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Fluid Oscillation Tool Restores Gas Delivery Rate from Storage Wells

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Abstract

Gas-storage wells experience gas deliverability decline over the lifetime of the well for a variety of reasons, but most often decline is caused by near-wellbore skin damage. Recent developments in diagnostic techniques enable operators to identify near-wellbore damage and apply a tailored treatment to reverse the deliverability decline. In a Sayre, Oklahoma gas-storage field, gas deliverability was improved 32.5% in 14 wells, using pretreatment damage diagnostic analysis to remove near-wellbore damage with new coiled-tubing-conveyed fluid-oscillation treatments.

A fluid-oscillating tool (FOT) is key to the damage-removal technology. The FOT sends out alternating bursts of fluid to create pulsating pressure waves within the wellbore and formation fluids. These pressure waves help break up near-wellbore damage and restore effective permeability by carrying the fluid past the wellbore into the formation. These oscillating pressure waves are not affected by standoff, which is common with conventional jetting or velocity tools. Kinetic energy in the pressure pulse travels through the wellbore fluid with no appreciable energy loss. The pressure waves expand spherically, providing 360° coverage as the tool is moved through the interval. As damage is removed, the waves penetrate deeper into the formation.

This paper presents a technical description of the processes incorporated to remediate damage in the Sayre field and the technology used in the oscillation treatments. A case study from West Virginia is also presented. Both cases illustrate pretreatment planning, job design, application procedures, and results.

Introduction

Each year, a wide variety of damage mechanisms cause gas-storage operators to experience approximately 5% deliverability loss.¹ Recently, a joint industry study identified many of these damage mechanisms, and a diagnostic

technique and damage-removal process has been described in detail.² The damage-removal method uses coiled tubing (CT), a jetting nozzle, and a tailored treatment fluid to remove the damage that limits gas-well deliverability

Hundreds of coiled-tubing cleanouts (CTCO) have been performed on gas-storage wells throughout the United States using the diagnostic process to identify damage mechanisms and assist in the design of appropriate procedures and treatment fluids.³ In most of these treatments, either a high-pressure blasting tool (HPBT) or a wash nozzle was used to clean the wellbore. In addition to cleaning the wellbore, various methods have been incorporated to pump additional treatment fluids into the formation to remove skin damage.

The FOT, used on over 3,000 wells throughout the world, had never been used in conjunction with the damage-diagnostic procedures for gas-storage wells described in this paper.

Previous tests performed with the FOT indicate that energy from the tool cleans the exposed formation surface (as blast-and-wash nozzles do) and more effectively penetrates into the formation to remove near-wellbore skin damage. Blast-and-wash nozzles alone have not proven effective in penetrating into the formation to remove skin damage. It is well-known that many of the damage mechanisms in gas-storage wells are not just at the formation or wellbore surface, but are embedded back into the formation itself in the near-wellbore area.⁴

To determine whether gas deliverability could be improved over historical CTCOs, it was proposed to use the FOT with a blasting tool and the in-place, damage-diagnostic process. Previous CTCOs used the HPBT alone or the HPBP in conjunction with selective injection packer (SIP) systems to convey customized treatment fluids into the formation to remove skin damage. In this project, past methods would be compared with the oscillation tool used alone.

FOT Theory

The FOT (**Fig. 1**) is used in conjunction with CT and is based on patented fluid-oscillator technology. Fluid oscillation produces emissions of alternating bursts of fluid that create pulsating pressure waves within the wellbore and formation fluids. These pressure waves can break up many types of near-wellbore damage, helping restore and enhance the permeability of the perforations and near-wellbore area. The pressure waves expand spherically, providing 360° coverage while the tool is moved through the interval. As damage is removed, the waves penetrate deeper into the formation (**Fig. 2**).

The treatment fluid is pumped through CT, then enters the FOT body and is accelerated into the fluid oscillator. The fluid stream enters the oscillator and preferentially attaches to the outer wall of one of the fluid passageways. The flow continues down the selected passageway to the outlet. As the flow passes a cross-channel, a low-pressure area is created, causing the main fluid stream to be interrupted and the flow to switch and attach to the other fluid passageway. The switch begins to oscillate, which causes alternating “bursts” of fluid to be ejected into the wellbore. As each burst is ejected, it forms a compression wave within the wellbore fluid. Compressive loading occurs when the wave enters the perforation tunnel or the openhole section and contacts the formation face. As the wave passes through the formation and is reflected back, it induces a tensional loading on the skin damage. The continuous cycling of these pressure waves causes the skin damage to reach its fatigue failure point. As skin damage is removed, the pressure waves penetrate deeper into the formation. The oscillating pressure waves are not affected by standoff, as occurs with conventional jetting tools.

The FOT is currently made in two sizes: 1¼-in. and 1½-in. OD. The small size of the tools enables easy passage through smaller-sized restrictions while still effectively cleaning wellbores and removing near-wellbore formation skin damage.

Case Histories

The following two case studies document the success of the damage-diagnostic analysis and CT-conveyed, fluid-oscillation treatment system. Following the Sayre project (Case History 1), another project was initiated in West Virginia (Case History 2). After learning about the initial success of the Sayre project, the West Virginia operator elected to use the FOT technology on a project to improve well performance in their field.

Case History 1: Sayre Field

The Sayre field is a depleted, dry-gas reservoir converted to gas storage; it is located in western Oklahoma near the town of Sayre. There are currently 27 injection/withdraw wells and 16 observation wells at the facility. Gas is stored in the Brown Dolomite formation at a depth of approximately 2,625 ft.

A deliverability-enhancement review of the field was performed in 1999 and wells were selected using a modified Gas Research Institute/Department of Energy (GRI/DOE) damage-diagnostic process. Well work was performed using coiled tubing with high-pressure blast tools and SIPs. Specific damage mechanisms were identified and treatment fluids were tailored to remediate the damage mechanisms identified. Overall, significant well performance was noted from the 1999 work, but no quantitative analysis was performed at that time.

Candidate Selection

In the summer of 2003, 15 well candidates were chosen for a Sayre field cleanout project following a 3-well pilot review of the SIP and FOT technology. Fourteen of the wells used the FOT in conjunction with a blasting tool to apply the treatment. On another well, the HPBT and the SIP tool were used to apply the treatment by conventional means.

A team of engineers and geologists from the gas-storage company and the service company was formed to determine

which wells would benefit most from a CTCO treatment. The team identified wells based on current performance data and reviewed the historic well files and data from candidate-selection work performed in 1999. The 1999 work included a review of historic deliverability, geologic analysis of formation thickness and porosity estimates, well restrictions, well locations, wellhead issues and wellbore geometry, damage-diagnostic results from downhole sample analysis, and permeability and skin damage results from previous and current well-test analyses.

A candidate list was created and wells were ranked according to expected deliverability improvement (maximum deliverability minus current deliverability). Further testing with the diagnostic process confirmed that many of the wells in the Sayre field were experiencing loss of deliverability and that a CTCO would benefit these wells. The team also used the diagnostic data coupled with physical well and logistic data to determine an optimal candidate list and the appropriate procedures and chemical makeup to use for the treatments.

Diagnostic Testing

Before any treatment is proposed or applied, it is extremely important to identify the degree and type of damage that is causing the loss in storage-gas deliverability. In Sayre, the following diagnostic testing was applied to help ensure that proper damage-removal techniques were used to recover optimal deliverability. The diagnostic process included well-test analysis, downhole sampling and analysis, and high-resolution downhole video (DHV). A solution research team then categorized and formulated treatment designs based on the diagnostic results of the sample analysis. Individual well potential was then determined from injection-and-withdraw historical performance data and well testing. The process also included measurable targets for deliverability enhancement. The following is a brief description of each diagnostic process used in the diagnostic testing.

Downhole Sampling and Sample Transfer. Physical downhole and surface (wellhead) samples were extracted using a bailer tool. Sample analysis was provided by qualified lab technicians; samples were characterized with X-Ray diffraction analysis, solvent extractions (using infrared spectroscopy), and acid-solubility studies. Depth measurements were taken on all of the well candidates to determine whether any fill or obstruction was covering the storage interval. Depth measurements are extremely helpful when performing CT operations and when the presence of fill or debris may be contributing to the reduction in deliverability. Wellbore restrictions or fluid levels are also of interest in designing effective gas-storage deliverability-enhancement treatments.

Downhole Video Inspections. Both pre- and post-treatment DHV inspections were performed on the three pilot wells. The images were used to identify physical damage in the wellbore and across the formation face and to show the effectiveness of the CTCO treatment and use of the FOT.

A high-resolution-dynamic (HRD), real-time DHV system can help determine mechanical problems in the wellbore. The system is critical to locating damage in the wellbore and in

determining the condition of tubulars and perforations before treatment. HRD-capable DHV systems can help determine (1) whether or not perforations are contributing to flow and injection, and (2) the general type of damage present in the wellbore and perforations. The location of damage mechanisms, such as scales, salts, leaking pipe, and plugged perforations can also be determined. DHV can also confirm wellbore integrity and identify the depths at which the wellbore needs to be cleaned.

Well-Test Analysis. Well testing is widely used in gas storage. Backpressure testing is a common method used to identify historical well performance and improvements obtained from remediation practices. Backpressure testing alone, however, cannot always identify variations in reservoir flow capacity and skin damage. Pressure-transient tests are more essential in determining the degree of damage in storage wells and the quantity of deliverability/injectivity uplift that can be achieved from remediation. When conducted properly, pressure-transient tests can provide quantified measurements of permeability thickness, skin damage, and reservoir pressure. These tests are applicable even when multiple zones are completed, as in some wells in the Sayre field. In addition, qualified and quantifiable data on reservoir heterogeneities can be determined, including boundary distances, boundary or fault types, gas-water contacts, layer communication, and changes in reservoir quality at distances away from the wellbore.

Well testing was performed to identify flow capacity and reservoir parameters necessary to achieve optimal recovery of deliverability in each well. Each well test included a comprehensive well-pressure transient analysis including rigorous superposition matching of early-time region (ETR), mid-time region (MTR), and late-time region (LTR) pressure-transient data. Pressure-transient analysis was compared with existing backpressure tests to assist with candidate selection. In some wells, a layered reservoir response was identified and average permeability was modeled with corresponding skin damage on each of the layers.

After effective permeability and skin damage was quantified for each well, a well-test design simulator was used to estimate deliverability uplift potential. In each case, calculated skin damage from actual well-test analysis was reduced in the simulator, based on estimates from damage treatment remediation. The project deliverability uplift from the simulator allowed economic and deliverability test objectives to be determined before conducting any work.

Wellsite Biocide/Bacteria Testing. Normally when downhole samples are taken, bacteria tests are performed to determine the presence of damaging bacteria, and if present, how to treat them. Trained personnel provide the necessary equipment to perform bacteria/biocide testing at the wellsite in accordance with recommended damage-identification practices. Results of the testing indicate the type of bacteria present and whether or not bacteria treatment is necessary.

The Sayre field operator recognized the need to treat all of their wells with biocide. A 1999 sample analysis (part of a self-funded program to enhance deliverability) showed the presence of iron-related, slime-forming, aerobic bacteria in

several wells. Although bacteria testing was not performed on the wells in this program, treating fluids included a biocide to treat for previously detected formation-damaging bacteria.

Estimation of Potential Deliverability and Ranking. The goal of performing CTCOs on gas-storage wells is to increase deliverability and injectivity to or beyond original/historical values. From the data gathered to remediate declining deliverability, estimation techniques can be used to predict deliverability uplift from stimulation treatments by CTCOs. All of the CTCO well candidates in the Sayre field were ranked according to potential deliverability uplift, based on pressure-transient testing and modified isochronal well testing. Well-test data was obtained from the Sayre field's continuous-pressure and rate-measurement system.

Ideally, it would be preferable to treat the top candidates in any field; however, factors such as well location, downhole restrictions, wellhead issues, etc. can eliminate some top-ranked wells. In Sayre, not all of the top candidate wells were treated; wells lower on the list were also selected based on mechanical and logistic issues affecting the ability to perform the necessary work.

Results of the Diagnostic Testing

Well-Test Analysis. Backpressure testing was performed shortly after the treatments were completed. In 13 FOT cases and the SIP case, improvements in deliverability were indicated. **Fig. 3** shows the backpressure test of the Brannon-Ramsey well before and after treatment. The shift from a lower estimated open-flow (EOF) to a higher EOF potential supports the remediation of skin damage diagnosed in the pressure-transient testing using the FOT process.

Fig. 4 shows the backpressure test results from the Davis 1 well. Again, a shift from a lower EOF to a higher EOF potential is indicated from the SIP process.

Table 1 shows the results of four wells with pre- and post-treatment, pressure-transient test results. Overall, most wells showed a decrease in effective skin (total skin to non-Darcy skin) and all wells showed an increase in effective K_{GH} , indicating that skin damage was affecting the effective connectivity to the wellbore in these wells. In each case, a higher K_{GH} is likely because of increasing net thickness (h) from the remedial treatments since permeability is not variable.

Downhole Sampling and Analysis

Downhole sample analysis was performed on 7 of the 14 wells treated with CT and the FOT, another five wells in the field also had samples analyzed. Results of X-Ray-diffraction testing and acid-solubility testing on four of these wells are shown in **Table 2**.

A review of the downhole sample analysis on all of the wells in the field reveals the presence of a large amount of sand, dolomite, salt, and clay in many of the wells. Identification of selected organic extracts by infrared spectroscopy also revealed varying amounts and types of hydrocarbon oils present in these wells.

The resulting fluid systems, treatment procedures, and chemicals pumped reflect the analysis from the well testing, DHV, and sample analysis. Certain chemicals and fluid

systems should be pumped to help remove the solids, minerals, bacteria, hydrocarbons, and other materials found in the wellbores. These materials could contribute greatly to the loss of deliverability experienced by these gas-storage wells. The means for pumping these fluids and chemicals and the procedures for placing them across the storage interval should also be designed for optimal cleaning.

DHV Inspections

DHV inspections were run on three wells both before and after the CTCOs. In viewing the DHV performed before the cleanouts, it was noted that little if any scale deposit was present in the top section of the well, from surface to 500 ft. In some gas-storage wells, significant amounts of scale sometimes exist in the first several hundred feet of casing below the wellhead. In the Sayre wells, this problem was not evident; therefore, no detailed cleaning had to be performed in the casings at surface. The real damage was evident across the perforated sections in the gas-storage interval on all three of the wells videoed.

Figs. 5 through 10 are pre- and post-treatment views of the three wells cleaned out in the Sayre project. Fig. 5 is the DHV taken prior to the cleanout on the Hawkins 1 well; the view is at 2,625.1 ft. Fig. 6 shows the same interval immediately after the CTCO treatment. In comparing the two, it is evident that the wellbore has been thoroughly cleaned by the CTCO treatment using a pre-treatment high-pressure blast run followed by the FOT with the applied treatment fluids and chemicals. On the pre-treatment video, no perforations are visible, whereas the post-treatment video shows clearly all of the perforations uncovered and the casing wall thoroughly cleaned.

Figs. 7 and 8 show the Elk City well, which was filmed using DHV both before and after cleanout. This view shows that the CTCO using the FOT with a blasting tool has done an exceptional job of cleaning the near-wellbore damage. The material on the casing wall was removed and the wellbore restored to a clean condition.

Figs. 9 and 10 show the Davis 1 well, which had the treatment fluid applied through an SIP tool following a pre-treatment high-pressure blast run. When using an SIP tool, treating fluid is pumped through the tool, which has packers above and below the interval to be treated. This arrangement allows the treatment fluid to be injected directly to the interval above and below the packer assemblies.

A comparison of the Elk City well (Fig. 8) and the Davis well (Fig. 10) shows that both wells have clean wellbores after treatments, indicating that the HPBT performed well in conjunction with both the FOT and the SIP treatments. Post-treatment injection-and-withdraw data demonstrate that (1) both the HPBT/SIP treatment and the HPBT/FOT treatments performed equally well, and (2) the FOT wells may have performed better. This observation could indicate that the FOT technology is capable of creating better distribution of treatment fluids in near-wellbore reservoir rock. Additional data is needed to confirm improved performance of the FOT process in this project.

Summary of Deliverability Change

Table 3 shows the results of well testing on the 14 wells treated with the FOT in the CTCO program. The table shows each well and its corresponding change in deliverability (positive or negative) and the total increase (or decrease) in deliverability. All measurements were at a Q100 (flow rate at ΔP^2 of 100,000). Of the 14 wells, indications are that they improved by 32.5% (an additional 43.2 MMcf/D).

Thirteen of the wells showed improvement, however, the 15th well declined in performance by 13.2%, or 0.26 MMcf/D. This well, in the poorest section of the field alongside Nos. 12 and 13, was difficult to evaluate because regular measurement of observation wells in the area was not practiced. The resulting spotty reservoir pressure measurements likely skew the ΔP^2 calculation for these wells. The Davis 1 well, treated through the SIP tool, also had a deliverability increase of 21%.

Compared to historic CTCOs (using blasting tools alone to pump treatment fluids), the FOT treatments alone were not as effective as those combined with SIP or FOT tools. The evaluation (using backpressure testing, pressure-transient testing, and historical measured pressure/rate data) clearly demonstrates that use of the SIP and FOT tools was effective in Sayre. In addition, the FOT tools are much easier to use and less costly to run and may perform better than the SIP tools. Additional data is needed to confirm better performance in this study.

Case History 2: West Virginia

Another CTCO project completed in the fall of 2003 used just the FOT to treat gas-storage wells in a 20-well program in the Appalachian basin. In previous cleanouts for this customer, a blast tool was used to clean the wellbores. After learning about the success of the Sayre project, the operator decided to use the FOT technology on his project.

Wells in this field have varying completions with most having casing top set above the storage zone with an openhole completion. Gas-storage intervals consist of shallow sandstone formations that had been producers in the past. This project involved several gas-storage fields within different formation types, and therefore different casing completions, treatment chemicals, and procedures were used in the cleanouts. In all the wells treated, the FOT was used with CT to apply the treatment. As in the Sayre project, a complete investigation into the reasons for deliverability loss was conducted using the damage-diagnostic tools at hand. Sample analysis, DHV, and well testing were used to design the proper treatment for each field.

Most the wells treated responded favorably in terms of increased deliverability, but the customer requested that no detailed information be disclosed. Nevertheless, two of the wells viewed by DHV before and after the CTCOs are represented in **Figs. 11–14**. Both wells were openhole completions.

Fig. 11 shows the pre-CTCO condition of the wellbore on Well A at 2,263 ft (storage interval). A large amount of scale is reducing the borehole diameter as well as probably contributing to loss of gas deliverability. Fig. 12 shows the same interval after treatment with the FOT (and tailored treatment fluid); the scale has been removed and the diameter of the wellbore has been restored. Figs. 13 and 14 show

before-and-after photos of another well in the same field in which the FOT tool was used. Again, the buildup across the formation face has been thoroughly removed and the wellbore has been restored to its original (or near-original) condition.

Conclusions

The Sayre field CTCO project (using the FOT and a blasting tool) demonstrates that use of the FOT is a viable means for cleaning out gas-storage wells. Both qualitative (DHV) and quantitative (well-testing) results indicate optimized borehole conditions as well as overall increased deliverability. When proper upfront damage diagnostics are performed and a tailored treatment is applied with the FOT through CT, positive results can likely occur on most wells. It is important to keep in mind that on many gas-storage well CTCOs, immediate increases in gas deliverability may not be seen. A season of injection/withdrawal may be required before realizing the benefit of the treatment. In the case of using the FOT, immediate results were seen in most of the wells treated. On the Sayre project, all wells, with one exception, showed immediate improvement.

In another recent CTCO project on gas-storage wells using only the FOT, over 60% of the wells treated showed immediate (same-day) improvement in gas deliverability. The operator claimed to have never seen such a high percentage of wells showing immediate increases on previous cleanouts, which had always included a blasting tool. In addition, the FOT effectively cleaned out bottomhole formation fill, saving the operator the expense of performing a separate mill and motor run to clean out the fill.

Recent technology involving the FOT enables it to be run in tandem with a blasting-nozzle tool without reducing the effectiveness of either tool. This technology delivers (1) the near-wellbore cleaning effectiveness of a blasting tool, (2) the deeper penetration of the FOT, and (3) the capability to clean formation fill from the flow out the bottom of the FOT. On the Sayre project, two separate runs had to be made, one for the

FOT and the other for the blasting tool. Combining the two eliminates an entire run, reducing cost while not sacrificing effectiveness.

Acknowledgements

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References

1. Young, *et al.*: "Development of Technologies and Techniques to Enhance Underground Natural Gas Storage Operations," Topic Report No. 1: State-of-Technology Assessment and Evaluation of Gas Storage Well Productivity Enhancement Techniques, Gas Research Institute, GRI Contract No. 5089-275-1853, December 1993.
2. Blaich, M.E., *et al.*: "Diagnostic Process Enhances Gas Storage Deliverability—A Case Study," paper SPE 51039 presented at the 1998 Eastern Regional Meeting, Pittsburgh, Pennsylvania, 9-11 November.
3. Guoynes, J.: "Deliverability Enhancement and Field Optimization of Gas Storage Fields," paper presented at the 2003 AGA Operations Conference and Biennial Exhibition, Orlando, Florida, 27-29 April.
4. Yeager, V.J., Blaich, M.E., Behenna, F.R. and Foh, S.E.: "Damage Mechanisms in Gas-Storage Wells," paper SPE 38863 presented at the 1997 Annual Technical Conference and Exhibition, San Antonio, Texas, 5-8 October; and the 1998 SPE Gas Technology Symposium, Calgary, Alberta, Canada, 15-18 March.
5. Azari, M., Guoynes, J., Soliman, M. and Fugate, M.: "Deliverability Enhancement and Well Testing of Two Gas-Storage Fields in Mt. Simon Formation—Case History," paper SPE 39208 presented at the 1998 India Oil and Gas Conference/Exhibition, New Delhi, India, 10-12 February.

Table 1—Pre- and Post-Treatment Pressure-Transient Test Results, Sayre

Rank in Field (% Uplift)	Well	Well Type	Test	K _{Gh}	Increase K _{Gh} (%)	Total Skin	Test DI (Mcf/psi ²)	Uplift (%)
8	Hawkins 1	I/W	Pretreatment	2670		20/-4.5	65.10	
			Post-treatment	5980	124	-1.9	115.16	77
9	Elk City 1	I/W	Pretreatment	6009		0.80	206.80	
			Post-treatment	18900	215	-2.50	400.65	94
11	Brannon 1	I/W	Pretreatment	10000		-0.9/20	124.54	
			Post-treatment	17300	73	2.81	177.05	42
14	Davis 1	I/W	Pretreatment	23700		1.20	224.79	
			Post-treatment	30400	28	2.50	291.51	30

Table 2—Lab Analysis Summary Results

Well	Identity	Acid Solubility 15% (1 hr)
Elk City 1	Smectite - large	88.35%
	Mackinawite - large	
	Halite - moderate	
	Dolomite - moderate	
Brannon Ramsey 1	Anhydrite - moderate to large	72.71%
	Dolomite - moderate to large	
	Quartz, calcite, halite - small	
	Mixed layer clay - small	
	Amorphous - moderate	
O. E. Beegle	Mackinawite - large	81.38%
	Dolomite - moderate to large	
	Ca-Siderite - moderate	
	Mixed layer clay - moderate	
	Calcite, unidentified - small	
Ensey 1	Dolomite - large	75.92%
	Halite - large	
	Calcite - moderate	
	Mackinawite - moderate	
	Amorphous - moderate	
	Quartz - small	
	Unidentified - small	

Table 3—Results of Testing on Wells Treated with FOT

Well	Q ₁₀₀ (%)	Mcf/D
OE Beegle 1	19.0	3,302.5
Marcum 1	22.0	3,618.1
Brannon 1	92.2	8,354.4
Ensey Consolidated 1	40.1	5,852.1
Elk City 1	43.2	4,232.8
Beegle TECI 1	31.2	3,186.5
Ensey Rubana 1	65.8	5,066.6
Davis 2	14.1	1,824.0
Thompson 1	21.0	3,330.7
E. L. Hawkins 1	15.3	1,044.6
Rutherford 1	43.0	2,998.8
C.L. Hixson 1	19.8	343.1
O'Shuskey 2	40.8	305.4
O'Shuskey 3	-13.2	-258.3
	Average	Total
	32.45%	43,201.30



Fig. 1— Fluid oscillator (FOT) used with CT.

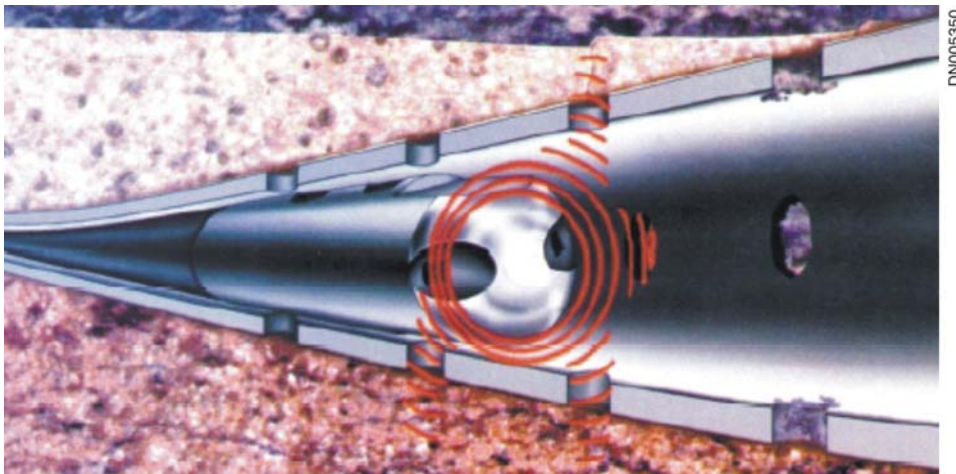


Fig. 2— Pressure waves expand spherically, providing 360° coverage while FOT is moved through the interval. As damage is removed, waves penetrate deeper into the formation.

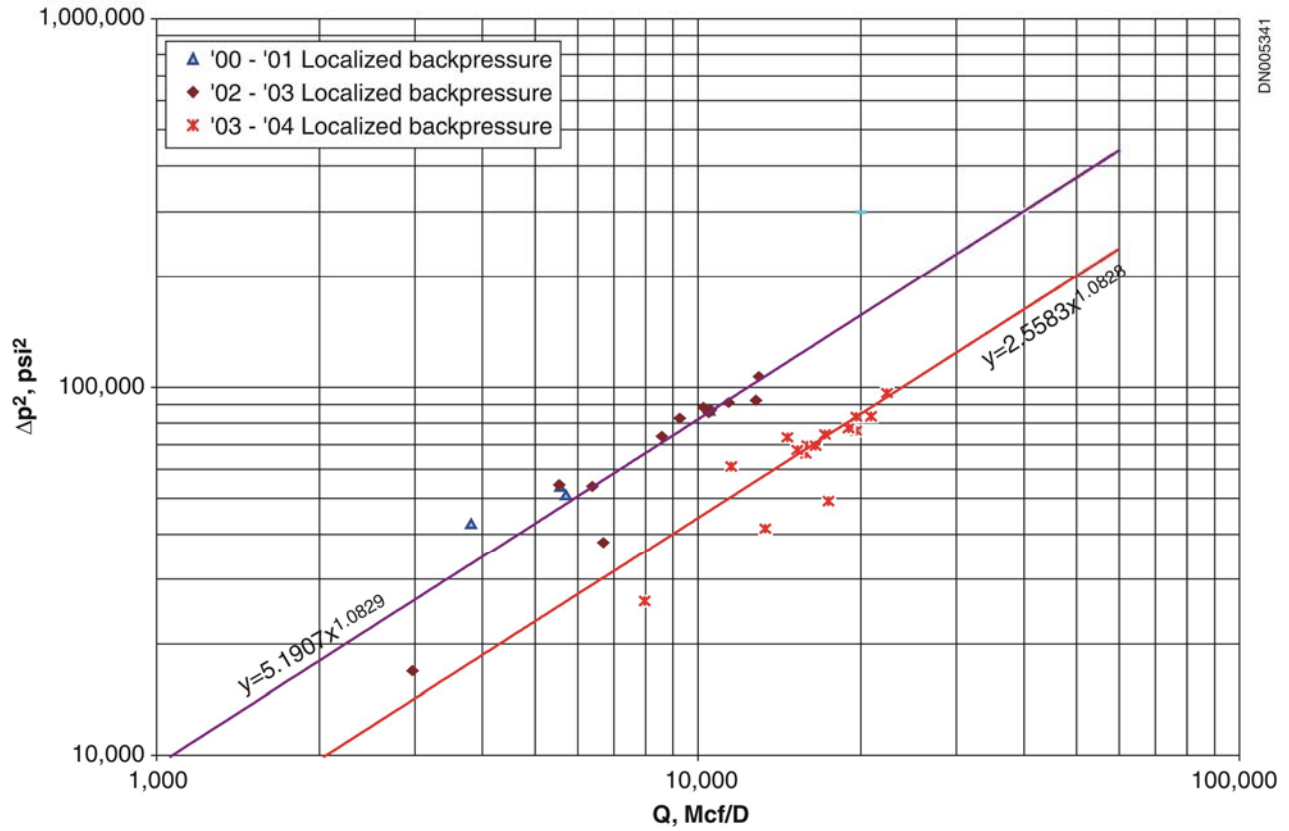


Fig. 3—Brannon 1 well backpressure test results from withdrawal data.
 Note: '00 - '01 observation data only available on a monthly basis.

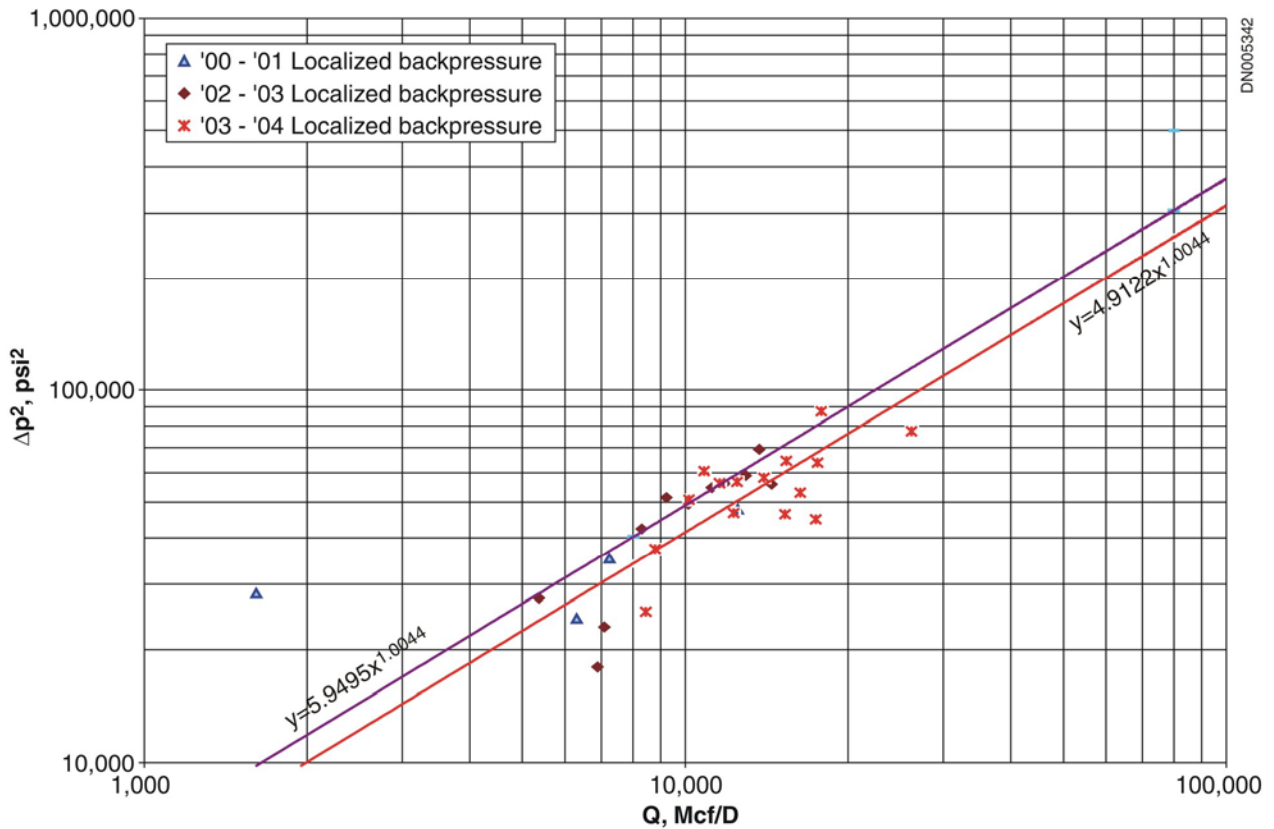
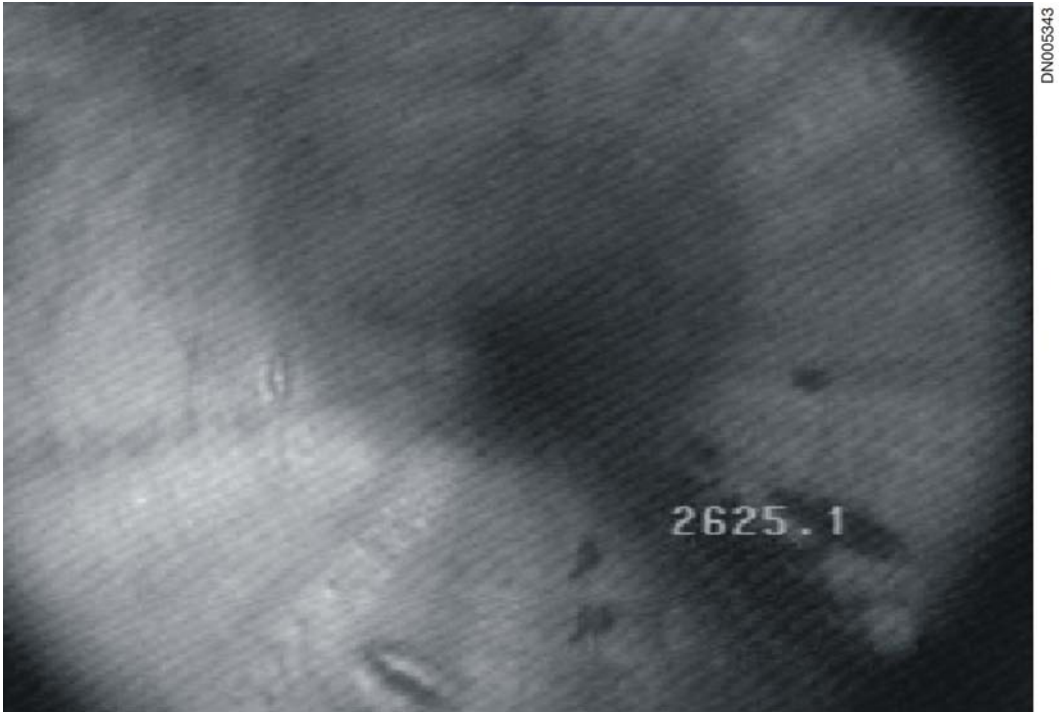


Fig. 4—Backpressure test results from withdrawal data for the Davis 1 well show a shift from a lower EOF to a higher EOF potential using the SIP process. Note: '00 - '01 observation data only available on a monthly basis.



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Fig. 5— Hawkins 1 well video before CT cleanout.



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Fig. 6— Hawkins 1 well video after CT cleanout.

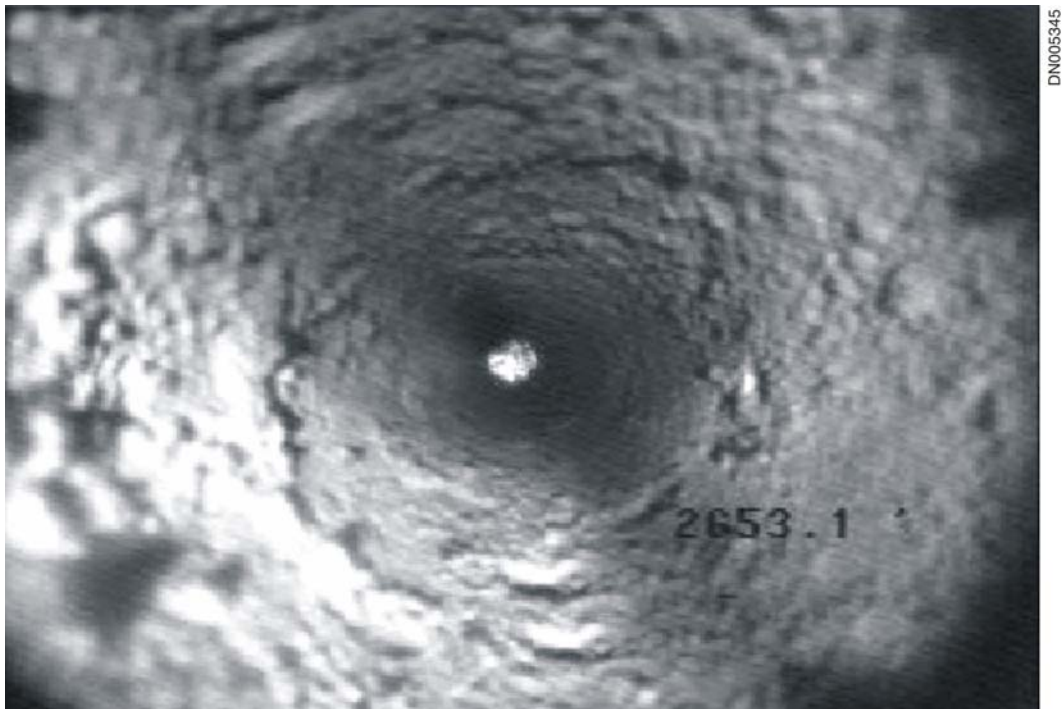


Fig. 7— Elk City 1 well video before CT cleanout.



Fig. 8— Elk City 1 well video after CT cleanout.

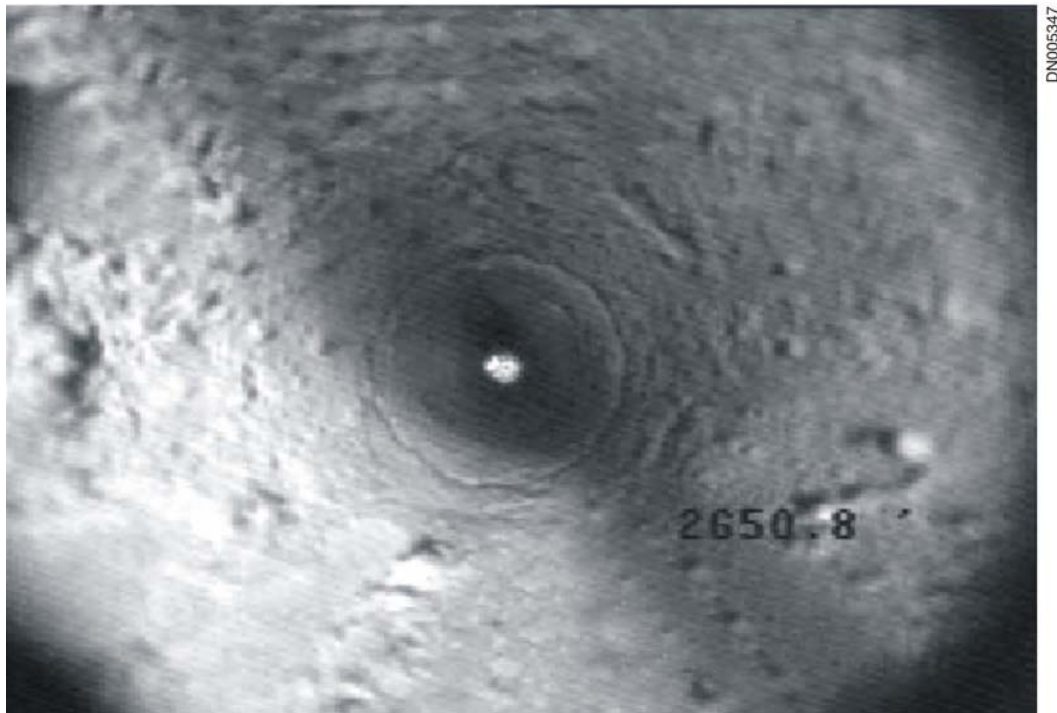


Fig. 9— Davis 1 well video before SIP treatment.



Fig. 10— Davis 1 well video after SIP treatment.

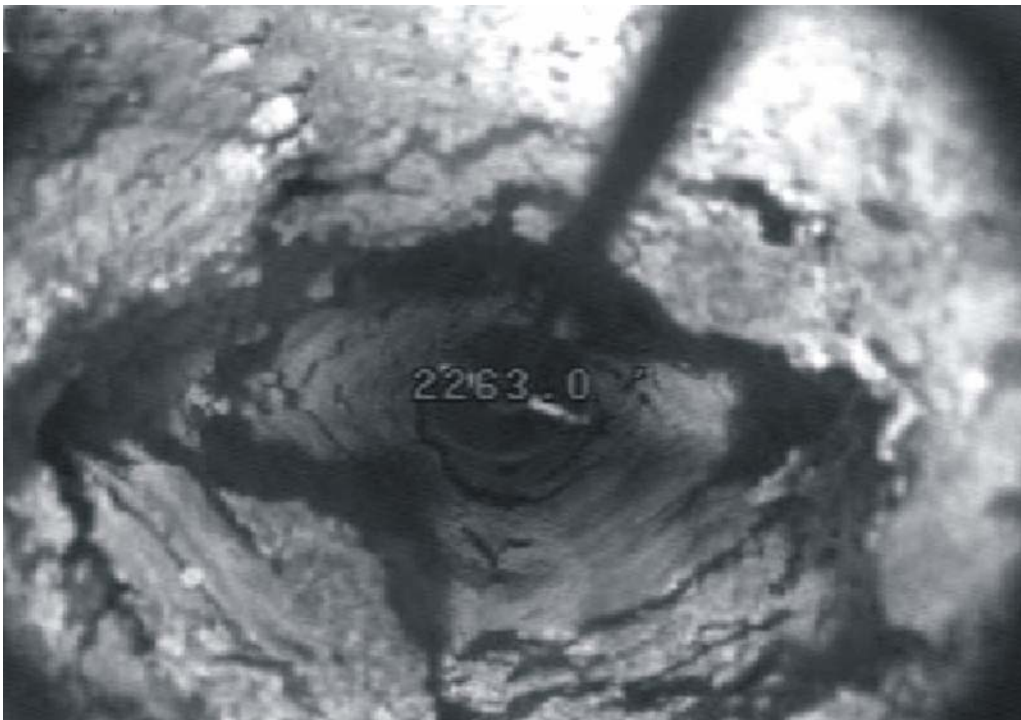


Fig. 11—Gas storage well ("A") video before treating with CT treatment.

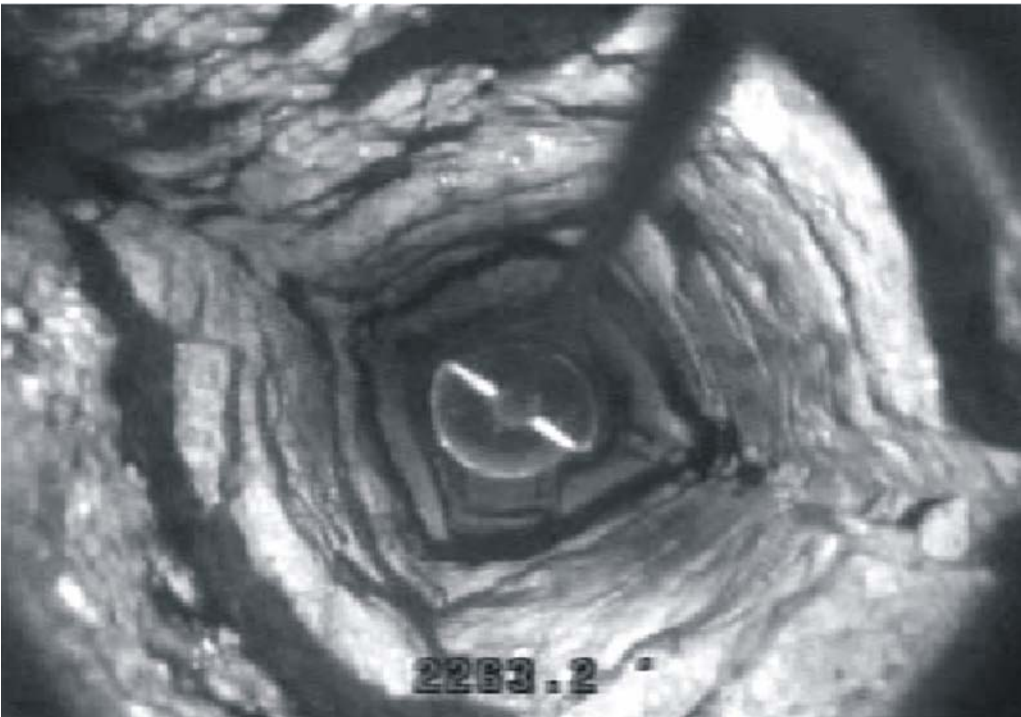


Fig. 12—Gas storage well ("A") video after treating with CT treatment.

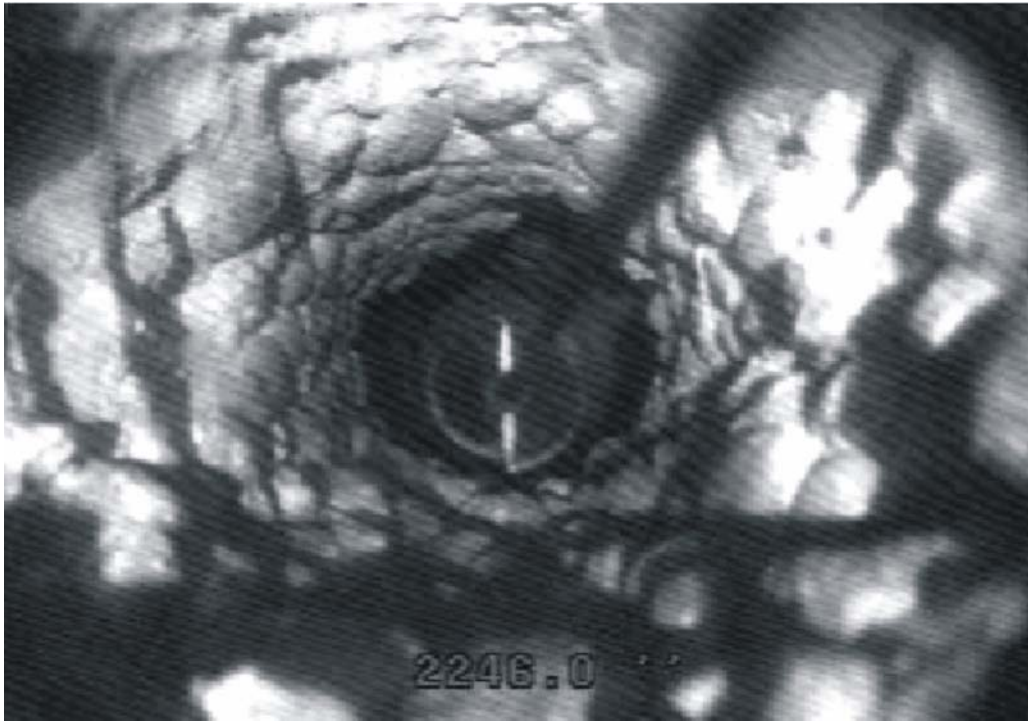


Fig. 13— Gas storage well (“B”) video before CT cleanout.



Fig. 14—Gas storage well (“B”) video after CT cleanout.