Solids-Free Viscoelastic Fluid Loss Pills and Dynamic Underbalance Improve Productivity from Newly Perforated Wells

R. Arangath, SPE, Y. Babalatirov, M. Griffith, and A. Umirbayev, Schlumberger

Abstract
Many operators in Kazakhstan are producing from carbonate reservoirs with fairly low permeability and porosity with the presence of dominant natural fractures. The completion and perforation of the reservoir are critical phases during which special attention must be placed on the well cleanup to obtain the maximum hydrocarbon productivity. Wells in the tight carbonate formation of certain fields in western Kazakhstan have historically been perforated in overbalance conditions or in static underbalance conditions that require killing the well immediately after the perforation for installing the permanent completion. After the permanent completion has been put in place, an acid wash must be performed to remove all the damage induced by the killing operation and the perforating debris. Both ways of perforating the wells expose the reservoir to potentially damaging fluids during and after the perforation. The exposure time of these fluids can be prolonged if adverse meteorological conditions are encountered. The damaging fluids can significantly impair the productivity by blocking the newly perforated tunnel, as well as by filtering through the natural fractures, which in turn makes it very difficult to remove even after as acid wash. As a result, the wells do not produce to their full potential.

A new perforating approach utilizing a dynamic underbalanced technique, in conjunction with a solids-free, viscoelastic-based, fluid loss pill, was introduced in several new wells in western Kazakhstan for a major operator. The fluid loss pill was designed to be solids-free and to be easily broken, leaving no residue downhole. There were four main requirements for the fluid pill:

- Effective—capable of stopping or minimizing completion brine losses at bottomhole static temperatures (BHSTs) up to 137°C.
- Degradable—easy to clean and with minimal residual damage to the reservoir or the perforations.
- Compatible—fully compatible with reservoir fluids and any well service fluids.
- Solids-free—making the post-completion cleanup operation easy.

The carbonate reservoir where this new approach was utilized has permeabilities varying from 6 to 38 mD, while the present reservoir pressure is approximately 4,200 psi at the reference depth of 3550 m. The new perforation approach allowed obtaining a cleaner perforation tunnel, increasing the average production compared with wells draining from the same reservoir that were completed with the traditional technique. The average production obtained with the new approach is approximately double that of the conventional technique. This has been verified on a campaign carried out on 11 wells, all located in the same area of the field, four of which were completed with the new perforation approach. Several other treatments have been performed and have indicated similar trends in production.

Introduction
Excessive loss of completion brines into the formation has always been a major concern during completion operations because it leads to formation damage and well control issues. For this purpose, fluid loss control pills are used to minimize the volumes of fluids lost to the formation to minimize formation damage and maintain the well controlled. Typically, the fluid loss control pills are composed of very high concentrations of crosslinked polymers with or without bridging particulates. The sealing mechanism of
these pills is a combination of viscosity, solids bridging, and polymer filter-cake buildup on the porous rock. Because of the presence of polymers, incompatibility with some divalent brine, and the necessity to clean up with acid, a new solids-free lost circulation pill that is stable for prolonged periods was developed for use in fissured reservoirs.

A new solids-free, non-damaging viscoelastic surfactant-based fluid loss pill was developed to be used in conjunction with a dynamic underbalanced perforating technique. The pill is placed in the well across the zone of interest prior to the perforating operation. The gel structure of this system sustains viscosity high enough to effectively control or stop fluid loss while maintaining a safe differential pressure into the formation. Several wells were completed for the first time with this technique in Kazakhstan. The pill was used in the field after extensive laboratory tests. The combination of the pill and the perforating technique allowed much higher production from the wells treated with this new approach as compared with traditionally completed wells.

**Reservoirs**

Located in western Kazakhstan, the field used in the deployment of this technology was delineated by seismic exploration in 1960, and exploration drilling started in 1961. The first commercial production was recorded in 1978. The field is hosted in a southerly trending symmetrical anticline fold with flanks dipping from 4 to 12° (Fig. 1). Because of the presence of faults, the field can be divided in three zones: Northern, Central and Southern.

The field has two productive members that are separated by terrigenous carbonate sediments with thickness ranges from 216 to 417 m. The lower productive reservoir consists of limestone with several thin intercalations of dolomite layers. In the reservoir, the
presence of natural fractures is dominant. The height of this reservoir ranges from 50 to 350 m across the field. The measured permeability varies from 6 to 38 mD with porosities in the 9.5 to 12.6% range. The average depth is 3350 m with BHSTs in the 77 to 84°C range. The initial reservoir pressure was approximately 5,870 psi at 3550 m. It is the main producing reservoir of the field.

The upper reservoir is more porous and consists of clastic limestone, dolomites, and their transitional varieties. The height of this reservoir ranges from 7 to 38 m across the field. The measured permeability varies from 8 to 17 mD with porosities in the 9.5 to 12.6% range. The average depth is 3350 m with BHSTs in the 57 to 62°C range. The initial reservoir pressure was approximately 3,050 psi at 2,800 m. This reservoir is not presently produced.

**Fluid Loss Control Pills**

Fluid loss control is very important in successful well completion operations. Loss of completion and workover fluids is unacceptable because of economics (preparation and filtration of brines), technical or safety reasons (formation damage, hole collapse, and well control issues) (Chang et al. 1998). Loss of brines into the productive zones can be highly damaging, especially to high-permeability formations. It is very difficult to unload brines, especially heavy ones, once losses have occurred. If the brine has a high density, stratification can occur, which tends to further inhibit its removal (Corley and Patton 1984). Calcium and zinc bromide brines can form stable, acid-insoluble complexes when they react with some formation brines (Cole et al. 1995). Hence, the most effective means of preventing formation damage is to limit completion brine losses into the formation by either chemical or mechanical means.

It is best to avoid the use of fluid loss control pills by incorporating mechanical fluid loss control devices into the completion string whenever possible (Parlar et al. 1998). However, in the absence or failure of such devices, or in situations where they cannot be used, chemical fluid loss pills are required. The use of a pill is normally required before and after sand control treatments and after perforating. In these treatments, the pill is spotted into the perforations or against the sand control screens. In addition, fluid loss control pills are required in several workover operations that need temporary zonal isolation. There are several reviews on the use of different types of fluid loss pills and guidelines on the selection of the pill (Schueerman 1983; Hodge et al. 1995; Parlar et al. 1998; Ross et al. 1999; Sas-Jaworsky and Ghalambor 2000).

A variety of fluid loss control pills have been used in the industry, such as foams, oil-soluble resins, fibers, acid soluble particulates, graded salt slurries, and highly concentrated linear and crosslinked nonbiopolymers and biopolymers (Himes et al. 1991; Cole et al. 1995; Hodge et al. 1995; Parlar et al. 1996; Beall and Suhy 1998; Chang et al. 1998; Araujo and Calderon 1999; Ross et al. 1999; Horton et al. 2001; Coughron et al. 2002; Ivan et al. 2002). The polymer systems are very effective in fluid loss control as long as the temperature limit of the specific polymer is not exceeded.

One of the important features of any fluid loss pill is its ability to maintain viscosity under bottomhole conditions (especially high temperatures). The viscosity reduction of gel at high temperatures is either because of polymer degradation or reduced molecular interactions (Kippie et al. 2002). The viscosity will not be regained on cooling if there is molecular degradation at high temperatures.

Studies with particulate systems in polymers showed irreversible plugging, which negatively influences the productivity or injectivity of the given zone. It has been reported that xanthan gum pills on Berea cores yielded less than 10% regained permeability (Himes et al. 1991). Because of this induced damage, polymer fluids with or without particulates may require remedial treatments to remove this damage. These treatments add cost and risk to the completion process.

Bridging agents are often used to combat severe fluid loss, and calcium carbonate (CaCO₃) is the most commonly used. However, removing the damage to the formation and proppant pack caused by CaCO₃ slurries can be difficult and costly. Salt pills are widely used to minimize this damage, but they are less effective in controlling losses and are more difficult to design properly because of solubility issues (Rosato and Supriyono 2002). Typical permeability of a CaCO₃ pack without polymers is in the range of 3 to 5 mD, whereas when polymers are used, it is lowered to the order of 1 μD (Parlar et al. 1998). Recently, studies have been reported on optimizing the particle size distribution of the bridging particulates in the fluid loss pill for specific screen types (Cargnel and Luzardo 1999; Luyster et al. 2000). They are normally removed by either flowback (when applied against screens) or breaker treatments (when used against prepacked or unpacked perforations). There are additives such as glycols that can be used in the pill to assist the sealing while pumping and peeling of the filtercake on reverse flow (Luyster et al. 2000).

CaCO₃ particulates, if not removed, will remain in the wellbore or formation and permanently impair the well productivity. Hence, additional treatments, including hydrochloric acid (HCl) washes, are required to remove these particulates. Therefore, a reliable viscous fluid system without solids is more desirable than a particulate system. Linear gels with high polymer concentrations without particulates are sometimes used as fluid loss pills. However, in highly permeable wells, deep invasion into the formation results in a substantial loss in well productivity. Crosslinked polymer gels are often considered to achieve fluid loss control in these cases.

Hydroxyethylcellulose (HEC) is well known for its low residual content, and even at 14 to 18 kg/m³, it will not form a compact filtercake if the formation permeability is higher than 20 mD (Parlar et al. 1996; Vitthal and McGowen 1996). Normally, HEC polymer solutions are difficult to crosslink and do not form rigid gels. They control fluid loss through viscous drag force and
gradual filtration. Hence, these fluids penetrate deeper into the formation than the crosslinked fluids and can cause severe permeability damage. The retained permeability for noncrosslinked HEC is typically in the 30 to 50% range (Hodge et al. 1995; Parlar et al. 1996). A neutral pH is needed for efficient hydration of HEC, whereas a high pH is required for it to crosslink. Under high pH conditions, the divalent metals precipitate as their hydroxides and are damaging. The high-polymer crosslinked fluids are rubber-like viscous materials and often need a delayed system to minimize friction while pumping the pill (Chang et al. 1998). Because of high friction losses associated with viscous kill pills, it is generally recommended to pump the pill down the tubing/casing annulus (Rosato and Supriyono 2002).

Chemically modified HEC derivatives were also used up to 105°C to control losses, but they are also difficult to crosslink (Cole et al. 1995). The crosslinked gel needs to break once the completion work is finished. If the gel is broken early, well control issues may result, and inclusion of a proper breaker package in the system can be critical. It is a challenge to formulate a stable, crosslinked HEC system for high temperatures with internal breakers that meets the requirement of low fluid loss while maintaining the ability to completely clean up before producing the well. Because of this reason, internal breakers are seldom used with polymer pills, and the gel is generally removed with an external acid treatment or an oxidizer soak (Ladva et al. 1998). Spotting acid to break HEC has been associated with long shut-in periods. It is very common for acid needing to be applied several times to contact all the in-place gel. Long-term cleanup is one of the major disadvantages of conventional polymer systems (Nguyen et al. 1996).

Another problem associated with polymer fluid loss pills is the difficulty in achieving effective polymer hydration in certain brines at higher densities (Dobson et al. 1996; Knox et al. 2002). Some prehydrated polymers and biopolymers, including succinoglycan, have been used for fluid loss control (Lau 1993; Cole and Ali 1994). Succinoglycan is a viscous fluid and relies solely on viscosity to reduce fluid loss. It will not form a filtercake that can cause considerable formation damage. The viscosity of this fluid will be significantly decreased at a transition temperature of about 170°F when low-divalent brine densities are used. Brine type and density have a minor influence on this transition temperature and generally higher brine concentrations lower the stability of pill at high temperatures. Formate-base pills are generally more stable than other heavy brines (Svoboda 1999). Under ideal conditions after breaker treatment, these fluids gave a return permeability of only 70 to 80%.

For a fluid loss control pill to remain in place, the density of the material must exceed the density of the wellbore fluids, and if not, the gel pill will tend to migrate in the wellbore, losing its effectiveness (Nguyen et al. 1996).

For fluid loss control, oil-soluble resins have also been widely used, and they clean up on contact with solvents. It has been shown that these resins lodge in perforation tunnels, where they remain isolated from the solvent for extremely long periods, delaying well production (Himes et al. 1991; Cole et al. 1995).

Polymeric materials, conventionally used with or without particulates for fluid loss control, have the following limitations:

- Polymers are damaging and yield low retained permeability.
- At high temperatures (above 120°C), polymers degrade and are not stable for extended hours (3 days required normally).
- The addition of starch and sized carbonate is required to minimize the fluid loss; however, it can cause further damage.
- Formulations are complex, and source water is sensitive.
- They are incompatible with most heavy brines at high temperatures.
- Breakers are required (internal or external).
- A high pH is needed to stabilize the gel.

In the past decade, there has been a substantial amount of research and testing in the oil and gas industry to develop nondamaging fluid loss control systems in drilling and completions that are capable of controlling losses without causing permeability damage on a potential producing formation (Bugbee 1953; Bruton et al. 2001; Ivan et al. 2001).† The following are the features of a good fluid loss control system (Nguyen et al. 1996):

- The system must be very effective in controlling the losses.
- It should be nondamaging to the formation and should be compatible with formation fluids and completion fluids.
- It must be simple and easily made at the wellsite with minimum on-site preparation, and a minimal hydration time is preferred.
- It should work under extreme conditions in the well, such as high temperature and high pressure.
- It requires long-term stability.

†Patent pending by M. Samuel, R. Marcinew, and Z. Xiao
- It should have the ability to suspend particles.
- The system should be able to be removed easily to achieve 100% retained permeability for maximum productivity.
- It should exhibit low friction pressure while pumping.
• There should not be an adverse pH requirement.
• It should be applicable in a variety of completions, such as perforated, gravel-packed, frac-packed, etc.

The development of a new fluid loss pill made it simple, non-damaging, polymer-free, and able to be used up to 137°C in conjunction with a dynamic underbalanced perforating technique.

**Viscoelastic Fluids**

In recent years, the oil and gas industry has started replacing several polymer systems with nondamaging, nonpolymeric viscoelastic fluids. Fluids based on viscoelastic surfactant technology have several distinctive advantages over polymer-based fluids (Samuel et al. 1997). The main feature of these surfactants is that gelled fluids can be prepared with no polymer content. The mechanism is based on the surfactant molecules that, in the presence of brine—such as potassium chloride (KCl), ammonium chloride (NH₄Cl), or calcium chloride (CaCl₂)—associate into aggregates called worm-like micelles. When present in sufficient concentration, those worm-like micelles will entangle and hinder fluid movement. The result of such interactions is the development of fluid viscosity. The worm-like structures are stable in aqueous environments; therefore, the fluid maintains its viscosity in the water-bearing formation. In the presence of hydrocarbon, however, the worm-like micelles are disrupted to form spherical structures. As a result, the fluid loses its viscosity. The phenomenon of micelle formation is depicted in Fig. 2. Little or no residue remains after the material degrades. An advantage of these surfactants is that they are mixed very easily. Batch or continuous mixing in brine generates the viscous gel with consistent properties. No additional equipment is required, as it is for foam injection.

![Viscoelastic Surfactant, Entangled Work-Like Micelles, Spherical Micelles](image)

**Fig. 2**—Formation of worm-like micelle by the viscoelastic surfactant in a brine environment and reversal back to spherical micelle in a hydrocarbon environment.

Viscoelastic surfactant-based fluids have been used successfully for hydraulic fracturing, diversion, matrix stimulation, sand control and acid fracturing (Samuel et al. 1999; Ali et al. 2001; Safwat et al. 2002; Al-Muhareb et al. 2003; Al-Mutawa et al. 2003). The knowledge gained from these technologies has now been used in the development of the solids-free perforating fluid loss pill.

**Viscoelastic Perforating Fluids**

The loss of brine to the hydrocarbon formation during well completion operations in this important field in western Kazakhstan has been a major concern for the operator. Conventional crosslinked gels for fluid loss control pills containing sized particulates have significantly impaired the well productivity, and, in certain cases, the productivity cannot be restored to the optimal level, even if large-scale acid stimulation treatments are carried out.

The approach adopted was a combination of a dynamic underbalanced perforating technique and a solids-free, viscoelastic-based, fluid loss pill to minimize losses at the anticipated downhole conditions (with a dominance of natural fractures and fissures). The fluid loss pill was designed to be solids-free and able to be easily broken, leaving no residue at the anticipated downhole conditions. There were four main requirements for the fluid pill:

• Effective—able to stop or minimize completion brine losses at BHSTs up to 137°C, considering the dominant presence of natural fractures across the perforated zones of the reservoirs.
• Degradable—easy to clean and with minimal residual damage to the reservoir or the perforations tunnel (of key importance, even after prolonged exposure to the anticipated downhole conditions, because it was evidenced by the operator in several laboratory tests that crosslinked systems tend to be less degradable after exposure at these temperatures for more than 12 to 18 hours).
• Compatible—fully compatible with reservoir fluids and any well service fluid used during the completion operation.
• Solids-free—simplifying the post-completion cleanup operation.

This fluid loss pill can be prepared by blending 10 to 20% (v/v) of viscoelastic surfactant in a blend of CaCl₂ brine and methanol. The methanol is added to enhance the long-term stability of the pill.

**Viscoelastic Perforating Pill Development**

Fann 50 rheometer measurements were used to determine the power law parameters n’ and K’ of the pill. From these data, the apparent viscosities of the fluid at various shear rates were calculated and are plotted in Fig. 3 for 26.7 and 107°C. The viscosity is also calculated for the low shear rates of 1 s⁻¹ and 10 s⁻¹ to simulate behavior of the fluid at downhole conditions once the fluid loss pill is placed in the well. As can be seen, the viscosity, at these low shear rates, is two to three orders of magnitude larger than that encountered during the placement of the pill in the wellbore. The rheology of the pill developed has excellent suspension capabilities and allows the addition of particulate materials if conditions dictate to enhance the fluid loss capabilities.

![Fig. 3—Effect of shear rate on the viscosity of 15% (v/v) viscoelastic surfactant in CaCl₂ solution at 26.7 and 107°C.](image)

Both Fann 50 rheology data and high-pressure bottle tests have shown that the fluid is stable for more than at least 72 at the anticipated BHST of 137°C (Fig. 4). During this period of time, no degradation of the fluid loss pill was observed. During additional bottle tests, the fluid showed to be stable for a period of 2 weeks at 137°C based on bottle tests. After this period of time, the test was halted, but the fluid loss pill was still stable.

The pill was also subjected to heating and cooling cycles from ambient to 137°C for 30 minutes and then back to ambient temperature. The applied temperature and the measured viscosity are illustrated in the plot in Fig. 5. The fluid recovers viscosity after each temperature/shear cycle. This recovery confirms that the fluid is temperature- and shear-sensitive (with a minimal temperature degradation observed). The data once again confirm the stability of fluid under drastic conditions that it could experience during a typical well operation.

The cleanup of the pill was analyzed in laboratory studies performed during the design of the pill. As mentioned above, the viscosity of the pill is reduced when the pill contacts a hydrocarbon fluid. This fluid can be either reservoir crude, diesel, or a brine solution with mutual solvents. The effect of each of the systems considered is detailed in Table 1.
Fig. 4—Stability of viscoelastic fluid loss pill during exposure for 3 days at 137°C. Data measured with Fann-50 rheometer.

Fig. 5—Effect of heating and cooling cycles on viscoelastic fluid loss pill apparent viscosity. The viscosity was measured during three heating and cooling cycles. During each cycle, the pill was continuously heated to 137°C for 30 minutes. As shown in the graph, the degradation rate of the surfactant is minimal.

### TABLE 1—BREAKING OF VISCOELASTIC FLUID LOSS CONTROL PILL

<table>
<thead>
<tr>
<th>Breaker</th>
<th>Concentration (% Volume)</th>
<th>Original Viscosity (cP)</th>
<th>Final Viscosity (cP)</th>
<th>Time Required to Reach Final Viscosity (hr:min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil</td>
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<td>225</td>
<td>60</td>
<td>24:00</td>
</tr>
<tr>
<td>Diesel</td>
<td>100</td>
<td>225</td>
<td>80</td>
<td>00:05</td>
</tr>
<tr>
<td>Mutual Solvent in Brine</td>
<td>10</td>
<td>225</td>
<td>40</td>
<td>00:01</td>
</tr>
<tr>
<td>Mutual Solvent in Brine</td>
<td>20</td>
<td>225</td>
<td>15</td>
<td>00:01</td>
</tr>
</tbody>
</table>

**Dynamic Underbalanced Perforating**

Today, many operators design their completion programs based around the industry-wide practice of sizing the magnitude of the initial static underbalance to remove perforation damage created during the perforating operation (Behrmann 1996). To achieve this sizing, the well completion procedure must include an operational step that results in an underbalanced condition being induced across the sandface prior to the actuation of the perforating gun system. This underbalanced scenario is usually achieved.
with the upper completions already in place or through the deployment of a temporary completion string to perforate and control the well, followed by isolating the newly created perforating tunnels or killing the well to later land the upper completions. Many times, these underbalance techniques increase the complexity of the completion operations, requiring major logistical arrangements and inflating the overall cost for the completion.

During recent years, a significant effort has been spent on research, field trials, and field operations focused on dynamic underbalanced perforating techniques. In these techniques, the underbalance is achieved by designing the gun system, while the well is overall in a overbalanced condition. The dynamic underbalance techniques are proving that a completion sequence where the well is perforated overbalanced with a suitably designed dynamic underbalanced perforating system can yield overall well productivity results that match or outperform results observed when perforating in a static underbalanced scenario (Walton et al. 2001; Chang et al. 2003; Pizzolante et al. 2006).

The design of a dynamic underbalance perforating system is based on the generation of a brief, transient underbalance that is generated by the inflow of wellbore fluids into the perforating gun system at the time of shooting. The transient underbalance is deliberately sized to be of a short duration, dramatic, and significantly larger in magnitude than the sized static underbalance for the same formation and wellbore conditions. The rate of change of the transient underbalance first induces shear failure of the crushed and damaged zone in the newly created tunnels created by perforator charge. This shear failure is accompanied by a surge, clearing the crushed debris out of the tunnels and into the wellbore (Fig. 6).

![Diagram](image)

**Fig. 6**—Almost any drilling process will create some damage to the formation adjacent to the wellbore. Minimizing this damage is a key objective while drilling and cementing the well. Bypassing the damage is a key objective when perforating to maximize the well production.

This high transient underbalance can be applied across all the perforated sandface, delivering a more consistent cleanout than that can be achieved with static underbalanced conditions (Chang et al. 2005). This key feature of the technique now allows performing the perforating operation with all the related safety and efficiency benefits without impacting the final productivity of the well.

**Field Application**
The field application of this technique was carried out in western Kazakhstan once the laboratory testing of the fluid loss control pill was completed and the results were fully analyzed in all their details to ensure that specifications were met.

The operator had always been perforating the wells in the field in an overbalanced condition using the “shoot and pull” technique. The wells were typically perforated with a 4 1/2-in.-outside-diameter (OD) high shot density gun system loaded at six
shots per foot and conveyed with drillpipe. After guns were actuated, the well was filled with brine, the perforating string was retrieved, a permanent production string equipped with gas lift mandrels was landed, and the well was put on production. During the period in which the perforating string was recovered to surface, fluid losses were encountered in a great majority of cases. The highest values of losses encountered were up to 2.50 m³/hr [15.7 bbl/hr]. The time required to run the permanent completion string, from when the guns were fired until the well was put on production, ranged from 48 to 120 hours, depending also on the meteorological conditions.

The first step of the new approach was to use a perforation modeling software to identify the best-available option for these wells. The simulations indicated that shooting with a 4 1/2-in.-OD gun with dynamic underbalance would improve both the cleanup of the perforation tunnels and the well productivity as compared with the conventional “shoot and pull” technique. To meet the transient underbalance design criteria, a 4 1/2-in.-OD dynamic underbalance gun system was designed and loaded at 4.5 shots per foot with deep penetrating charges. No packer was used, and the guns were fired using a redundant hydraulic firing system with a delay and actuated via a sequence of pressure pulses from surface. The gun string was equipped with an intelligent firing system that was reconfigured to monitor the wellbore pressure and to detect the pressure sequence being sent to the hydraulic firing head. This configuration allowed the electronic firing system to start high-speed logging of wellbore pressure data and as such, record the generated transient underbalance. The details of the perforating string are shown in Fig. 7.

The wells are typically prepared by displacing mud in the casing with 9.34-ppg brine. This preparation typically results in a 1,580-psi overbalance across the perforations. The new approach included the spotting of the viscoelastic fluid loss pill across the lowest 300 m of the well prior to pulling the cleanout string to surface. The perforating string was then lowered in the well and correlated, and then the guns were actuated. The underbalance achieved during the perforation was measured to be approximately 2,800 psi (Fig. 8). After the perforation, an additional batch of the viscoelastic fluid loss pill was placed across the formation, the perforating string was retrieved, and the permanent completion was run. The well was monitored during the period from perforation until production, and no sign of fluid loss was noted.

**Results**

Eleven wells were drilled and completed in the southern sector of the field. As part of the deployment efforts agreed upon with the operator, a total of four wells were completed with the new approach, while the remainder were completed with the traditional “shoot and pull” technique.
Fig. 8—High-speed data recorded during the perforation with the dynamic underbalance technique on Well 2. The reservoir pressure is 4,200 psi, which corresponds to an initially overbalanced well with 1,580 psi. The minimum measured pressure was 1,320 psi, which corresponds to an underbalance of 2,880 psi.

The stabilized production achieved after the wells were completed and put on production are illustrated in Fig. 9, and the following conclusions can be made:

- The production achieved with the viscoelastic fluid loss pill and the dynamic underbalance were the highest among the wells considered.
- Well E had significantly different reservoir properties from the other wells.
- The average production achieved with the new approach is slightly more than double the average production obtained from the wells completed with the traditional approach.

Actual well production data are in Table 2, along with computed averages for each technique (Table 3).
TABLE 2—STABILIZED WELL PRODUCTION DATA

<table>
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<tr>
<th>Well</th>
<th>Stabilized Production (STB/d)</th>
<th>Completion Method</th>
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<tbody>
<tr>
<td>1</td>
<td>202</td>
<td>Traditional “shoot and pull”</td>
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<tr>
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<td>New approach</td>
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<td>3</td>
<td>222</td>
<td>Traditional “shoot and pull”</td>
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<td>4</td>
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<td>Traditional “shoot and pull”</td>
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<tr>
<td>5</td>
<td>151</td>
<td>New approach</td>
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<td>6</td>
<td>237</td>
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<td>11</td>
<td>76</td>
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TABLE 3—AVERAGE STABILIZED PRODUCTION DATA

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<tr>
<th>Completion Method</th>
<th>Average Stabilized Production (STB/d)</th>
</tr>
</thead>
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<td>Traditional “shoot and pull”</td>
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<tr>
<td>New Approach</td>
<td>291</td>
</tr>
</tbody>
</table>

Conclusions
The new perforating approach that combines a viscoelastic fluid loss pill and the dynamic underbalance perforating approach allowed higher production when compared WITH the traditional perforating technique. There are several advantages for this new approach:

- The fluid loss pill is a simple system composed of two additives: surfactant and brine.
- The fluid loss pill does not form external filtercake and is not damaging to the formation.
- The fluid loss pill exhibits long-term stability (more than 3 days at 137°C).
- The fluid loss pill is simple to clean from the wellbore and does not require additional remedial treatments.
- The fluid loss pill controlled fluid losses effectively in all field cases without encountering well control issues.
- The perforating system allowed for effective clean up of all debris from the new perforation tunnels.
- The perforating system allows higher productivity with a smaller number of charges.

References


