AN ALTERNATIVE TO CEMENT SQUEEZES FOR WATER AND GAS SHUTOFF APPLICATIONS

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ABSTRACT

This paper presents the development of a new system for water and gas shutoff operations. This system combines a conformance sealant (based on an organically crosslinked polymer) with non-cement particulates. The particulates provide leakoff control, which leads to shallow matrix penetration of the sealant. This filtrate from the leakoff is thermally activated. After exposure to the bottomhole temperature of the well, it forms a three-dimensional gel structure that effectively seals off the targeted interval. This system can be considered an alternative to standard cement squeeze operations, casing leak repairs, sealing of thief zones, and perhaps many other wellbore operations.

The system can be bullheaded into the well allowing for easy placement and calculation of treatment volume. The limited and controlled leakoff into the matrix during the squeeze results in a controlled depth of invasion. Selective perforation of the oil zones re-establishes the desired hydrocarbon production from the targeted interval. The system can be easily washed out of the wellbore, as compared to cement, which must be drilled out. The temperature range of the particle-gel system is 70 to 350°F (21 to 177°C). To date, more than 30 jobs have been performed with this system. This paper will present results obtained from laboratory evaluations, the methodology of the job design, and limited case history information.

INTRODUCTION

The production of unwanted fluids (either water or gas) is a major problem in fields throughout the world. Water tends to become the dominant produced fluid as hydrocarbon fields mature. Unwanted water production may adversely affect well economics because of water disposal costs, environmental issues, and reduced hydrocarbon production. Other problems may develop at some point as a result of the undesired water production, including sand production, scale, corrosion, and others. Water-production problems can vary from: (1) leaks in casing, producing tubing, or packers, (2) flow behind casing, (3) water coning (or water cresting in horizontal wells), and/or (4) direct communication from injector to producer through natural or induced fractures.

Numerous methods are available to combat these problems, with each method having its own advantages and drawbacks. One of the earliest methods was to simply carry out a cement squeeze operation to shut off either an isolated section of a wellbore or an entire wellbore. Cement squeezes have been effective in many cases, but there are drawbacks to the system. One drawback is the need to drill out cement left in the wellbore when an entire interval is to be treated, so that the productive zone can be re-perforated. This requires the use of a rig and is costly and time consuming. During this drillout process, cement in perforations can be damaged and the intended seal over the offending zone can be compromised, allowing water or gas to continue to flow into the wellbore.

The other main type of treatment that has been utilized involves the use of sealants to plug the offending zone. These are materials that can be easily mixed and pumped into the wellbore and into the rock matrix. Following a shut-in period, a chemical reaction transforms the liquid into a gel that effectively plugs the treated zone. Again, these systems have been used effectively for many years, but a drawback is that the offending zone must be isolated from the productive zones. If these sealants are allowed into a productive zone, they will damage hydrocarbon permeability and potentially completely seal the hydrocarbon zone. Thus, it is necessary to use some type of isolation technique, which can be costly and in some cases is not feasible due to the wellbore configuration.

Although unwanted fluid production has been resolved in many cases using various techniques, there are opportunities for improvement. This paper will discuss a technique that utilizes a sealant with a particulate fluid-loss additive that limits leakoff into the formation. The sealant left in the wellbore is easily removed and the limited leakoff of the sealant allows the re-perforation of hydrocarbon zones.

SEALANT/PARTICULATE SYSTEM

The base polymer of the sealant system is a copolymer of acrylamide and t-butyl acrylate (PAtBA), a high-activity liquid with enhanced thermal stability. The crosslinker is polyethyleneimine (PEI), a high-activity liquid that forms strong covalent bonds with the base polymer. A water-soluble carbonate retarder is used only for applications in which the bottomhole injection temperature exceeds 250°F (121°C). More recently, a polyacrylamide polymer has been introduced to cover the low temperature range of application of the sealant system from 80 to 140°F (27 to 60°C).

The sealant system components are easily diluted in the mixing brine. The crosslinking process is activated by the temperature of the well. The crosslinking rate is dependent upon temperature, salinity, pH, and base polymer and crosslinker concentrations. The sealant system offers the following advantages:

- Low-viscosity fluid system (20 to 30 cP) that can be easily injected deep into the matrix of the formation without undergoing hydrolysis and precipitation. It is well known that chrome-based systems tend to hydrolyze and precipitate, especially with increasing pH and temperature.[1]
- Adequate pumping times in environments up to 350°F (177°C) to obtain adequate placement time before the system undergoes the phase change from liquid to a three-dimensional gel structure. **Figure 1** shows a typical gelation time curve for the sealant system (viscosity vs. time). The inflection point of the curve corresponds to the gelation time of the system. This transition time is completely controllable and predictable with the crosslinker concentration for a given temperature.
- Effective water permeability reduction and sufficient strength for resisting drawdown pressure inside the wellbore and stopping water and gas flow. The system provides sufficient strength for resisting differential pressures of at least 3,600 psi (based on laboratory data).
- Thermal stability up to 375°F (191°C).

In addition, the sealant system is not sensitive to formation fluids, lithology, and/or heavy metals. This system has been used throughout the world in a wide variety of applications, for both water and gas shutoff.[2]

In the original formulation of the sealant/particulate system, cement was used as the particulate material. The idea was to have both a hard-setting material such as cement, as well as the filtrate, which would gel and aid in blocking fluid flow. However, chemical interactions between the sealant and cement made this system difficult to apply, so an alternate particulate material was investigated.[3] The particulate material currently used to provide fluid-loss control is simply silica flour. This material was chosen because of its inert nature and ability to provide leakoff control. The main laboratory work carried out to prove the ability to provide leakoff control and an adequate seal was conducted using cores in Hassler sleeves. Representative data from this testing is shown in **Table 1**.

The variables investigated were temperature, permeability, and % silica flour (measured as weight % of the total mixture). As shown, the amount of leakoff and the pressure required to initiate flow of the brine was independent of the temperature or the core permeability. However, the % silica flour did influence the amount of leakoff seen. The formulations containing 50% silica flour had an average total leakoff of 13 mL. The formulations containing 35% silica flour had an average leak off of 63 mL. Therefore, 50% silica flour was chosen for field usage. Note that in most of the tests, the 1,000 psi or greater differential pressure was applied to the cores with no resulting flow of brine. In two cases, brine flow was seen at differential pressures less than 1,000 psi, but the calculated permeability reduction was >99%.

Table 2 shows rheological and free water data. As shown, none of the slurries exhibited excessive viscosity and all were easily mixed and pumped with standard oilfield equipment. The free water values were all within reasonable limits also, indicating that settling of the silica flour is not an issue up to at least 290°F (143°C).

As mentioned previously, silica flour is an inert fluid-loss additive. **Figure 2** illustrates this by showing that gel times for a neat sealant mixture and the filtrate from a sealant/silica flour mixture are very close. Therefore, the only design criteria for this system is to determine the gel time of the sealant formulation, which is based on the temperature and amount of time needed to place and squeeze the treatment.

CASE HISTORIES

To date, approximately 44 jobs have been run with this sealant/particulate system. In one job, a production logging tool (PLT) indicated the zone that was producing the majority of water from the well.[3] The sealant/particulate system was spotted over this zone with coiled tubing and approximately 1,800-psi overbalance was applied. After washing out the material in the wellbore, another PLT indicated that the treated zone was completely sealed. In another well (offshore), pressure and well fluid from the reservoir were in communication through a pipe-in-pipe annulus.[4] A decision was made to use the sealant/particulate system to provide a permanent barrier between the tubing/packer and the annulus. Following the treatment, the annulus was vented to 0 psi, then the tubing was pressured to 200 psi and held for 10 minutes. No communication was seen. Following the treatment, no increase in annulus pressure was observed. Before the treatment, there was a continuous rise in pressure even when the well was shut in.

REFERENCES

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2. Eoff, L. *et al*: "Worldwide Field Applications of a Polymeric Gel System for Conformance Applications," paper SPE 98119 presented at the 2006 SPE International Symposium and Exhibition on Formation Damage Control, Lafayette, LA, 15-17 February.
3. van Eiden, G.J.M., *et al*: "Development and Field Application of a Shallow Perforation Shut Off System for HP-HT Oil Wells," paper SPE 94518 presented at the 2005 European Formation Damage Conference, Scheveningen, The Netherlands, 25-27 May.
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Table 1
Core Data

Temp.	Core Brine Permeability	%Silica Flour by Weight[1]	Fluid Loss (mL of Filtrate at Given Time in Minutes						Pressure Applied to Initiate Flow, psi
			Spurt	1	2	5	10	30	
190	144	50	2.8	6.1	7.2	8.3	9.2	11.6	1,000[2]
190	128	50	3.1	6.6	8.2	9.1	9.8	11.8	1,000[2]
190	92	35	5.8	12.8	18.7	32.0	46.0	55.5	1,000[2]
190	128	50	2.2	5.2	8.1	10.6	11.4	13.4	1,000[2]
190	101	50	0.1	0.9	2.0	4.2	7.0	9.5	471[3]
190	3,115	50	2.5	6.0	8.5	10.0	10.8	13.0	1,165[2]
230	119	50	3.5	8.7	9.3	10.6	12.0	18.0	1,000[2]
230	105	35	6.1	15.3	23.8	42.2	55.5	71.0	1,000[2]
260	124	50	5.0	7.0	8.6	10.0	12.5	17.0	1,000[2]
260	121	35	8.2	20.0	33.0	41.0	47.0	62.0	571[3]
260	63	50	1.5	5.1	8.5	9.8	11.2	14.1	1,271[2]

[1]By weight of total mixture.

[2]No flow.

[3]Flow initiated at this pressure; permeability reduction was 99%.

Table 2
Rheology and Free Water Data

<table>
<tr><th rowspan="2">Temp., °F</th><th rowspan="2">Free Water, mL</th><th colspan="7">Model 35 Dial Readings (75°F)</th></tr>
<tr><th>300</th><th>200</th><th>100</th><th>60</th><th>30</th><th>600</th><th>YP</th></tr>
<tr><td colspan="9">40 gal/Mgal Crosslinker</td></tr>
<tr><td>160</td><td>12</td><td>129</td><td>88</td><td>46</td><td>28</td><td>15</td><td>243</td><td>6</td></tr>
<tr><td colspan="9">30 gal/Mgal Crosslinker</td></tr>
<tr><td>75</td><td>4</td><td rowspan="3">126</td><td rowspan="3">86</td><td rowspan="3">45</td><td rowspan="3">27</td><td rowspan="3">14</td><td rowspan="3">237</td><td rowspan="3">6</td></tr>
<tr><td>160</td><td>8</td></tr>
<tr><td>190</td><td>10</td></tr>
<tr><td colspan="9">40 gal/Mgal Crosslinker + Retarder</td></tr>
<tr><td>290</td><td>4</td><td>146</td><td>101</td><td>54</td><td>34</td><td>19</td><td>276</td><td>9</td></tr>
</table>

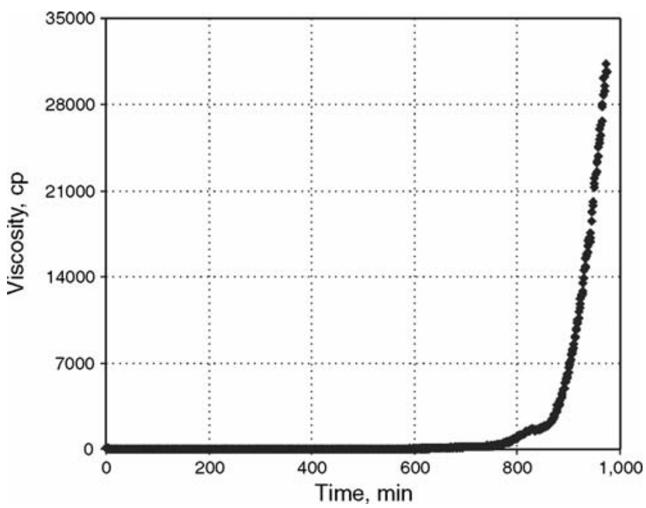

Figure 1 - Typical Gelation Time Curve for the Sealant System Using a Brookfield Viscometer (at 185°F)

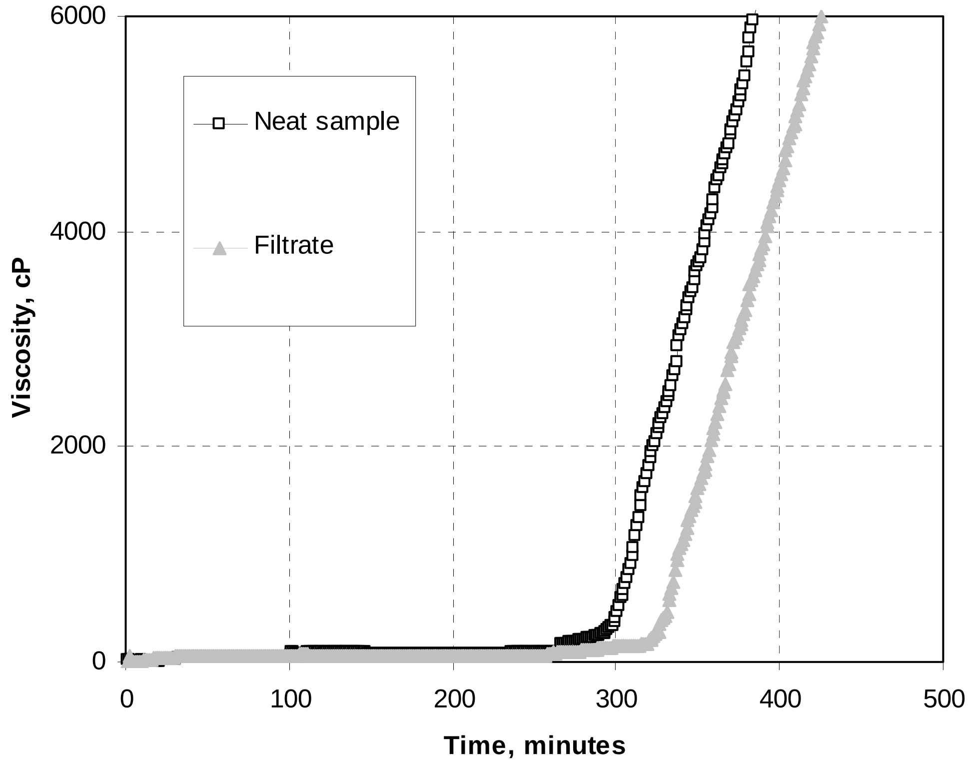

Figure 2 - Gel Times for Neat Sealant and Filtrate