Solid Expandable Tubular Technology: 
The Value of Planned Installation vs. Contingency

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Abstract

Narrow pore pressure/fracture gradient windows commonly encountered in deepwater Gulf of Mexico (GoM) often require additional casing strings to reach the objective depths. The inability to make accurate predictions for pore pressures and fracture gradients may result in casing strings that do not reach the designed depth. Because of the limited number of conventional casing strings that can be run, operators attempt to push casing points, which can result in loss circulation, well ballooning, well flows and other operational difficulties.

Planning a solid expandable tubular in the upper sections of the well design preserves hole size from the onset and allows more casing strings to be run, without having to push casing points to the frac-gradient limit. Preserving hole size contributes to drilling efficiency, reduces equivalent circulation density (ECD) and minimizes risk associated with small hole size in deeper sections of the wellbore.

Running expandable tubulars reactively deeper in the well denotes more of a “survival” mode when operating parameters are more severe. Planned installations allow operators and engineers more time to assess how best to optimize the expandable tubular design. More time also permits analysis of details, such as the shoe joint, base casing connection and base casing weight, to obtain the desired pass through and drill out. Solid expandable tubulars run in the upper hole section still allow for contingency expandable liners in the deeper sections, if required.
This paper compares two deepwater offset wells in Mississippi Canyon. In the first well, expandable casing was set deep and used as a contingency casing string. The second well incorporated a planned solid expandable tubular high in the wellbore as part of the base design. This paper explains the planning process for the second well and how this process optimized the use of a planned expandable liner. The planned expandable system in the second well also contributed to operational efficiency. The second well was drilled to depth in 48 days as opposed to the 140 required by the previous operator in the block to reach an equivalent depth on the first well. Actual pore pressure and fracture gradient data from the first well was used in the design of the second well.

**Introduction**

Even the best well designs fall prey to modifications when formations and formation pressures differ from that in the original plan. Contending with narrow pore pressure/fracture gradient windows, fighting loss circulation zones or experiencing borehole instabilities can create a minor inconvenience at best or wreak havoc at worst on wells that require a particular hole or casing size at total depth (TD). An effective well plan that addresses both known and potential formation challenges uses best practices that employ a peer review design process, risk assessment, contractor management plan and a management of change process.

**Expandable Application History**

The history of solid expandable tubular applications is relatively short considering the technology was first field tested in 1999. Although many expandable systems have been used as last-resort contingencies to preserve hole size, the technology has also been applied as a planned measure to mitigate difficult drilling conditions and preclude problems associated with challenging formations. The more advantageous approach is to plan the expandable system into the well design thereby allowing the engineer more time to optimize the technology and ship the equipment.

This case-in-point is illustrated with nine solid expandable tubular installations by the current operator in the GoM. Eight of the expandable systems were unplanned and run as contingencies while one was planned into the well design. The application of the planned expandable system was a textbook installation. Of the eight contingency applications, four were textbook installations, two did not get a good pressure test, one failed during installation and one failed post-installation. Two of these eight contingency liners were installed in a single well in the Mississippi Canyon and had to be run to reach the TD objective. The solid liners were expanded in a distressed well with wellbore ballooning, flowing and sticky formations. Although both solid expandable liners were successfully set and the operator reached the planned TD, additional trouble time was associated with each liner due to the deeper depths and the hole conditions experienced while running the expandable liner.

**GoM Drilling Conditions**

As operators push into greater water depths and deep shelf exploration opportunities, drilling engineers are required to design wells to much deeper objectives, through higher pore pressure transition zones and through steeper gradient drops in depleted zones. The traditional solution to drilling in narrow pore pressure/frac gradient windows is to run more casing. Currently, operators are limited to the number of conventional casing strings that can be run through the
wellhead. The large-bore subsea wellhead and tight tolerance liners can add casing strings to the well design, but the maximum is typically six casing strings. Many ultra-deepwater wells with target objectives of 30,000 feet and greater require eight or more casing strings to reach TD with an acceptable hole size. Without the capacity to run additional casing strings, the potential for borehole instability increases. Results of these instabilities include well flows, mud losses, rubble zones, wellbore ballooning and equivalent circulating density (ECD) problems. Solid expandable liners provide the only means to run additional casing strings through subsea wellhead equipment.

**Well Design Theory and Best Practices**

Establishing a design process with standard operating procedures (SOP), best practices, a contractor management plan (CMP) and then implementing the process in the field has made the current operator a leader in deepwater drilling performance. This operator’s well design approach ascertains that the basis of any well design is an accurate pore pressure and frac gradient prediction. A cross-functional team consisting of geophysicists, geologists and drilling engineers develop a pore pressure and frac pressure prediction based upon seismic, regional and nearby offset data models. From the pore pressure and frac pressure prediction, the drilling engineer designs the casing program to obtain the maximum depth that each casing string can be set at without fracturing the previous shoe using a rig-specific kick tolerance and kick intensity safety factor. Drilling deeper into a narrowing pore pressure/frac gradient window requires more casing strings to prevent the drilling operation from straying out of the stability window and into well control and well-ballooning situations.

After casing point depths are selected, the engineer can choose casing and hole sizes for each casing point. From an evaluation, completion, ECD management and bottomhole assembly (BHA) management perspective, the engineer must provide for a sufficient usable hole size plus allow for contingency options due to pore pressure inaccuracy or wellbore problems. If the hole size is too small at the bottom of the well, the engineer performs another iteration of the casing design with larger size casing. Once it has been determined that hole size requirement cannot be satisfied with conventional casing strings, the engineer reconfigures the design using a solid expandable tubular. After the initial well design is established, a complete risk assessment is performed to identify potential risks and to determine actions to help eliminate, mitigate or accept the expected risks. Changes in the plan may result after a formal assessment is performed with the design team.

As part of their best practices approach, this operator advocates planning solid expandable tubular systems if the well design deems it necessary to reach TD with adequate hole size and to mitigate downhole risk. The engineer retains more control of the wellbore by looking for the most appropriate section to install an expandable liner during the design stage rather than in the operational stage. If the engineer considers the solid expandable tubular as only a last resort to drilling problems, choice of size, length, and depth of the installation is dictated by the situation after a problem occurs. These challenges are difficult to plan for and lead to running the expandables in or around hole sections with the greatest risks.

Once it has been determined that an expandable tubular liner is needed, the most appropriate place for running it is determined. Expandables set higher in the wellbore have many advantages over those set lower in the wellbore. Some of those advantages include the following:
The wellbore in general is more stable because the pore pressure/fracture gradient window is larger.

More annular clearance exists between the expandable tubular outside diameter (OD) and the hole inside diameter (ID) than in smaller sizes.

Expansion parameters are lower.

Larger expandables run higher in the wellbore reduce need to use less common casing sizes to run through the expandable liner.

Additional expandable tubulars can be run deeper in the wellbore if needed.

The 13-3/8 x 16 in. solid expandable tubular has the highest reliability rating.

The 13-5/8 x 13-3/8 in. long string covers the expandable tubular.

Designing a solid expandable tubular system for a specific well requires consideration of a number of the operator's best practices and SOPs. The OD and weight of the base casing is fundamental information that governs the design since the tubular expands in the base casing. Additional factors that warrant consideration include the following:

- Inline centralizer ID
- Float equipment
- Shoe joint
- Dogleg severity in the overlap and open hole section
- Liner hangers
- Any other equipment in the base casing that may have a restrictive ID

The Contractor Management Program (CMP) is another part of the design process. By identifying a single source vendor for each service associated with drilling operations, a partnership is formed between the vendor and the operator. Part of the CMP is to develop SOPs and best practices to ensure that learnings from previous jobs are implemented on future jobs. Also, timelines are set for post-job analysis, so that information on the installation is available immediately. When possible, the same personnel are used in the installations since familiarity with the drilling rig and operator personnel reduces potential non-productive time (NPT).

**Putting Well Design Theory into Practice**

Pre-drill well design kick tolerance calculations and actual well information from an offset well in an adjacent block in Mississippi Canyon exposed a tight window between pore pressure and fracture gradient. In the design phase for this GoM well, the drilling engineer determined that running another casing string in this situation would require less time than that needed to address drilling challenges that might be encountered.

To make a practical and informed decision, calculations were run with and without an expandable casing string. Using a solid expandable casing string high in the wellbore resulted in a margin between the mud weight (MW) and the leakoff test (LOT) greater than the minimum required for design purposes. By maintaining hole stability with the margin between the MW and LOT, the chances of maintaining hole integrity were increased, thereby reducing associated flat times.

Approaching the design from two perspectives helped determine that the best use of expandable pipe would be to run it as early as possible in the wellbore. By placing the solid expandable tubular system below the proposed 16-in. casing string, a pass-through ID of 13.950
allowed a 13-3/8 x 13-5/8 in. casing string to be run through and cover the expandable liner. In addition, the placement of this expandable liner would allow for additional expandables to be run below the intermediate casing string if necessary.

The two wells evaluated in this paper both used solid expandable tubulars to reach the desired target. The first well used an expandable as a contingency, while the second well incorporated an expandable into the well design. These wells illustrate how running a solid expandable tubular as an additional casing string not only required less time than NPT associated with hole instability but also required less time than running an expandable in a distressed hole.

**Case Histories**

**Mississippi Canyon Well 1**

The previous operator designed a drilling plan for Well 1 to a TD of 25,000 ft (Figure 1). The operator had considered using an expandable at several points throughout the installation. Since the expandable was being used as a contingency, the drilling engineer evaluated the need for an additional casing string at every casing point. Once 16 in. base casing had been set, a 13-3/8 x 16 in. solid expandable tubular was considered, but the operator elected not to run an expandable at that point. The same situation occurred once the 11-7/8 in. casing and 9-7/8 in. casing had been set. In each case, the risk of the running the expandable was considered to be greater than the risk associated with fighting the well down. The operator fell behind in casing points during drilling operations and was unable to make up the point loss on each casing string set. The operator eventually determined that reaching TD with adequate hole size would not be possible and elected to run a 6 x 7-5/8 in. solid expandable liner.

**Designing the Solid Expandable Tubular System**

This installation was performed two years before the completion of the second case history. While the mechanics of the system did not change, the design considerations did. Previously, openhole liner sizes were based mainly on the base casing OD and weight, and not optimized according to casing-specific criteria such as connection and grade. This new process of tailoring the expandable systems to each well was a result of learnings captured in 2003.

**Installation Preparation**

The operator prepared the hole by underreaming the 6-1/2 in. hole which had been drilled below 7-5/8 in. casing to 7 in. By enlarging the hole section, the expandable could be run to bottom easily without encountering any tight spots or creating a surge situation. In this installation, the operator used synthetic mud and cleaned the hole using best practices. The float was tabbed open (a first for the system) to reduce surge. The operator elected to execute a squeeze cement job on this installation. The squeeze cement job would be performed prior to drilling out through squeeze perforations, thereby eliminating a trip during drillout. A polycrystalline diamond compact (PDC) bit was selected for drillout.

**Installing the Solid Expandable Tubular System**

The openhole liner system installed in this first well extended the 7-5/8-inch casing shoe in order to isolate a hole interval with possible loss circulation conditions. This shoe extension was achieved without having to sacrifice diameter. Approximately 2,000 feet of 6 x 7-5/8 in. solid expandable pipe was run to TD. Expansion pressures required for this installation were within
the expected parameters, at approximately 3,000-3,500 psi. Once expanded, the entire system was pressure tested to 2,750 psi for 30 minutes. This installation, at over 20,000 ft measured depth (MD), was the deepest solid expandable tubular installation of any size at the time of its installation. Also, this installation was the first to be drilled out with a PDC bit.

**Mississippi Canyon Well 2**

The current operator acquired the Mississippi Canyon block and used their experience running solid expandable liners by incorporating them into subsequent drilling designs (Figure 2).

**Designing the Solid Expandable Tubular System**

Designing the system for the second well included many iterations in selecting float equipment and connections for the base pipe. At each iteration, the post-expansion dimensions of the expandable were compared to the ID of the base casing and its components to calculate and evaluate an OD/ID interference report. This report was examined for acceptable levels of interference. The post-expansion ID of the solid expandable tubular system was reviewed to ensure that the appropriate tools are on-hand for the required drill out of the expandable tubular to enable running the next casing string.

Had the desired drillout not been obtained after these iterations, then the overlap section of the base casing could have been further modified. By running a lighter weight casing in the overlap section, a larger post-expansion ID can be obtained, however in this design, modification to the casing joint selection resulted in an acceptable expansion dimension. Once the base casing equipment had been finalized in accordance with the current operator’s criteria, the expandable tubular was designed accordingly. Limiting potential ID restrictions enabled the engineer to design a plan that used the expandable with the largest pass-through ID possible. In this case, the current operator was able to drill out with a 13-3/4 x 16-1/2 in. tricenter bit, as desired, and then run conventional 13-3/8 in. casing.

The operator, pulling from past experience with expandable casing, requested two additional system criteria be considered in addition to the standard information. The first design request was for an eccentric guide shoe to be added to the shoe joint. If there were hole obstructions, then the system could be worked to the bottom of the hole section more easily. The second design request was for a second anchor hanger (which contains the elastomers seals that compress into the base pipe) in the overlap section. By having two anchor hangers in the overlap, the potential that the hole section would be isolated was increased.

**Installation Preparation**

Because the operator knew that running the expandable system required an enlarged hole, the operator chose a bicenter bit (14-1/2 x 17 in.) to drill the hole section, thus saving an underreaming trip. In this installation, the operator used synthetic mud and cleaned the hole using best practices. As in the first case history, the float was tabbed open to reduce surge. The operator elected to execute a primary cement job, where cement is pumped prior to expansion. A 12-hour, two-stage cement slurry, with reduced thickening time and increased compressive strength on the tail slurry, was designed to improve the integrity of the shoe. A tricenter bit was selected for drillout. The operator also planned to utilize offline capabilities of the dual-activity drillship to make up the expandable casing in triples while preparing the hole for installation.
Installing the Solid Expandable Tubular System

The openhole liner system installed in this well extended the shoe of the 16-inch casing in order to drill deeper with a larger diameter. Over 2,700 feet of 13-3/8 x 16 in. solid expandable pipe was run to TD. Once the expandable liner reached the proper setting depth, the surface high-pressure liners, kelly hose and standpipe were pressure tested to 5,000 psi prior to the pumping operation. To initiate expansion, the dart was landed with 364 bbl of mud and the pressure increased to 1,400 psi. Expansion pressures required for this installation were within the expected parameters, at approximately 1,900-2,300 psi. After expansion, the liner was successfully tested for 30 minutes at 1,100 psi.

As predicted, the use of a planned solid expandable tubular system high in the wellbore resulted in significant reduction in flat time. Compared with the first case history, the number of days required to drill this well decreased 65%, from 140 days to 48 days to reach a comparable depth (Figure 3), which resulted in significant cost savings.

Conclusion

Taking full advantage of the solid expandable tubular technology requires incorporating it into the original well design. Preplanning gives the operator more options to address conditions that can result in the following:

- Optimization of system designs that result in desired post-expansion dimensions
- Reduction of risk due to proper planning and risk analysis
- Flexibility in wellbore design by allowing the drilling engineer to have more strings of casing, thereby reducing the chance of drilling outside the pore pressure/fracture gradient window
- Decrease of NPT
- Option of using surface stack technology and still reaching deeper drilling objectives
- Utilization of lower expansion pressures during installation

Instead of being used as just a remedial solution to problems encountered during drilling or production, solid expandable tubulars are an important construction element to drilling “better” wells. “Better” wells reduce costs, minimize environmental impact and/or address challenges proactively.

The current operator was able to capitalize on a wealth of experience and insight by using solid expandable tubular technology and incorporating best practices, lessons learned and the CMP into the design procedures. Since implementing this process, this operator has realized a 100% success rate with the application of solid expandable tubulars worldwide.
Figure 1 – Drilling design for Mississippi Canyon Well #1 case history
Figure 2 - Drilling design for Mississippi Canyon Well #2 case history
Figure 3 – Comparable days versus depth for both Mississippi Canyon wells