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Scab Liner Cementing – Successful Cement Placement Technique applied for Subsalt Deepwater Wells in the Gulf of Mexico

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Abstract

One of the well construction challenges in the Deepwater Gulf of Mexico (GoM) is to drill through long extensions of salt bodies. Scab Liner is normally run inside another casing string or liner designed to provide additional protection to the outer casing against any potential salt collapse loading in a blow-out scenario.

The objective of the cement job was to place the cement slurry in the tight annular gap between scab liner and previous casing or liner and bring the top of cement above the tieback hanger. An additional imposed challenge was to maintain a maximum differential pressure across the liner hanger to avoid exceeding the setting pressure. Such challenges became the main drivers for a detailed analysis of the Equivalent Circulation Density (ECD) during the cement placement as well as an exhaustive laboratory testing to optimize the density and rheological properties of the cement slurry and other fluids pumped during the job.

With these objectives in place, scab liner cementing operations are carried out in following stages.

- The detailed pre-job planning including several job design scenarios
- The sensitivity analysis to determine the impact of independent variables to the liner hanger's differential pressure limit, such as internal diameter, fluids rheologies and density, mud volumes
- The post job pressure match analysis between acquired surface pressure and simulated surface pressure

This paper will review the application on the above engineering practices on successful cementing of three subsalt wells in GoM.

Introduction

The Gulf of Mexico (GoM) continues to provide great opportunity with associated challenges for oil and gas development. The huge subsurface salt structures that characterize the GoM are responsible in part for trapping hydrocarbons and creating huge new prospects for over the years, however it also presents new and unique challenges to maintain well integrity throughout the life of the producing oil and gas well.

The presence of salt domes has long been problematic for drilling, completion, and long-term production. The high water solubility and plasticity of salt zones increase the difficulty of obtaining better wellbore geometry and` successful primary cementation. The cement slurry can dissolve large quantities of formation material (salt), resulting in a modification of cement slurry performance. Plastic salt zones can also encroash upon the casing before the cement sets. Nonuniform formation movement exerts point loading on the casing string, sometimes resulting in casing failure and collapse.

A high quality well architecture with strong structural and casing integrity will ensure longetivity of well. Selection of hevay-wall casings to including additonal tie-back/scab liners in casing design are normally employed to prevent casing deformation across salt zones.

Scab/tie-bak liners with tight annulus (< 0.5 in) cementing pose several challenges, not only to design cement slurry and spacer fluids for effective mud removal and better cement placement but also to execute the cement job within the materials' limits.

Extensive enginnering and various simulation scenarios to understand cement placement surface pressure needs to be first analyzed. Fluids properties are optimized based on best possible scenario for successful cement placement not exceeding liner hanger's pressure limits. Careful selection of pumping rates for each fluid stage and maintaing it while job exection stage is very critical to ensure the acquired surface pressure matching with anticipated treatement pressure. This will finally verify the annular coverage of cement after placed.

Well Construction – Scab Liner

One of the deepwater operators in the Gulf of Mexico recently planned and drilled several wells with a unique well construction schematic by running a 13-7/8 in scab liner, seated at the top of a previous 13-5/8 in liner and with length more than 11,000 ft to provide annular coverage for salt zone.

The wellbore schematic illustrating scab liner is presented in Fig.1.

The 13-7/8 in Scab Liner was run and cemented from the top of the 13-5/8 in liner to 500 ft above the top of salt. This section was designed to mitigate any potential collapse load on the 16 in casing in a blow-out scenario by isolating the 16 in to above any potential collapse point. In addition, the concentric 13-7/8 in pipe cemented inside 16 in casing would provide additional protection against a long term salt collapse load.

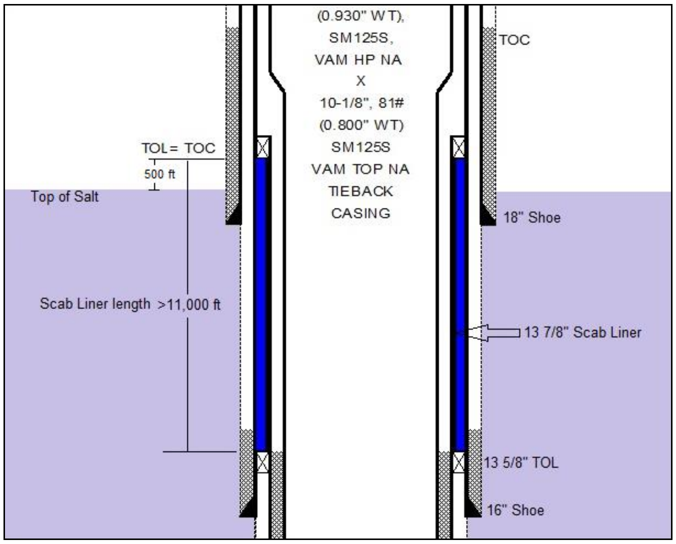


Figure 1: Wellbore Schematic with Scab Liner

Cementing Challenges

This casing configuration resulted in an annular gap as small as 0.408 in (clearance between the 16 in casing internal diameter (ID) and the averaged calipered outside diameter (OD) of 13-7/8 in scab liner) for achieving cement sheath integrity. Such annular restriction created several cementing and related challenges:

- High friction pressure during cement placement, which would cause a high Equivalent Circulating Density (ECD).
- Maintaining maximum 3,600 psi differential pressure across the liner hanger to avoid exceeding the setting pressure limit.
- Risk of packing off the small annulus and cement not covering the full scab liner interval.
- Risk of properly centralize the 13-7/8 in pipe to keep it concentric with the 16 in casing ID (restriction with the OD of the centralizers)
- Risk of not being able to sting in with the mule shoe into the 13-5/8 in liner hanger upper tie-back receptacle. Need to sting into avoid U-tubing.

Such challenges became the main drivers for a detailed analysis of the ECD during the cement placement to determine the optimum flow rate to pump the fluids in a tight annulus space as well as an exhaustive laboratory testing to optimize the rheological properties of the slurry and achieve extended cement setting time.

With the risk acknowledged, the scab liner cementing operation was designed and executed using the following sequence of steps explained in following sections.

Pre-job Planning and Design

The collection and analysis of all relevant well information available, such as accurate tubular information (weight, grade, burst and collapse pressure limits of tubular), liner hanger specifications and geometry, drilling fluid type and properties, casing hardware (equipment specifications), length of the interval to be cemented, and temperature gradient along the interval; were crucial data to design the scab liner cement job.

The criteria for slurry selection and mud removal design were determined from the collection and analysis of these data and with consideration of achieveing job specific objectives. In addition, a sensitivity analysis approach was used to determine how different values (i.e. effect in annular gap variations assuming small changes in 16 in casing ID and the average calipered OD of 13-7/8 in; fluid rheologies and densities; mud volumes to pump ahead and behind the cement slurry; mud circulation at different flowrates, etc.) would affect the slurry placement pressure. A hydraulic cement placement simulator was used to perform these simulations.

During the phase of design, all the well data (surface line description, tubular, wellbore geometry, directional survey, formation pressures – pore and fracture - and temperature survey) were input into the hydraulic cement placement simulator to properly define the wellbore geometry and characteristics of the section. After it, a fluid train was designed with the purpose to:

1) provide good mud removal in the interval to be cemented,
2) reduce friction pressures as much as possible by decreasing rheological values in the fluids to be pumped and
3) place an economical low-density high-yield slurry that could develop enough compressive strength and provide good zonal isolation in the scab liner interval.

Fluids Selection

With these above criteria in place, the following fluids were designed:

Low rheology mud

A low density / low rheology mud to be pumped ahead of the spacer. This optimized mud had a density of 14.1 lbm/gal (1.7 lbm/gal lower than the original Synthetic Base Mud -

SBM in the wellbore) and the rheological properties were optimized to its minimum values in order to generate the lowest possible friction during placement. In addition, based on the simulations run and the sensitivity analysis made, a volume of 1,300 bbls was designed to minimize the hydrostatic head in the annulus above the 13-7/8 in liner hanger and maintain a differential pressure lower than 3,600 psi across the liner hanger depth. Fig.2 shows an illustration of the expected fluid positions in the well after placement.

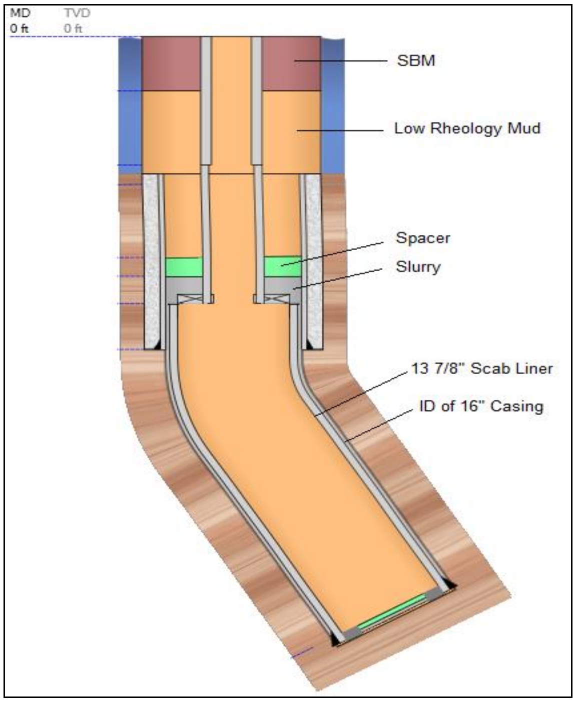


Figure 2: Wellbore schematic with estimated fluid positions after placement

Spacer:

A 14.3 lbm/gal viscous spacer fluid was designed to act as a buffer between the low rheology mud and cement. The volume of the spacer was designed to have at least 10 min. of annular contact time and to have the density and rheology between those of the low density / low rheology mud and cement slurry. The total volume of spacer was 100 bbl and its composition is showed in Table 1.

Cement slurry:

A single cement slurry was designed using TXI lightweight cement blend. The slurry system was chosen since TXI blend can be designed in density ranges from 12 lbm/gal to 14 lbm/gal. However, extensive lab testing was made in order to achieve a density of 14.5 lbm/gal with optimized low rheological properties and a longer thickening time. The thickening time was calculated based on maximum permissible flow rates to pump the fluids in the narrow annular gap and to avoid exceeding 3,600 psi across the liner hanger. The flow rate range was designed to be between 2.0 bbl/min to 4.0 bbl/min.

This special formulation was proposed based on the cement job objective, the simulations performed during the design phase and, as an economical low-density high-yield slurry solution to cement the 13-7/8 in scab liner. The slurry composition is presented in Table 2.

Table 1: Generic composition of spacer pumped

Spacer (Composition)
Fresh Water
Antifoam Agent
Bentonite
Viscosifier
Surfactant 1
Surfactant 2
Barite

Table 2: Generic composition of cement slurry

Tail Slurry
Fresh Water
TXI Cement
Silica
Antifoam Agent
Dispersant
Fluid Loss Control Agent
Retarder

Table 3 shows a summary of the train of fluids designed, its annular length, density, pump rate and volume.

Table 3: Summary of fluids designed

Fluid	Ann. Length (ft)	Density (lbm/gal)	Pump Rate (bbl/min)	Volume (bbl)
Low Rheology Mud	5,701	14.1	2.5	1,300
Spacer	599	14.3	2.5	100
Tail Slurry	11,986	14.5	2	263
Spacer		14.3	2.5	10
SBM		15.8	2.0 – 4.0	1,824

With respect to the ECD sensitivity analysis made, the main two variables used to calculate the volume of the low density / low rheology mud, as well as the maximum possible flowrates while placing the fluids in the annulus were:

1) ID of the 16 in casing vs. the averaged calipered OD of 13-7/8 in scab liner; and
2) Maximum possible differential pressure at the liner hanger to avoid premature setting of the device.

A scrapper run on 16 in casing was completed before running the 13-7/8" scab liner. The maximum OD of scraper centralizer was 14.668 inches. However, due to the scrapper work across this area, a second scenario was considered assuming an ID of 14.768 inches to determine the effect of such change in the calculation of differential pressure at the liner hanger.

Table 4: Sensitivity analysis to the well geometry

Well Geometry			
Previous Casing ID (in)	**Differential pressure at liner hanger (psi)**	**Max. displacement rate (bpm)**	**Pumping time (hr:mn)**
14.668	3600	4	23:41
14.768	3600	6	20:54

Table 5: Sensitivity analysis applied to determine volume of low density / low rheology mud

Low ECD mud	
Volume (bbl)	**Differential pressure at liner hanger (psi)**
1300	3600
1200	4096
1100	4254

Several simulations were run to analyze the effect of those variations and ultimately, estimate the pumping time in preparation for the thickening time requirements. The results showed that 1,300 bbls of low density / low rheology mud ahead were needed to maintain less than 3,600 psi differential pressure when pumping at a maximum flowrate of 4 bbl/min. The time to pump the schedule of fluids designed for the job was 23:41 hr: mn. Table 4 and Table 5 show a summary of the sensitivity analysis made.

In addition, different iterations allowed optimizing the rheological properties of the fluids, especially the cement slurry. Knowing the minimum and maximum values of flowrate to pump the fluids (2 bbl/min and 4 bbl/min), it was possible to complete a rheological assessment and calculate the shear rate range (sec^{-1}) corresponding to these flow rates.

As rotational speed (rpm) is proportional to shear rate in a Couette-Type coaxial cylinder rotational viscometer, The calculated shear rates (350 sec^{-1} and 710 sec^{-1} respectively), were converted to rotational speed (rpm), and the resulting average value was used as a critical parameter to determine the maximum Bob angular deflection (deg) at this reading. This approach helped to optimize the rheological properties of cement slurry to be within design parameters.

Table 6 shows a summary of the steps followed to control the viscometer readings.

Table 6: Control of viscometer readings to optimize the rheological properties of the cement slurry

Rheology Readings			
Rate (bpm)	**Shear rate (1/s)**	**RPM (deg)**	**Aver. RPM (deg)**
2	350	205	≈ 300
4	710	417	

Centralizer Placement and Mud Removal

As the annular space for cement placement is better known on this job, solid centralizers were utilized to achieve effective mud removal, Due to tight annuli between 16 in casing and 13-7/8 in scab liner, any solid gauge OD of the centralizers was restricted to allowable maximum of 14.50 in.

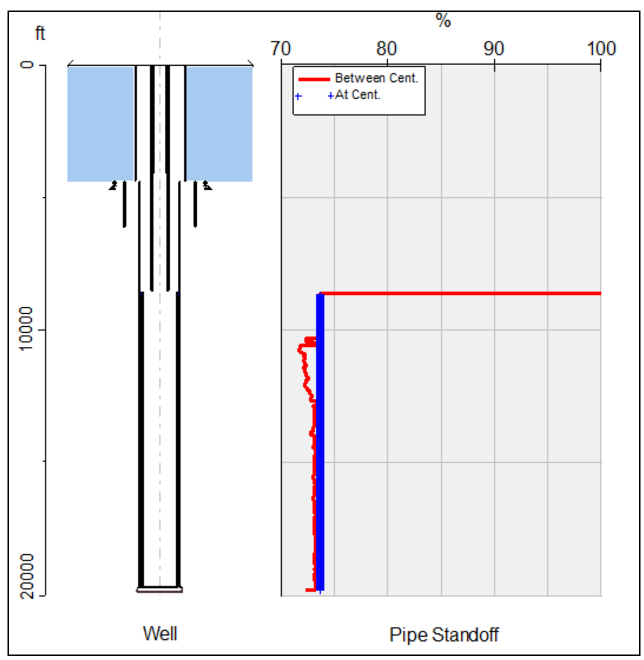


Figure 3: Simulated casing standoff with planned centralizer placement

The next parameter analyzed was understanding whether the original mud in the wellbore is effectively displaced by the spacer and then spacer by the cement slurry.

Fig. 4 below shows that fluids displacement simulator results, showing good separation between all the fluids during placement. It also shows that there was small risk of leaving the mud on the wall (unable to remove the static mud in the annulus) but it was above the zone of interest.

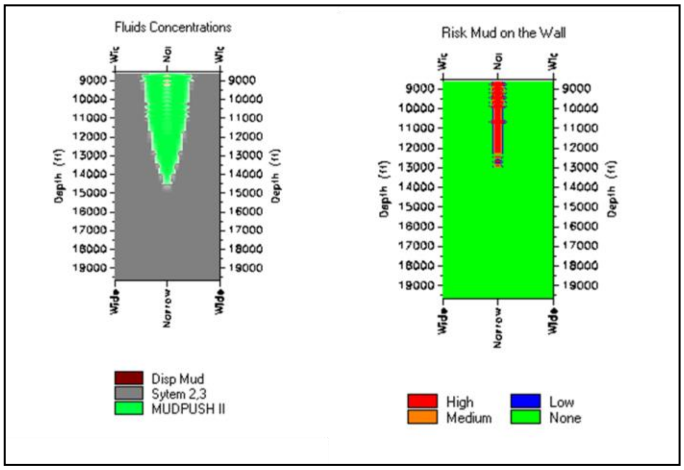


Figure 4: Mud removal simulation

Pre-job mud rheology calibration:

A table predicting circulating pressures associated with cement displacement rates was issued to the rig prior the job and it was agreed that the final selection of cement displacement rates would be performed by the rig and the cementing technical engineer in charge of the cement job design. The initial readings input in the simulator - during the job design - were theoretical values based on offset data and the best estimation provided by the mud company, founded on their hydraulic simulations for the job conditions. Therefore, prior the job and during the mud circulation, a mud rheology calibration was made in order to determine the “current” rheology of the mud based on actual recorded circulating pressures.

The methodology applied for the mud calibration can be summarized in the following steps:

- Start mud circulation with the scab liner in place without exceeding 3,000 psi at any time during circulation (setting pressure of the liner hanger: 3,600 psi).
- Record cement unit surface pressure and stand pipe pressure values at different flow rates; from 0.5 bbl/min up to 3.5 bbl/min.
- Using a graph with Mud Surface Pressure in the Y-axis and Time in the X-axis, compare the rig actual mud circulation pressure with the simulated mud circulation pressure.
- Calibrate the mud circulation pressure in the simulator until it matches with the actual mud circulation pressure. For it, different iterations were needed to adjust the rheological values (Fann 35 readings of the mud rheology).
- Once the simulated mud circulation pressure matched the actual mud circulation pressure, the calibration was achieved and the rheological parameters were adjusted and saved in the fluids section of the cementing simulator.

Table 7 shows the step sequence followed during the pre-job mud rheology calibration:

Table 7: Methodology used during the pre-job mud rheology calibration

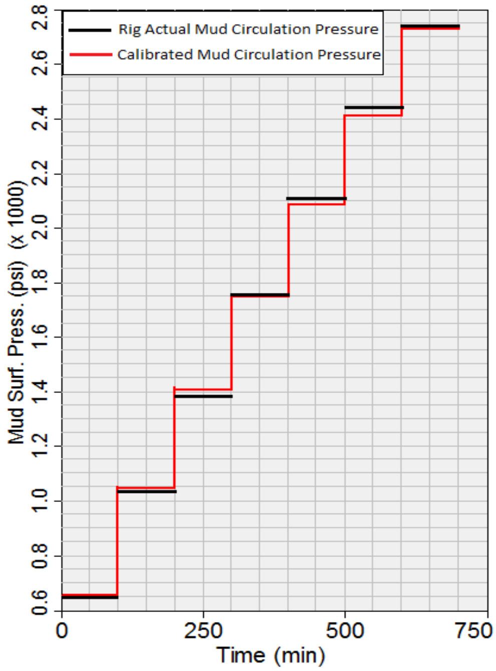
Initial Mud Rheology

RPM	Deg
600	91
300	57
200	43
100	29
6	11
3	10

Recorded circulating pressures with the scab liner in place

Pump Rate	Cement Unit	Stand Pipe
BPM	psi	psi
0	0	0
0.5	700	640
1	1,140	1,035
1.5	1,475	1,350
2	1,920	1,760
2.5	2,340	2,120
3	2,650	2,440
3.5	3,150	2,740

Calibration of mud surface



Calibrated mud rheology

RPM	Deg
600	71
300	45
200	29
100	12
6	5
3	3

The calibrated mud rheological values also allowed reviewing further the fluid mixing interfaces based on the rheological properties of each fluid and the determination of the maximum allowable flowrates to avoid exceeding the setting pressure at the 13-7/8 in liner hanger. Since a lower mud rheology was obtained from the exercise, it was found that slightly higher flowrates could be used to pump the fluids faster and reduce the pumping time in approximately 2 hours. Fig, 5 and Fig. 6 show the simulations run to maintain at all times a differential pressure ≤ 3,600 psi.

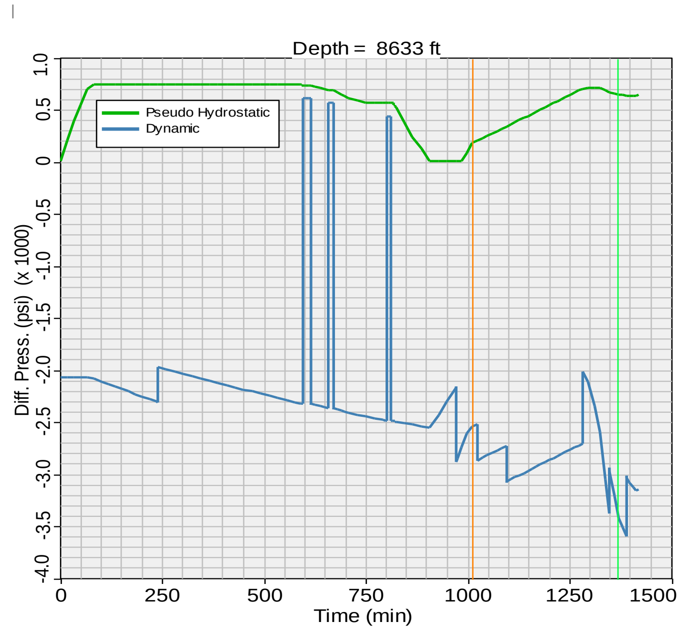


Figure 5: Simulated differential pressure at liner top

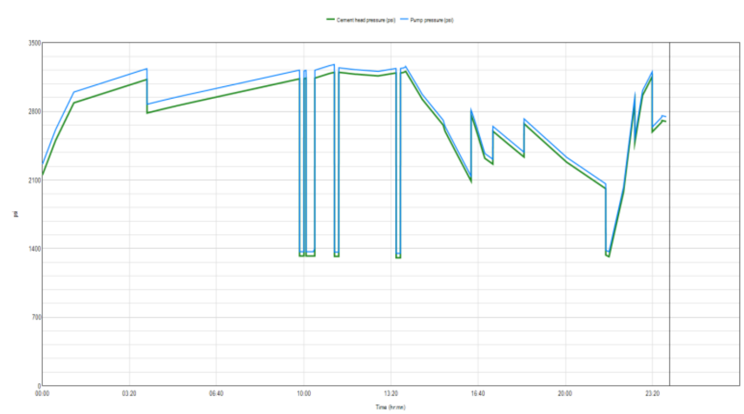


Figure 6: Simulated surface treatment pressure

Table 8 and Table 9 show the difference between the initial job time and the new job time once the flow rates were adjusted. A total of 2:18 hr: mn pumping time reduction was achieved from this analysis.

Table 8: Initial job time based on original mud rheological properties

Activity	Time (min)	Slurry Time Cum. (min)
Tail Slurry	227.0	227
Pause	10.0	237
Tail Slurry	9.3	194.8
Spacer	6.7	237.3
SBM Mud	690.8	928.1
Liner Hanger operations	120	1048.1
Tail Slurry Job Time		**17:28 hr:mn**
Tail Slurry Thickening Time		39:33 hr:mn
Tail Slurry Safety Margin		22:05 hr:mn

Table 9: Revised job time based on the calibration of mud rheological properties

Activity	Time (min)	Slurry Time Cum. (min)
Tail Slurry	170.2	170.2
Pause	10.0	180.2
Tail Slurry	7.0	187.2
Spacer	5.0	192.2
SBM Mud	597.8	790.0
Liner Hanger operations	120	910.0
Tail Slurry Job Time		**15:10 hr:mn**
Tail Slurry Thickening Time		39:33 hr:mn
Tail Slurry Safety Margin		24:23 hr:mn

Job Execution

Cement job was executed as per design. The placement of a homogeneous cement slurry with a constant density in the annulus as well as a strict control of the pump rates to satisfy the ECD requirements and ensure proper cement placement in the full interval.

A total of 1,300 bbls of low rheology mud was pumped using rig pumps to maintain the differential pressure below 3600 psi at all times during the cementing operation. Below table illustrates the sequence of fluids pumped during the cementing operation along with the pump rates. On an average most of the fluids were pumped at 1.8 bbl/min. Displacement stage was completed by rig pumps with an average pump rate of 3.0 bbl/min.

Fluid Name	Volume (bbl)	Density (lb/gal)	Pump Rate (bpm)
Low ECD Mud	1300.0	14.10	2.5
Spacer	100.0	14.30	1.8
Slurry	263.0	14.50	1.8
Spacer	10.0	14.30	1.8
SBM	1824	15.80	3

Acquired treatement data (surface pressure, pump rates and measured density) during the cementing job was plotted in relationship with time (shown in Fig. 7). The chart clearly shows the pressure signature as both bottom plug and top plug are sheared. Also it shows clearly the end of displacement stage.

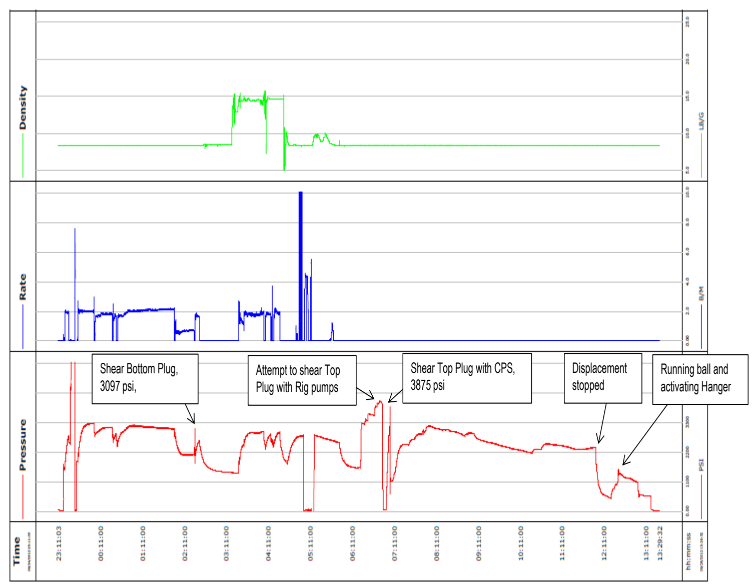


Figure 7: Cement job acquired data (pressure, rate & density)

Job Evaluation

Data acquired during the job execution (i.e., fluids density, pump rate, surface pressure and calculated volumes) are imported into a cement job design software and the hydraulic simulation of cement placement is completed using the acquired data. Pressure match analysis is then performed by comparing the simulated surface pressure and the acquired surface pressure from job execution data. The objective of this comparison analysis is to understand the pressure trends of each fluid stage. If the trends are match, it will confirm that all the fluids are being placed in the annulus as per the cement job design. This pressure match analysis is meant to confirm the cement placement in the annulus and ensure that the TOC is at the depth planned in the original design.

Fig. 8 shows the pressure curves of acquired and simulated pressures are at the same profile indicating pressure spikes as bottom and top plugs are sheared and annular fill-up of cement slurry during displacement stage. Final displacement pressure between two curves are within 200 psi differential. This clearly demonstrated cement slurry was placed as expected in the annular between 13-7/8 in scab line and 16 in casing, achieving top of cement as planned.

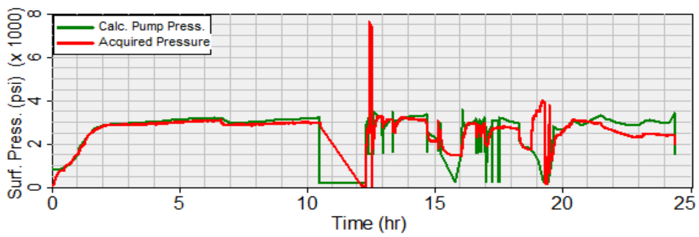


Figure 8: Comparison of acquired surface pressure and simulated surface pressure

Fig. 9 highlight the comparison of measured pump rate with simulated pump rate to understand if any deviation is noted during the cementing job. It clearly shows, the cement slurry and other fluids stages are executed

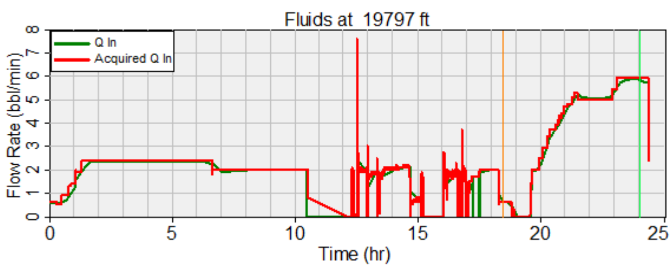


Figure 9: Comparison of acquired pump rate and simulated pump rate

With all the existing design challenges and limitations the job objectives were met and all the lessons learned were utilized in future well designs.

Conclusions

Successful cementing design and execution in several scab liners jobs demonstrated having better pre-job design with comprehensive analysis is critical step followed with:

- Selection of fluids' properties to lower the friction pressure due to tight annulus cement placement
- Maintaining pumping rates not to exceed maximum differential pressure of liner hanger
- Pre-job mud rheology calibration for accurate surface pressure prediction
- Selection of centralizer type with less frictions.

The application of these detailed engineering analysis provided successful cement placement and good mud removal for cement sheath thickness as small as < 0.5 in in Deepwater Gulf of Mexico envrioment.

References

1. Nelson, E.B. and Guillot, D.J. 2006. *Well Cementing*, second edition, Chapter. 7, pages 140–142., Chapter 11, pages 397 – 432, Houston, Schlumberger.
2. Farmer, P., Miller, D., Pieprzak, R., J., and Woods, R.: "Exploring the Subsalt." *Oilfield Review* v. 8, No.1, (Spring 1996) pages 50 – 64.
3. Piot, Bernard, and Loizzo, Matteo, 1998, "Reviving the Job Signature Concept for Better Quality Cement Jobs", paper IADC/SPE 39350, presented at IADC/SPE Drilling Conference, Dallas, Texas, 3 – 6 March, 1998.
4. Hunter, B., Tahmourpour, F., and Faul, R.: "Cementing Casing Strings across Salt Zones: An Overview of Global Best Practices" paper SPE 122079, presented at SPE Asia Pacific Oil & Gas Conference, Jakarta, Indonesia, 4 -6 August, 2009.