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Aqueous Based Tunable System for Shut-Off and Consolidation Applications

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Abstract

Water production from oil or gas wells can have significant economic drawbacks, such as reduced well productivity, increased operating expenditures, and damaged well production. Controlling and eliminating unwanted water influx is a major concern. This paper describes an organically modified silica material used with a crosslinker to completely seal water-producing zones and control gelation time, allowing the system to remain pumpable over predictable time periods.

To control water production from subterranean formations, operators often block formation pores or channels using polymer or resin materials. In-situ gelation of polymers inside the formation is widely accepted. Polyacrylamide-based gels are commonly used for this type of application. Unfortunately, these gels do not meet all environmental regulations in certain parts of the world. This paper presents an alternative organically modified silica material combined with a crosslinker to help control water production and eliminate issues of cost and environmental acceptance.

Laboratory testing demonstrated that silica-based materials help seal formation permeability. This was further verified by changing initial permeability of a sandpack from 2 darcies to 30 millidarcies (md). Reduced initial permeability helped prove system efficiency in terms of sealing the sandpack. Incorporation of silica into the crosslinked network helped improve thermal stability. This was further confirmed by thermogravimetric analysis (TGA), demonstrating the crosslinked network was stable at temperatures up to 572°F.

Introduction

Unwanted water production generally occurs when hydrocarbons are produced from wells, particularly as the wells mature over time. Currently, global daily water production from oil wells is approximately four to five times higher than global oil production. It costs money to lift water and then dispose of it (Shafian et al. 2010). For example, in a well producing oil with 80% water cut, the cost of handling water is double the normal lifting costs.

Excessive water production can be caused by a variety of occurrences, such as water coning, water cresting, bottom water, channeling at the wellbore, etc. This excessive water production largely affects the economic life of producing wells and is also responsible for many oilfield-related damage mechanisms, such as scale deposition, fines migration, corrosion, etc. This also leads to increased operating costs to separate, treat, and dispose of the produced water according to environmental regulations (Crespo et al. 2013).

Throughout the years, the industry has developed different techniques to control water production, these include mechanical isolation, squeeze cementing, and various chemical treatments. Some techniques involve the injection of particulates, foams, gels, sealants, and resin systems. These techniques are commonly referred to as conformance-control techniques (Mack et al. 1994). The general approach of any chemical-treatment technique has been to inject a mixture of reagents, initially low in viscosity, into high-permeability, water-producing zones. After sufficient time and at elevated temperatures, the mixture of reagents forms a barrier that partially blocks the flow of water.

In chemical treatment techniques, polymer based gels have been widely used as conformance-control materials since the 1960s. These types of gel treatments are one of the most aggressive types of conformance control methods. They are more aggressive because they can completely block certain porous features associated with the porous media (Huh et al. 2009).

In addition, to design effective gel treatments, several reservoir parameters must be considered, which would include but are not be restricted to, pore size distribution, oil viscosity, source of the water problem, permeability trends, fracture orientation, and all production, completion, and log data for the wells in the field. Treatments for water shutoff can be very effective technically and economically if the product exhibits appropriate characteristics relative to the deficiencies of the well.

Thus, there is a need for an efficient conformance system, which is inexpensive and environmentally acceptable (Boye et al. 2011). This paper presents a novel organic-inorganic hybrid polymeric composition that could be used for shut-off applications by following usual mixing and pumping protocols (Boul et al. 2015). This paper also presents test results evolved from laboratory experiments evidencing the uses of the presented composition for conformance. Advantageously, thermal degradation of this hybrid polymer was determined to occur at a significantly higher temperature compared to conventional thermosetting conformance polymers.

Description of the System

The new conformance sealant is a two-component system consisting of organic-inorganic hybrid polymer and a crosslinker. This formulation can be placed as a single, low-viscosity solution (<5 cp) into the water-bearing zones of the formation around the wellbore, where it is allowed to propagate through the rock matrix. The initial low viscosity of the system allows for low injection pressures. The gelation process is activated by the formation temperature. In-situ gelation takes place and the gel plugs pore spaces and channels, thereby limiting undesired water and gas production. The system can effectively prevent water and gas flow in sandstone and carbonate formations up to 200ºF. The gelation time can be controlled by adjusting the amount of delaying agent added to the liquid system. It gives a predictable and controllable pumping time, ranging from a few minutes to several hours at a given temperature. The set gel appears as a crystalline solid. It could remain homogenous and stay in place under confined conditions, such as fractures and pore spaces. Variations to the formulations can be made for different applications.

Methods and Procedures

Performance of the proposed system was evaluated using the following test methods:

A) Gelation time
B) Permeability measurements
C) TGA

Gelation Time by Sealed Tube Method

Gelation time is one of the most important factors that define the amount of time available to the operator in field operations. A reasonable gelation time must be known to ensure that the treating pressures while pumping the gel into the near-wellbore region (NWB) can be maintained below the maximum pressure as determined by the operator. Static gelation tests were conducted using the sealed tube method in the presence of respective delaying components to help prevent premature gelation.

A borosilicate glass bottle with a cap was filled with the proposed composition and a delaying agent to approximately 1/3 of its volume. A Teflon® plug was also used inside the cap. The bottles were placed in a preheated oven set at the test temperature of 200°F and removed for observation periodically. This method defines the gelation time as the time necessary for a system to reach specified gel strength and relies on visual evaluation.

Permeability Measurements

Permeability measurements were performed by using a sandpack comprised of 50% silica flour and 50% of 20/40-mesh sand. They were mixed thoroughly to help ensure proper distribution of particulates. This sandpack represents the formation with heterogeneity in terms of packing. The sand mixture was then loaded into a brass cell as per the following procedure:

1. Insert 300 and 40-mesh screens at the bottom of the brass cell before packing.
2. Weigh 10 g of 20/40–mesh sand and place it on the screen. Using a large packing rod, tap the sand layer and make it flat.
3. Above the sand layer, add the mixture of sand (50 g silica flour + 50 g 20/40-mesh sand), which is premixed thoroughly. Keep tapping intermittently after every addition of the mixture so that the pack will be uniformly tightened.
4. Weigh 10 g of 20/40-mesh sand and place it on the top of the sandpack mixture. Tap the layer of sand until it becomes flat.
5. Place 300 and 40-mesh screens on top of the 20/40 and install the cell end and nut.

Figs. 1 through 3 show the schematic representation of the sandpack and flow apparatus.

Fig. 1—Sandpack assembly used for testing.

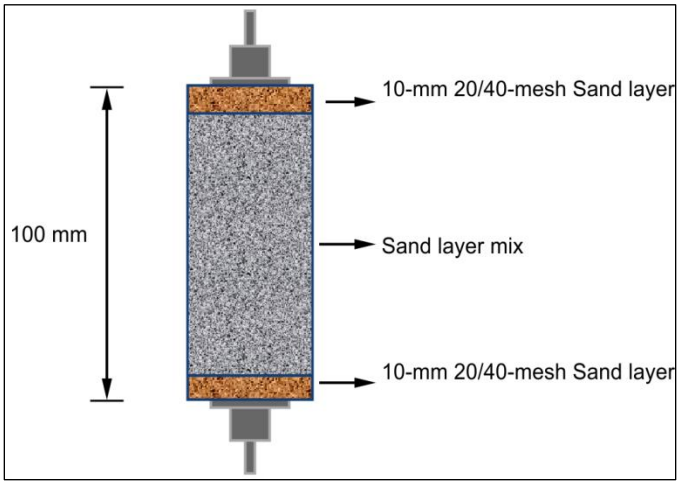

Fig. 2—Schematic representation of sandpack.

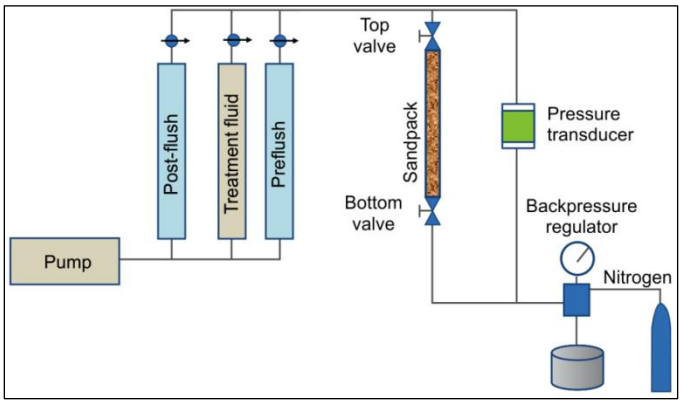

Fig. 3—Schematic representation of the flow setup used for testing.

Unconfined Compressive Strength (UCS) Testing

UCS testing helps predict the strength of the sandpack after treatment with a newly introduced system. The UCS of the pack was measured using the standard test method for unconfined compressive strength of cohesive soil, (ASTM D2166/D2166M (2013). The procedure followed is also presented next:

1. Once initial brine permeability measurement and pumping of treatment are complete, remove the brass cell from the flow apparatus. Close both ends of the cell and kept it inside the oven for the necessary curing time. After a predetermined curing time, remove the consolidated sandpack using a press machine with the utmost care to help ensure the sandpack is not damaged.
2. The consolidated sandpack was cut into two sections, noting the core sections as the top and bottom. Each core section should have specific diameter to height ratio of 1:2.
3. Each section of the sandpack was evaluated by UCS for consolidation strength. UCS measurements were taken using electromechanical compression systems of appropriate loading capacity.

TGA

The thermal degradation of the current polymer composition was measured using TGA. TGA was performed using a TGA Q500® Analyzer from TA Instruments.

Results and Discussion

Evaluation of Gelation Time

Fig. 4 describes the gelation time under different pH conditions at 200°F wherein gelation of respective mixtures with corresponding delaying substances (D-1, D-2, and D-3) were evaluated under static condition.

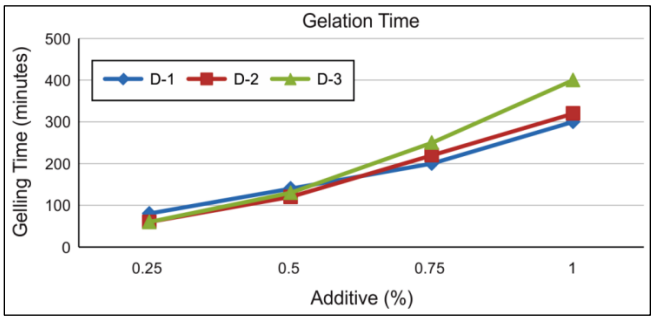

Fig. 4—Gelation time experiments at 200°F.

D-1, D-2, and D-3 are organic acid based delaying agents, which would temporarily protect and eventually release the crosslinker at a given temperature. The D-1 agent with 0.25% with respect to overall polymer composition was tested at 200°F where gelling was observed at approximately 80 minutes. Similarly, 0.5, 0.75, and 1% concentration of delaying agent resulted in gelation at approximately 140, 200, and 300 minutes, respectively. Additionally, D-2 delaying agents were also tested at 200°F, which resulted in gelation times of 60, 120, 220, and 320 minutes with 0.25, 0.5, 0.75, and 1%, respectively. The same procedure was repeated with the D-3 agent as well where in similar delayed results were observed. Test results provided clear insight into understanding how to optimize the current composition for the necessary delay while pumping the fluid.

Test Results of Sandpack Experiments

To gain a good understanding of the performance of the system, the following tests were performed on sandpacks. The permeability and UCS measurement of sandpacks helps better understand the effectiveness of the system in terms of blocking the water producing zone.

After the sandpack was prepared as per the discussed procedure, the initial permeability of the sandpack was measured using a 3% KCl brine. A backpressure of 200 psi was applied to help ensure proper distribution and saturation of brine solution throughout the sandpack. After pumping three pore volumes of treatment solutions at different concentrations (Table 1), the cell was removed from the setup and caps were placed on both ends and the cell was placed in an oven heated to 200°F for a predetermined curing time of three to four days. After the desired curing time, the cell was then placed back into the test apparatus and the final permeability was measured using the same brine concentration used during the initial permeability test. This was followed by UCS measurements for the two sections of each sandpack core and results were very similar; the average values are reported. Table 1 presents the test results.

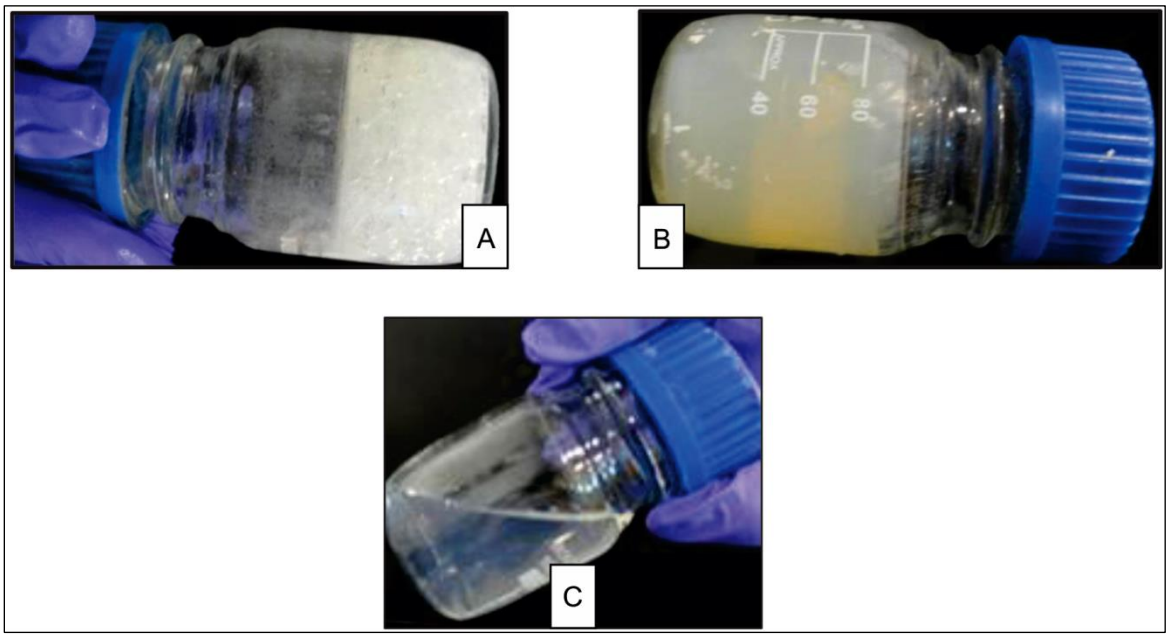

Fig. 5—A) C-1 gel after complete crosslinking; B) C-1 with 0.5 % D-1 gel after complete crosslinking; C) C-1 with 0.5 % D-1 before crosslinking.

Combination	Component	Concentration (%)	Initial Permeability (md)	Final Permeability (md)	UCS (psi)
C1-with delaying agent D-1	Organic-inorganic hybrid polymer	9	62	0	593
	Crosslinker	0.75			
C2-with delaying agent D-1	Organic-inorganic hybrid polymer	3	83	64	289
	Crosslinker	0.25			

Table 1—Permeability and UCS measurements.

Fig. 6—Sandpack after curing using C1 composition.

From the test results, it was confirmed that the combination C1 can be a good candidate for conformance applications. The final permeability of 0 md indicates that said package helps in terms of completely blocking water production.

After curing the treated sandpack with combination C1, during final permeability measurements, the pack was successfully able to hold 550 psi differential pressure. This proves the pressure-holding capacity of the treated pack at high pressures.

The test results in Table 1 also indicate that altering the concentration of the polymer package can affect the performance of the system in terms of final permeability and UCS values. It is clear from the table that combination C2 cannot be used as an option for blocking water production because the final permeability is in the range of 64 md. However, the good regained values indicate that the system may be a candidate for consolidation applications.

TGA

Further evaluation of the thermal degradation of the current polymer composition by performing TGA has been conducted. TGA of the resultant gel degradation began at 572°F, which is very high and suitable for a broad range of well temperatures (Fig. 7), whereas the majority of existing acrylate polymer based compositions are known to degrade at much lower temperatures in comparison to the current composition.

Initial degradation in Fig. 7 was attributed to the removal of water, whereas remaining degradation was from the set polymer.

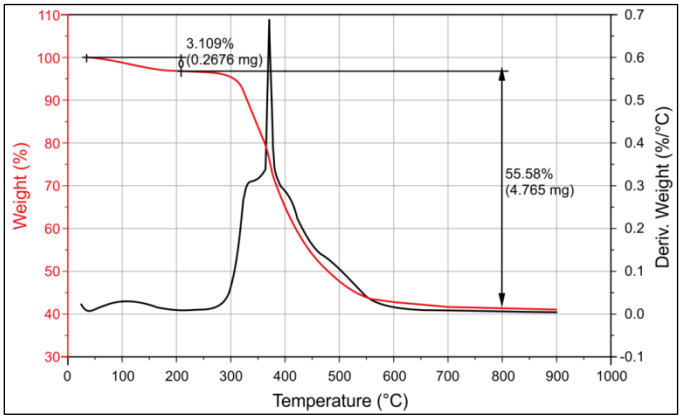

Fig. 7—TGA of gelled polymer.

Conclusions

The following conclusions are the results of this work:

- Laboratory testing proves that that organic–inorganic hybrid composition helped form a hard impermeable seal.
- Gelation time could be easily controlled by tailoring the concentration of delaying agent.
- Incorporation of organic–inorganic into the crosslinked network helped improve thermal stability.
- The basic composition can be tuned for consolidation applications as well.

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TGA Q500® is a registered trademark of TA Instruments, New Castle, Delaware, USA.

References

1. ASTM D2166 / D2166M. 2013. Standard Test Method for Unconfined Compressive Strength of Cohesive Soil. ASTM International, http://www.astm.org/Standards/D2166.htm (accessed 15 January 2016).
2. Boul, P., Ye, A., Pang, X. et al. 2015. Nanosilica-based Conformance Gels. Presented at the SPE European Formation Damage Conference and Exhibition, Budapest, Hungary, 3–5 June. SPE-174265-MS. http://dx.doi.org/10.2118/174265-MS.
3. Boye, B., Rygg, A., Jodal, C. et al. 2011. Development and Evaluation of an New Environmentally Acceptable Conformance Sealant. Presented at the SPE European Formation Damage Conference, Noordwijk, The Netherlands, 7–10 June. SPE-142417-MS. http://dx.doi.org/10.2118/142417-MS.
4. Crespo, F., Reddy, B.R., Lewis, C.A. et al. 2013. Recent Advances in Organically Crosslinked Conformance Polymer Systems. Presented at the SPE International Symposium on Oilfield Chemistry, The Woodlands, Texas, 8–10 April. SPE-164115-MS. http://dx.doi.org/10.2118/164115-MS.
5. Huh, C., Bryant, S.L., Sharma, M.M. et al. 2009. pH Sensitive Polymers for Novel Conformance Control and Polymerflood Applications. Presented at the SPE International Symposium on Oilfield Chemistry, The Woodlands, Texas, 20–22 April. SPE-121686-MS. http://dx.doi.org/10.2118/121686-MS.
6. Mack, J.C. and Smith, J.E. 1994. In-Depth Colloidal Dispersion Gels Improve Oil Recovery Efficiency. Presented at the SPE/DOE Improved Oil Recovery Symposium, Tulsa, Oklahoma, 17–20 April. SPE-27780-MS. http://dx.doi.org/10.2118/27780-MS.
7. Shafian, S.R.M., Hassan, A.A., Ismail, S., Teng, L.K., and Irawan, S. 2010. Blocked Isocyanate Fluid System for Water Shut off Application. Paper IADC/SPE 132813 presented at Asia Pacific Drilling Technology Conference and Exhibition, Ho Chi Minh City, Vietnam, 1–3 November. doi: 10.2118/132813-MS.