

# Deepwater cement design optimized for record-length expandable liner in Gulf of Mexico

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DURING A SIDETRACK operation out of 9 <sup>7</sup>/<sub>8</sub>-in. casing on a deepwater well in Green Canyon Block 243, Gulf of Mexico, unexpected hole conditions were encountered that required the use of an additional casing string. The decision was made to run a 7 <sup>5</sup>/<sub>8</sub> x 9 <sup>5</sup>/<sub>8</sub>-in. expandable liner in the 8 <sup>1</sup>/<sub>2</sub> x 9 <sup>1</sup>/<sub>2</sub>-in. wellbore. The liner would expand to provide an inside diameter of 7.71 in., allowing space for a 7-in. production liner in the targeted interval.

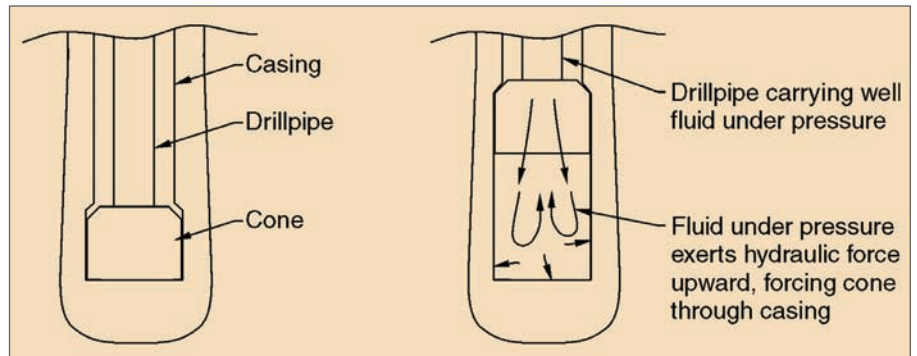
The 6,867-ft liner (pre-expansion length) was the world record for the longest expandable liner set to date and presented several challenges for cement job design. The liner would be cemented conventionally before the expansion operation. Expansion time was calculated to be approximately 17 hours, allowing the fluid time for the primary lead cement, with a safety factor, to exceed 19 hrs.

The tail cement had to exhibit good compressive strength around the shoe track, and the operator specified top of cement (TOC) at 17,000 ft to protect a secondary pay zone. Slurry properties were simulated to meet fluid times required for the liner expansion. Standard API lab tests used for cement testing were modified to accommodate this lengthy operation.

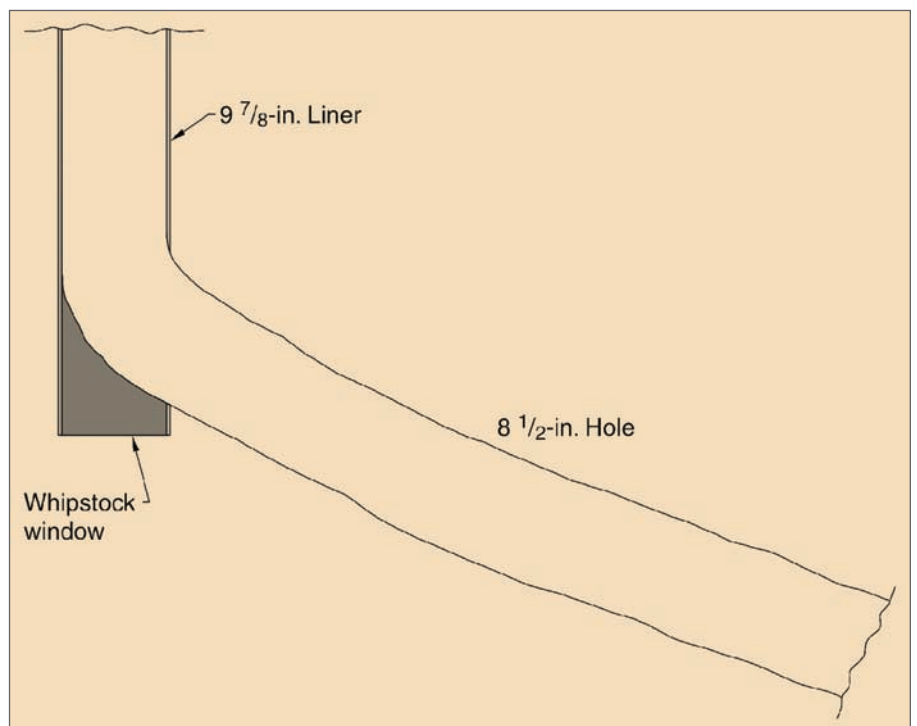
The expandable liner was set at 20,605 ft measured depth (MD) and 19,930 ft true vertical depth (TVD) with a maximum hole angle of 36°. The liner was cemented successfully using an extended thickening-time lead slurry mixed at 15.7 lb/gal, followed by a 16.2-lb/gal tail slurry with a shorter pumping time to achieve good strength at the liner shoe.

After drilling out the liner, the operator obtained a 16.8-lb/gal equivalent formation integrity test (FIT) and resumed drilling to the target depth. The cement-evaluation log showed excellent bonding behind the expandable liner with TOC at 17,000 ft as planned.

Operational details and cement design considerations are provided here. Emphasis is placed on wellbore configuration, expandable installation



**Figure 1:** To expand a casing from the bottom up, the casing is installed with a cone in the casing bottom. Drilling fluid is pumped through a drill pipe, out the bottom of the cone, against the casing wall and well bottom, forcing the cone upward, expanding the casing. Expansion cones can also be pumped down from the surface to expand casing.



**Figure 2:** In this case history well, the operator kicked off through the 9 <sup>7</sup>/<sub>8</sub>-in. liner and drilled an 8 <sup>1</sup>/<sub>2</sub>-in. deviated section.

procedures and hole preparation, a full understanding of which is the beginning of a successful cement job.

## INTRODUCTION

The Aspen field is located in a prolific development area in the Green Canyon Block 243 in 3,000-ft water depth. This field development has been in progress since 2000 with five major production horizons drilled in the area. Through high-rate production, certain sands have seen some depletion and, thus,

significant pressure regressions have been observed throughout the productive intervals. Operators following proper equivalent circulating density (ECD) management and using synthetic-based drilling fluids with optimized particle-size distributions to maximize the sealing of depleted sand packages have achieved success.

This case history well was a re-entry sidetrack to reach a lower objective known to be in a narrow pore pressure/fracture gradient window because of

the pressure-depleted interval. The planned completion program consisted of sidetracking out of the original wellbore through a 10 <sup>3</sup>/<sub>4</sub> x 9 <sup>7</sup>/<sub>8</sub>-in. tieback at 14,000 ft and directionally drilling an 8 <sup>1</sup>/<sub>2</sub>-in. pilot hole to planned TD.

The hole would subsequently be opened to a 9 <sup>1</sup>/<sub>2</sub>-in. hole size to run a 7 <sup>5</sup>/<sub>8</sub>-in. production liner. During drilling operations through the production interval, wellbore pressures indicated that it would not be possible to continue without encountering significant losses. To still reach lower objectives and complete with a 7-in. production liner, the use of a 7 <sup>5</sup>/<sub>8</sub> in. x 9 <sup>5</sup>/<sub>8</sub>-in. expandable liner installation became critical to the well's success. Because there were secondary completion objectives behind this installation, it was also critical to obtain a TOC back to 17,000 ft.

## JOB PLANNING

Solid (no slots, holes, screens, etc.) expandable tubular technology has proven its reliability in meeting the challenges of a wide range of applications in the deepwater arena. Engineered system improvements over a number of years have led to enhancements in the launcher assembly to satisfy longer setting

lengths. Reductions in surge effect have been accomplished by using a more compact launcher assembly with a flapper valve that allows for better filling while running the liner into the wellbore.

These improvements have led to minimizing surge effects of weak formations and provide a major saving on potential mud losses, which translates into better hole conditions for cementing operations. Hole size and preparation should be satisfactory to accept the liner for pass-through plus adequate final expansion.

In the GC 243 project, an 8 <sup>1</sup>/<sub>2</sub>-in. hole was initially drilled, followed with a hole opener run to increase the hole size from 8 <sup>1</sup>/<sub>2</sub> in. to 9 <sup>1</sup>/<sub>2</sub> in. to the planned liner-shoe setting depth. Before running the liner, an open-hole caliper log was run to obtain formation data and confirm the open-hole size and volume. When considering the installation of an expandable liner to be run through a milled window, extra precaution regarding the window dressing should be considered. As noted in a previous paper (Grant 2005), the following should be considered:

- Extra mill runs may be necessary to help ensure the window is as clean

as possible and has sufficient pass-through diameter for the launcher at the bottom of the liner assembly.

- While milling to clean up the whipstock window, extra care should be taken to assure that all debris are removed and not accumulated at or below the window exit.
- Give attention to the possibility that debris might have accumulated just below the window section and might be circulated back once the liner is at setting depth.
- Consider whipstocks with longer whip blades that provide lower doglegs for more compatibility with expandable liners.
- Directional control in the open hole just past the window exit should be performed carefully. This helps to avoid creating unfavorable doglegs that might create problems for running and expanding the liner.

## HOW THEY WORK

In Figure 1, the expandable principle is illustrated. The casing is lowered to setting depth with a cone in an expanded

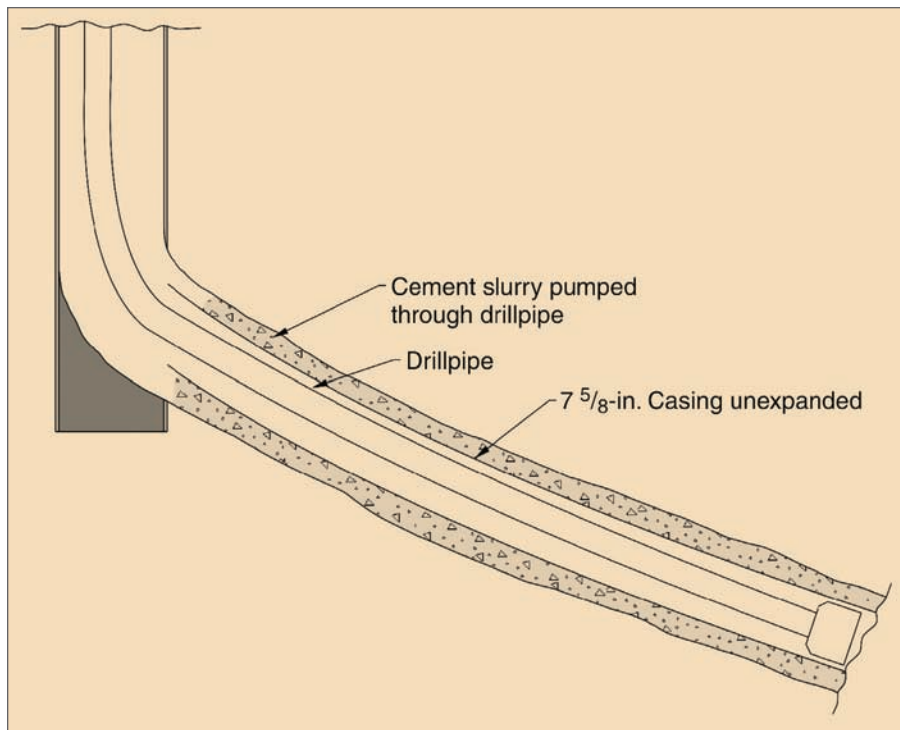


Figure 3: A 7 5/8-in. casing with an expansion cone included. Before expanding the casing, the operator pumped cement slurry through the drill pipe.

Cement test data	Lead Cement	Tail Cement
Density (lb/gal)	15.7	16.2
BHST / BHCT (° F)	200 / 200	200 / 200
Pressure (psi)	16842	16842
Heat-up time (hr:min)	2:40	2:40
Shut-down time (hr:min)	0:45	0:45
Cycles at 4 min on/6 min off	69	21
Thickening time (hr:min)	19:24	6:08
Fluid Loss, cc/30 min	38	40
Free Water, %	0	0
12-hr comp str, psi	0	1200
24-hr comp str, psi	0	2000
36-hr comp str, psi	1300	No data
48-hr comp str, psi	1500	No data
Gel str, lbf/100 ft2		
RPM ( 300/200/100)	174/126/70	306/218/128

Table 1: The final properties of the lead and tail cements used for the operation. No provision was made to deliver special blends to the rig. Both designs featured bulk cement available on the rig, with liquid additives to influence final properties.

section at the bottom of the casing. Drill pipe made up to the cone delivers well fluid pumped under high pressure to exit the cone. With no exit possible, the hydraulic pressure created pushes the cone upward, expanding the cas-

ing. It is also possible to push the cone downward, using hydraulic pressure, to expand the casing from top to bottom.

Figure 2 shows schematically the case history well after a whipstock was set and a deviated section of borehole was

drilled to 8 1/2-in. diameter. This wellbore section was then reamed out to 9 1/2 in. In Figure 3, the 7 5/8-in. OD casing has been cemented by pumping cement through the drill pipe. After the casing was expanded by pumping well fluid through the drill pipe to drive the expansion cone upward through the casing, the casing ID was 7.71 in. Figure 4 shows the new wellbore section ready for perforation, stimulation and other completion procedures. Expanding the casing into the unset cement helps ensure a good bond of casing to cement and cement sheath to wellbore.

### JOB PLANNING: CEMENTING CONSIDERATIONS

The following information was considered in the design effort for this job:

- Expandable liner size, 7 5/8 in. x 9 5/8 in.
- Planned setting depth, 20,605 ft MD (19,930 ft TVD).
- Liner length, 6,867 ft.
- Hole size, 9.5 in. (underreamed).
- Open-hole caliper used.
- Mud weight and type, 14.65 lb/gal synthetic.
- Planned TOC, 17,000 ft.
- BHST/BHCT, 200°F.

### Slurry design and volume

When designing (Heathman 2007) for an expandable liner operation, cement design considerations are not much different from other operations. The major consideration is allowing for the required “fluid” time associated with the liner expansion performed by the expansion cone, which is moved up by well fluid pumped through the drill pipe (inner string), expanding the liner from bottom to top.

In the case of this installation, expansion time was calculated to be at least 17 hrs. Thus, thickening time of the slurry is based on this calculated expansion time plus a safety factor of 2 hrs. Since there was a long fluid time required for the lead cement, a tail cement with shorter thickening time was designed so that drill-out time was optimized.

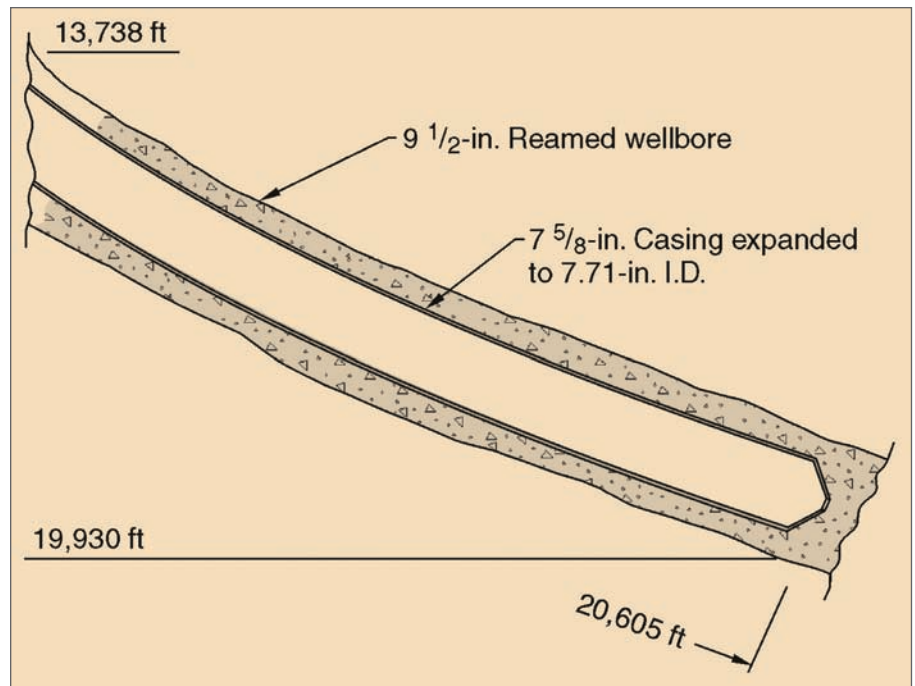
Table 1 gives the final properties of the lead and tail cements used for the operation. Note that no provision was made

to deliver special blends to the rig. Both designs featured bulk cement available on the rig, with liquid additives to influence final properties. Cement volumes were determined by open-hole caliper volumes performed during the open-hole logging program. The actual volumes calculated were based on this caliper volume considering the post-expansion outside diameter of the liner.

#### Spacer design and testing

Synthetic-based muds have proved to be an excellent system for deepwater drilling operations. Because these systems (1) impart oil-wetting properties to the formation for hole stability, and (2) provide improved drilling rates, drill pipe and tubulars also have the same oil-wet surface. Therefore, it is imperative to design a weighted spacer with a surfactant package for optimal water-wetting capability.

A properly designed spacer system used ahead of a cementing system should provide separation of incompatible fluids (cement-mud interface) and displace residual mud when traveling down the drill pipe tube and between the liner and formation. In conjunction with the weighted spacer is a surfactant-design

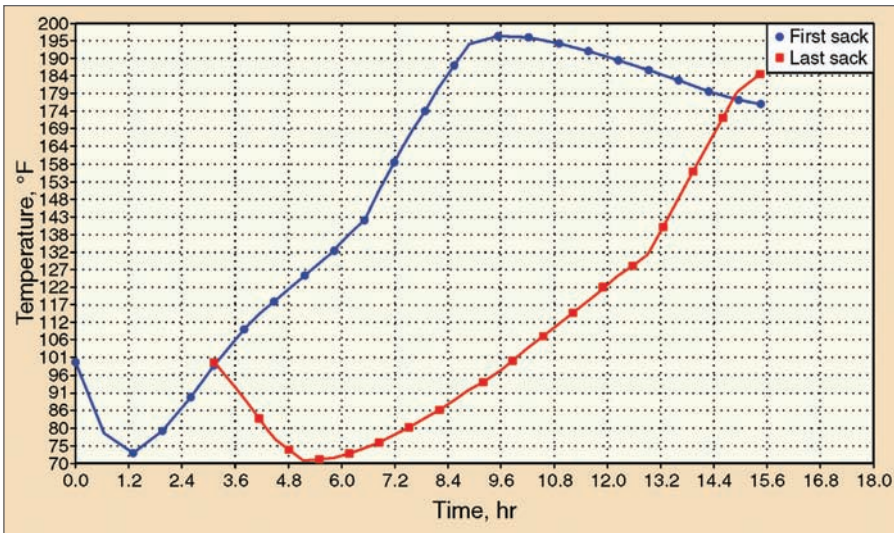


**Figure 4: The new deviated section is ready for perforating, fracturing and other completion procedures. Expanding the casing into the unset cement helps ensure a good bond of casing to cement and cement sheath to wellbore.**

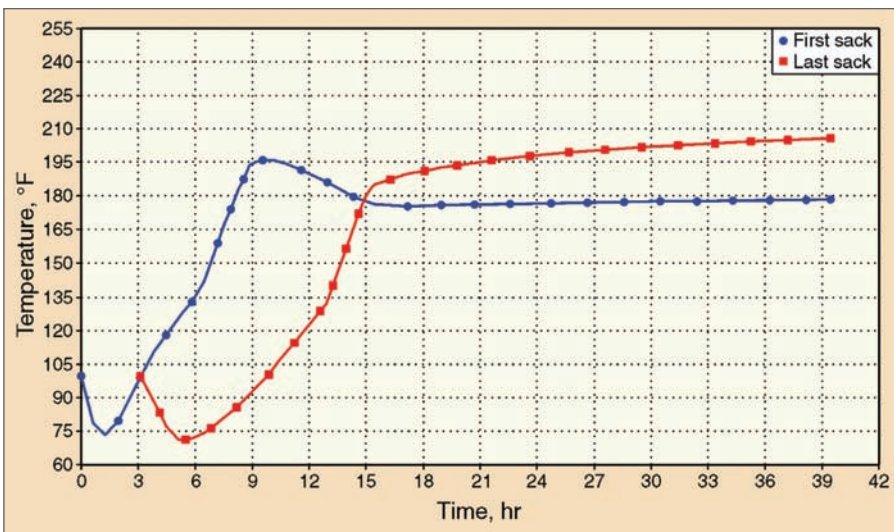
package with engineered water-wetting characteristics as determined by lab testing (Heathman 2000). When perform-

ing an expandable cementing operation, the spacer/surfactant system must also provide (1) stability for prolonged peri-





**Figure 5: A temperature simulation based on well conditions and planned pump rates to perform the job was performed for thickening-time tests. The tests were performed using a modified schedule to simulate liner expansion.**



**Figure 6: Temperature simulation for compressive-strength tests using the ultrasonic strength analyzer. In conjunction with data from downhole simulations, the API schedule for heat-up rate is modified for best heat-up rate to match placement time.**

ods of both weighting material of the system, and (2) a compatible interface between the synthetic-based mud and spacer.

#### Lab testing

Thickening-time (TT) tests were performed using a modified schedule to simulate liner expansion. This revised schedule was developed based on obtaining the most accurate BHCT from temperature data available (BHST) and performing a temperature simulation based on well conditions and planned pump rates to perform the job. Final temperature simulation provided data for TT testing on the high-pressure, high-temperature consistometer using information from Figure 5.

Figure 6 provides data for performing compressive-strength determinations using the ultrasonic strength analyzer (UCA). In conjunction with data from downhole simulations, the API schedule for heat-up rate is modified for the best heat-up rate to match placement time. Following this procedure, a detailed pump schedule is determined based on required cycles necessary for total liner expansion (Sanders 2003).

The cycles determined are based on each joint of liner expansion, which would coincide with slurry static time and dynamic movement based on pipe expansion downhole. Laboratory testing consisted of starting and stopping the motor that turns the slurry cup in the consistometer. Each cycle consisted

of an ON/OFF schedule (four minutes on/six minutes off) for this specific lab project. Final lab schedule and results are presented in Table 1, including fluid-loss analysis, free-water test, rheological properties and compressive strength results from the UCA.

#### JOB EXECUTION

Weighted-spacer (with surfactant) volumes used ahead of the cementing operation consisted of adequate length in the annulus to account for 1,000 ft. Because no dart-and-wiper plug was provided ahead of the cementing operation, extra spacer volume was used to effectively displace and provide residual water-wetting characteristics to pipe and formation. A small volume of weighted spacer was also used behind the cement for separations between cement, drill pipe dart and mud displacement.

Cement volumes used for operation were determined based on open-hole caliper and post-expansion outside diameter. Planned TOC was confirmed from the position of productive zones and adequate cement coverage. Final lab results obtained for spacer, lead and tail cement rheological properties were used in the engineering design program to obtain effective ECD data based on planned mix rates and displacement volumes and rates to minimize potential mud losses. Figures 7 and 8 represent data obtained from the engineering design program used to prepare the final cement program. Considering the design for lead cement used with the liquid-additive package, it was determined to be most effective to mix this slurry with a 100-bbl blender. The tail cement was mixed with the cementing unit available.

The lead and tail cement slurry was displaced following drill pipe-dart launch and a small volume of weighted spacer (10 bbl) and enough synthetic-based mud (341 bbl of 14.65-lb/gal mud pumped down at 4 bbl/min) to land the dart at profile for initiation of liner expansion. The dart was landed with 2,500 psi, and expansion operations were performed.

#### POST-JOB RESULTS

The expandable liner was run, cemented and drilled out with very good results; full mud returns were observed during the entire operation. Total casing-expansion time was 17 hrs, following placement of cement. Final differential pressure of cement in place indicated good lift, including information of no observed mud losses during the opera-

tion. The expandable liner was successfully pressure-tested to 3,500 psi with 14.6-lb/gal synthetic-based mud. The liner was drilled out, and a successful shoe test was performed to 16.8 lb/gal equivalent mud weight (EMW). The well was drilled ahead for the planned setting of a 7-in. production liner. A bond log was run across the expandable liner section, and results indicated good bonding across intervals up to the planned TOC at 17,000 ft.

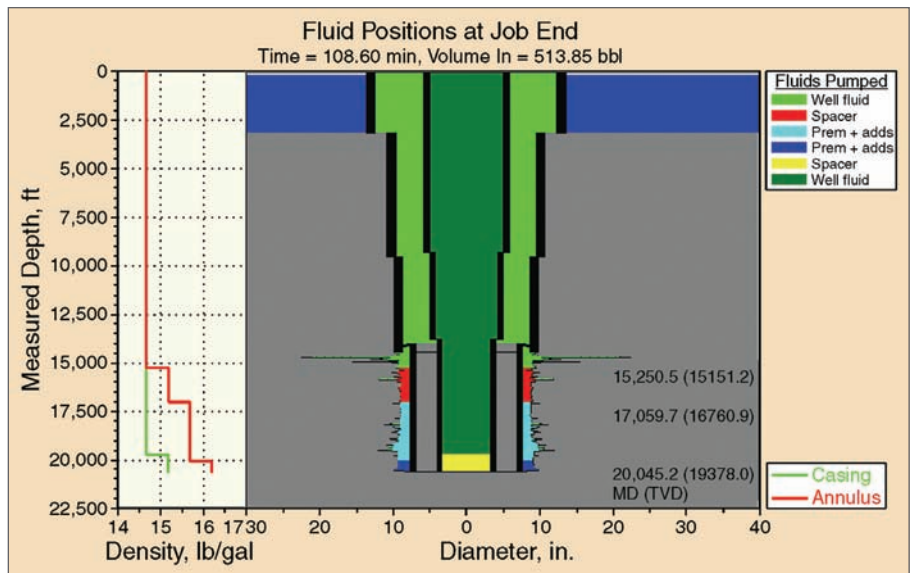
**SUMMARY, CONCLUSIONS**

Solid expandable tubulars offer the industry an excellent solution for gaining a pipe size for completions when well conditions necessitate the setting of additional drilling liner. For operators to take full advantage of expandable liner technology, a successful cementing job is critical.

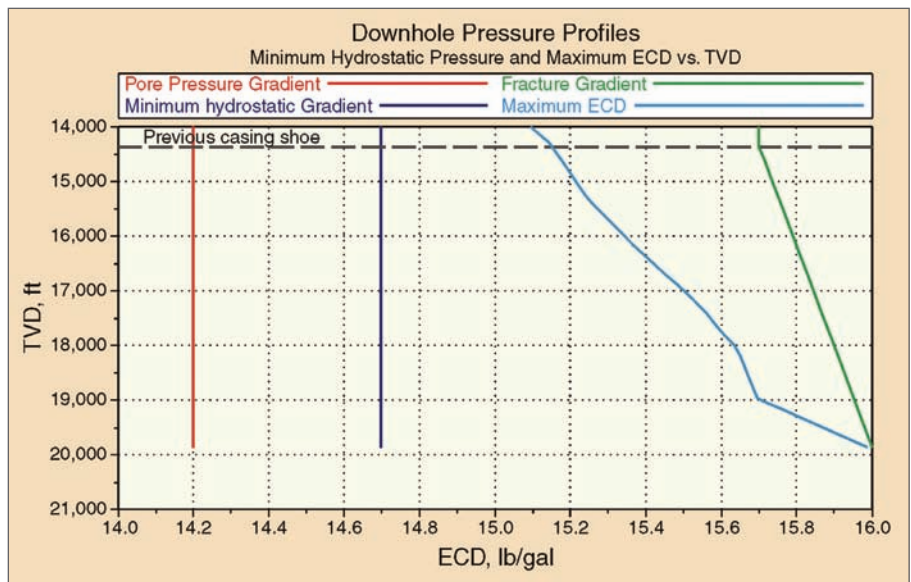
Without a successful cement job, the expandable installation itself can be jeopardized by complicating and, in some cases, preventing remaining well operations from moving forward. For this reason, a well-engineered approach to cementing is vital to obtaining a good cementing result. The engineering needs to begin with the drilling of the hole section and continue through leaving acceptable hole conditions for the liner installation and eventual cementing.

Results obtained from this case history provided the opportunity to reach the main zones to be drilled and evaluated and still obtain a satisfactory completion program. Conclusions drawn from this case history and other installations performed are:

- Proper window preparation and hole cleaning before running expandable casing is recommended.
- Determine placement time needed based on liner length and expansion cycles required.
- Perform temperature simulations to determine BHCT and heat-up rate for thickening time required.
- Prepare a schedule for TT test based on cycles required for motor shut-down (on/off schedule).
- Perform proper lab testing based on this modified lab schedule for both TT and compressive strength.
- Perform lab testing to obtain optimum spacer and surfactant design for synthetic-based mud system.



An engineering design program shows the final fluids position in the cement program (Figure 7, above) and the downhole pressure profile (Figure 8, below).



- Perform engineering simulations using cementing software for proper ECD management during cementing operations.
- Deliver these designs to the well site with a plan for placement using offshore equipment capabilities.

Using these practices has led to excellent results, delivering better wellbore architecture and opportunities to drill deeper wells in deepwater.

IADC/SPE 112626, "Optimized Deepwater Cement Design for Record-Length Expandable Liner," was presented at the 2008 IADC/SPE Drilling Conference, Orlando, Fla, 4-6 March.

Acknowledgements: The authors thank Nexen Petroleum and Halliburton for permission to present this paper. Without the support of our engineering and laboratory staff and the operational team, this successful cementing operation would not have been possible.

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