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Managed Pressure Cementing in Deepwater Environment, Evolving from Saving the Well with Perfectly Executed Challenging Primary Cementing Operations to Bring Back Wells to Productive Life with State-Of-The-Art Remedial Cementing Jobs on Controlled Pressure Manner

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Abstract

Managed Pressure Cementing has been utilized in many applications where MPD equipment is installed on the rig. This came as a consequence of having operators challenging the initial scope of using the MPD technology not just for drilling through a narrow operating window, in many cases by using a statically underbalanced mud weights, but also for tripping, logging, coring, running casing. Then of course to cement it and guarantee the isolation required for a subsequent successful hole section or simply a well set production tubular.

Particularly in deepwater operations where the riser represents a benefit in terms of balancing the well and get the hydrostatic column to help with the execution of balancing the well, running the casing, and performing the multistage cementing job. Where the booster pumps bring the benefit of constant monitoring and annular pressure control. Many operators have seen the benefit of using MPD on its wider solutions range adopting Managed Pressure Cementing from the planning phase.

However, we are currently witnessing a step ahead on what the technique can provide as smart solution when performing remedial cementing operations. These usually involve different environment and restrictions as well as regulations, and what is brought to the convenience of the project revamping purpose.

This paper gives examples for planning and execution of primary and remedial Managed Pressure Cementing in deepwater drilling operations.

Introduction

This project consisted of drilling four wells in GOM with a water depth of approximately 5,900 ft and a total average depth of 31,000 ft MD. The wells were drilled with an 8th generation "Ship Shaped Drilling Unit" with DNV 1A1 classification and described as DSME 12000 Ultra Deepwater Drillship. The production section of each well was planned to be drilled using Managed Pressure Technology.

For the primary cement job of the first Well (Well A), a very basic MPC approach was used during the job where SBP was applied to compensate BHP during the pauses to drop the darts. The second well (Well B) considered a conventional primary cement job and the results were not as expected. A remedial cement job was then planned and carried out using Managed Pressure Technology. The results obtained were satisfactory. The third and fourth wells (Well C and Well D) considered Managed Pressure Cementing for the primary cement job of the production section and the results were satisfactory. Additionally on Well D, five cement plugs to abandon the main hole and perform a sidetrack were carried out using Managed Pressure Cementing.

The planning, execution and results of these operations will be described in the following sections of this paper.

Background

The main objective of the wells drilled during this campaign was to provide drainage for the reservoir development in the leased area. The mobile offshore drilling unit (MODU) used to drill the wells was a "Ship Shaped Drilling Unit" with DNV 1A1 classification and described as DSME 12000 Ultra Deepwater Drillship. The Rotating Control Device (RCD) used for this application was a Below Tension Ring (BTR) type, complemented with an Applied Back Pressure (ABP) MPD system at surface which included a PLC controlled automated drilling choke (Moghazy et al. 2018)[1] and (Valecillos et al. 2019)[2]. Figure 1 shows a schematic representation of the implemented closed loop circulation system used for primary and remedial cementing operations on the MPD sections.

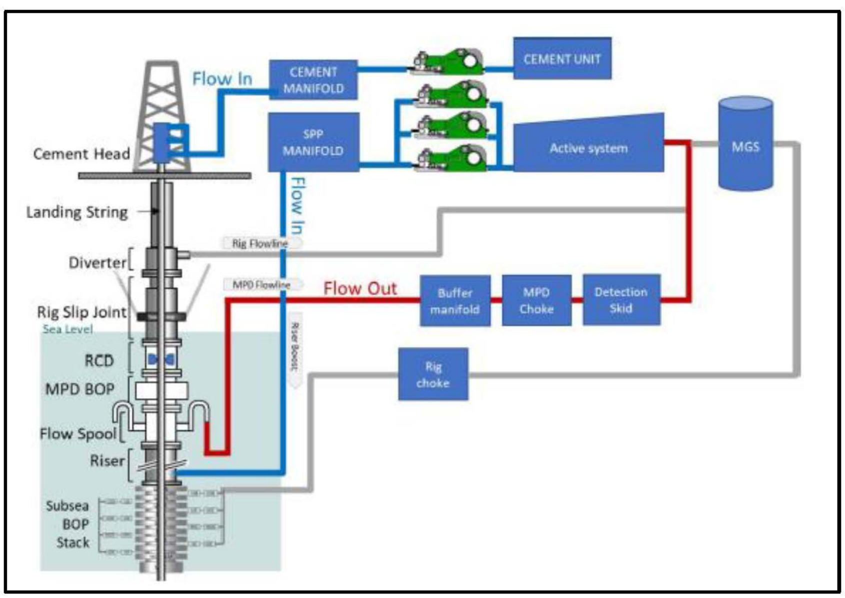

Figure 1—Deepwater MPC circulation system schematic

The typical well bore schematic for the wells discussed in this paper is shown below in Figure 2. MPD was utilized to drill the production hole section on Wells A, B, C and D.

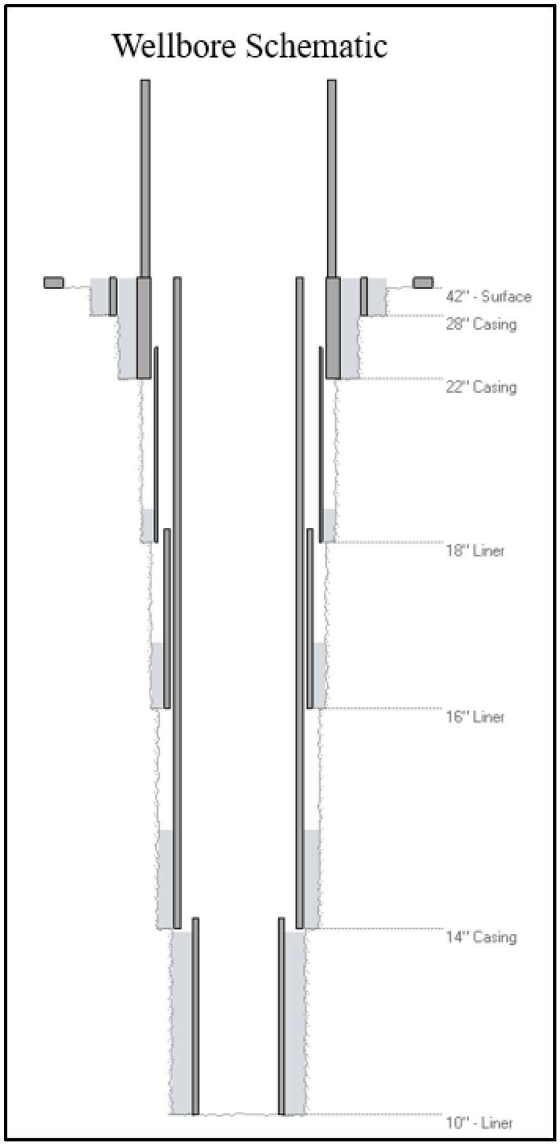

Figure 2—Typical Wellbore Schematic

The general plan for the production interval is:

- Displace well to light mud.
- Drill Shoe Track and Perform FIT
- Drill with MPD to TD
- Displace to heavy mud and POOH.
- RIH with 10″ Liner
- Displace well to light mud.
- Perform Managed Pressure Cementing.

A very simple approach was used to perform MPC during the primary isolation for the production 10″ Liner on Well A. Surface Back Pressure was used to maintain Bottom Hole Pressure during pump shutdowns to prepare the slurry, drop darts and plugs.

A conventional approach was used to perform the cement job of the production liner on Well B and proved to be insufficient due to the high losses encountered during the job. For this reason, a remedial cement job for the 10″ Liner was subsequently planned and performed. The remedial cement job, done using MPC proved successful.

On Wells C and D, MPC was planned and utilized for primary isolation of 10″ liner. Losses were observed during both jobs however the results obtained provided an acceptable isolation of the pay zone. Additionally, on Well D, five cement plugs in preparation for sidetracks and bypasses drilled from the original wellbore were performed using MPC.

The need to perform MPC, the engineering planning and execution involved, and the challenges faced while performing MPC are discussed in the following sections of this paper.

Problem Description

The utilization of MPD equipment for drilling and zonal isolation for these wells stems from the narrow operating window as shown in Figure 3. In addition to that, the presence of pore pressure ramps, weak zones, and uncertainties in the drilling window predictions make these wells ideal candidates to drill and provide primary isolation using surface back pressure manipulation. While drilling the production sections, losses were experienced in most of the wells. Upon curing the losses and reducing the bottom hole pressure using MPD, ballooning effect was observed, making it challenging to run the 10″ liner and perform cementing operations conventionally.

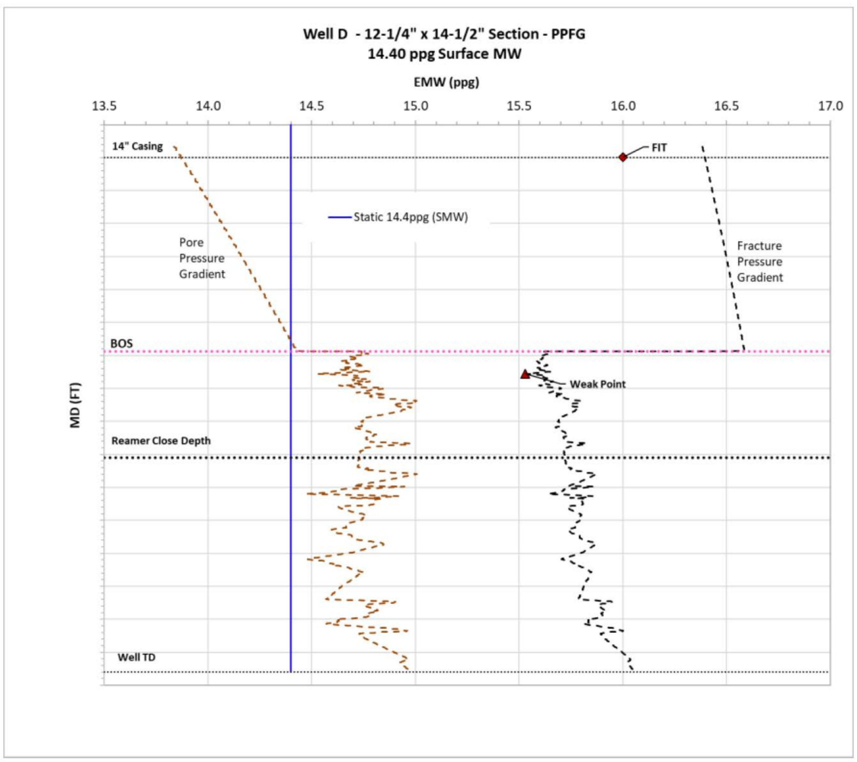

Figure 3—Pore Pressure and Fracture Pressure Gradients

In addition to this, some of the wells encountered Tar formations while drilling. This caused pack-off events above the bit, leading to an increase in bottom hole pressure at the bit which resulted in the loss and ballooning cycles mentioned previously.

The hydraulic profiles obtained using a statically overbalanced mud while circulating at cementing rates with 10″ liner on bottom resulted in bottom hole pressures higher than open hole losses or formation fracture limits.

All these challenges called for the implementation of a precisely engineered MPC program to successfully isolate the 10″ liner and render the wells producible.

In the case of Well B, conventional cementing operations were performed on the 10″ liner and heavy losses were experienced; hence the results were not optimal, and isolation was insufficient. Navigating a hole section with high zones of high pore pressures and areas with weak fracture gradient at the same time becomes a challenge for drilling and cementing operations. A decision was made to plan and execute a remedial cement job utilizing MPC. This is one of the pioneering remedial cementing operations performed by exploiting MPC techniques. The details of this operation will be discussed in upcoming sections of this paper.

In the case of Well D, multiple sidetracks and bypasses had to be drilled to reach the planned reservoir targets. This was due to the unexpected occurrence of tar formations in the well. As mentioned previously, this posed a challenge with multiple pack-off events and forced sidetrack and bypass operations. The cement plugs needed to successfully abandon the production zone and drill the sidetrack and bypass were placed using MPC. The detailed planning and execution of the MPC jobs proved to be vital to future production from these wells.

Well B Remedial Cement Job Execution

After being drilled, Well B was placed back in the drilling sequence right after a scheduled BOP maintenance break. The plan was to conduct a remedial cement job. The central principle for the remedial cement job consisted of making two sets of perforations on the production Liner on an interval with no cement and circulating the cement from the lower perforations to the upper perforations throughout the 10″ liner-Formation annulus. This will ensure the necessary isolation around the producing formations. The challenge was to overcome the losses encountered on the primary cement job with statically underbalanced mud and still be above the pore pressure of the producing formations. To achieve this, the job was designed to be performed using Managed Pressure Technology. Key operations in preparation for the remedial cement job performed using MPC are mentioned below:

- Logging the 10″ liner with wireline
- Selecting the optimum interval to make the perforations.
- Perforating the 10″ liner
- Setting the Fas Drill SVB Packer right above the lower perforations
- Displacing the heavy synthetic mud by light synthetic mud.

The workstring used to perform the remedial cement job is show in Table 1 below.

After the heavy mud was displaced by light mud, the first step of the remedial cementing operations was to spot cement at the end of the workstring. 15.8 ppg spacer, 16.2 ppg lead cement slurry and 16.2 ppg tail cement slurry were spotted at the end of the workstring, leaving 70 bbl of 15.8 ppg spacer on the 4 ½" Drill Pipe - 10″ liner annulus and 65 bbl inside the 4 ½" workstring. Figure 4 below shows the graphic representation of the steps to spot the fluids at the end of the workstring. The MPC SBP scheduled was modelled using the pump schedule shown in Table 2.

Table 1—Workstring for 10″ Liner Remedial Cement Job

Schematic	Item	Description	OD (in)	ID (in)	Length (ft)
	1	Workstring: 6-5/8" 40# FH	8.50	4.25	5950.00
	2	Baker XACT Component - ST6	7.25	2.95	75.00
	3	Workstring: 6-5/8" 34# V150 GPDS65	8.50	4.25	5425.00
	4	Baker XACT Component - ST5	7.25	2.95	75.00
	5	Workstring: 6-5/8" 34# V150 GPDS65	8.50	4.25	3426.00
	6	Workstring: 6-5/8" 27.7# V150 GPDS65	8.50	4.25	1499.00
	7	Baker XACT Component - ST4	7.25	2.95	75.00
	8	Workstring: 6-5/8" 27.7# V150 GPDS65	8.50	4.25	4225.00
	9	Baker XACT Component - ST3	7.25	2.95	75.00
	10	Workstring: 6-5/8" 27.7# V150 GPDS65	8.50	4.25	2833.00
	11	X-Over: 6-5/8" GPDS65 Pin x 4-1/2" 20# S135 XTM-40	8.50	2.69	3.00
	12	Workstring: 4-1/2" 20# S135 XTM-40	5.25	2.69	1183.00
	13	Baker XACT Component - ST2	7.25	2.95	75.00
	14	Workstring: 4-1/2" 20# S135 XTM-40	5.25	2.69	2525.00
	15	Baker XACT Component - ST1	7.25	2.95	75.00
	16	Workstring: 4-1/2" 20# S135 XTM-40	5.25	2.69	1005.00
	17	X-Over: 4-1/2" XTM-40 Box X 4-12" IF Pin	5.50	2.69	2.00
	18	Extended Weatherford Dart Catcher : 4-1/2" IF	6.63	N/A	10.58
	19	Sentinel Float Valave: 4-1/2" IF	6.63	2.13	3.00
	20	X-Over: 4-1/2" IF Pin x XTM-40 Pin	5.25	3.00	2.00
		Existing Perforations			
	21	Workstring: 4-1/2" 20# S135 XTM-40	5.25	3.00	1999.00
	22	Baker XACT Component - ST0 + Isolator	7.25	2.95	135.00
	23	X-Over: XTM-40 pin x 4-1/2" IF Pin	5.50	3.00	3.00
	24	Mechanical Setting Tool: 4-1/2" IF Box	8.00	1.19	4.00
	25	9-7/8" Fas-Drill SVB (Cement Retainer)	7.75	N/A	4.38
		Existing Perforations			

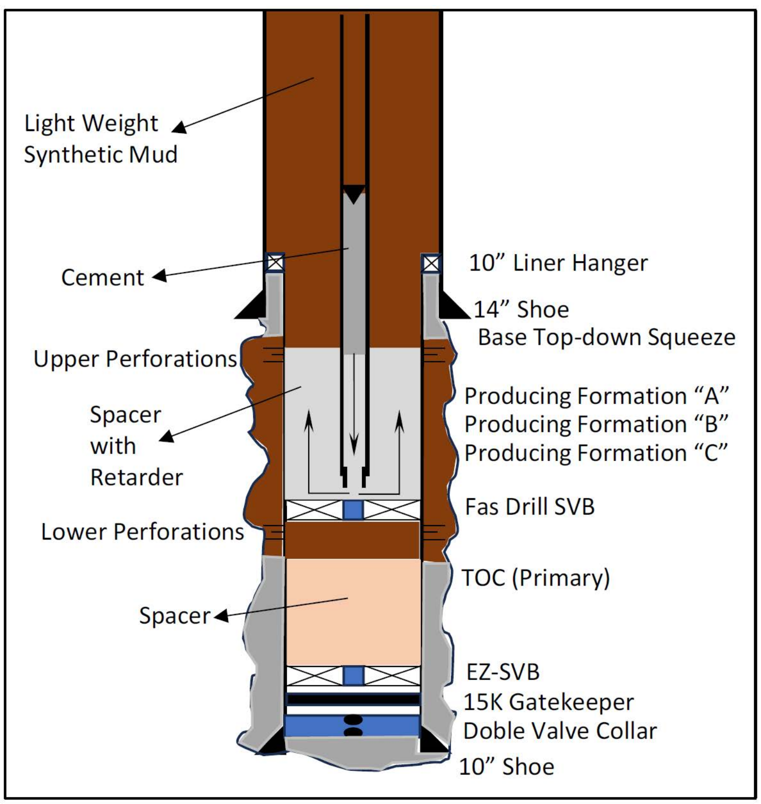

Figure 4—Spotting Spacer and Cement to the End of the Workstring

Table 2—Pump Schedule to Spot Fluids at the End of the Workstring

Stage	Density (ppg)	Flow Rate (bpm)	Volume (bbl)
Spacer	15.8	4	65
Bottom Plug			
Lead Cement Slurry	16.2	4	55
Tail cement Slurry	16.2	4	50
Top Plug			
Spacer	15.8	4	25
Displacement	14.35	4	560
Displacement	14.35	4	196.53

In accordance with the pump schedule, extensive hydraulic simulations were run to get the SBP schedule needed to maintain the required BHP while spotting the fluids at the end of the workstring. The MPC schedule is shown below on Table 3 and graphically shown in Figure 5 below.

Table 3—MPC Schedule for spotting Spacer and Cement at the end of the Workstring

Sim. Time	Drill String Flow Rate		Total Vol. Displaced	Boost Rate up Riser	Dynamic SBP	ECD at Upper Perf	ECD at Lower Perf (Back Side)	Static SBP	Comments
(min)	(gpm)	(spm)	(Stk)	(gpm)	(psi)	(ppg)	(ppg)	(psi)	
0.0	0	0	0	Booster Pump aligned on Surface Loop for SBP Control, pumping light mud at 400 gpm	910	15.20	15.20	910	Static EMW Apply 910 psi
0.1	168	40	3		450	15.05	15.28	910	Start pumping 135 bbl of Spacer at 4 bpm
33.7	168	40	1337		450	15.05	15.28	910	Stop and Drop Bottom Dart
33.8	0	0	1337		698	15.17	15.20	698	Stop and Drop Bottom Dart
38.7	0	0	1337		698	15.17	15.20	698	
38.8	168	40	1340		450	15.05	15.28	698	Start Pumping Lead Cement at 4 bpm
51.2	168	40	1831		450	15.05	15.28	698	Start pumping Tail Cement at 4 bpm
63.7	168	40	2327		450	15.05	15.28	698	Stop pumping
63.8	0	0	2327		591	15.12	15.20	591	Drop Top Dart
68.7	0	0	2327		591	15.12	15.20	591	
68.8	168	40	2330		450	15.05	15.28	591	Start pumping 10 bbl of Spacer
71.2	168	40	2426		450	15.05	15.28	591	
71.3	251	59	2426		430	15.05	15.38	591	Start displ with light SMW at 6 bpm
160.7	251	59	7722		430	15.05	15.38	591	65 bbl of 15.8 ppg Spacer inside pipe
160.8	0	0	7722		710	15.18	15.30	710	Apply 710 psi - 70 bbl Spacer in Annulus

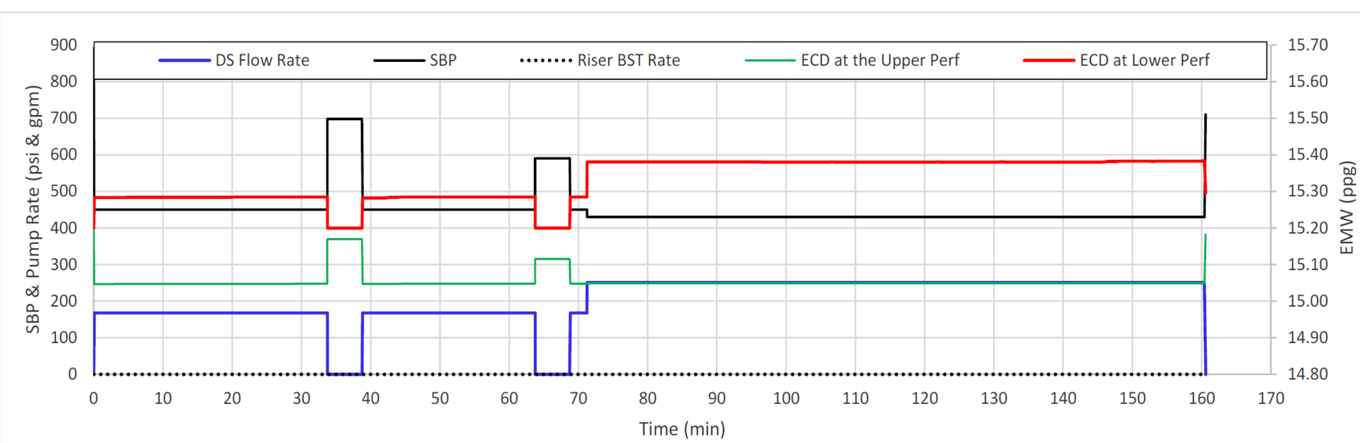

Figure 5—MPC Schedule for Spotting Spacer and Cement to the End of the Workstring

The second and final step of the remedial cement operations consisted in filling the void between the 10″ liner and the 12 ¼" open hole with cement to obtain the required isolation in the Producing formations. After spotting the spacer and cement at the end of the workstring, it was stung into the Fas-Drill SVB packer. Displacement using light mud was continued as per Table 2 to circulate the cement throughout lower and upper perforations. The Figure 6 below shows a graphic representation of steps involved to circulate cement through the perforations. In accordance with the pump schedule, extensive hydraulic simulations were run to get the SBP schedule needed to maintain the required BHP at the lower perforation (15.20 ppg) while circulating cement through the perforations. One of the challenges for the hydraulic simulation was the pressure drop originated at the perforations itself but since the cross section of the perforations was larger than the cross section of the pipe, it was neglected. The MPC schedule is shown below in Table 4 and graphically on Figure 7 below.

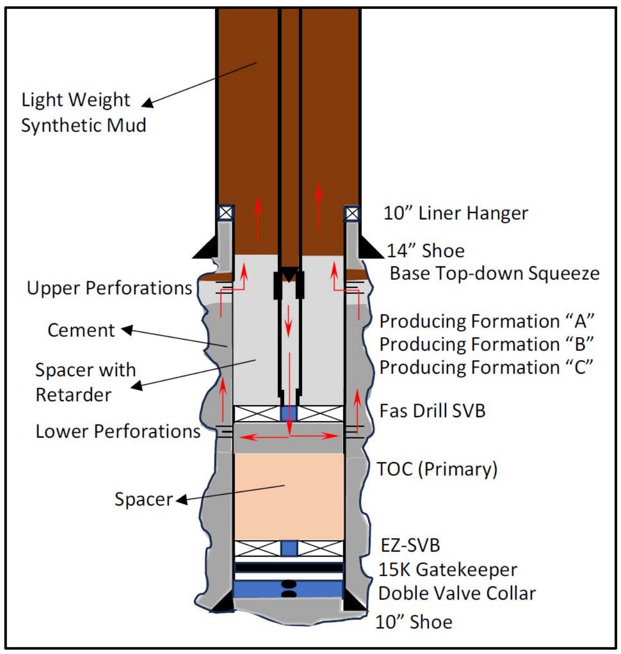

Figure 6—Circulating Cement through lower and upper Perforations.

Table 4—MPC Schedule for circulating the cement through lower and upper Perforations.

Sim. Time	Drill String Flow Rate		Total Vol. Displaced	Boost Rate up Riser	Dynamic SBP	ECD at Upper Perf	ECD at Lower Perf	Static SBP	Comments
(min)	(gpm)	(spm)	(Stk)	(gpm)	(psi)	(ppg)	(ppg)	(psi)	
0.0	0	0	0	Booster pump aligned on Surface Loop for SBP Control pumping light mud at 400 gpm	710	15.19	15.20	710	Static EMW Apply 710 psi
0.1	167	39	3		710	15.19	15.20	710	Start pumping light ppg mud at 4 bbl/min
1.3	167	39	49		694	15.19	15.20	709	Start Reducing SBP
5.4	167	39	211		651	15.18	15.20	705	
10.3	167	39	405		641	15.18	15.20	700	
15.2	167	39	599		602	15.15	15.20	695	
20.1	167	39	792		562	15.12	15.20	690	
22.9	167	39	903		540	15.11	15.20	687	
27.8	167	39	1096		496	15.09	15.20	682	
32.7	167	39	1290		444	15.07	15.20	677	
38.3	167	39	1511		386	15.06	15.20	671	
43.2	167	39	1705		346	15.05	15.20	665	
48.1	167	39	1899		315	15.06	15.20	661	
49.4	167	39	1950		306	15.06	15.20	660	
49.4	167	39	1950		306	15.06	15.20	660	
49.4	0	0	1950		660	15.14	15.20	660	End of Job Apply 660 psi

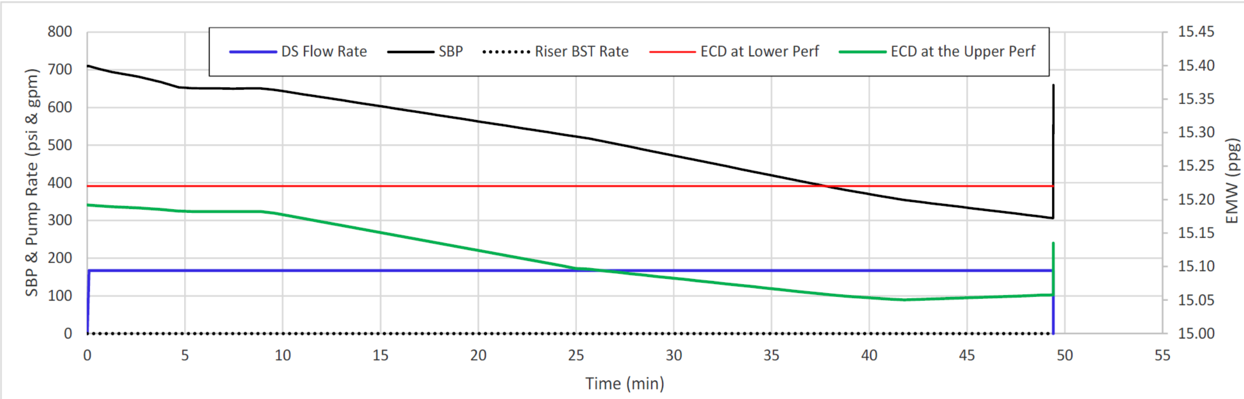

Figure 7—MPC Schedule for Circulating Cement through Upper and Lower Perforations

During the operation, 247 bbl were lost and circulation rate was about 50%. After the cement was in place, stung out from the fas drill packer and displaced well to heavy fluid to prepare to Trip out of the hole.

Well B Remedial Cement Job Results

The operation was executed as per plan; however, losses were observed during displacement of cement. Figure 8 shows the time plot of Flow In, Flow Out, SBP and ECD measured using a tool in the workstring. The sequence of operations denoted in Figure 8 is shown in Table 5. It is to be noted that due to limitations in instrumentation and data transmission, the MPD control system was unable to receive cement pump flowrate data during the cementing operations. The Flow In data shown in Figure 8 represents the flow from the booster pump only. It can be observed that the green curve which represents the measured ECD, follows the same trend as the SBP.

Table 5—Operational Sequence for Remedial Cement Job

#	Event Description
1	Pump 15.8 ppg tuned prime spacer
2	Shut down pumping and mix cement
3	Pump 16.2 cement slurry
4	Spot cement in workstring, placing 70 bbl of spacer above Fas-Drill Packer, filling liner to top of perforations
5	Displace cement to bottom perforations
6	Sting out of Fas-Drill Packer

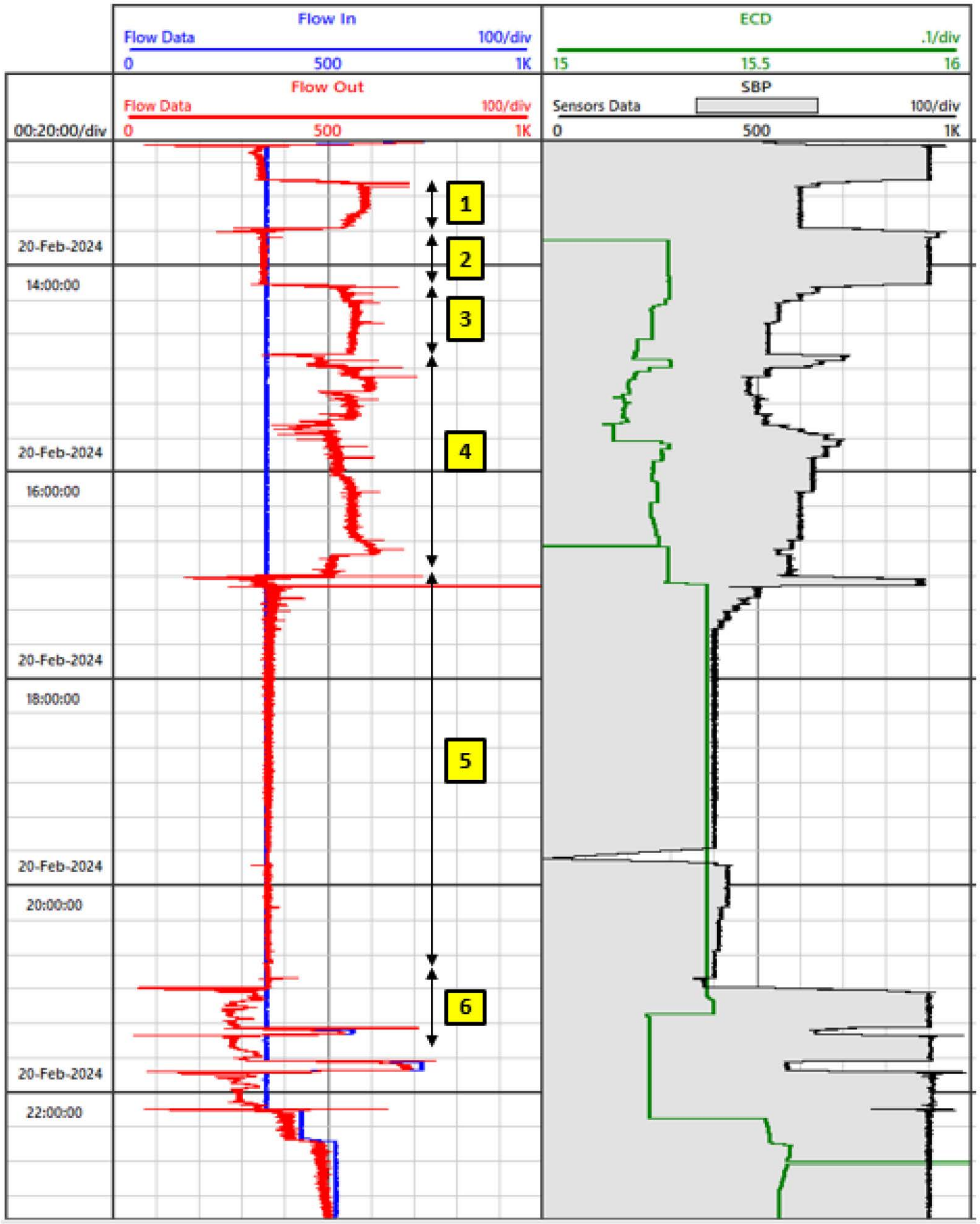

Figure 8—Time plot of Remedial Cement Operation

Figure 9 below shows the Cement Bond Log for the entire interval between the lower and upper perforations represented by the black dashed line. It is evident that the cement bond and volume behind the liner has significantly improved after the remedial cement operation. The improvement in isolation has rendered the well producible.

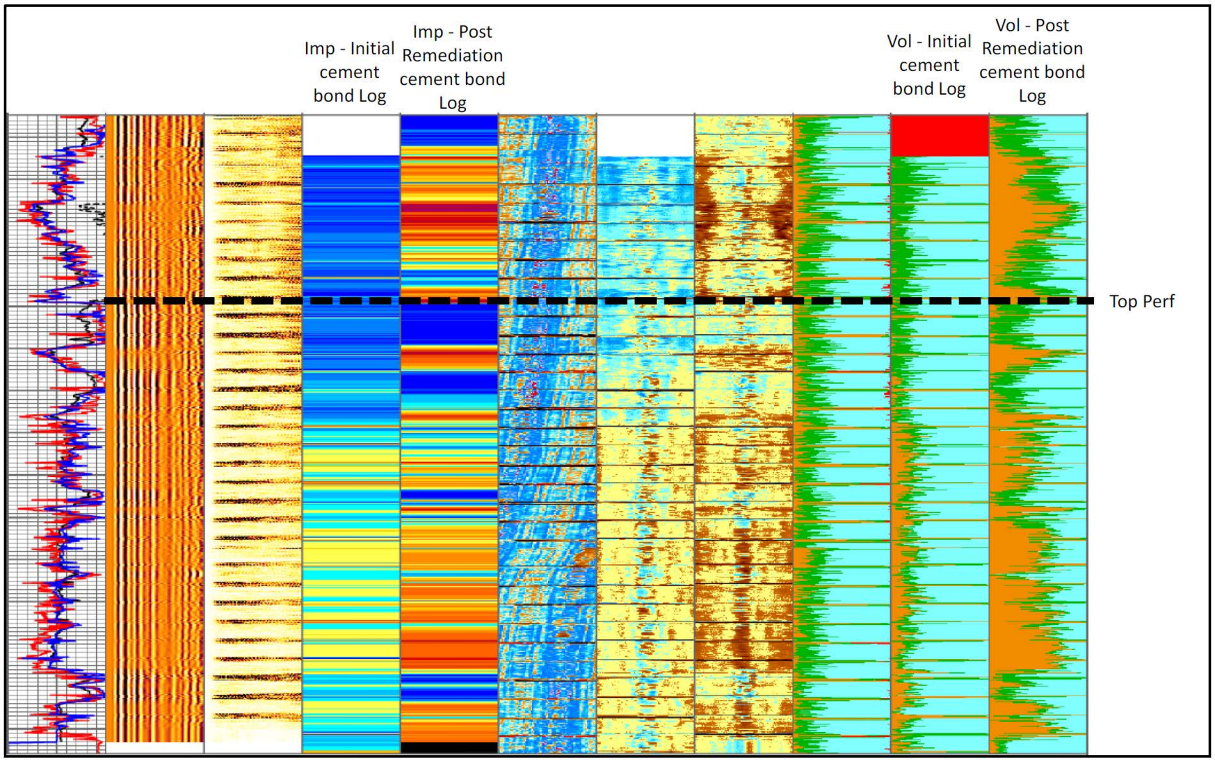

Figure 9—cement Bond Logs Before and After Remedial Cement Job

Well D Cement Plugs for Abandonment Execution.

During the drilling operations of Well D, as mentioned before, very reactive Tar formation was encountered. It caused pack off and severe losses. Ballooning effect was also present causing an unnecessary increase of mud density and Surface Back Pressure. As drilling operations were not possible to resume, it was decided to abandon the main wellbore and perform a Sidetrack. To properly abandon the main wellbore Five Cement plugs were needed as shown below on Figure 10. The main drive for performing the operation with Managed Pressure Technology were the losses and the need to increase Mud weight to counteract the ballooning effect. All the Five Cement Plugs were executed similarly, in that sense, only one will be covered on this paper to show non-conventional cementing operations performed under Managed Pressure. The pumping and SBP schedule for the Cement Plug # 1 can be observed on Table 6 and graphically shown on Figure 11 on the following page.

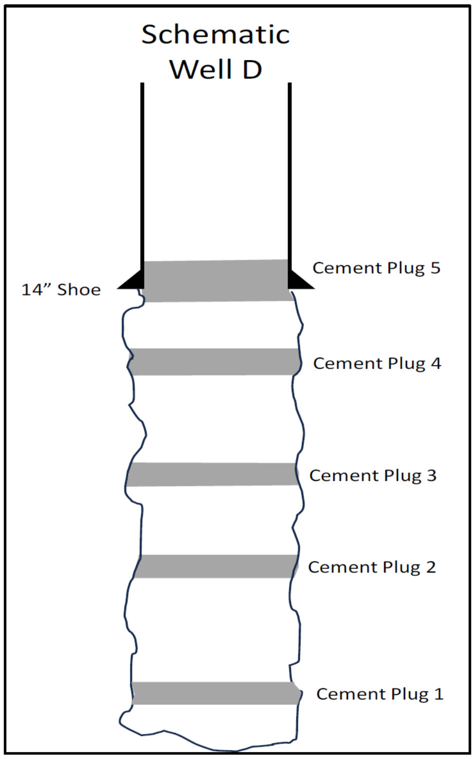

Figure 10—Well D abandonment Cement Plugs

Table 6—Pumping Schedule for the Cement Plug # 1

Sim. Time	Drill String Flow Rate	Fluid Density	Total Vol. Displaced	Boost Rate up Riser	Dynamic SBP	Casing Shoe ECD	ECD at Obs. Point	ECD at TD	Static SBP	Comments
(min)	(bpm)	(ppg)	(bbl)	(gpm)	(psi)	(ppg)	(ppg)	(ppg)	(psi)	
0.0	0	14.75	0.0	Booster Pump aligned on Surface Loop for SBP Control, pumping 14.75 ppg mud at 350 gpm	607	15.57	15.50	15.48	607	Static EMW Apply 607 psi
0.1	5	15.80	0.4		425	15.55	15.50	15.49	607	Start pumping 70 bbl Spacer at 5 bpm
0.3	5	15.80	1.2		425	15.55	15.50	15.49	607	Apply 425 psi
14.0	5	15.80	70.0		425	15.55	15.50	15.49	607	
14.1	0	15.80	70.0		607	15.57	15.50	15.48	607	Stop to Premix 16.2 ppg Cement
14.2	0	15.80	70.0		607	15.57	15.50	15.48	607	Apply 607 psi
44.0	0	15.80	70.0		607	15.57	15.50	15.48	607	Drop Plug
44.1	5	16.20	70.2		425	15.55	15.50	15.49	607	Resume Pumping 182 bbl of Cement
63.9	5	16.20	169.2		425	15.56	15.50	15.49	607	
80.4	5	15.80	251.3		421	15.55	15.50	15.49	607	Chase Cement with 16 bbl of Spacer
83.7	6	14.75	267.8		423	15.55	15.50	15.49	607	Displace with 14.75 ppg Mud at 6 bpm
175.1	6	14.75	846.8		415	15.55	15.50	15.49	607	Spacer Turning the Bit
189.2	6	14.75	934.6		416	15.55	15.50	15.52	599	Cement Turning the Bit
214.6	6	14.75	1051.5		414	15.55	15.50	15.57	572	
214.6	0	14.75	1051.5		572	15.56	15.50	15.57	572	Apply 572 psi

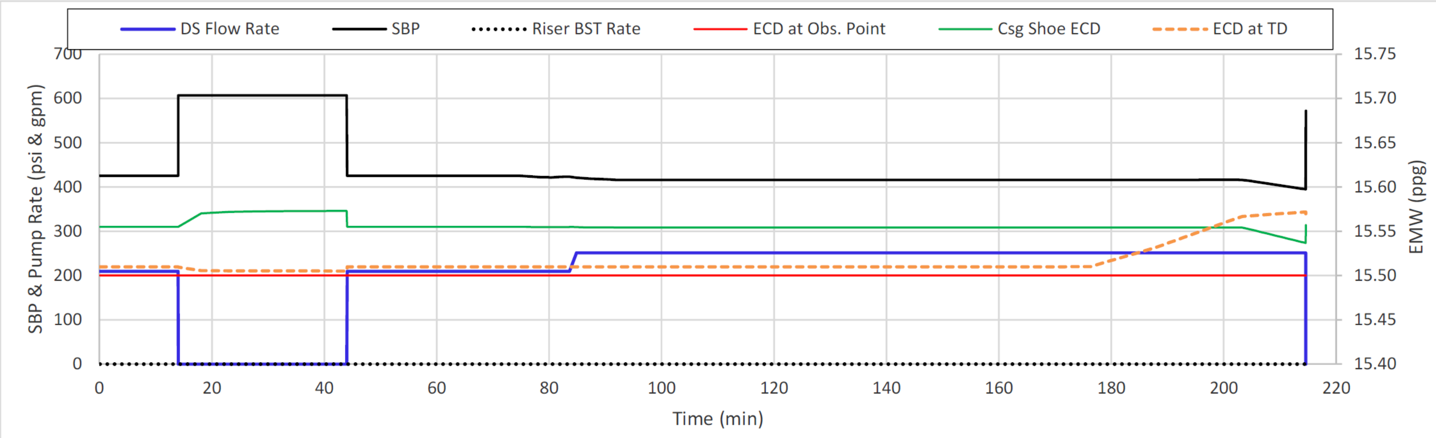

Figure 11—Pumping and SBP Schedule for Cement Plug # 1

Conclusions

The results obtained during the primary cement job on the production Liner carried out with MPC on the Wells C and D allowed the operator to save time and resources on further remedial cement jobs with an approximate estimation of US$30 million per well.

The excellent results obtained on the remedial cement job on Well B allowed the operator to save the well and avoid a Sidetrack as well as proved the technology to be useful during remedial cement operations.

On Well D, the benefits of using Managed Pressure Technology were also observed during the main hole abandonment by cement plugs preparing the well for Sidetrack operations were also valuable to save time.

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Abbreviations / Nomenclature

Bbl = barrel
BPM = Barrels per Minute
BSEE = Bureau of Safety and Environmental Enforcement
CBHP = Constant Bottom Hole Pressure
ECD = Equivalent Circulating Density
FIT = Formation Integrity Test
POOH = Pull Out of the Hole
ppg = Pound per Gallon
ppge = Pound Per Gallon equivalent
MD = Measured Depth
MW = Mud Weight
RIH = Run in Hole
SBP = Surface Back Pressure
TD = Total Depth
TOC = Top of Cement
TVD = True Vertical Depth

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