WELL REMEDIATION USING EXPANDABLE CASED-HOLE LINERS – SUMMARY OF CASE HISTORIES

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INTRODUCTION

Even with rapidly evolving technology, important issues that continue to challenge the oil and gas industry include conservation of hole size, hydraulic isolation of selected zones, maximization of well life, and economic feasibility. Addressing these issues with conventional tubular technology became more difficult, especially in deep-drilling and extended-reach applications, in wells using liner hangers, and in aging wells containing deteriorating casing. Solid Expandable Tubulars (SET), a revolutionary technology, successfully addresses these issues in commercial applications.

The basic piece of equipment that underlies SET technology is a mechanical expansion device known as an expansion cone that is propagated through downhole tubulars using hydraulic pressure. The movement of the cone expands the tubulars to the desired internal and external diameters in a plastic deformation process known as cold drawing.

In drilling applications, a specially designed, expandable liner hanger conserves hole size by eliminating the need for a conventional liner hanger/liner hanger packer, and provides a superior pressure seal compared to conventional technology. In cased wells, expandable casing is clad to existing casing to repair or strengthen the existing casing with minimal decrease in wellbore inside diameter (ID) and flow potential. SET solutions have been successfully installed in the Gulf of Mexico, in U.S. inland wells, as well as in large-scale field trials.

This paper briefly describes the technical concepts upon which SETs are based and gives an overview of their applications. The paper then focuses on two recent field installations where cased-hole liners were used to help increase well productivity.

TECHNOLOGY OVERVIEW

Previously published papers have discussed the concepts of SET technology[1] and the effect of the expansion process on the system's tubulars[2, 3] and connectors[4]. In this light, the basics of SET technology will be reviewed, and the emphasis will be on how this technology was applied to remediate wells to increase productivity from subsequent operations.

The Expansion System Operation. The underlying concept of solid expandable casing is cold drawing steel tubulars to the required size downhole - a process that is mechanically very unstable by its nature. Thus, there are many technical and operational hurdles to overcome when taking the cold working process and accomplishing it in a downhole environment.

An expansion cone mechanically deforms the pipe permanently **(Fig. 1).** The cone is propagated through the tubular by a differential hydraulic pressure across the cone itself and/or by a direct mechanical pull or push force. The differential pressure is applied by pumping through a workstring connected to the cone, and the mechanical force is applied by raising or lowering the workstring. The progress of the cone through the tubular deforms the steel past its elastic yield limit into its plastic deformation region, stopping short of its ultimate yield strength **(Fig. 2).** Expansions of over 25%, based on the ID of the pipe, have been accomplished. Most applications require expansions of less than 20%.

At the bottom of the system is a canister containing the expansion cone. This canister is called the launcher and is constructed of thin-wall, high-strength steel and has a wall thickness less than the expandable casing. The thinner wall results in a launcher with an outside diameter (OD) that is the same or less than the drift of the previous string of casing. This design enables the launcher to be tripped into the hole through the previous casing string.

An elastomer-coated hanger joint is positioned at the top of the expandable system (and just above the launcher for cased-hole applications). The difference in the OD of the expanded tubular and the ID of the base casing allows the elastomer wrapped expanding pipe to be "clad" (sealed) to the previous casing string. After expansion, the result is expanded pipe with an OD greater than the OD of the launcher (due to the small wall thickness), while the ID of the pipe expands to the same ID of the launcher.

SOLID EXPANDABLE TUBULAR PRODUCTS

The following expandable products are derived from SET technology:

- Expandable Openhole Liner (OHL) System
- Expandable Cased-Hole Liner (CHL) System
- Expandable Liner Hanger (ELH)

Expandable Openhole Liners. The OHL system is used to overcome operational problems associated with borehole instabilities, pore-pressure/fracture gradient issues, and the effects of salt or subsalt formations. The OHL is run through the existing casing or liner and positioned in the open hole. The expandable OHL is then expanded from the bottom up. When the expansion cone reaches the overlap between the expandable OHL and the existing pipe string, the cone expands an elastomer wrapped hanger joint to provide a permanent seal between the two strings.

OHLs are expanded from the bottom up due to the shortening of the liner during expansion and because it is easier to generate greater forces by pumping through and pulling on the workstring than it is by adding weight to the workstring.

Liners are often difficult to position at their planned total depth, and consequently may be positioned somewhat higher. A top-down expansion would first anchor the expandable liner in the previous pipe string, and the ensuing expansion would shorten the liner from the bottom up. The shortened, expanded liner may not cover an adequate interval at the bottom of the hole. A bottom-up expansion first anchors the expandable liner at its lowest depth, and the subsequent shortening experienced during the remaining expansion occurs in the overlap. Liner coverage at the bottom of the hole is thus ensured.

Because the workstring is already being pulled out of the hole as a part of the bottom-up expansion operation, additional tensional forces can be added to the workstring, if necessary, to serve as a secondary force to drive the expansion. With a top-down expansion, downward force or additional weight to the workstring would serve as the secondary expansion force, placing the workstring (drill pipe) in compression. Drill collars and heavyweight drill pipe would be needed as part of the workstring to supply additional weight. This would only add time to workstring makeup with minimal compressional forces being added in comparison to the tensional forces available. For example, propagation forces in expandable operations when expanding 13-3/8 in. casing can approach 300,000 Ib. The casing's size and mechanical properties typically determine the propagation forces required to expand the liner.

The following steps outline the running sequence for the installation of the expandable OHL **(Fig. 3):**

1. Drill the hole section to facilitate the expandable liner installation.
2. Run in the hole with the expandable liner, expansion assembly, and launcher.
3. Cement the expandable liner.
4. Install the latch-down plug to facilitate liner expansion.
5. Expand the expandable OHL.
6. Expand the expandable liner hanger joint.
7. Drill-out the expandable liner float shoe.

Expandable Cased-Hole Liners. The CHL system is used to repair or reinforce existing casing. The system is mechanically similar to the expandable OHL system except that the elastomer wrapped hanger joints are located at both the top and the bottom of the assembly.

The CHL system can be run in two modes: open-ended system or bull-plugged. In the open-ended system mode, the latch-down plug is pumped after the system has been run into the well and positioned. In the bull-plugged mode, the system is run into the well and positioned with the latch-down plug in place. In the latter mode, the liner is filled with fluid when run to prevent collapse. Because the bull-plugged mode eliminates one operational step, thus reducing time on location, this mode may be preferred in shallow and low-pressure environments.

The following steps outline the running sequence for the installation of the expandable CHL **(Fig. 4):**

1. Run the bit and scraper assembly to clean the casing of scale and corrosion.
2. Evaluate the casing to determine its integrity, ID, wall thickness, and ovality.
3. Run in the hole with the expandable liner, expansion assembly, and launcher.
4. Install the latch-down plug to facilitate liner expansion.
5. Expand the expandable CHL.
6. Pressure test the expanded liner.

7. Drill out the expandable liner float shoe.

Expandable Liner Hangers. The ELH system is run when a conventional liner is used. Machined from a single bar stock, the ELH joint does not have the threads, slips, j-slots, and weep holes found in conventional liner-hangers. A wiper-plug system or a subsurface-release plug kit is attached to the bottom of the joint. Inside the joint, a toroidal expansion cone, mounted on a mandrel, runs the length of the joint. Collets lock the mandrel to the bottom of the joint, supporting the liner's weight and allowing the liner to be rotated and reciprocated during installation. Tests have indicated that the ELH system provides a better pressure seal when compared to conventional liner hanger systems with packers.

The following steps outline the running sequence for the installation of the ELH **(Fig. 5):**

1. Drill the hole section to facilitate the conventional liner installation.
2. Run in the hole with a conventional liner with the expandable liner hanger attached.
3. Cement the conventional liner.
4. Install the latch-down plug to facilitate ELH expansion.
5. Expand the ELH.
6. Remove the ELH running tool.
7. Drill out the conventional liner float shoe.

EXPANDABLE APPLICATIONS

Probably the most significant advantage of solid expandable products is its enabling technology. Currently, certain critical wells can not be drilled to their objectives without SET technology. An example of this would be ultra deepwater wells (over 5,000-ft TD), where the operator uses every casing string available in the well design, yet the drilling environment requires more casing points than there are casing sizes.

Cost-effective Well Remediation. The first step in any well remediation plan is to fully evaluate and understand the condition and make-up of the casing in the well. Often wells that were drilled in the 1940's and 1950's have very little data on the weight and grade of casing installed during their creation. In fact, because the API casing standards did not come into existence until later, the variation of casing sizes (IDs and ODs) and weights was extensive. Because the casing "wear" can originate from erosion either inside or outside of the casing, electric wireline logs must be run to evaluate the current condition of the casing. Knowing the condition of the casing allows for effective placement of the Expandable Cased-hole Liners.

It is critical to have the elastomeric sealing elements of the Cased-hole Liner expanded onto pipe of good integrity both inside and out. Placing the liner over casing that currently has a hole or leak path in it does little good if there is severe casing "rot" from the outside of the casing just beyond the end of the expandable solution. The resulting expenditure will only be a temporary remediation.

Using electric wireline logs, such as those generated by an ultrasonic acoustic pipe inspection tool, casing can be evaluated to determine its inside and outside integrity, ID, wall thickness and ovality. At the same time the quality of the cement bond can be evaluated to determine if remedial action is needed to achieve the necessary hydraulic isolation over the interval. Use of these logs greatly improves the chance for an effective expandable solution. Alternatively, if the casing's outside condition is known, a multi-fingered caliper can be used to accurately determine the ID within 0.05 in. and the casing's inside condition.

The following wells used SET technology to address significant operational downhole challenges that demanded the utmost of the mechanical, metallurgical, and physical properties of the post-expanded tubulars[5, 6] These applications required expanded tubulars hundreds of feet in length, with collapse ratings similar to conventional oil country tubular goods (OCTG), and with enough mechanical integrity to allow the operator to either drill through or traverse the string without incurring significant damage.

Case History #1. The William Miller Gas Unit #2, Well #4 was drilled in 1989 to a TD of 7768 ft. and completed with 5-1/2", 15.5 lb/ft K-55 casing. The zones originally perforated in the dual-completed well included three in the Boonsville (Bend Conglomerate, Gas.) Field, 5,960 to 5,970 ft., 6,237 to 6,242 ft., and 6,416 to 6,423 ft.. and zones in the Newark, East (Barnett Shale) Field, 7,416 to 7,629 ft. The three Atoka Conglomerates zones were tested and commingled together producing up the casing tubing annulus. The well produced as such until a workover plan was initiated to re-stimulate the Barnett Shale and test additional zones below the upper completions. The workover plan called for covering or abandoning the shallower zones to adequately stimulate and produce the entire Barnett Shale interval from 7,215 to 7,629 ft.

A frac job was needed to re-stimulate the production from the original Lower Barnett Shale zone and stimulate additional perforations in the Upper Barnett Shale. However, the calculated rates and necessary pressures for the frac job were too large to use a standard tubing and packer arrangement. The existing 5-1/2 in. casing was used as the fracture conduit to achieve the desired rates and pressures. One scenario considered for isolating the shallower perforations consisted of a cement squeeze. However, due to the anticipated high pressure required for the subsequent frac job, a more robust solution was needed. An expandable CHL was developed that was used to isolate the shallower perforated zones.

The CHL installed in this well was 569 ft before expansion **(Fig. 6).** The CHL measure 4-1/4 in. OD (10.7 lb/ft) and was clad inside the 5-1/2 in., 15.5 lb/ft well casing. The expansion resulted in a 16% increase in ID of the expandable casing and a decrease of 4% in length (post-expansion length was 546 ft). The resulting mechanical properties of the expanded casing included the following:

- internal yield of 6,840 psi
- collapse of 3,770 psi
- ID of 4.349 in.

Installing four elastomer hanger joints, using one in between each zone, isolated the three perforated zones. The isolation of each perforated zone allows for later re-completion of one or more of the zones, if desired.

Following the successful installation of the expandable Cased-hole Liner, the well was fractured down the 5-1/2 in. casing with the liner installed opposite the upper completion. A maximum fracture pressure of 3,637 psi, at 65 bbl/min successfully stimulated the lower zone. The resulting production increased from 100,000 scfiday to 1,500,000 scf/day, an increase of 1,500%.

Case History #2. The W. A. Askey Well #1 was drilled in 1989 to a TD of 8,010 ft. and completed with 5-1/5 in., 17.0 lb/ft K-55 casing. After perforating from 7,514 to 7,740 ft. and acidizing, the Barnett Shale was abandoned. The well was initially completed in three Atoka Conglomerates from 5,886 to 5,900 ft, 6,050 to 6,072 ft, and 6,181 to 6,191 ft and placed in the Boonsville (Bend Conglomerate, Gas) Field. Like the William Miller well, the workover strategy for the Barnett Shale consisted of covering over the higher zones to stimulate and produce deeper zones in the wellbore, 7,229 to 7.740 ft.

The CHL solution was selected to address the anticipated high frac pressures and volumes. The CHL installed in this well was 469 ft in length before expansion **(Fig. 7).** The CHL was 4-114 in. diameter (10.7 lb/ft) that was expanded and "clad" inside the 5-1/2 In. 17.0 lb/ft casing in the well. The expansion increased the CHL ID 14.3% and decreased the length 4% (post-expansion length was 450 ft). The resulting mechanical properties of the expanded casing included the following:

- internal yield of 6,960 psi
- collapse of 3,940 psi
- ID of 4.287 in.

Again, installing four elastomer hanger joints, using one in between each zone, isolated the three perforated zones. The isolation of each perforated zone allows for later re-completion of one or more of the zones, if desired.

Following the successful installation of the expandable CHL, the Barnett Shale formation in the well was successfully fracture stimulated down the 5-112 in. production casing string. A fracture stimulation pressure of 3,890 psi, at 58 bbl/min successfully treated the lower zone. A second fracture stimulation was performed on the previously untested Upper Barnett Shale formation from 7,229 to 7,317 ft with a maximum treating pressure of 3,943 psi at 55 bpm. Following the stimulations, a commingled Upper and Lower Barnett Shale production was established at an average of 650 MCFD.

Application Evaluation. Expandable products are not a panacea for all operational problems involving downhole tubulars and little more than a novelty if cost-effective applications are not the end result. The economics of SET products must work for the long-term benefit of the operator.

Careful consideration must be given to the economics when evaluating candidates for well remediation. Factors such as replacement cost of the well, lost production, indirect costs such as site remediation, and the direct costs of the intervention, all must be weighed against the benefit of extending the life of the well. Situations that lend themselves to economic feasibility include:

- Larger hole size and/or greater mechanical properties for additional production and/or production enhancement.
- Marginal wells that develop leaks. Expandable products are a viable alternative when other remedial techniques such as cement squeezes fail, and the production does not justify running a full steel liner.
- Isolating zones in an openhole completion to reduce production of water. Rather than leave behind recoverable reserves when the oil/water ratio becomes unfavorable, expandable products can be used in conjunction with cement to isolate viable producing intervals from those producing water.

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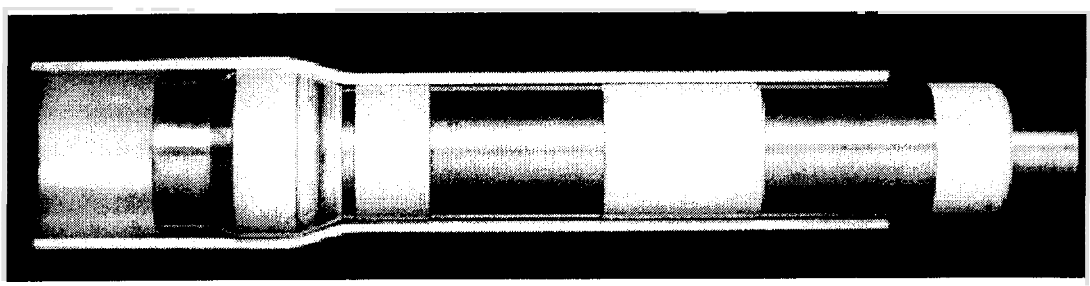

Figure 1 – Early Expansion Cone Used to Expand Solid Expandable Tubulars

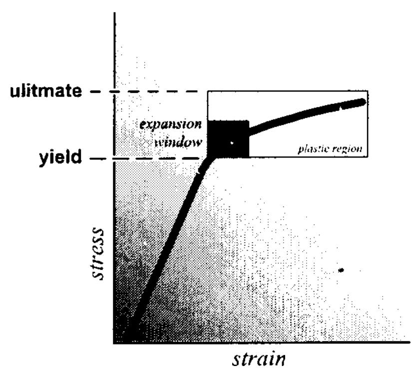

Figure 2 – Stress/Strain Curve for Solid Expandable Tubulars

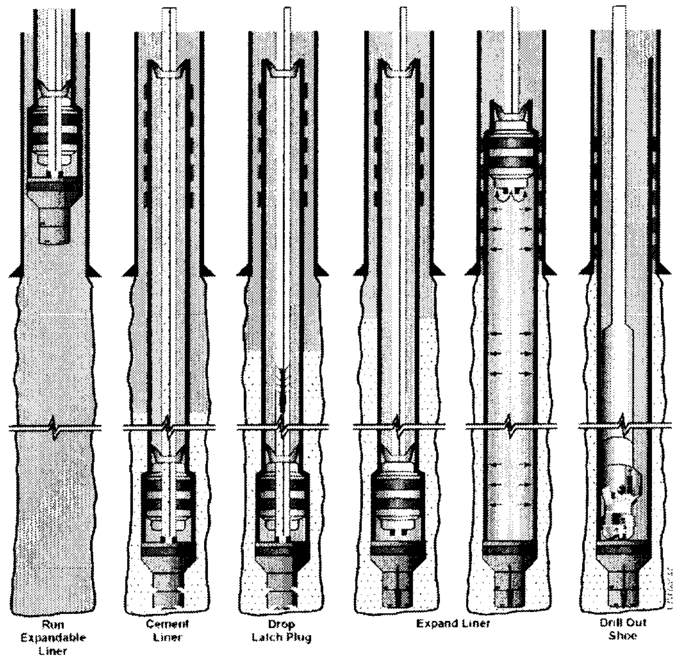

Figure 3 – Operational Running Sequence for Openhole Liner

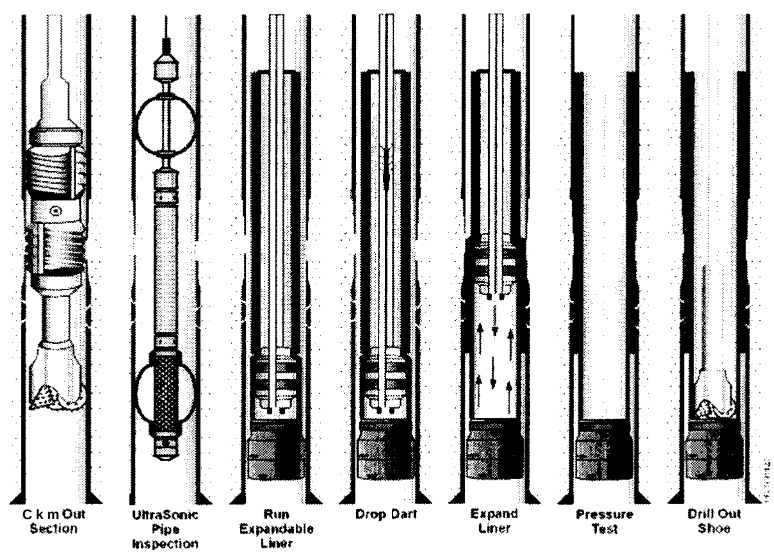

Figure **4** - Operational Running Sequence for Cased-Hole Liner

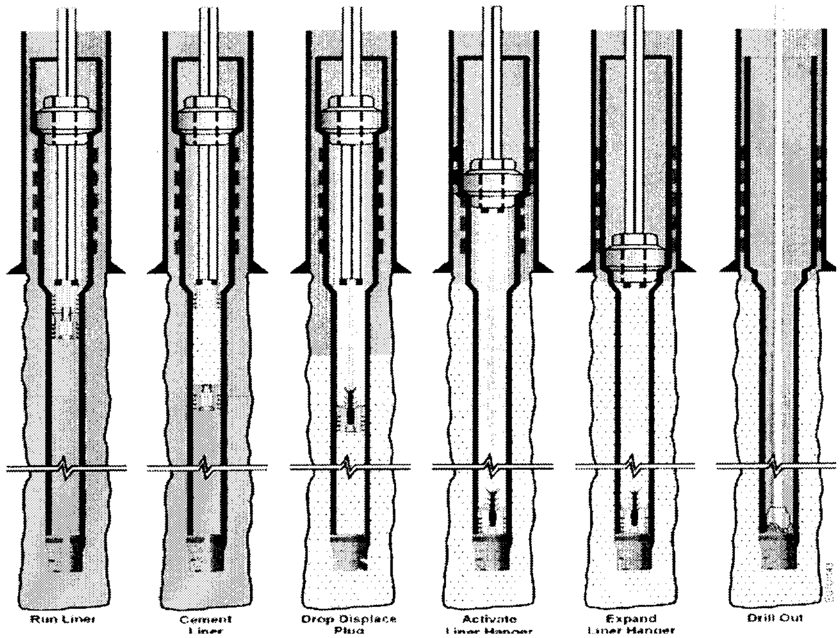

Figure 5 - Operational Running Sequence for Expandable Liner Hanger

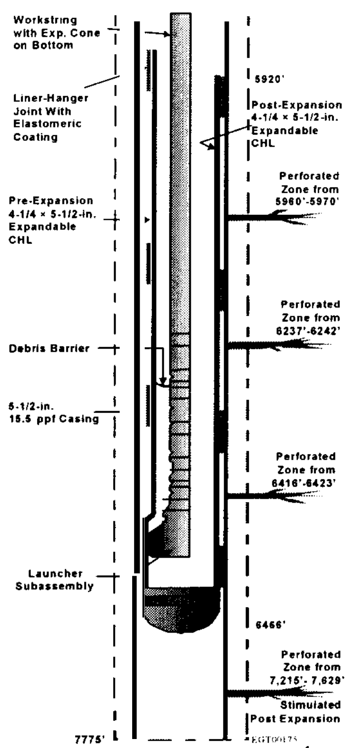

Figure 6 - Well Schematic for the William Miller Gas Unit #2, Well #4

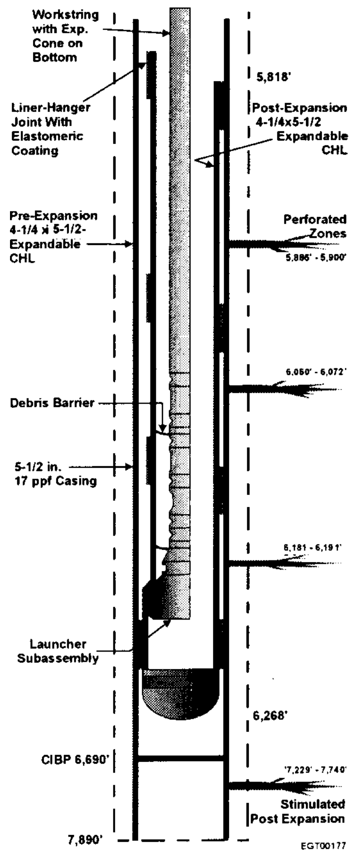

Figure 7 - Well Schematic for the W.A. Askey #1