NEW CHEMICAL AND MECHANICAL TECHNOLOGY FOR INJECTION PROFILE CONTROL

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ABSTRACT

Injection profiles of West Texas waterflood projects have been improved by the application of sequential zirconium complexed polymer treatments. Alternating stages of polymer and a new zirconium complexor were applied using specially designed skid mounted injection units. These units automatically monitor waterflood rate and adjust chemical pumps to maintain constant chemical concentrations. A small scale injection unit has been built to imitate the larger unit. This unit enables on-site, pre-treatment adjustments to design concentrations, to account for the effects of injection water variables.

Mechanisms behind sequential metal complexed polymer treatments are discussed, along with field variables which affect these mechanisms, and the advantages of the new zirconium complexor.

Treatment design theory is presented, as well as the change from theortically to empirically based job designs.

Design of the skid mounted injection unit is described, including monitoring and recording capabilities, the automatic tracking feature, and pressure activated shut-off controls.

Field results of 100 sequential zirconium complexed polymer treatments are summarized, with results of three treatments presented in detail.

INTRODUCTION

Early water breakthrough is a common problem in reservoirs under artificial water drive. Vertical stratification of formations results in high permeability streaks which provide an easy access between injector and producer, limiting the waterflood sweep efficiency. The layering of rock with different permeabilities is termed "non-conformance." Corrective methods are termed "conformance control" or "profile improvement." Conformance control techniques can be applied in either the injector or producer. Injection well treatments offer the distinct advantage of improving reservoir conformance throughout the flood path between the injector and its offset production wells. Improved conformance translates into improved oil recovery.

Current profile improvement processes include silicates, in-situ polymerization, surface complexed polymers, and sequential metal complexed polymers. Silicates are pumped as low viscosity fluids which form inorganic gels, drastically reducing permeability in the contacted zones. In-situ polymerization involves pumping low viscosity monomer solution into the formation, which polymerizes in place to a high viscosity, high concentration polymer. For surface complexed polymer treatments, the polymer and complexor are combined on the surface, with the complexation reaction "delayed" so a "gelled" polymer forms in the formation. Sequential metal complexed polymer treatments use alternating stages of polymer and complexing metal solutions to build a polymer gel network within the matrix, gradually reducing effective permeability.

A sequential metal complexed polymer process has been developed which uses a new zirconium complexor with advantages over previously used complexors, such as chromium and aluminum. The new complexor has a greater tolerance to injection water variables such as pH, salinity, and to the presence of hydrogen sulfide and iron in solution. The zirconium complexed polymer treatments have been applied using a skid mounted, automatically controlled, injection unit, which has proven to be mechanically reliable in the field.

CHEMISTRY

The effective application of sequential metal complexed polymer treatments depends on two mechanisms: polymer adsorption and complexation. Adsorption, in this application, can be defined as the adhesion of polymer molecules in an extremely thin layer to the contacted surfaces of the formation. This permanently attached layer of polymer causes a resistance to fluid flow. Complexation defines the chemical reaction to form a bond between the metal complexor and the polymer. This reaction builds a polymer "gel" network which is much more efficient at resisting fluid flow than the polymer alone. The combined resistance due to the adsorption and complexation of the polymer in the non-conforming zones equates to an effective permeability reduction, or an increase in conformance.

Several factors affect adsorption, including the anionic character of the polymer, polymer concentration, the nature of the injection water, and the reservoir temperature. "Anionic character" can be defined as the sodium acrylate concentration, in percent, of a sodium acrylate/acrylamide copolymer. One of the most common polymers used in sequential complexed processes is actually this polyacrylamide copolymer. Polymer adsorption on silica rock surfaces is inversely proportional to anionic character. Adsorption is generally proportional to polymer concentration, that is, an increase in polymer concentration corresponds to an increase in adsorption. Injection water conditions such as salinity, pH, and hardness can adversely affect polymer adsorption, but these effects are usually disregarded since sufficient adsorption occurs regardless of these factors and because it is normally impractical to change the water supply. Temperature effects are generally neglected except when considering polymer stability. The upper limit for polyacrylamide stability is normally accepted to be between 180 and 200°F.

For sequential metal complexed polymer treatments, polymers in an oil external emulsion are commonly used. Emulsion polymers are commercially available in high polymer concentrations, and are easy to apply. The emulsion consists of aqueous phase polymer droplets suspended in an oil phase, and must be broken or "inverted" to activate the polymer. The inversion is accomplished with a combination of chemical and mechanical means. A surfactant, or inverter, is included in the mixing water, and the emsulsion polymer is added to the mixing water under mechanical shear. The surfactant must be chosen considering the quality of the injection water, and its concentration must be adjusted to assure inversion. The amount of mechanical shear imparted to the system must be watched since too much can cause polymer degradation.

The new zirconium complexed system uses a relatively high molecular weight polymer with a low anionic character in an oil external emulsion. The molecular weight enables a fairly rapid build-up of resistance, while the low anionic character assures good adsorption in both sandstone and dolomite/limestone formations.

The complexation reaction rate increases proportionally to the complexor concentration, and the polymer's anionic character and concentration. The anionic character regulates the number of complexation sites available, and additional sites can be obtained by increasing either the anionic character or the polymer concentration. The reaction rate can be hindered by many factors commonly found in water injection systems, but the complexor concentration and anionic character may be simply increased to counter these adverse effects.

Unlike other complexing metal systems, the new zirconium complexor is tolerant of many of the adverse conditions common in waterflood systems. The zirconium complexor has a low toxicity, and can be used in injection waters with wide ranges of salinity and pH, and in the presence of hydrogen sulfide and iron in solution.

DESIGN

Calculations of treatment design volumes of polymer and complexor began with theoretical predictions of treatment radii, derived from D'Arcy's laws for radial and series flow, assuming constant pressure:

$$\frac{Qf}{Qi} = \frac{\ln(re/rw)}{RRF\ \ln(rt/rw) + \ln(re/rt)}$$

where, Qf, Qi = final and initial water flow rate, bpd,
re, rw, rt = drainage, wellbore and treatment radii, ft,
RRF = residual resistance factor.

Residual resistance factor values were measured in the laboratory using core samples or estimated from a core with a similar lithology. Using a desired water flow rate reduction (Qf/Qi), known drainage and wellbore radii, and a measured or estimated residual resistance factor, a treatment radius was determined. The treatment radius translated easily into the amount of polymer required and the minimum treatment volume by using the rock volume, an appropriate adsorption factor, usually given as pounds per acre foot, and basic formation fluid volumes based on porosity:

$$Vp = \frac{AF\,\pi\, rt^2 h}{43560} \quad \text{and} \quad V = \frac{\pi\, rt^2 h}{5.6146}\,\phi$$

where, Vp = required polymer, lb,
AF = adsorption factor, lb/ac-ft,
h = height of zone, ft,
V = volume, bbl,
ϕ = porosity, decimal.

The treatment polymer concentration was reduced from the calculated value (Vp/V) if the formation permeability indicated potential injectivity problems. Complexor volumes were directly proportional to the polymer volume, based on chemical reactivity.

General, but formation specific, treatment designs replaced theoretical designs as soon as field experience was acquired. The actual job results from a given formation became a determining factor for subsequent treatment design in that area. The cumulative results from all the treated formations are now used to empirically design jobs for a new formation or area. Further treatments in a new area would take job performance into consideration.

EQUIPMENT

A specially designed skid mounted, automatically controlled, injection unit was developed to apply the sequential zirconium complexed polymer process. Fig. 1 gives a schematic of the unit. The unit can handle injection wells with rates to 2000 bpd, surface pressures to 3000 psi, and design polymer concentrations up to 1500 ppm. The unit constantly monitors and records injection rate and pressure, delivers a constant chemical concentration to a varying flood rate, and features high and low pressure limit switches. The strip chart of injection rate and pressure provides an in-progress review of treatment performance, allowing for any required adjustments. The chemical injection pumps are ratioed to the flow meter, supplying constant concentrations of chemicals, as opposed to constant rates, to minimize injectivity problems. The high and low pressure limit switches are safety features so the unit automatically shuts down if a pre-set maximum surface injection pressure is reached, or if the water injection system shuts down. A treatment involves operating the "inverter" and "polymer" pumps during the "polymer" stage of a cycle, and manually switching to the "complexor" pump during "complexor" phase of a cycle. All three pumps are inactive during the "spacer" stages.

A laboratory scale injection unit was built to imitate the mixing of the large scale unit because field results for job designs based on simpler laboratory testing did not always match expected results. Fig. 2 shows a schematic of the small scale unit. The time delay between the collection of a field water sample and its arrival at a laboratory hinders analysis and testing. The chemical composition and pH can change enough after sampling to significantly alter lab test results from those obtained on location. The 100 lb small scale unit was set up on various locations to adjust the concentrations of inverter, polymer, and complexor in the actual injection water. The effects of water composition and contamination were accounted for by concentration adjustments under actual flow. The small scale unit can handle an input of 750 gal/day at 3000 psi.

FIELD RESULTS

The zirconium complexed conformance control process has been applied in many different formations in West Texas. The results of 100 of these treatments in four particular sandstone and carbonate formations and their injection waters indicate the success of this process. Initial injection rates varied between 150 and 900 bpd, with surface pressure varying between 80 and 1550 psi. A common indicator of job performance is the injectivity index, the ratio of injection rate to pressure (bpd/psi). Injectivity index was reduced an average of 43% in these 100 wells.

The sequential zirconium complexed polymer treatments generally consisted of two cycles of polymer and complexor, with a final stage of polymer. Injection water spacers between each stage served to flush the tubing and overdisplace the previous stage. Analysis of job results indicated the third polymer stage contributed little to the overall treatment effectiveness. Individual well treatments averaged 1400 to 2000 lbs polymer at 1000 to 1500 ppm, and 150 lb complexor at 150 to 200 ppm. Average treatment time was 25 to 30 days.

Treatment data and results for three well treatments are given in Tables 1 through 3, and Figs. 3 through 6. Wells A and B have sandstone formations, while Well C is a carbonate. Tables 1 and 2 give the treatment times and chemical usage for each of the three jobs. Table 3 compares initial and final injectivity data. The injectivity indexes in Fig. 3, normalized with the initial injectivity index, show the gradual decline in injectivity expected from zirconium complexed polymer treatments. Figs. 4 to 6 compare before and after treatment injection profiles, indicating conformance control has been achieved and new zones are being swept.

CONCLUSIONS

1. The zirconium complexed polymer process has proven to be a successful conformance control method, even under harsh conditions.

2. The zirconium complexor has performed in at least four different field injection waters.

3. Treatment designs incorporating two cycles of polymer and complexor have been effective in conforming both sandstone and carbonate formations.

4. The large scale skid mounted injection unit has proven reliable in the field.

5. The small scale injection unit has modeled the behavior of the large scale unit, improving treatment designs.

6. A method of designing zirconium complexed polymer treatments has been followed, in which initial theoretical designs were altered based on field results.

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Table 1
Zirconium Complexed Polymer Treatments
Treatment Times

Well	Treatment Time (days)				
	Stage 1		Stage 2		Stage 3
	Polymer	Complexor	Polymer	Complexor	Polymer
A	4	2	5	2	6
B	8	3	6	2	8
C	8	2	6	3	-

Table 2
Zirconium Complexed Polymer Treatments
Chemical Usage

Well	Polymer Concentration (ppm)	Total Polymer (lb)	Total Complexor (lb)
A	1500	2192	135
B	500	2174	133
C	1000	1466	125

Table 3
Zirconium Complexed Polymer Treatments
Injectivity Data

Well	Initial Rate (bpd)	Conditions Pressure (psi)	Final Rate (bpd)	Conditions Pressure (psi)
A	400	100	380	620
B	300	570	210	830
C	300	370	270	1270

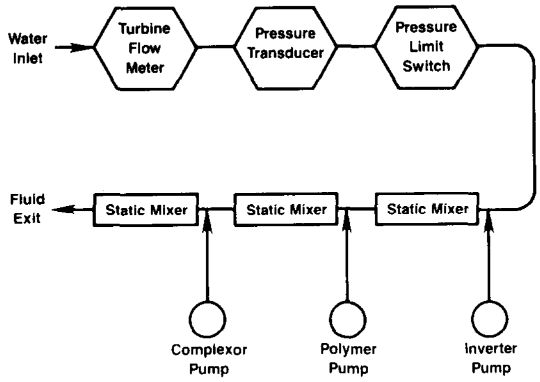

Figure 1—Schematic of the large scale skid mounted injection unit

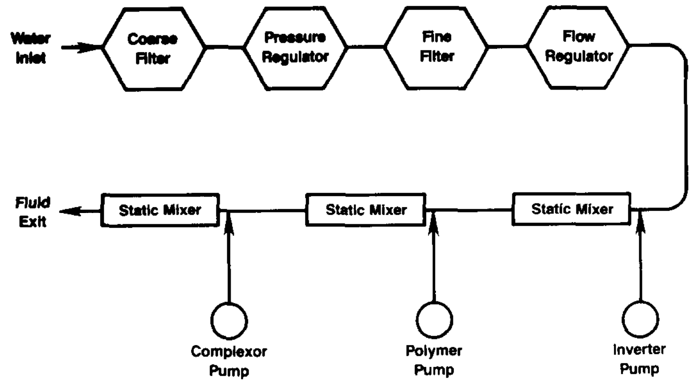

Figure 2—Schematic of the small scale injection unit

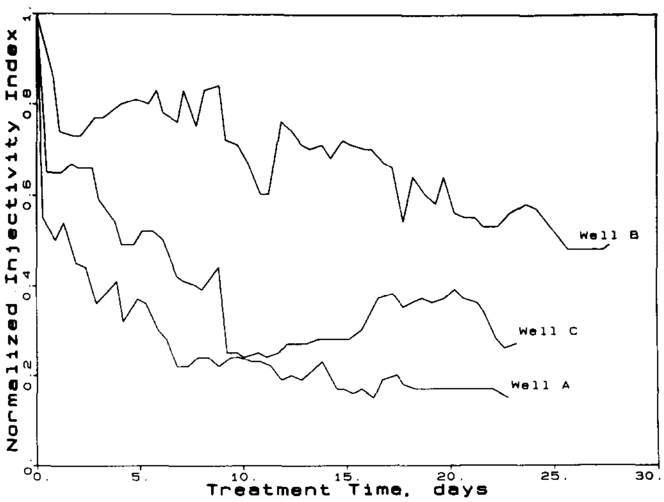

Figure 3—Injectivity index data during sequential zirconium complexed polymer treatments

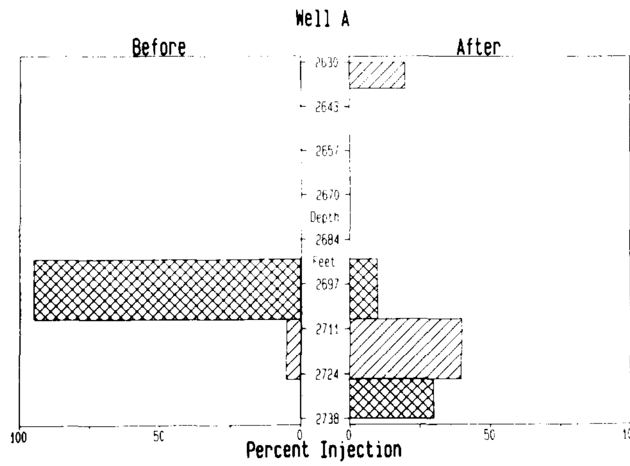

Figure 4—Injection profile improvement due to a sequential zirconium complexed polymer treatment

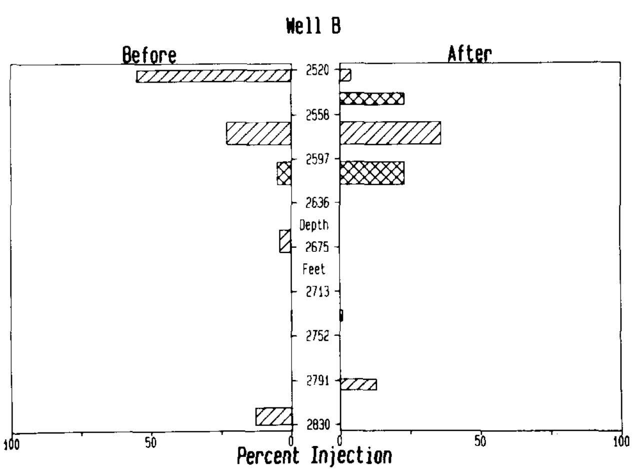

Figure 5—Injection porfile improvement due to a sequential zirconium complexed polymer treatment

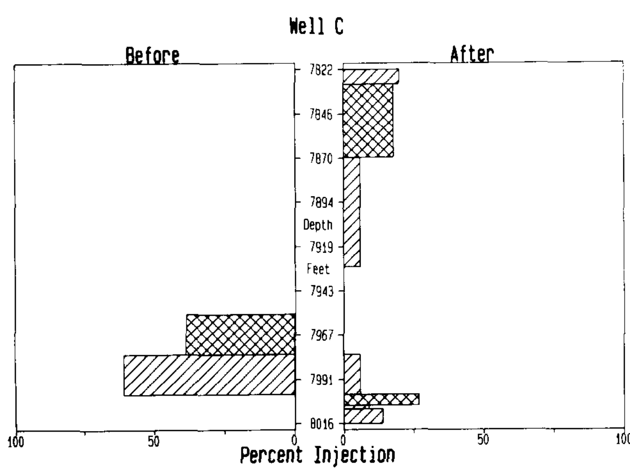

Figure 6—Injection profile improvement due to a sequential zirconium complexed polymer treatment