# MARATHON OIL COMPANY'S EXPERIENCE WITH PRODUCED WATER CONTROL AND CONFORMANCE IMPROVEMENT USING POLYMER GELS

by

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### Abstract

In this paper, Marathon's experience with the use of Cr(III)carboxylate/acrylamide-polymer (CC/AP) gel technology for use in oilfield conformance-control, sweep-improvement, and fluid-shutoff treatments, is discussed. Marathon has performed this technology on over 250 production wells resulting in the reduction of nearly 500,000 barrels per day of produced water. The CC/AP gel technology, which was conceived in late 1984, is characterized as having robust gel chemistry and as being insensitive to petroleum reservoir environments and interferences. This gel technology has been employed in over 1,600 conformance-control treatments worldwide. Highlights of field applications and results involving the CC/AP conformance-control gel technology are presented.

### **Introduction**

Conformance-control treatments include jobs to improve volumetric sweep efficiency during flooding operations and treatments to reduce excessive water and gas production. Polymer gels act as permeability-reducing agents and, as such, act as blocking and plugging agents. These gels operate by reducing the fluid-flow capacity within the treated portion of the reservoir.

The gels are polyacrylamide, crosslinked with chromium (III) acetate and are formulated to take two different forms for different applications. A high molecular weight low concentration polymer is used for deep placement into fractures. This product is used on both injection wells and producers to treat the reservoir's areal conformance problems and is called MARCIT-CT. The same chemistry is used to produce a gel from a low molecular weight polymer which in it's pre-gel from can enter matrix. When final gellation occurs, the material completely shuts off permeability. This product is called MARA-SEAL<sup>SM</sup>.

The major application s for MARCIT-CT<sup>SM</sup> are improved areal sweep in injection wells completed in naturally fractured reservoirs, and water reduction in producers completed in similar reservoirs.

Throughout the development of this technology, Marathon has patented various aspects of the technology, allowing commercialization through licensing qualified service companies. This has made the technology available to Marathon through these service companies and has also made the process available to the industry.

### **Injection Well Conformance Treatments**

Poor reservoir injection conformance is a major factor in ultimate recovery and economical performance of enhanced recovery and waterflood projects. Injectant can channel from injector to producer, bypassing high oil saturation portions of the reservoir. Pattern flood efficiency and economics can be affected to the point of offset producing wells being shut in. This is especially true in  $CO_2$  floods where gas injection results in almost immediate breakthrough to the producer resulting in non-commercial rates of  $CO_2$  utilization. Large volume MARCIT-CT<sup>SM</sup> treatments are performed which reduce the flow through the interconnected fractures and result in diversion of the injection fluid into higher, unswept portions of the reservoir.

### **Producing Well Treatments**

MARCIT-CT gels have been used extensively to reduce water production from producing wells completed in naturally fractured reservoir. This process works in cases where the water production either from injection wells or from an underlying aquifer is connected to the producing wellbore by fractures. The MARCIT-CT gel is typically bullheaded into the completion and the gel only enters the fracture with very little or no leak off of the gel into the matrix rock. As of May 1998 resulting from applying in total 252 CC/AP gel water-shutoff treatments to production wells throughout our company, we have shut off a total of 500,000 BWPD of water production. In addition, these gel treatments have increased oil production by 8,000 BOPD.

### **Treatments on CO<sub>2</sub> Injectors**

Because of the pH insensitivity of MARCIT-CT gels when formulated with acrylamide polymers having an optimum hydrolysis range, the gels are uniquely well suited for application  $CO_2$  floods in naturally fractured reservoirs. D. C. Borling's SPE/DOE paper<sup>5</sup> reported on successful CC/AP gel treatments at the Wertz field  $CO_2$  WAG flood in the Wind River Basin of Wyoming. He discussed 10 injection well gel treatments applied to the 165°F fractured Tensleep sandstone reservoir. The following benefits were reported to have been derived from having applied these CC/AP gel treatments:

- Resulted in incremental oil recoveries of up to 140,000 barrels per well pattern
- Increased oil production rates by 100-300 BOPD per well pattern.
- Extended the economic lives of marginal well patterns by nearly two years
- Reduced GORs and WORs
- Reduced gas and water cycling
- Reduced gas and water breakthrough times
- Improved water and gas injection profiles
- Reduced operating expenses
- Contributed substantially to the field-wide decline-rate reduction in 1992 from 24% to 9%
- Were effective where conventional oilfield foams had failed
- Had rapid payout times of often less than three months
- Recovered substantial reserves that would not have been otherwise recovered

Hild and Wackowski in another SPE paper<sup>6</sup> have reported on 44 injectionwell CC/AP gel treatments applied between 1994 through 1997 at the large CO<sub>2</sub> miscible WAG flooding project of the Rangely Weber Sand Unit is located in northwestern Colorado. The Rangely Weber Sand Unit is the largest field in the Rocky Mountain region in terms of daily and cumulative oil production. The economic rate of return on these large volume (~10,000 bbl) injector gel treatments was reported to be 365%. The success rate of these treatments was stated to be 80%. The authors reported on modeling results forecasting that polymer-gel conformance improvement treatments will, for the most likely mid-case scenario at Rangely, yield in the year 2007 a daily incremental oil production rate in excess of 2,500 BOPD.

Recent work with only early results on a West Texas San Andres CO2 injector shows very promising results. An injector in a pilot ROZ (residual oil zone) project was loosing all injection into the upper previously flooded

Main pay zone. The two zones are in communication through vertical fractures and through poor primary cement behind casing. A 13,700 MARCIT-CT treatment followed by a 75 barrel MARA-SEAL treatment was placed into the Main pay zone using dual injection placement. The dual injection consisted of pumping radioactive traced gel down the tubing casing annulus while pumping water as a protection fluid down the tubing under a packer. This arrangement prevented gel entry into the ROZ. Wire line logging during the injection was used to monitor the interface of radioactive tagged gel and the water. The attached figures show the results of the work..

### **Gel Jobs Combined with Stimulation Treatments**

Two papers have been published demonstrating how CC/AP gel jobs can be synergistically applied in combination with stimulation treatments in naturally fractured reservoirs.

Whisonant and Hall<sup>8</sup> have reported on the success of applying MARCIT-CT treatments to fractured production wells in the Oregon Basin field of Wyoming, in conjunction with applying foamed acid stimulation technology and a newly developed propellant stimulation technology. They state: "The combination of the three different technologies allowed the treatment of a number of wells that had not previously been considered stimulation candidates due to their high total fluid production rates." The authors reported that such combined treatments of the naturally fractured Embar carbonate reservoir of the Oregon Basin field have resulted in 675,000 STBO of Embar reserve development, untapped by 70 years of previous reservoir development. The average incremental reserve development per for the 28 producing well treatments. which treatment were conducted in 1996 in this field, was reported to be 24,100 STBO, at an average reserve development cost of \$2.50/bbl.

Kintzele<sup>9&10</sup> has reported recently on a series of CC/AP gel water-shutoff treatments that were performed in combination with acid stimulation treatments prior to the gel jobs and applied to the Madison formation of a field in the Big Horn Basin Area of Wyoming. The treated Madison carbonate formation was characterized as being highly fractured and/or containing a significant amount of vugular porosity. There is a prolific natural water drive associated with the Madison formation in this area. The field in question has a production history dating back at least to the 1930's. The stimulation treatments were extreme-over-balanced acid/nitrogen surge treatments.

The following quotes are taken from the Summary section of Kintzele's second paper. "The success of the gel conformance treatments in the Madison has tremendously impacted the overall development plan." "Recompletions and drill well activity had [previously] nearly come to a standstill due to the risky nature of the remaining candidates. The field drill well and recompletion program is now booming, due in part to the success of these [combined gel/acid] treatments. Ten recompletions were performed in 1996, and eleven are planned or in progress in 1997. These are more recompletions in a two-year period than were ever performed previously in this [highly mature] field. Nearly half of the recompletions and over half of the 1997 drilled wells utilized....[CC/AP gel] treatments."

The author in the same paper reported that the 17 CC/AP gel water-shutoff treatments have, on the average, reduced water production rates by over 2,000 BWPD, increased oil production rates by 50 BOPD, reduced WOR to less than one third of pre-gel treatment ratios, and lowered producing well fluid levels by over 1,100 feet per well. The overall oil reserve development cost was reported to be, on the average, \$2.01/STBO, while the reserve development cost for the treatments of the "recent optimized design" was reported to be \$1.11/STBO. Perhaps, the most significant outcome that was discussed in the paper was the field-wide production "effects of the recent recompletion and drill well activity sparked by successful....[CC/AP] gel treatments." This field-wide production effect is shown in Fig. 3 which is adapted from a figure in reference 16.

#### MARA-SEAL for Zone Shut-Off and Casing Repair

Isolated intervals can be squeezed using MARA-SEAL<sup>SM</sup> gels which are high concentration (~5% and higher) polymer of low molecular weight (~400,000). Unlike areal conformance treatment using MARCIT-CT<sup>SM</sup> gel, these treatments require zonal isolation to confine the treatment to the unwanted water or gas zone. Relatively small volume treatments, typically less than 2 barrels per treated foot of interval, are used to shut off zones permanently, seal open-hole during drilling, or shut-off casing leaks. MARA-SEAL<sup>SM</sup> is more effective than traditional Portland cement in many applications because the pre-gel solution is of a low enough molecular weight and viscosity to allow entry into the matrix resulting in permeability elimination when the gel fully sets. Odorisio and Curtis<sup>11</sup> reported on this in their short radius horizontal drilling paper and Southwell and Posey<sup>7</sup> discussed it in detail in a paper on gel applications. The application discussed in these papers where re-entries are made into vertical wells for the purpose of drilling short radius horizontals continues to be highly successful. Over 110 of these treatments have been performed to date.

Many state agencies require the periodic hydrostatic testing of tubing casing annuli to demonstrate the integrity of the injection completion's isolation from groundwater sources. In the state of Texas, for example, the Texas Railroad Commission requires the H-5 test be performed. This test involves pressuring the annulus to 500 psi and then allows only a slight fall of pressure over a specified time increment. In most cases the TRRC requires the use of Portand cement to repair leaks in the casing identified from this test. Often times these leaks are small "pin-hole" leaks or a series of "pin-hole" sized leaks which are the result of external corrosion of the casing. There are at least two reasons for such a casing corrosion problem 1) the interval of casing intersects a water productive zone containing corrosive water and 2) such a zone may have prevented an adequate primary cement job upon initial completion of the well. It has been the general experience of this operator and many others in the industry that such casing leaks are difficult if not impossible to repair using Portand cement due to the bridging of cement particles when passing through small openings such as these "pinhole" sized openings. Therefore it is the belief of this author that products such as MARA-SEAL<sup>SM</sup> that are clear fluids are ideally suited for this application. Clear fluid gels are capable of propagating through such a leak and then crosslinking and becoming a permeability reducing gel both in the leak orifice and also reducing or eliminating flow from the water zone which initially prevented and adequate primary cement job and which may have caused the external casing corrosion problem. This application is being thoroughly tested in well applications and results will be forthcoming.

### **Conclusions**

- CC/AP treatments continue to be used for a wide range of conformance problems.
- MARCIT-CT<sup>SM</sup> Gel Technology has been proven to be effective in treating injection wells in CO<sub>2</sub> floods including those in the San Andres reservoir
- Over 1600 MARCIT<sup>SM</sup> treatments have been performed to date.
- Correct identification of the conformance is essential for success
- MARA-SEAL<sup>SM</sup> has been proven effective at sealing open-hole while drilling.
- MARA-SEAL<sup>SM</sup> seal has many applications in remedial well repair including drilling applications and casing repair.

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# MARCIT<sup>SM</sup> Technology

- Cr(III)carboxylate/acrylamide-polymer
- Chromium acetate the preferred crosslinker in most but not all applications
- Developed by Marathon in mid 1980's

over \$30 million spent in development over 64 ++publications on the technology

# MARCIT<sup>SM</sup> Technology

- 34 US Patents and numerous international
- Over 1400 treatments to date, 500 on Marathon operated wells
- Four licensed service companies to choose from

over \$30 million spent in development over 64 ++publications on the technology

### MARCIT Technology Licensees

- CIBA (formerly Allied Colloids Inc.)
- Gel Tec
- Dowell
- TIORCO

# Applications .

Near wellbore matrix gels MARA-SEAL

- Chemical Liner to Seal Open-Hole
- Zone Abandonments
- Behind Pipe Channels
- Casing Leak Repairs

Far wellbore fracture gels MARCIT-CT

- Injection Wells Improved Sweep (in naturally fractured reservoirs)
- Producing Well for Reducing Water (in naturally fractured reservoirs)



























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### Possible Pitfalls of Producing well jobs

- Can have back-production of gel - Corrosion problems
  - Separation problems
- Can reduce oil rate
  Water rate reductions are generally always
  sustained, but not always oil increases
- Oil must be in matrix and water must be in fractures

Production Well MARCIT<sup>SM</sup> Results in Marathon Operated Fields

- 250++ production wells treatedShut off 500,000 BWPD
- Increased oil production by 8000 BOPD (rates following treatment)

## Advantage of Producing well jobs

- Low cost
- Reduce water almost every time
- Get results immediately
- Very quick pay out in the right application
- Have saved marginal fields - Big Lake, Circle Ridge, Maverick Springs

### Possible Pitfalls of Injection well Treatments

- Greater cost than producing wells due to large volumes of gel required
- Sometimes see no improvement
- Can reduce injectivity

### Advantages of Injection well treatments

- Potential for large incremental recovery on dual porosity reservoirs
- Little if any concerns of polymer production
- Little if any downside from lost oil production
- Producing well not out of service during treatment



# MARA-SEAL

- Low molecular weight allows matrix invasion
- Zone shut-off
- · Casing leak repair
- · Seal open-hole



# MARCIT-LC Poly-Plug

- Cellulose Fibers pre-mixed with MARCIT Gel
- Severe Lost Circulation Problems
- Available through any mud company licensed to M&D Industries

### Conclusions

- MARCIT Gel Technology gels continue to be applicable to a number of conformance problems
- MARCIT Gel Technology gels have demonstrated effectiveness in a San Andres CO2 injection wells
- Over 1400 MARCIT treatments have been applied to date
- Correct identification of the conformance problem is essential for success