FIELD IMPLEMENTATION OF A NOVEL SOLIDS-FREE SYSTEM TO MINIMIZE FLUID LOSS DURING OVERBALANCED WORKOVER OPERATIONS

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ABSTRACT

Fluid loss into the formation matrix can be a serious problem during overbalanced workover operations, Invasion by the completion fluid can cause near-wellbore damage and can also cause problems associated with poor wellbore cleanout and loss of hydrocarbon reserves. In addition, fluid loss can increase costs associated with rig time and treatments devoted to restore the initial condition of the formation. Traditional techniques to minimize fluid loss use solids or viscous pills, although it has been amply documented that these systems can damage the formation if not properly removed after the treatment.

This paper presents the laboratory development and validation of a novel solids-free fluid-loss (SFFL) system used during overbalanced workover operations. This system relies on an ionic polymer that decreases matrix permeability to aqueous fluids, limiting leakoff into treated zones. This polymer immediately adsorbs to the surface of the rock, eliminating the need to shut the well in. In addition, this system does not require the use of breakers, which eliminates negative impact on post-stimulation well productivity. Laboratory test data show the capability of the material to control fluid leakoff and achieve high levels of regained permeability to hydrocarbons.

To date, about 110 jobs have been performed with this novel SFFL system. The paper discusses field results from the application of this system during overbalanced workover operations and other applications where maintenance of a hydrostatic column is necessary for well control. This system has been proposed for solving partial and total loss to full circulation in overbalanced operations such as: (1) lost-circulation events occurring during cementing, fracturing, and drilling, (2) well intervention cleanouts by coiled tubing (CT) and hydraulic workover (HWO), (3) gravel packing, (4) replacement of artificial lift equipment (i.e., electrical submersible pumps), and (5) overbalanced tubing-conveyed perforating (OTCP), among others.

INTRODUCTION

During workover and completion operations, even a small overbalanced hydrostatic pressure can result in a large loss of fluid to the formation, especially in high-permeability formations. This situation becomes even more drastic in depleted reservoirs, horizontal wells, or in zones that have been fractured and packed. Fluid-loss control has been long recognized as a major concern when determining completion costs and assessing well management, thus the need in the oil industry for an effective fluid-loss-control method (mechanical devices or chemical systems). It is also important to understand where in the reservoir and/or wellbore fluid control is needed. Listed below are possible locations where fluid control might be needed.

- In the formation matrix
- At the formation face
- Inside the perforation tunnel
- Inside the casing
- Inside a gravel pack
- Inside a bottomhole assembly
- Inside tubing

Mechanical fluid-loss-control systems (installed downhole) include devices that can temporarily or permanently block fluid flow into the formation. These mechanical systems can be separated into discrete devices or multicomponent installations. The discrete devices are usually downhole valves or some type of plug that can be removed later in the life of the wellbore. The multicomponent installations are completion systems designed to eliminate, or at least minimize, fluid loss into the formation (Ross et al. 1999).

The chemical methods can be further classified as linear gels, crosslinked gels, and bridging particulate systems. Below is a brief general description of these chemical systems commonly used to control fluid loss into the formation.

- Linear gels are typically hydroxyethel cellulose (HEC), xanthan, and/or succinoglycan (Kippie et al. 2002). These systems help reduce fluid loss to the formation by viscosity. These gels must enter the permeability of the formation to develop the resistance to fluid flow. Linear gels do not completely stop fluid loss, but reduce the rates to an acceptable level. In addition, linear gels require removal by either an internal breaker (a chemical that breaks down the polymer chain) or by an external wash (i.e., acid treatment) (Ross et al. 1999).
- Crosslinked gels are generally HEC derivative (Chang et al. 1998) or CMHEC-based systems (Cole et al. 1995). They function by forming a filter cake at the formation or by entering the permeability of the formation and stop losses by plugging the pore throats with the crosslinked, gelled structure. Similar to linear gels, crosslinked fluids also require the aid of an internal or external breaker. However, in some cases, there is some degree of permeability damage (depending on factors, such as polymer type and concentration, overbalance pressure, permeability, and temperature, among others) (Ross et al. 1999; Hardy 1997).
- Bridging particulate systems allow for fluid-loss control by having a range of particle sizes sufficient enough to bridge on the pore throat and, with the smaller particulates, bridge on themselves to eventually form a relatively impermeable filter cake. These particulate systems can be pumped as a slurry formed with a polymer-based fluid. Most of these pills require an external wash with breakers or may be removed once production is resumed.

The main focus of this paper is the laboratory evaluation and field application of a novel solids-free, noncrosslinked, low-viscosity system for fluid-loss control of water-based fluids. This innovative technology does not really fit in any of the previously described chemical fluid-loss categories because the system relies on an ionic polymer that decreases matrix permeability to aqueous fluids, which immediately limits their leakoff into the treated zones.

DESCRIPTION OF THE SFFL SYSTEM

This solids-free fluid-loss system uses a hydrophobically modified polymer that was initially developed for water-control applications in hydrocarbon-producing wells (Eoff et al. 2003). The polymer attaches to the surface of the rock immediately as it encounters the formation face by simple electrostatic attraction. The polymer attached to the rock diminishes the flow path of any aqueous-based fluid (i.e., completion brine, formation water, or acid) providing leakoff control properties without significantly affecting the flow path of hydrocarbons. Treating solutions of the SFFL system exhibit low viscosity, typically less than 2 cP. The hydrophobic modification of the water-soluble polymer allows multiple layers of the polymer to build up because of the association of the hydrophobic groups, as illustrated in **Fig. 1**.

As previously published (Eoff et al. 2003, 2004), numerous laboratory tests have demonstrated the capability of the SFFL system to reduce water-effective permeability with little or no effect on hydrocarbon-effective permeability. In many of the early tests, when this system was injected into cores, a rapid pressure increase was seen. This led to the conclusion that this kind of chemistry might function as a diverter for water-based fluids (Eoff et al. 2003) and also as a fluid-loss-control agent. **Fig. 2** illustrates the typical pressure increase observed when pumping the SFFL system into a core, and, in this case, a carbonate core was used. In this test, the following sequence was used: water – oil – water – SFFL – brine. The evaluation water was API brine (9% NaCl and 1% $CaCl_2$) and evaluation oil was kerosene. Fig. 2 shows the water stage before the SFFL treatment and the SFFL treatment stage. Note that the water-stage flow rate was 10 mL/min, while the SFFL-treatment flow rate was 2 mL/min. Even with this lower flow rate, the differential pressure across the core increased rapidly from 200 to more than 500 psi when the SFFL treatment began entering the core.

Following this, additional tests were run looking specifically at the capability of the polymer to provide fluid-loss control. Leakoff tests were run in several different types of setups, including the use of cylindrical and hollow cores. **Fig. 3** shows an example of a hollow core used in this testing. These cores were mounted in a device that allowed for fluid to be circulated through the hole, under pressure, allowing leakoff to take place through the core. As shown in the picture, drilling mud was first circulated through the core, allowing a mud filter cake to form on the surface of the hole. In this test a water-based drilling fluid that contained calcium carbonate as a fluid-loss additive was used. Following deposition of the filter cake, brine was circulated to clean the hole, followed by a breaker (10% acetic acid). As shown in **Fig. 4**, the breaker very quickly dissolved the calcium carbonate, resulting in rapid leakoff. When the breaker was swapped out with a 0.1% solution of the SFFL, the leakoff rate slowed dramatically, and this low leakoff rate was held for ~20 hours. When the SFFL was swapped out with 7% KCl, the low leakoff rate was maintained. This test was done to mimic a damaged mud filter cake, which could result in rapid loss of completion brine.

Fig. 5 illustrates a more standard set up. In this test, the filter medium is an approximately 1-in. thick layer of 70- to 170-mesh sand. As shown, this system provides excellent leakoff control when compared to fresh water under the same conditions. Based on this test and many others not reported in this publication, it was concluded that the SFFL system was able to provide excellent and immediate leakoff control properties for aqueous fluids in numerous applications and yet would not damage hydrocarbon permeability.

Fig. 6 illustrates a core flow test designed to mimic a leakoff situation in a well in which fluid is lost to the formation followed by oil production from the same zone. In this test, regained permeability to water and oil were evaluated using an aloxite core with the following test sequence: water – oil – water – oil – SFFL system (1 PV injected at 500 psi) – water – oil. The evaluation water was API brine (9% NaCl and 1% $CaCl_2$), and the evaluation oil was kerosene. The test was conducted at 120°F. In this case, the treatment was pumped in at a constant differential pressure, rather than at a specific rate, which seems to better mimic a real-life scenario. Following the treatment, brine was once again pumped through the core, mimicking that wellbore fluid might continue to leak off, although now at a lower rate than before the treatment. The treatment resulted in 96% reduction to water permeability (4% regain), illustrating that some measure of leakoff control was obtained; and this was maintained for two days following the treatment. After this stage, oil flow was resumed and resulted in 95% regained oil permeability.

CASE HISTORIES

To date, about 110 jobs have been performed with this novel SFFL system during overbalanced workover operations for well control. A few case histories are described more in detail below.

Case History 1. In these cases, *inside casing gravel packs* (ICGP) were challenged by high completion-fluid losses to the formation. Because of the high permeability of the formation in a particular field (500 mD to 2000 mD), fluid-loss pills were always necessary during ICGP interventions. In the past the operator had used sized-carbonate pills that require a subsequent acid wash stage to clean the wellbore. In one well, three SFFL pills were used as follows to alleviate the losses:

- After GP in Zone 1, completion fluid losses were 12 bbl/hr. Fluid losses were reduced to zero after 15 bbl of SFFL followed by 30 bbl of 60-lbm linear gel.
- After TCP in Zone 2, completion fluid losses ranged from 24 to 48 bbl/hr. Fluid losses were reduced to zero after 30 bbl of SFFL only.
- After GP in Zone 2, well kicked and losses of 100 bbl/hr were observed. Fluid losses were reduced to zero after 40 bbl of SFFL followed by 80 bbl of 60-lbm linear gel.

Case History 2. A well was completed when an unexpected gas zone started flowing after perforating the pay zone interval. The completion fluid density was slightly increased to control the gas entry, but this new fluid weight caused completion fluid losses into the perforated interval that prevented the operator from conditioning the well and finishing the well completion. Fluid losses were not successfully controlled even after a few conventional attempts (particulates and viscous pills). To control the completion fluid losses and minimize formation damage, a 10-bbl SFFL pill was pumped. The volume was sufficient to stop the completion fluid losses into the formation, enabling the operator to finish the well completion intervention with no more delays. Fluid losses were cut from 4.75 bbl/hr to zero.

CONCLUSIONS

The following conclusions are a result of this work.

- This SFFL system is a low-viscosity solution that does not rely on solids or viscosity to provide water-based fluid-loss control. It immediately decreases formation permeability to aqueous fluids, limiting leakoff into the matrix of the rock.
- This system selectively decreases formation permeability to aqueous fluids without significantly affecting hydrocarbon permeability.

- This system does not require a breaker or shut-in time.
- This system has been successful in solving partial and total losses to full circulation in overbalanced operations such as: (1) lost-circulation events occurring during fracturing (2) well-intervention cleanouts by CT and HWO, (3) gravel packing, and (4) replacement of artificial-lift equipment (i.e., electrical submersible pumps), among others.
- To date, about 60 jobs have been performed with this novel SFFL system during overbalanced workover operations and other applications where maintenance of a hydrostatic column is necessary for well control.

Nomenclature

A	Cross-sectional area, cm^2
API brine	9% NaCl and 1% $CaCl_2$
BHT	Bottomhole temperature
$CaCl_2$	Calcium chloride
CT	Coiled tubing
d	Diameter, cm
ESP	Electrical submersible pump
K	Permeability, mD
K_f	Final permeability, mD
K_i	Initial permeability, mD
k_{wro}	Effective permeability to water at residual oil saturation, mD
L	Core length, cm
NaCl	Sodium chloride
PPR	Percent permeability reduction
Q	Flow rate, mL/min
SFFL	Solids-free fluid-loss system
t	Time, days
T	Temperature, °F
ΔP	Pressure drop along the core, psi and atm
Δ	Change, drop
μ	Viscosity, cP
f	Final
i	Initial
o	Oil
w	Water

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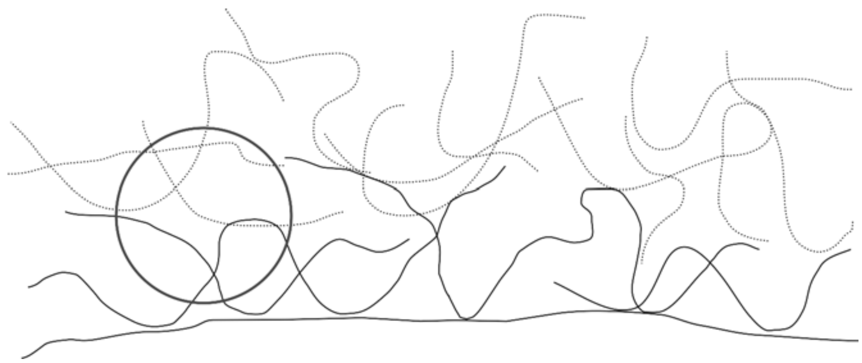

Figure 1—SFFL system base polymer: the hydrophobic modifications allow the polymer to build up because of the association of the hydrophobic groups.

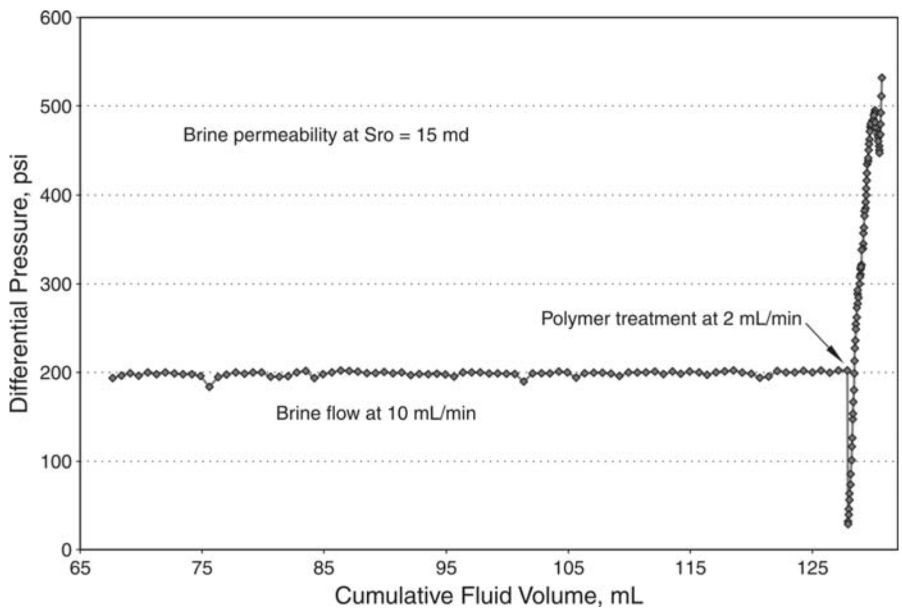

Figure 2—SFFL system: immediate pressure buildup during the treatment stage (carbonate core at 175°F).

Figure 3—Hollow core with mud filter cake.

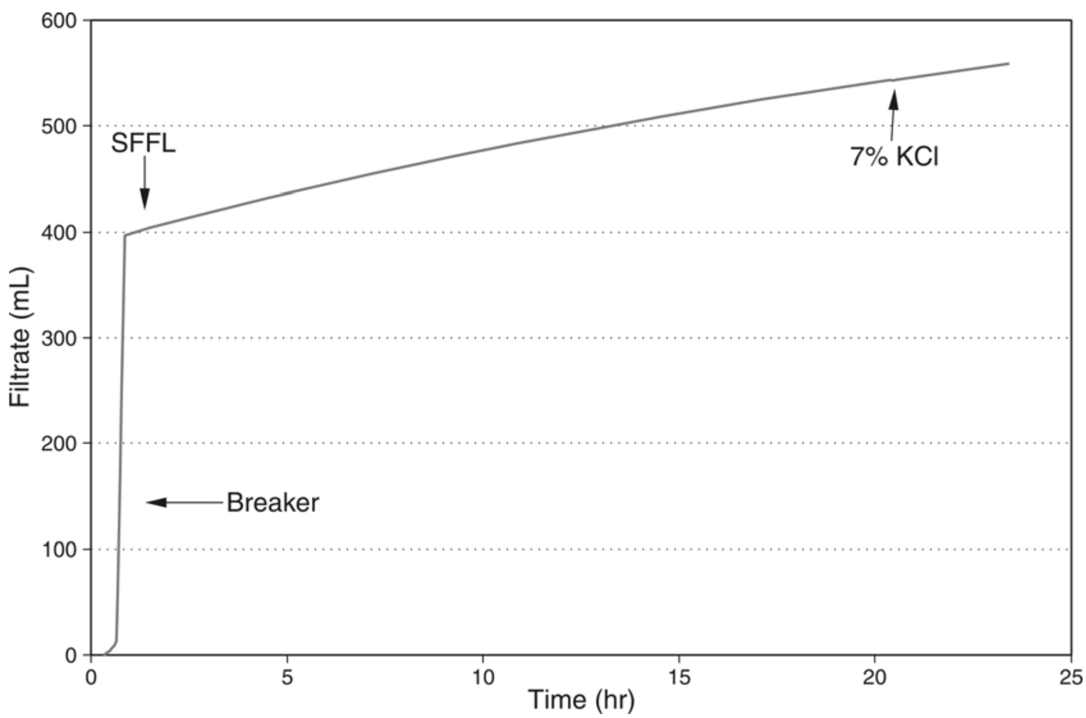

Figure 4—Hollow-core leakoff test.

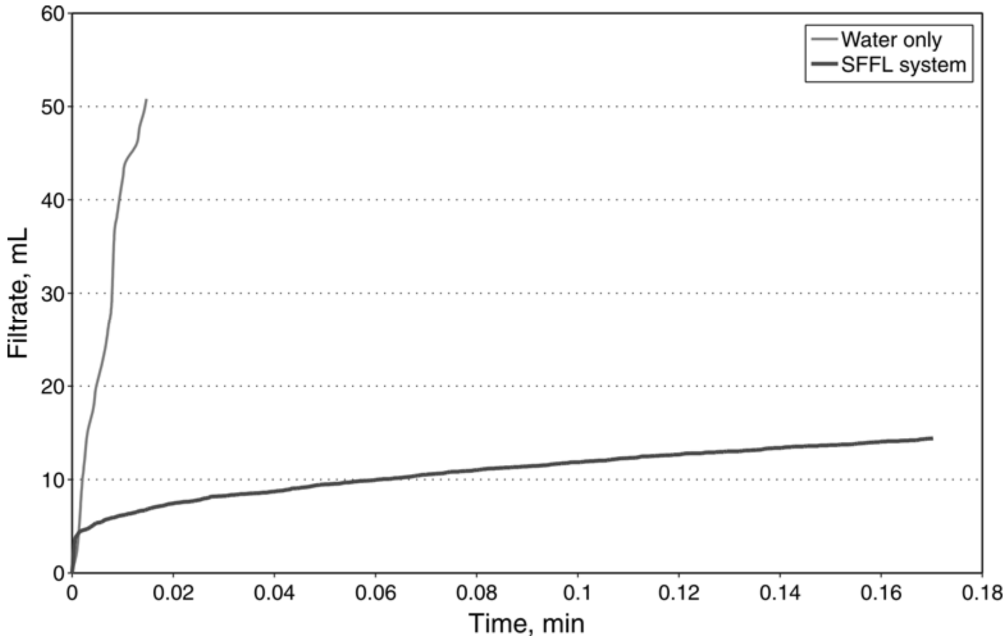

Figure 5—SFFL system: leakoff test through 70- to 170-mesh sand.

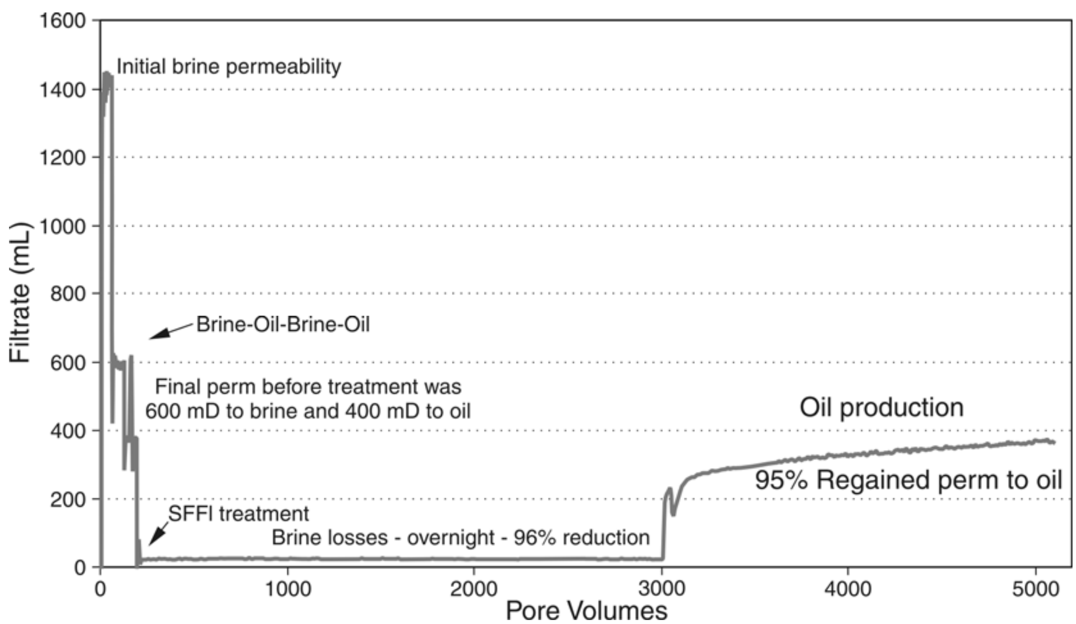

Figure 6—SFFL system regained-permeability test (500 psi, 2,000 ppm SFFL at 120°F) followed by a brine soak followed by oil production.