SUCCESSFUL FIELD IMPLEMENTATION OF A BULLHEAD WATER REDUCTION SYSTEM

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ABSTRACT
For many years, bullhead systems to reduce water production have received a great deal of attention from the oil and gas production industry. Previous papers have discussed the laboratory development of a new bullhead system based on a hydrophobically modified polymer. This paper will outline the field implementation of this system and will describe some of the successes (and failures) of the bullhead water reduction system (BWRS). Even though bullhead systems do not seal off water zones and thus do not have the capability to completely stop water production, it will be demonstrated that these treatments can be economically attractive. While field-wide multi-well treatments are attractive from the viewpoint of fully assessing system capabilities, single-well treatments can be beneficial to small and large operators alike.

INTRODUCTION
Excessive water production from hydrocarbon reservoirs is one of the most serious problems in the oil industry. Watercut greatly affects the economic life of producing wells, and it is estimated that unwanted water production costs the petroleum industry about $45 billion a year.[1,2] These costs include the expense to lift, dispose of, or reinject 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 systems are also referred to as bullhead systems, disproportionate permeability modifiers, and relative permeability modifiers (referred to in this paper as RPMs). These nonsealing systems (RPMs) are typically dilute polymer solutions that perform because of adsorption onto the pore walls of the formation flow paths. A large number of 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 crossflow.

A previous paper[3] describes the BWRS polymer upon which this work is focused. The polymer is a hydrophobically modified polyDMAEMA (HMpolyDMAEMA). In the referenced work, the following conclusions were discussed:

- Hydrophobic modification appears to improve the brine permeability reduction for both polyacrylamide and polyDMAEMA.
- The hydrophobic modification of polyDMAEMA improves the brine permeability reduction in high-permeability sandstone cores at residual oil saturation.
- The target goals of 80% brine permeability reduction and much lower oil permeability reduction have been met with the HMpolyDMAEMA.

TECHNOLOGY OF THE HYDROPHOBICALLY MODIFIED POLYMERIC BWRS
The solution properties (such as rheology and viscosity) of both ionic and nonionic water-soluble polymers are uniquely modified when hydrophobic groups are introduced into the polymer chains.[3-6] The primary factor responsible for this property modification is the associative tendency between the hydrophobic groups when placed in aqueous medium. The associative interactions of the hydrophobic groups may lead to either lower or higher solution viscosities, depending on the polymer concentration, which determines whether intra- or inter-molecular interactions dominate. These attractive interactions are often depicted as transient and reversible crosslinks among polymer chains that form under static or low-shear conditions but rupture at high-shear rates. This property is useful in oilfield applications requiring particle transport, such as in fracturing or transporting of drill cuttings. Commercially, this property has found extensive application in the coatings industry.

Another unique property of hydrophobically modified water-soluble polymers is their behavior in aqueous brines. The viscosity of a polyelectrolyte solution decreases with added salts because of the screening of the charges on the polymer chain by the component ions of the salt. While this phenomenon still occurs with hydrophobically modified ionic polymers, the reduction in viscosity caused by charge screening is more than compensated by the increased intermolecular associations among the hydrophobic groups caused by the presence of salts. Thus, hydrophobically modified polymers find use as viscosifiers for brines such as those used in drill-in or drilling fluids.[4,5]

The shear-dependent rheological properties of hydrophobically modified water-soluble polymers can be modified without altering their behavior toward salts by the addition of surfactants. This factor has found use in polymer-flooding applications for enhanced oil recovery.[6,7]

The adsorption behavior of hydrophilic water-soluble polymers can also be modified in a unique manner by the introduction of hydrophobic groups. Rather than reaching a plateau adsorption isotherm (common for hydrophilic polymers), hydrophobic modification appears to produce a continued growth in adsorption with greater polymer concentration. This behavior is attributed to associative adsorption of polymer chains on previously adsorbed layers of polymers.[8]

In general, hydrophobic modification of water-soluble polymers adds new properties while retaining features typical for hydrophilic polymers. The extent of these new properties can be controlled by the synthesis method, polymer concentration, hydrophobe type and amount, quality of the solvent, and monomer distribution along the polymer chain.

The technology of using hydrophobically modified polymers to selectively reduce the permeability to water without altering or damaging the permeability of hydrocarbon zones, allowing the treatment of the open interval without isolating the zones, is what this paper refers to as BWRS. This polymer is believed to function by adsorption onto the pore throat walls of the formation flow paths. It is felt that the hydrophobic modification increases the level of polymer adsorption, thus increasing its ability to hinder the flow of water, while having a minimal effect on the flow of hydrocarbon.

PROPOSED RPM MECHANISM OF HYDROPHOBICALLY MODIFIED POLYMERIC SYSTEM

It is theorized that water flow paths and oil flow paths are separate (even in the same capillary/flow channel), that water flow is close to the rock, and oil flow is in the middle of the capillary/flow channel, surrounded by the water layers against the rock surface (**Fig. 1**).

The polymer attaches to the rock and diminishes the flow path of the water without significantly changing the flow path of the oil. The mechanism of attachment is assumed to be simple electrostatics, a positively charged polymer attracted to a negatively charged surface. The hydrophobic modification of water-soluble polymer causes multiple layers of the polymer to build up, due to the association of the hydrophobic groups.

Figure 2 shows hydrophobic alkyl chains on a polymer backbone and the associations that cause two polymer chains to “stick together.”

CANDIDATE WELLS

Wells having the following conditions are possible good candidates for the BWRS treatments:

- 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
- Capable of sustained production if the water-oil ratio (WOR) can be reduced

No factor has as much bearing on the economic success of the BWRS 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 that has no energy remaining to move hydrocarbons to the wellbore may not be a good candidate. It may be possible to restrict water entry, 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 BWRS may not be the preferred treatment. Other permanent plugging or positive shut-off materials should be considered first.

Selection of a well for treatment with BWRS 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.

DESIGN AND EXECUTION OF THE JOB

Treatment concentration ranges from 300 ppm to 4,000 ppm, depending on permeability and temperature of the targeted interval. The treatment volume to be used is then calculated using the rock porosity, desired treatment radius, and the height of the treatment zone (**Fig. 3**).

An over-displacement of ~1/3 the treatment volume is recommended to displace the polymer treatment away from the wellbore, out to unreacted rock.

Prior to placing the BWRS, tubular goods through which the treatment is to be pumped should be cleaned. There should be no sludge or corrosion scale. These materials can loosen during the treatment and act as a mechanical diverting agent, causing the treatment to be diverted and/or reacted with a considerable amount of the polymer.

The zone should have an injectivity that is representative of the formation permeability; otherwise skin damage probably has occurred and should be repaired by a small acid stimulation or other suitable nonfracturing technique. Suspected paraffin or asphaltene deposits may be removed by use of organic solvents.

The method preferred for applying the treatment requires that an adequate supply of clean formation compatible water be obtained. This water should be free of suspended solids. On over-displacement, the clean formation compatible water should be used. This step is particularly important in that it permits maximum coverage by the polymer and reduces the risk of some of it being returned during initial production.

To properly evaluate a treatment, either the drawdown pressure must be noted for the production tests, or the drawdown must remain constant. In many cases after a treatment the average water permeability may be significantly reduced while the water-production rate remains essentially unchanged. This indicates that the fluid level in the wellbore may have been significantly lowered resulting in increased drawdown pressure. This increased drawdown often yields an increased oil production rate.

CASE HISTORIES

Jobs related to water reduction, acid diversion, and fracturing have been performed with the BWRS. **Table 1** shows results from several geographical regions. These case histories include oil and gas production wells in sandstone, carbonate, and dolomite formations. Of the twenty examples, four resulted in little or no response to the BWRS which corresponds to an 80% success rate. The average oil production increase was 48 BOPD, the average water-production decrease was 363 BWPD. Gas production following the BWRS treatment was shown to be typically unchanged (the one case that indicated a decrease in gas also resulted in an increase in oil production by an order of magnitude while decreasing the water by over 64%).

CONCLUSIONS

- Field results have shown examples of the successes (and failures) of the BWRS (85% success rate)
- The BWRS does not completely stop water production.
- The BWRS can be economically attractive (average results following treatment indicated an oil increase of 184%, a water reduction of over 30%, a WOR reduction of over 20%, and a WGR reduction of over 90%).
- 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 be beneficial.

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Table 1
Case History Examples

Well Type	**ϕ, %**	**Lithology**	**Gas**		**Oil**		**Water**		**WOR**		**WGR**	
			Before	**After**	**Before, bbl/day**	**After, bbl/day**	**Before, bbl/day**	**After, bbl/day**	**Before**	**After**	**Before**	**After**
Gas Producer	—	Sandstone	720 mcf	600 mcf	—	—	30	0	—	—	42	0
Oil Producer	—	Sandstone	—	—	327	259	1490	1470	4.6	5.7	—	—
Oil Producer	22	Sandstone	—	—	219	203	3775	1750	17.2	8.6	—	—
Gas Producer	16	Sandstone	.386 mmcf	.484 mmcf	—	—	457	59	—	—	1184	236
Oil Producer	22	Sandstone	—	—	57	104	350	150	6.1	1.4	—	—
Oil Producer	—	Carbonate	—	—	31	70	94	90	3	1.3	—	—
Oil Producer	25	Sandstone	—	—	164	159	1242	1110	7.6	7	—	—
Oil Producer	—	Shale	2.7 mcf	.9 mcf	0.61	6.1	659	237	1080.3	38.9	24407	263
Oil Producer	10	Sandstone	-	-	10	14	36.2	35	3.6	2.5	—	—
Gas Well	8	Sandstone	301 mcf	350 mcf	—	—	290	7	—	—	963	20
Oil Producer	14	Sandstone	—	—	1	1	1645	1346	1645	1346	—	—
Oil Producer	14	Sandstone	—	—	14	14	2721	1986	198.9	141.9	—	—
Gas Producer	—	Sandstone	—	—	—	—	325	157	—	—	—	—
Oil Producer	29.6	Sandstone	250 mcf	257mcf	3	—	2000	612	—	—	8000	2381
Gas Producer	10	Sandstone	1.1 mmcf	.965 mmcf	—	—	700	300	—	—	636	311
Oil Producer	—	Carbonate	—	—	28	45	2500	2000	89.3	44.4	—	—
Oil Producer	—	Carbonate	—	—	25	25	2500	2500	100	100	—	—
Oil Producer	—	—	—	—	6	6	285	245	47.5	40.8	—	—
Oil Producer	—	Dolomite	—	—	16	16	1225	1225	76.6	76.6	—	—
Oil Producer	—	Sandstone	—	—	56	280	1344	1120	24	4	—	—
			459.95	**459.98**	**26**	**74**	**1183**	**820**	**67**	**53**	**5872**	**535**

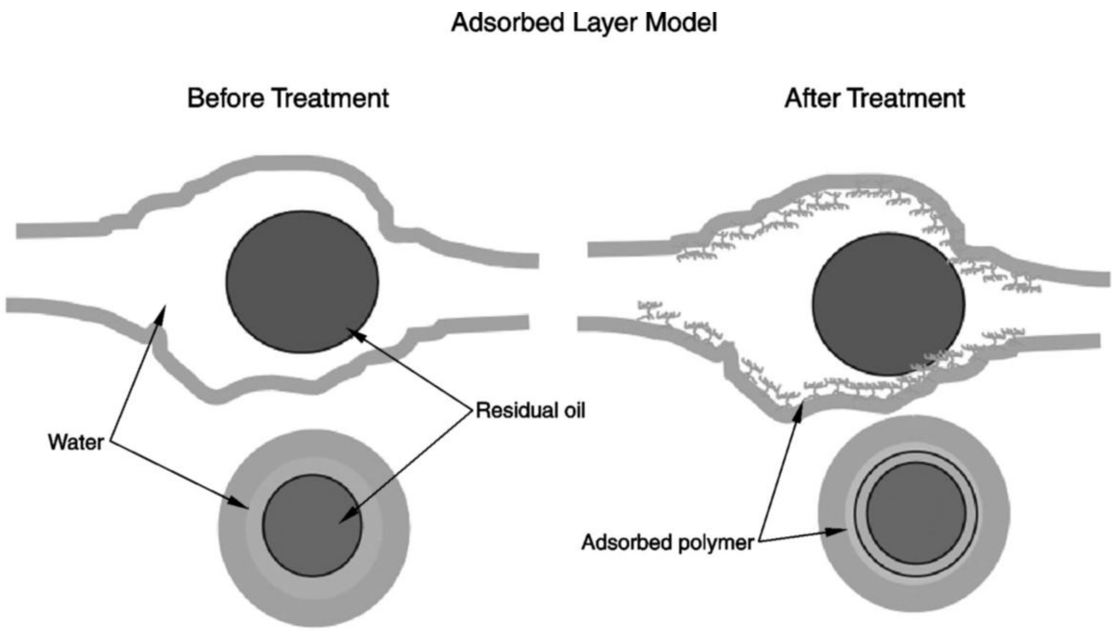

Figure 1 — Proposed BWRS Mechanism

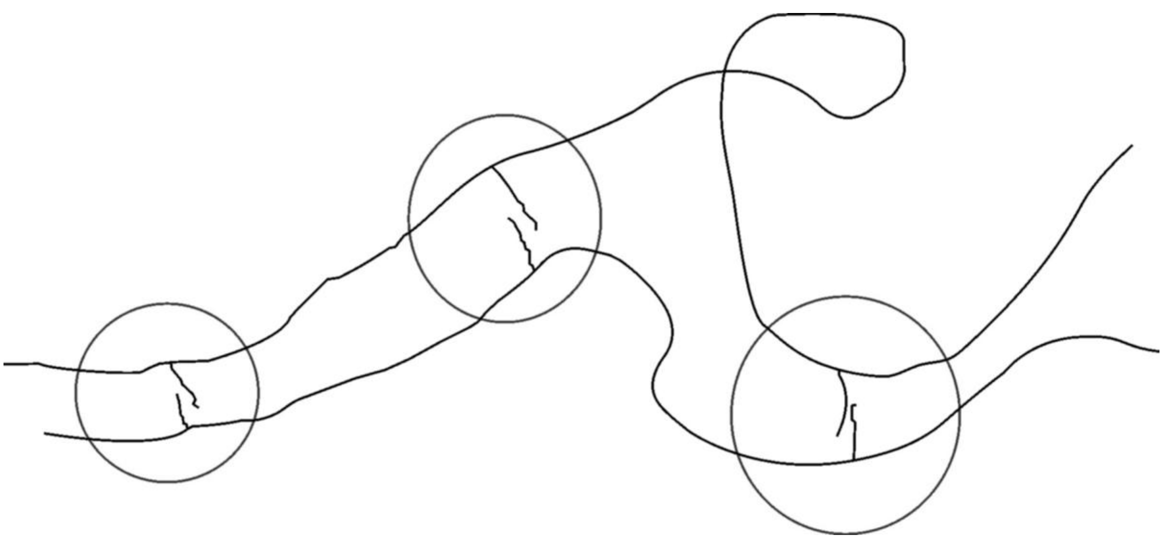

Figure 2 — Hydrophobic Interactions

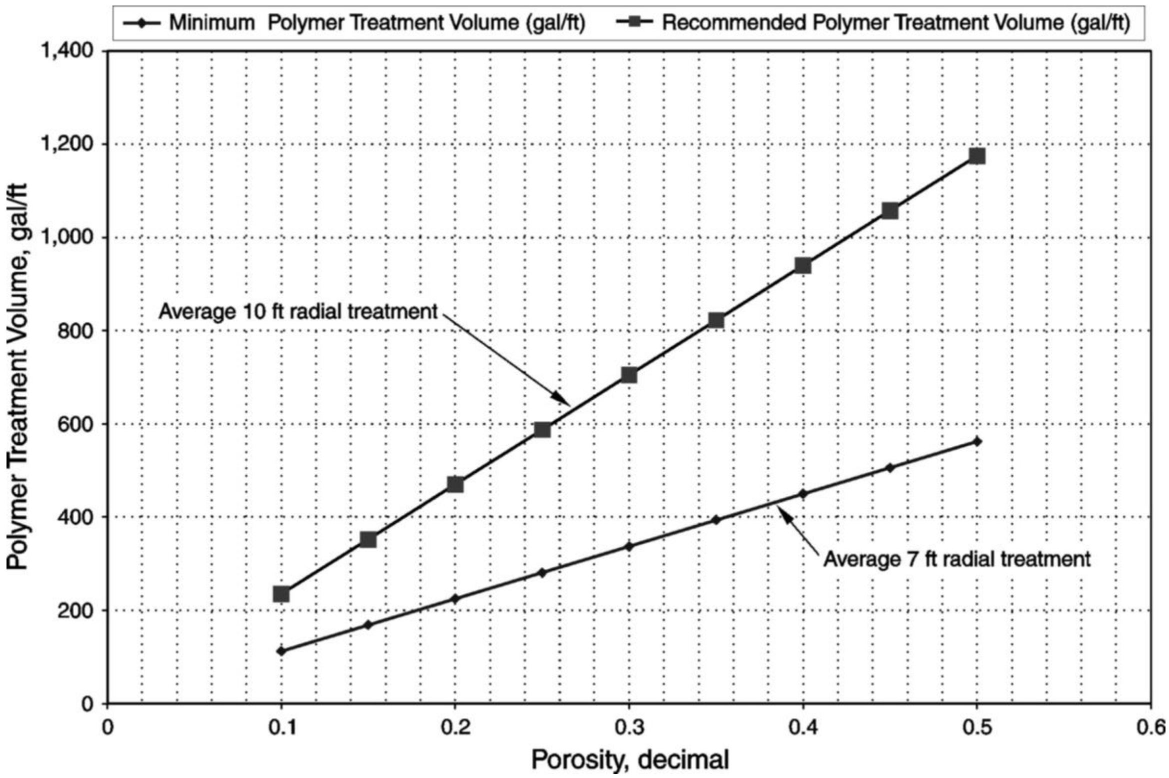

Figure 3 — Polymer Treatment Volume Estimate