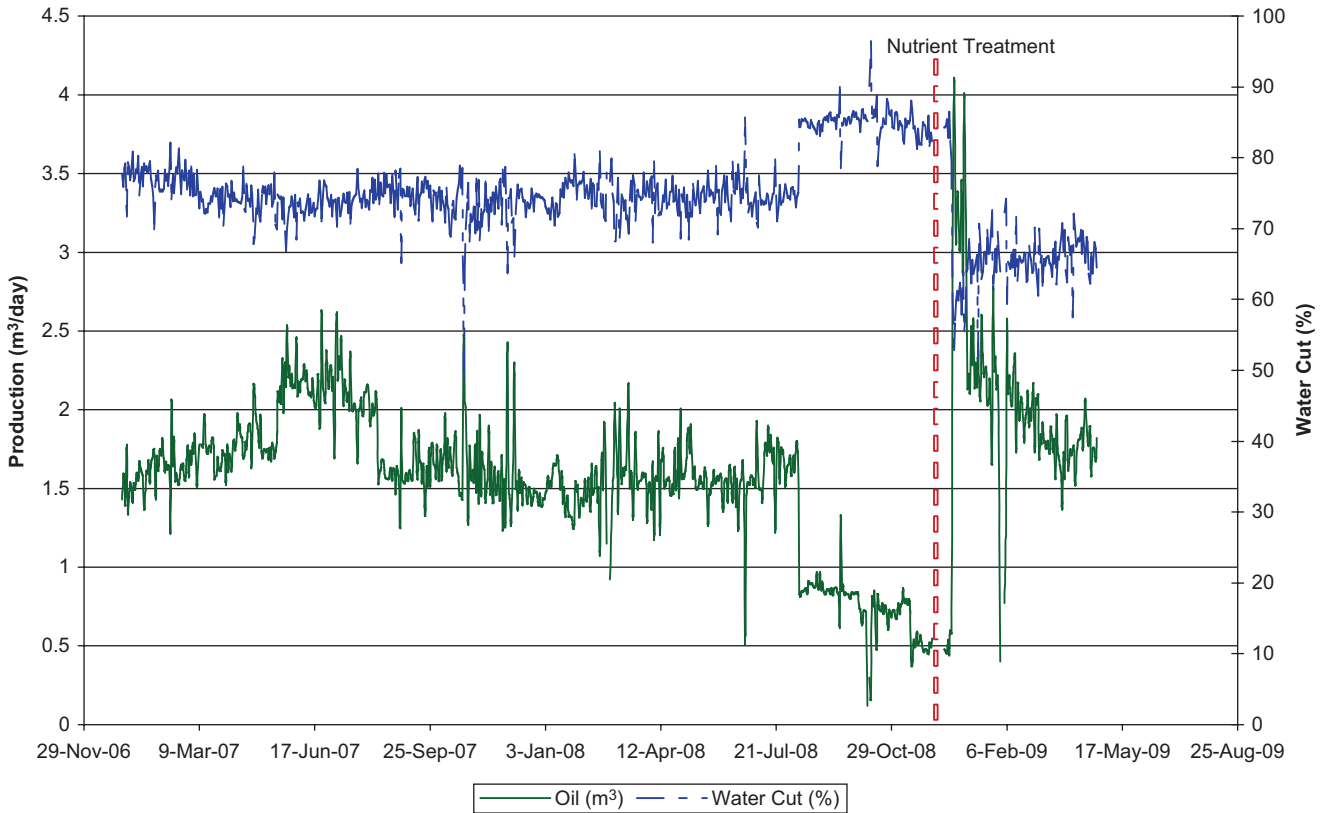


Fig. 7—Producing Well H responds to cyclic treatment.

Well F Prod

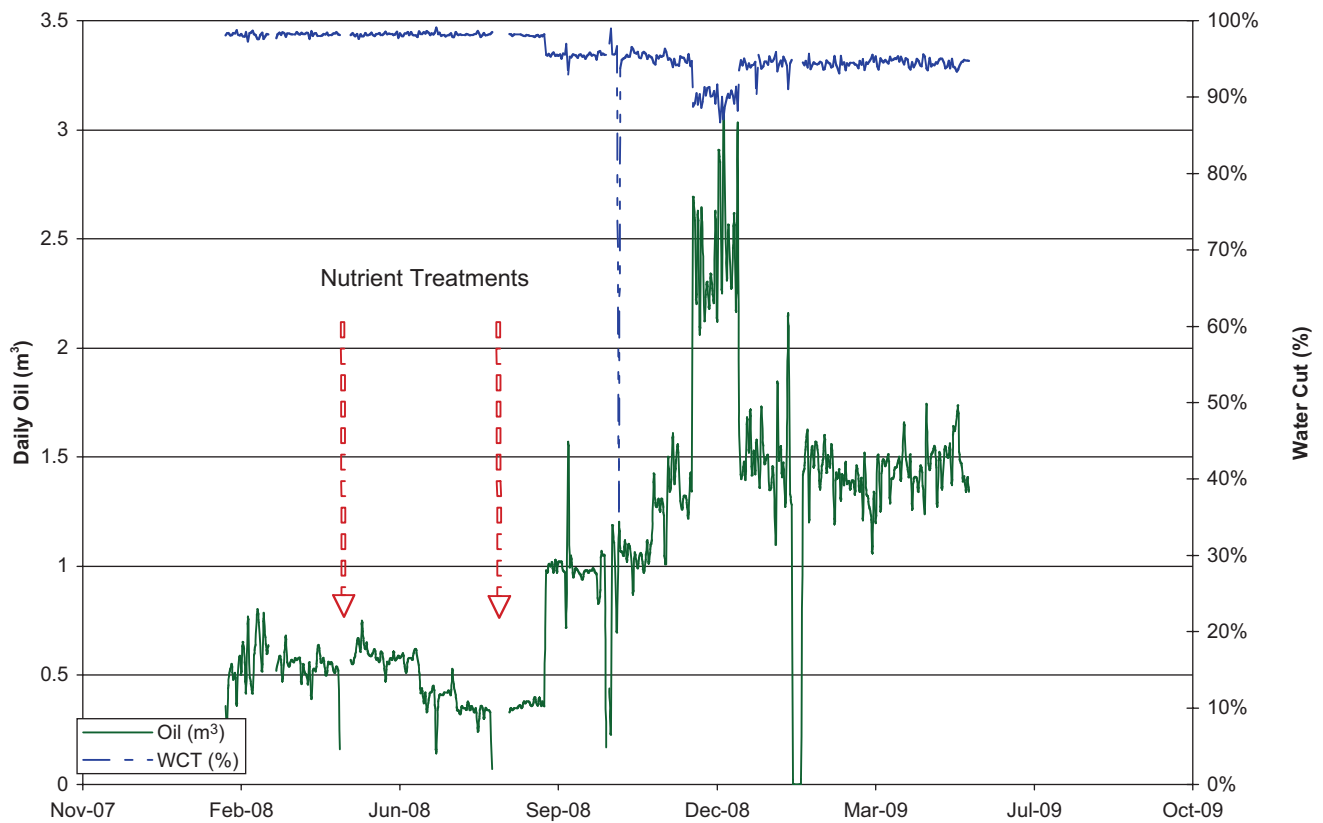


Fig. 8—Idle F producer is reactivated and treated with nutrients.

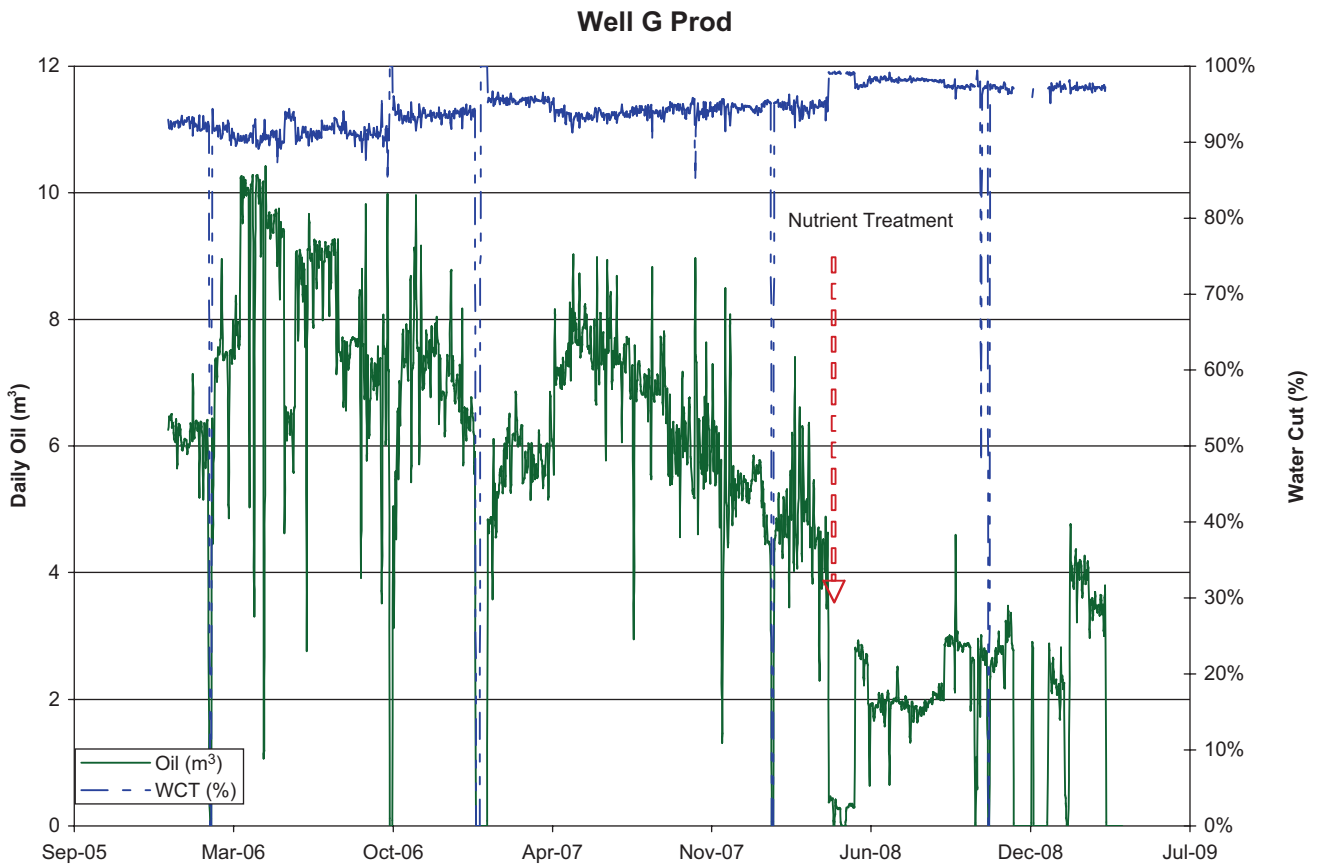


Fig. 9—Producer G is treated with nutrients.

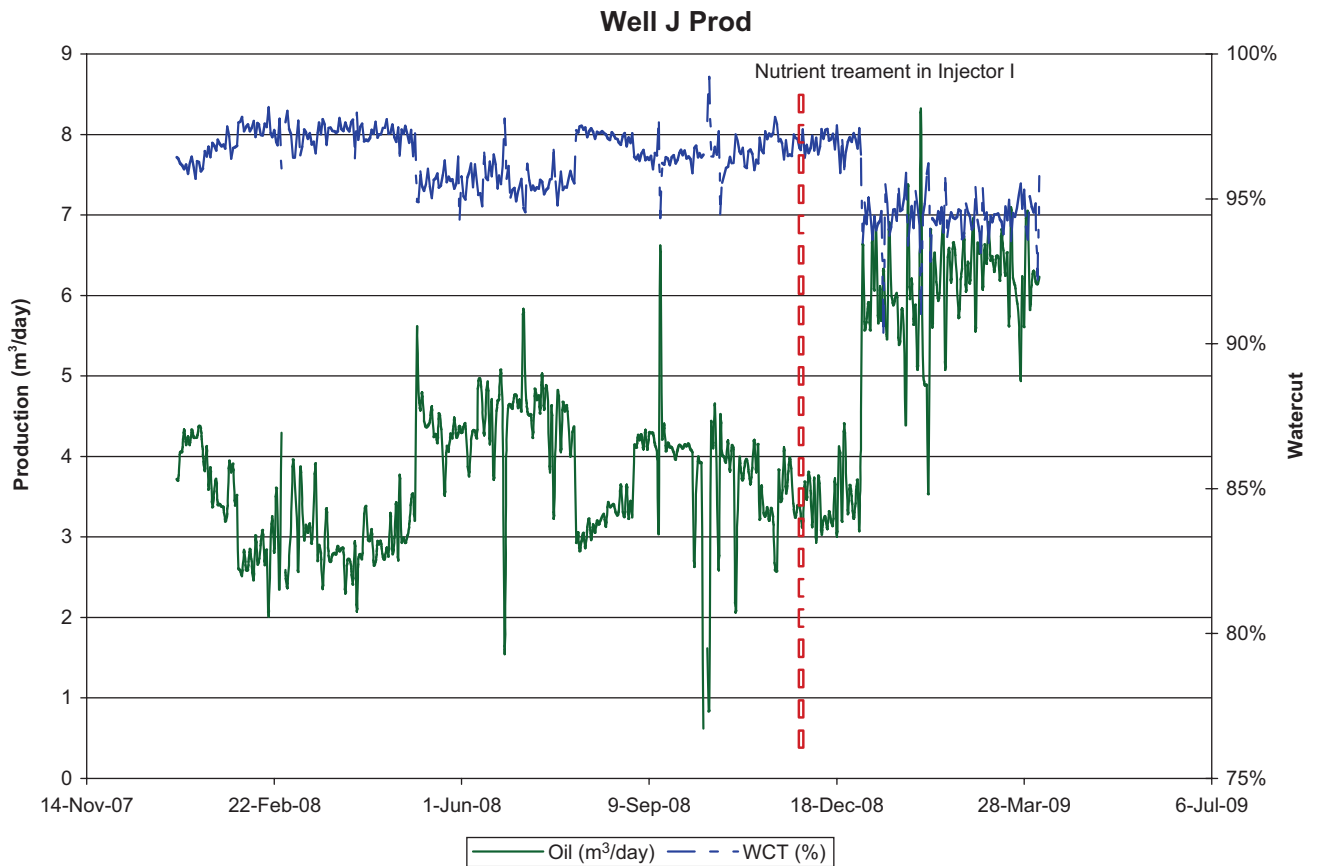


Fig. 10—Producer J responds to treatment in offset Injector I.

Well K Prod

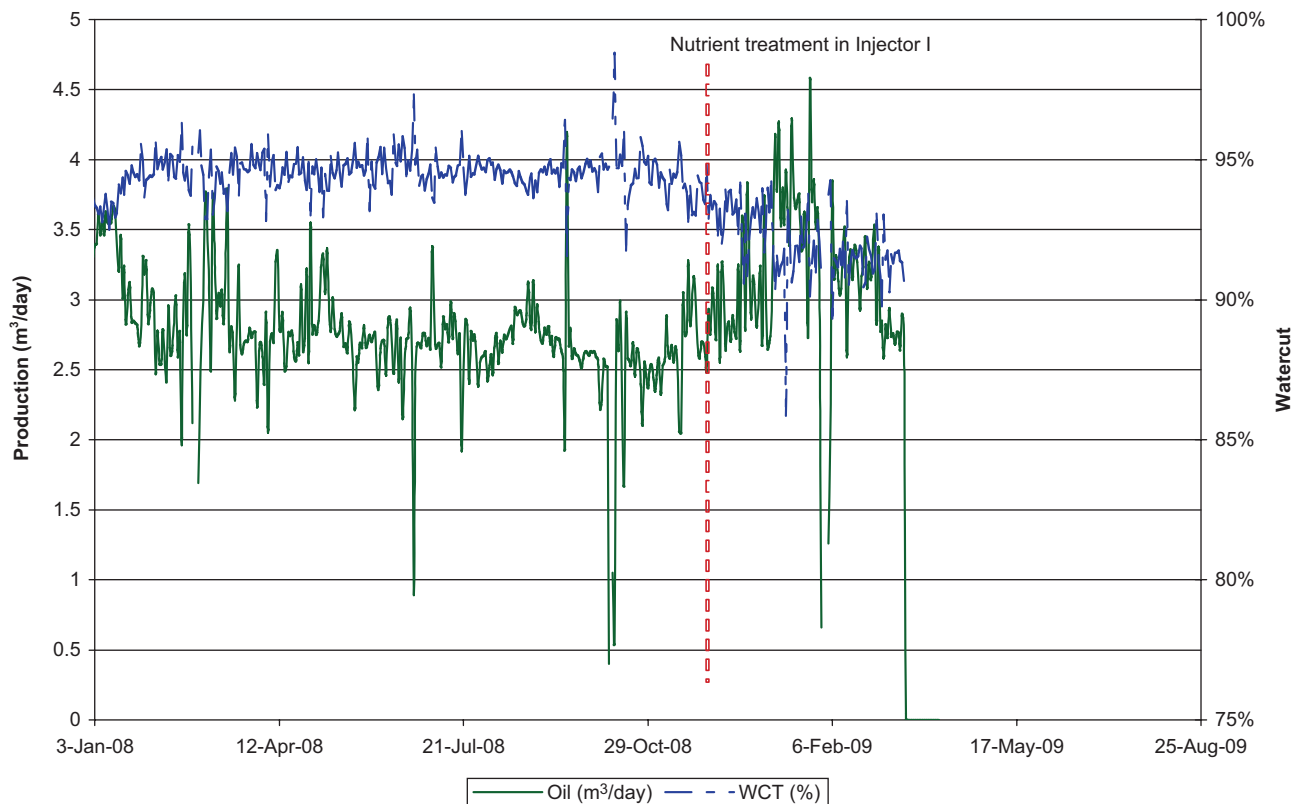


Fig. 11—Producer K responds to treatment in offset Injector I.

Well L Prod

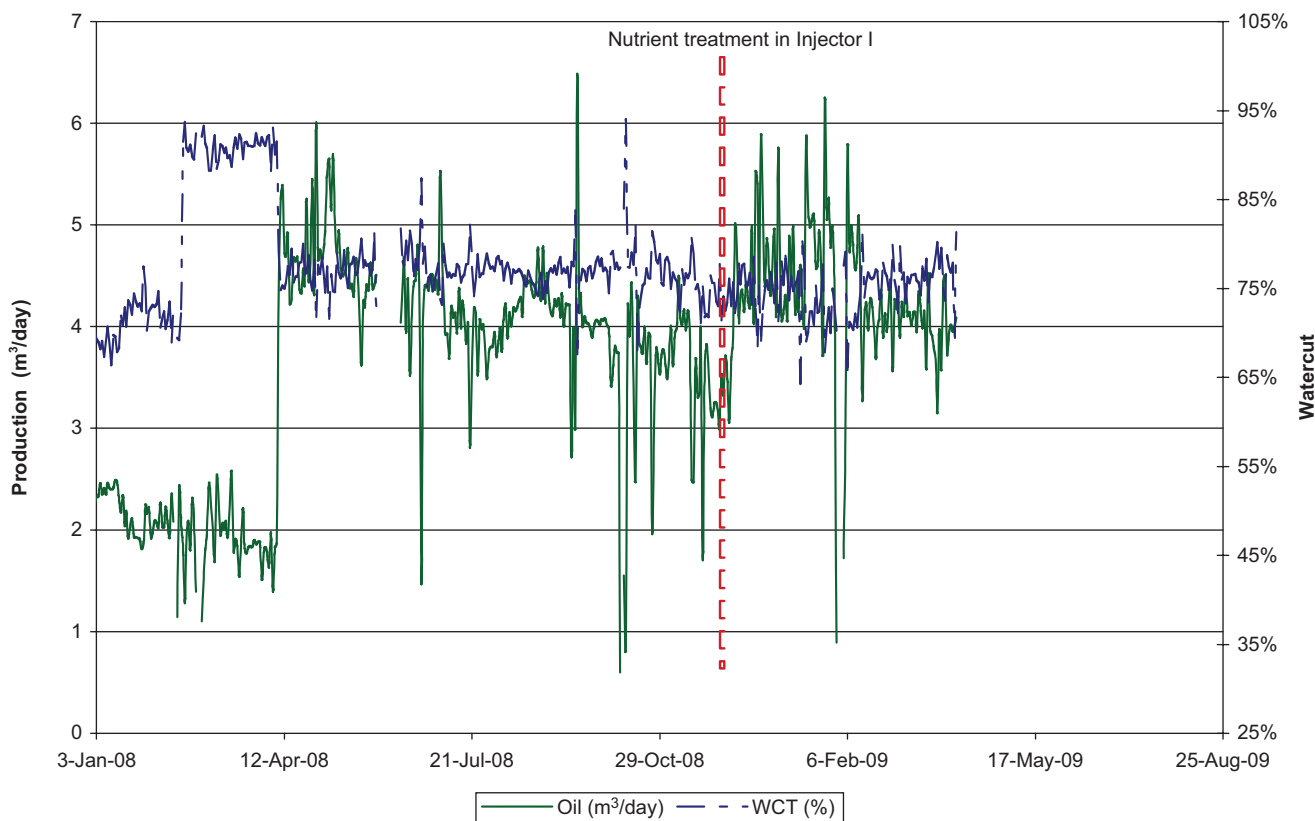


Fig. 12—Producer L responds to treatment in offset Injector I.

no capital outlay required to implement a project. Since the nutrients are batch treated even in injectors, permanent equipment is not required. There is little cost required to test the concept. Costs to conduct laboratory testing and to test nutrients in the field are minimal. Also, with batch treatments, the impact on field personnel is minimal. Another advantage is that it is low risk to implement. No microbes are injected, which minimizes the potential to cause reservoir plugging. The nutrient solutions that are injected are environmentally benign.

Future Plans

It is planned to expand the MEOR application throughout the entire field. Both injectors and producers can be treated to capture commercial quantities of oil. On the basis of response, the frequency of treatments will vary. For producers, frequency could be anywhere from 6 months to 2 years. For injectors, it could be as often as every 4 weeks or as widely spaced as every 4 months, depending on field performance. It is recognized that microbial response will likely vary from location to location throughout the field and that the response time to the treatment will also vary as water transit times change with varying water-injection conformance.

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