Power of Design: Solid Expandable Installation Sets Multiple New Records in Deepshelf HP/HT Well
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Abstract
With each installation of solid expandable tubulars, the opportunity exists to redefine the operating parameters of this enabling technology. A recent planned-in installation of a 6,935 ft (~2,115m) solid expandable openhole liner not only set a record as the longest expandable installation to-date, but also marked the first offshore-well application that combined swellable elastomer technology and solid expandable tubulars.

Operators have relied on solid expandable tubulars to mitigate and manage downhole wellbore problems for several years. However, the recent fundamental change in advanced drilling engineering philosophy is to plan solid expandable liners into the basis of design (BOD) to preserve hole size and reduce non-productive drilling time (NPT). For example, the most-recent record-setting solid expandable openhole liner (7-5/8 x 9-5/8 in.) was planned into the wellbore architecture of a previously drilled well to help explore deeper high-pressure high-temperature (HP/HT) reservoirs approaching 24,000 ft (7,315m) TVD. The swellable elastomers used on the expandable system ensured the required zonal isolation for a successful leak-off test, thereby greatly reducing the possibility for costly cement squeeze operations.

This paper discusses how solid expandable liner systems have facilitated multiple exploration and development projects in the region to address drilling and completion challenges. This paper also describes how combined technologies enable a greater application realm and uses the record-setting case history to illustrate the value gained by planning and using solid expandable technology.

Challenges Inherent to the Gulf of Mexico
The Gulf of Mexico presents inordinate drilling challenges be it from salt and sub-salt zones, pore pressure/frac gradient issues, overpressured and depleted sands, or excessive water and target depths. Although shelf drilling continues to yield significant reserves, ventures into deep and ultra-deep waters are becoming more commonplace with thorough planning, state-of-the-art technologies, and enhanced processes.

Increasing water depths require larger equipment with extra hoisting capacity and more mud-circulating capacity. Drilling in 8,000 to 9,000 ft (~2,450 to 2,750m) of water looking for a target 20,000 ft (~6,100m) below the mud line requires latest-generation drill ships that have the size, horsepower, and lifting capacity to reach these extreme depths. (Massey 2002) Bigger may not always be better when size hinders efficiency, reliability, and economic feasibility. Rather than rely solely on more powerful hardware, a methodology step-change has been possible with innovative software that can model and detect downhole conditions, enhanced chemistry that makes for more effective muds and stimulation treatments, and enabling tools such as swellable elastomers and solid expandable tubulars that can facilitate a stable wellbore.

How DesignAddresses Conditions, Environments, and Situations
Developing a Versatile Tool
One of the ingenious aspects of solid expandable technology is its ability to address a myriad of conditions and challenges. A one-joint expandable system installed in a benign formation has proven to be as effective and efficient a solution as an extended-length expandable liner installed in extreme environments. By trending operator requests and gaining experience of running jobs (trial and error) throughout the years, a suite of expandable tools that met the majority of industry demand was determined. Using a basic design that fits most applications, specifics of each well can be addressed through the modification of a few solid expandable system attributes.
The record-setting Gulf of Mexico installation’s success was determined less by customization of an expandable system and more on it being planned in as a key element in the project strategy. As with any application, this record-setting one required ascertaining the problem, defining the objective, and identifying the best solution. Modifications were then designed for the required system size along with add-ons, such as elastomers, based on objectives and downhole determiners—size, length, and formation.

Variables Considered for System Design per Application

Because the variables in each well differ, the expandable tool system must be flexible enough to support a broad range of well geometries. Restrictions present in a well above the setting point can limit the diameter of the expandable running tool, which may subsequently place a limit on the amount of expansion that may be performed. One of the critical variables adjusted to each expandable installation is the necessary expansion ratio, which is primarily a function of the operator’s required post-expansion pass-through to set subsequent casing strings. Occasionally, the operator may require certain functional properties of the post-expanded solid tubular system, such as specific yield or collapse limit, in which case the expansion ratios are chosen to accommodate those requirements. Another factor may be the openhole size where the solid expandable system is to be installed and the possibility of underreaming the hole. The typical expandable application requires a ratio of post-expanded ID to pre-expanded ID between 4 to 15%, although special applications and systems have been designed with expansion ratios up to 23%.

Requirements for post-expanded drift set the limits of maximum or minimum diameters required to provide sufficient drift for subsequent casing strings, running tools, or completion operations. The fact that the liner is mechanically deformed downhole by the expansion process allows the post-expansion drift to be more accurate with tighter tolerances than standard OCTG casing.

Once the drift is determined the seals must be designed. Seal design involves balancing between a compression rate high enough to anchor the solid expandable system and perhaps hang succeeding liners, and low enough to allow reliable installation at reasonable pressures (Figure 1). Specific wellbore conditions may also affect the seal design therefore seal geometry can be tailored to the specific well application. For example, when repairing older wells where corrosion has weakened or thinned the base casing, a lower seal compression is necessary to prevent damage to the original casing.

The diameter of the launcher, the load-carrying portion at the bottom of the liner, has to be selected to not only drift through the well but to offer the best expansion cone diameter and reduce any swab/surge issues while running in hole.

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Figure 1. Example of seals compressed between solid expandable tubular and casing.
Planned-in Wellbore Architecture

By incorporating the solid expandable tubular system from the initial outset, an operator can achieve a slimmer well profile while still maximizing hole size at TD, reduce drilling time to TD, and reduce overall drilling costs. Operators with offshore projects have used these systems to capitalize on the existing infrastructure with sidetracking or slot recovery operations. Reservoirs that were previously out of reach because of economic factors or technical constraints have become much more accessible.

Expandables planned as part of the well design avails more options. Application objectives and wellbore fluids are determining factors when selecting seal materials that best suit the needs of a hostile or high-temperature environment. The material used for the seals range from standard viton to high-temperature aflas to specialty swellable rubbers designed for an individual well. Planning a system enables more customization to the application (Figure 2). Obstacles such as unusual well restrictions from partially collapsed casing, ID upset connections to float collars, and wellhead restrictions can be overcome. Exceptionally long liner lengths may be run by modifying the launcher. Fit-for-purpose expansion systems can be designed to reduce drill out, enable longer liner lengths, increase post-expansion ID, and provide cost savings. Seizing application opportunity rather than waiting on trouble-oriented need optimizes the technology and the installation process.

Figure 2. Solid expandable pipe wrapped with high-temperature elastomer seals.

Planned

As planned-in contingencies, solid expandable tubulars allow for aggressive well designs in the event of trouble zones or unexpected problems. Exploratory well designs have used expandable systems as contingency strings to achieve the set targets and discovery objectives. Solid expandable tubulars are a cost-effective alternative in the well design when drilling the unknown. These systems integrated into the BOD as an element in field development projects enables completion consistency whether or not the well requires an expandable solution.
Technical Ingenuity
System Attributes that Enable Technical Integration

Certain attributes of specific well applications need to be considered when planning an expandable job, especially when being used in conjunction with other technologies. If designed into the initial well plan, certain openhole sizes can enhance the benefits of the systems. In one example, an operator was able to eliminate the usual squeeze job by drilling a certain size pilot hole because a solid expandable system with swellables was an integral part of the BOD. A similar well previously drilled without the sized pilot hole had to be squeezed seven times. Preparation for a job can vary based on the type of expandables being used and the installation environment (wellbore condition and formation characteristics) of the installation.

Conventional installation usually requires underreaming or hole enlargement to expand and cement the liner. In another example, a hard rock formation enabled an operator to plan in solid expandable systems with swellable elastomers to attain zonal isolation without underreaming or cementing. Zonal isolation was achieved by setting the elastomers at the shoe of the expandable liner. The operator estimated that by dispensing with these steps, an additional four to six days of rig time was saved. (Wallace 2009)

Combined Technologies – Examples of Application and Value Added

**Swellable Elastomers**

Swellables can be used in place of the standard elastomers on solid expandable systems. Depending on the fluids and type of swell needed, a specific compound for the application is wrapped through a cold-wrap process and bonded in an autoclave directly to the expandable casing. The swellable elastomer is made over-sized so that it can be ground down to the specific thicknesses needed for the application.

While expandables themselves are a value-adding technology, the results are multiplied when combined with other complementary technologies. This integration with swellables is possible because of the time required by most elastomers to swell before they are activated. Compression from the expansion process enables the swellable to attain an immediate seal. Greater compression is also realized from the activated elastomer as it swells, which leads to a more reliable seal and isolation.

**Pinpoint Fracturing**

Either a combination tubular cladding system or a solid expandable system can provide an integral component in new wells or re-entry wells where low-permeability reservoirs, such as those characteristic of unconventional gas formations, require isolation and separation for selective or pinpoint hydraulic fracturing or re-fracturing. (Durst 2009)

**Jet Perforating**

Fracturing methods that focus on treating intervals individually can result in many hours of NPT mainly as a result of discrete process steps that require trips in and out of the well between treatments while pumping equipment resources remain idle or are required to leave and return to the well site. These discrete steps include trips for perforating, setting or moving tools such as bridge plugs, and wellbore cleanouts. (East 2008) A solid expandable system equipped with swellable elastomers and combined with hydrajet perforating and fracturing methods require only a single trip in to install the expandable swellable production conduit and a single trip in to carry out all the perforating, fracturing, and cleanout operations (and if required, the production kickoff). (Durst 2009)

**Smart Completions**

Solid expandable liners deployed as enablers in a workover strategy helped convert single lateral wells into multi-lateral/maximum-reservoir contact wells by providing the platform for installation of downhole flow control systems. (Salamy 2007)

Case History – Record-setting Exploratory Well

An operator in the Gulf of Mexico identified deep exploratory targets on 3D seismic surveys that indicated potential pay intervals below a current field development. The existing infrastructure provided access to the deep shelf target zones by sidetracking through the 13-5/8 in. and 11-7/8 in. casing, but the subsequent 9-5/8 in. extended shoe would require an uncompromised leak-off test (LOT). To further complicate the challenge, the new wellbore section would have a BHST of 327°F and pore pressure of ~19,000 psi.

To drill in an HP/HT environment, reach the planned target depth, and evaluate the formation with optimum hole size, the operator determined that the best approach would utilize solid expandable technology as a planned-in solution rather than as a reactionary fix. By taking the anticipatory approach, the operator was able to optimize the technical advantages attained when using expandable tubulars proactively—fit-for-purpose design, more control of downhole environment.
Developing a Plan

After defining the objective, the operator engaged the necessary services providers to help implement the plan. Because solid expandable tubulars were being used, planning commenced that drew from varied disciplines—engineering, operations, tool development, etc., to optimize system and installation design. Thorough planning considered and communicated:

- Initial Risk
- Risk Mitigation
- Installation Procedures
- Best practices
- Lessons Learned

The application plans for solid expandable systems, be it for a new drill, re-entry, or workover, cover multiple issues from wellbore preparation to system expansion to drilling ahead.

Implementing the Strategy

The operator prepared the wellbore and facilitated optimal swellable elastomer design (eliminated wait time, enabled proper compression, attained greater sealing capability, etc.).

A 7-5/8 x 9-5/8 in. 53.5 lb/ft openhole expandable system with a pre-expansion length of 6,935 ft (~2,115m) was installed from ~14,000 to ~21,000 ft (~4,270 to ~6,400m) and anchored back to the 9-5/8 in. casing (Figure 3). The openhole liner featured an expandable shoe with swellable elastomers (to ensure a successful LOT). The liner was made-up at an average of ~16 joints per hour and run to depth. After cementing as planned, the dart was displaced, landed, and expansion was initiated with 2,600 to 3,000 psi. Once installed in the 8-3/4 in. hole, the liner was expanded at about 700 feet per hour. Water-activated swellable elastomer seals rated to 360° F were located on the expandable anchor directly above the shoe and achieved immediate compression against the formation as the liner expanded. The shoe was drilled out in five hours and a successful LOT was performed with 1,189 psi at surface with 17.9 ppg in the well.

Realizing the Value

Planning a solid expandable system as part of the wellbore architecture optimized the use of pre-existing infrastructure, providing substantial savings and facilitating discovery of a ~150 ft (~45m) deep gas pay zone. The swellable solution ensured a successful LOT without the need for remedial shoe squeeze operations (a savings of ~$1,000,000). This approach ultimately maximized hole size for continued drilling to the target, for proper evaluation of the pay zone, and for future completions.

Figure 3. Deep exploratory HP/HT well using a solid expandable system with swellable elastomers to extend the casing shoe.
Case History – Reducing Non-productive Time

This same operator used the same size expandable system in a different Gulf of Mexico prospect to extend the shoe of the 9-3/8 in. casing through a window exit. In addition to extending the shoe, the solid expandable system was outfitted with swellable elastomers that enhanced the LOT. After running the system through the window and to depth, the well was circulated, cement was pumped, and the dart was displaced and landed with 389 bbl as calculated. Expansion was initiated with 4,000 psi and full liner pick-up weight. The liner was tested successfully with 2,350 psi for 30 minutes. The shoe of the liner was drilled out in 2 hours and a successful LOT was performed with 19 lb/gal result. As with the previous well, the operator realized significant savings by using swellable elastomers deployed on a solid expandable liner in lieu of a cement shoe squeeze.

Another major operator in the Gulf of Mexico used the same strategy to extend the 11-3/4 in. casing shoe and cover a depleted zone. The application consisted of installing a 9-5/8 x 11-3/4 in. solid expandable openhole liner in a directional well with a 2 deg/100 ft dogleg severity (DLS). This system included 22 joints of expandable liner banded with swellable elastomers. After reaching setting depth at over 18,500 ft (~5,640m), expansion was initiated with 3,100 psi (full pick-up weight applied) and averaged 2,500 psi. The liner was successfully pressure tested to 1,500 psi for 30 min. This approach enabled the operator to maintain the planned casing points, cover the trouble zone, and streamline operations by eliminating the cement shoe squeeze.

Case History – Mitigating High Pressure Zones

The previous record-length for a solid expandable system, also in the Gulf of Mexico, was installed as part of a re-entry program to sidetrack out of the 9-7/8 in. production casing at ~15,000 ft (4,570m) and drill an 8-1/2 in. hole below ~23,000 ft (7,010m) across depleted pay sands. During drilling operations, higher-than-expected pore pressures (up to 15.6 ppg) were encountered at ~21,000 ft (6,400m), which resulted in the loss of the original wellbore due to lost returns in the depleted sands. To isolate the depleted sands and preserve hole size for the 7 in. production casing, a 7-5/8 x 9-5/8 in. solid expandable liner (over 6,865 ft [2,092m]) was installed as an intermediate drilling liner for redrill operations.

The liner, which consisted of ~190 joints of expandable pipe, was made up and run into position slowly to mitigate surge pressures and had to be washed through a tight spot ~980 ft (300m) above final TD in the openhole section. The dart landed as calculated and expansion was initiated with the expected pressure of 3,600 psi and the full weight of the liner resting on the expansion face. The liner was expanded at a rate of ~700 ft/hour (213m/hr). The liner was pressure tested successfully prior to drilling out the float equipment. After drilling out the shoe, the operator was able to drill to the targeted depth and move forward with the production of the desired zone.

The expandable system enabled a cost-effective re-entry for the operator. Preserving hole size with the solid expandable system greatly reduced the mechanical risks associated with a smaller completion and prevented a significant decrease in production if completed with 5-1/2 in. hole. (Bagley 2008)

Case History – Eliminating Cement Shoe Squeeze

In another deep shelf application in the Gulf of Mexico, a different operator leveraged offset well data to identify possible and probable challenges. This referenced data revealed two deep pressure regression zones where low fracture gradients had resulted in high NPT due to lost circulation and hole stability problems in the offset wells. The objective was defined and a plan initiated to use two solid expandable systems to isolate these zones. The solution consisted of a 9-5/8 x 11-3/4 in. solid expandable openhole liner in a directional well with a 2 deg/100 ft dogleg severity (DLS). This system included 22 joints of expandable liner banded with swellable elastomers. After reaching setting depth at over 18,500 ft (~5,640m), expansion was initiated with 3,100 psi (full pick-up weight applied) and averaged 2,500 psi. The liner was successfully pressure tested to 1,500 psi for 30 min. This approach enabled the operator to maintain the planned casing points, cover the trouble zone, and streamline operations by eliminating the cement shoe squeeze.

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The operator saved ~$24M (USD) by significantly reducing NPT and drilling risks. This expandable solution using dual systems in a single wellbore enabled completion of several high-rate production wells at the targeted depths with a larger completion size. The larger completion size translated into increased production rates. The success of this strategy to minimize NPT set a precedent for reducing costs and mitigating drilling challenges in future development wells.
Figure 4. Two planned solid expandable openhole systems isolate trouble zones and reduce NPT.

Conclusion
The challenges presented in the Gulf of Mexico make for operational difficulties but also spur innovation regarding tools, processes, and methodologies. As with other enabling technologies, solid expandable tubulars evolve to keep pace with operator need and also encourage pushing the application envelope. Technical enhancements have contributed to systems that can be deployed deeper, longer, and in more extreme conditions. Equipment and production records frequently mark milestones in the petroleum industry and solid expandable tubular technology is no exception with record lengths and innovative applications. The operating envelope encompasses a wide range of applications including extended-reach drilling (Holland 2007), as a diagnostic tool, multiple systems in a single wellbore, extended-reach completions, and long horizontal re-frac liners. Although initially conceived as a technology to help mitigate unexpected downhole challenges, expandable tubulars realize greater return and attain increased reliability when incorporated into the plan whether for exploratory, development, repair and remediation, or revitalization projects.

References
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