RESULTS OF ADVANCED TECHNOLOGY UTILIZATION IN SELECTIVE WATER REDUCTION

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ABSTRACT

This paper presents the results of a successful application of a new-generation polymeric selective water reduction (SWR) treatment that reduces water production without requiring zonal isolation. The SWR treatment can be bullheaded into open intervals without isolation of water zones from hydrocarbon zones. As a result of this treatment, the productive life of a well can be extended with a gradual increase in water cut. This translates to a high potential profitability value for mature fields with a high water cut. It can increase the hydrocarbon recovery percentage in formations that otherwise would be destined for abandonment.

Previous papers have discussed the laboratory development of the SWR treatment based upon the use of a hydrophobically modified polymer. This paper will focus upon the field implementation results of this technology. Specifically, this paper will focus upon candidate selection, job design, and summary of the results of treatments performed.

INTRODUCTION

Excessive water production from hydrocarbon reservoirs is one of the most serious problems in the oil industry. Water cut greatly affects the economic life of producing wells, and it is estimated that unwanted water production costs the petroleum industry about $45 billion each year.[1,2] These costs include the expense to lift, dispose of, or re-inject this water, as well as the capital cost of surface facility construction, water treatment, and efforts to ensure that environmental regulations are met.[2]

Many methods are available to mitigate water-production problems. Among the chemical methods, both sealing and nonsealing systems have been in use for many years. Nonsealing SWR systems are also referred to as bullhead systems, disproportionate permeability modifiers, and relative-permeability modifiers. These nonsealing systems are typically dilute polymer solutions that perform because of adsorption onto the pore walls of the formation flow paths. Many such polymer systems have been promoted through the years, and a large volume of literature has been devoted to this topic. One relatively common theme mentioned for such systems has been that they are best applied to layered, heterogeneous formations without reservoir cross flow.

A previous paper[3] describes the SWR polymer upon which this work is focused. The polymer described in that reference is a hydrophobically-modified water-soluble polymer

TECHNOLOGY

One of the greatest challenges for mature fields at present is water production; produced water significantly impacts maintenance costs and decreases the hydrocarbon recovery percentage. Water cut also brings about ecological problems, issues with product handling on surface, corrosion problems, and a waste of the reservoir's energy. All these strongly impact the profitability of gas- and oil-producing fields.

Methods to mitigate this problem include, among others, blocking gels, cement, microcement, and silicates. Because these materials all act as sealing agents, the water zone must be isolated from the hydrocarbon zone, implying the use of mechanical or chemical systems, and, in most applications, the use of equipment for major workovers. The class of materials known as relative-permeability modifiers do not require zonal isolation and function by selectively decreasing permeability to water without altering or damaging the permeability of hydrocarbon zones.[1,2] This process allows treatment of the open interval without the need to isolate the zones; subsequently, it has the execution benefit of being a bullhead treatment.

Residual-resistance factor (RRF) is defined as the initial permeability divided by the final permeability (RRF= $K_{initial}/K_{final}$). Water RRF values with the SWR systems are in the range of 8 to 10. The RRF values of the hydrocarbon are typically less than 2. The SWR systems adsorb permanently to the walls of the pore throat. Laboratory testing has indicated no removal or “washing off” occurring even after over 10,000 pore volumes of brine flowed through treated cores, even at temperatures up to 325°F.

Fig. 1 illustrates the adsorption of a generic water-soluble polymer onto a rock surface pore throat wall, as well as the adsorption of SWR polymer onto the rock pore throat surface. The presence of the hydrophobic groups on the polymer serves to increase the level of polymer adsorption by allowing polymer to adsorb to polymer. This process, as well as the theory that this hydrophobically modified polymer leads to higher levels of water permeability reduction than a nonmodified polymer, without damage to hydrocarbon permeability, has been described[3] previously.

CANDIDATE SELECTION

Wells having the following conditions are possible candidates for SWR:

- Bottomhole temperatures up to 325°F.
- Permeability greater than 0.10 md and less than 6,000 md.
- Layered formation without crossflow within the reservoir.
- Capability of sustained production if the water-oil ratio (WOR) can be reduced.

No factor has as much bearing on the economic success of the SWR application as proper well selection. The most important point is that the well must have a potential for the production of hydrocarbons. A depleted reservoir or one with no energy remaining to move hydrocarbons to the wellbore may not be a good candidate. It may be possible to restrict water entry in such wells, but oil or gas production will not necessarily be improved.

If poor cement sheaths, channels, or near-wellbore fractures or similar anomalies provide access to aquifers above or below the hydrocarbon producing interval, the SWR application may not be the preferred treatment. Other permanent plugging or positive shut-off materials should be considered first.

The criteria selecting a well for SWR treatment should consider not only the production rates but also the drawdown pressure. If reduced water production rate is the desired result, it is important to maintain the same drawdown pressure after treatment as before the treatment. However, if increased oil-production rate is desired with similar water production rate, then the drawdown pressure should be increased.

Factors to Consider in SWR Candidate Selections[10]

- **Recoverable Hydrocarbon:** SWR treatments can only be successfully applied to a production well if there is an economically sufficient volume of recoverable hydrocarbons in the reservoir surrounding the treated well.

- **Hydrostatic Pressure:**
  - If the well is fully “pumped off” before a treatment, and the treatment is not applied above parting pressure, the application of an SWR treatment (alone) provides no opportunity to increase the post-treatment oil-production rate. At best, only a reduction in the water production would be anticipated.
  - If the well is not fully “pumped off” before application of an SWR treatment, then it is possible to achieve an increased drawdown pressure in the wellbore. This would greatly increase the potential for a higher oil-production rate after the SWR treatment.

- **Crossflow** :
  - SWR treatments are not generally considered applicable when crossflow within the reservoir exists (such as when there is no impermeable shale break or other barrier between the reservoir hydrocarbon layers and adjacent water bearing layer(s)).
  - SWR treatments are applicable when crossflow does not exist within the reservoir and the hydrocarbon and water are being produced from distinctly different layers.
  - In the case of multiple zones (with or without crossflow), the applicability for an SWR treatment on wells which are already pumped off must be considered individually. If the well has not been pumped off, then an SWR treatment would be applicable.

- **Fractured Production Wells:**
  - Hydraulically Fractured Wells—When performing hydraulic fracture stimulation, the fracture often can extend into an adjacent water zone(s). This can result in a significant, undesirable increase in water production. SWR treatments have a significant potential to correct this problem. The SWR polymer enters into the rock matrix along the fracture face. The unique feature of the SWR polymer is its ability to reduce the effective permeability to water much more so than to hydrocarbon. The magnitude of the reduction of the effective permeability to water is theorized to be a function of the actual leakoff distance from the fracture face and into the rock matrix, coupled with the RRF caused by the SWR polymer. Because the SWR polymer does not form a 3-dimensional gel structure, the fracture conductivity is not reduced significantly. In this scenario, an SWR treatment should provide acceptable results even if crossflow can occur between the water-bearing and oil-bearing zones (which would be the case because of the hydraulic fracture).
  - Naturally Fractured Wells—This condition should be evaluated and treated using the same criteria as discussed previously for conditions regarding multiple zones (with or without crossflow).

- **Drawdown Pressure:** For radial matrix flow conditions in wells that are not already “pumped off,” it is believed that an increase in the drawdown pressure after an SWR treatment will be the primary driver regarding the success and/or failure of the job. If the post-treatment drawdown pressure is not significantly increased, it is unlikely that oil production will increase as a result. That is, the increase in oil production will be proportional to the increase in the drawdown pressure. But, if the treated wells were already fully drawn down prior to the SWR treatment, then there is the possibility that some oil production will be lost when applying an SWR treatment.

JOB DESIGN

After the origin of water breakthrough has been identified, the job can be designed and executed. Because SWR treatments are typically performed without zonal isolation, the design and execution are simple and consist of:

1. Creating the operational procedures, execution plan, and quality control tests for the fluids to be used.
2. Determining the volume to be used for each fluid.
3. Planning the pumping and monitoring of operational parameters with all due safety measures and environmental protections.

The operational procedures consist of:

1. Performing an injection test with treated water to verify the mechanical conditions of the well.
2. Establishing injection followed by pumping of the SWR system for the selective reduction of water.
3. Applying an overflush with treated water to place the greatest quantity of polymer inside the formation in the desired radius.

A typical composition of the SWR treatment system fluid is as follows:

- 2.0 % KCl clay stabilizer.
- 0.5% hydrophobically modified SWR polymer (typically 0.2% by weight).

The quality control tests for the SWR system are carried out by monitoring the appearance and viscosity of the system. It should fall within the ranges established by the laboratory tests (12 to 25 cp at room temperature) without generating emulsions in a blend of 50/50 SWR/oil.

The SWR volume design is typically sufficient to achieve a penetration of 10 radial ft (3 or 4 m), approximately 250 barrels (40 m^3). The aqueous overflush is 1/3 the SWR volume. Following the treatment, no shut-in period is required. The well is returned to production as soon as possible.

RESULTS

Over 100 SWR-type treatments have been performed up to the time of this paper. The database available contained information for 38 jobs (Table 1), but only 31 case histories were available with enough data to assess “success” or “failure.” A job was considered successful if significant decrease of the WOR resulted and/or water-gas ratio

(WGR) was observed after the treatment. The trends on production data before and after treatment were analyzed to estimate the impact of the treatment on the well. The average WOR reduction was 46%. The average oil-production increase was 13% with an average water production decrease of 20%.

CONCLUSIONS

- When properly designed and executed and when they function downhole as intended, SWR treatments can be successfully applied to a limited range of excessive-water-production problems occurring in either oil or gas production wells.
- When a treatable excessive-water-production problem occurs, SWR treatments can be applied using bullhead injection (not requiring the use of mechanical zone isolation).
- When a multi-zoned, unfractured production well (radial-flow through matrix rock) suffers from excessive water production and the well is not fully drawn down prior to the application of a SWR treatment, the oil production rate can possibly be increased if the post-treatment drawdown pressure can be "substantially" increased.
- SWR treatments can be applied to most production wells (that are not totally watered out) in matrix rock reservoirs where radial flow is occurring.
- Field results have shown examples of the successes (and failures) of the SWR (71% success rate)
- The SWR treatment does not completely stop water production.
- The SWR treatment can be economically attractive (average results following treatment indicated an oil increase of 13%, a water reduction of over 20%, and a WOR reduction of 46%.
- Based upon these results, it is believed that while field-wide, multi-well treatments are attractive from the viewpoint of fully assessing system capabilities, single-well treatments can also be beneficial.

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Unmodified polymer Hydrophobically modified polymer

Figure 1—Adsorption of nonmodified (left) and hydrophobically modified (right) polymers.

Table 1
Selective Water Treatment Case Histories

Treatment Results	**Lithology**	**Well Type**	**T, °F**	**$Q_{oil, before}$ BOPD**	**$Q_{oil, after}$ BOPD**	**$Q_{gas, before}$ MSCF/D**	**$Q_{gas, after}$ MSCF/D**	**$Q_{water, before}$ BWPD**	**$Q_{water, after}$ BWPD**	**WOR Before**	**WOR After**	**WGR Before**	**WGR After**	**Placement Technique**
Failure	Sandstone	Oil Producer	140	-	191	-	-	-	250	-	1.3	-	-	Mechanical Plug
Failure	Sandstone	Oil Producer	190	34.15	33.34	-	-	1289	1340	37.7	40.2	-	-	Mechanical Plug
Success	Sandstone	Gas Producer	115	-	-	720	600	30	0	-	-	41.7	0	Coiled Tubing
Failure	Sandstone	Oil Producer	180	95	97	N/A	N/A	4100	5418	43.2	55.9	-	-	Coiled Tubing
Failure	Dolomite	Oil Producer	119	327	259	-	-	1490	1470	4.6	5.7	-	-	Bullheading
Success	Sandstone	Oil Producer	209	219	203	-	-	3775	1750	17.2	8.6	-	-	Bullheading
X	Sandstone	Oil/Gas Producer	224	-	-	-	-	-	-	-	-	-	-	Coiled Tubing
Failure	Dolomite	Oil/Gas Producer	167	50.3	46.5	22.8	27	129	224	2.6	4.8	5657.9	8296.3	Bullheading
Failure	Dolomite	Gas Producer	320	603	377	2613	1236	270	440	0.4	1.2	103.3	356.0	
Success	Sandstone	Gas Producer	207	-	-	386	484	457	114	-	-	1183.9	235.5	Bullheading
Success	Sandstone	Oil Producer	160	57	104	-	-	350	150	6.1	1.4	-	-	Bullheading
Success	Carbonate	Oil Producer	207	31	70	-	-	90	94	2.9	1.3	-	-	Bullheading
Failure	Sandstone	Oil Producer		156.8	136.8	-	-	1248.8	1117.1	8.0	8.2	-	-	Bullheading
Success	Shale	Oil Producer	195	0.61	6.1	2.7	0.9	659	237	1080.3	38.9	244	263	Bullheading
X	Sandstone	Oil Producer	214	-	-	-	-	-	-	-	-	-	-	Bullheading
Success	Sandstone	Oil/Gas Producer	150	-	-	-	-	-	-	-	-	-	-	Bullheading
Success	Dolomite			-	-	-	-	-	-	-	-	-	-	Bullheading
Success	Sandstone	Gas Producer	165	-	-	-	-	325	57	-	-	-	-	Coiled Tubing
X	Sandstone		190	-	-	-	-	-	-	-	-	-	-	Bullheading
X	Sandstone		175	-	-	-	-	-	-	-	-	-	-	Bullheading

Table 1
Selective Water Treatment Case Histories

Treatment Results	**Lithology**	**Well Type**	**T, °F**	**$Q_{oil,\ before}$ BOPD**	**$Q_{oil,\ after}$ BOPD**	**$Q_{gas,\ before}$ MSCF/D**	**$Q_{gas,\ after}$ MSCF/D**	**$Q_{water,\ before}$ BWPD**	**$Q_{water,\ after}$ BWPD**	**WOR Before**	**WOR After**	**WGR Before**	**WGR After**	**Placement Technique**
Success		Oil Producer		-	-	-	-	300	114	-	-	-	-	Bullheading
Success	Sandstone	Oil Producer	200					775	320					Bullheading
Success	Sandstone	Oil Producer	223	3	-	250	257	2000	612	-	-	8	2	Bullheading
Success		Oil Producer	180	6	6	-	-	285	245	47.5	40.8	-	-	Bullheading
Failure	Dolomite	Oil Producer	110	16	16	-	-	1225	1225	76.6	76.6	-	-	Bullheading
Success	Carbonate	Oil Producer	100	28	45	-	-	2500	2000	89.3	44.4	-	-	Bullheading
Failure	Carbonate	Oil Producer	100	25	25	-	-	2500	2500	100.0	100.0	-	-	Bullheading
X		Gas Producer	210	-	-	-	-	-	-	-	-	-	-	Bullheading
Success	Sandstone	Gas Producer	180	-	-	1100	965	700	300	-	-	0.64	0.31	Straddle packer
Success	Sandstone	Oil Producer	122	20	55	-	-	400	375	20.0	6.8	-	-	Bullheading
X	Sandstone	Oil Producer	180	-	-	-	-	-	-	-	-	-	-	
Success	Sandstone	Oil Producer	139	10.5	14	-	-	35	23	3.3	1.6	-	-	Bullheading
Success	Sandstone	Gas Producer	120	-	-	301	350	290	7.5	-	-	0.96	0.02	Bullheading
Success		Gas Producer	125	-	-	-	-	150	-	-	-	-	-	Bullheading
Success	Sandstone	Oil Producer	100	1	1	-	-	1645	1346	1645.0	1346.0	-	-	Bullheading
Success	Sandstone	Oil Producer	130	13.68	14	-	-	2721	1986	198.9	141.9	-	-	Bullheading
OP	Sandstone	Oil Producer	180											Coiled Tubing
Success	Sandstone	Oil Producer	160	56	280	-	-	1344	1120	24.0	4.0	-	-	Bullheading