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INSTITUTO ARGENTINO DEL PETROLEO Y DEL GAS

IMPROVING ZONAL ISOLATION IN HORIZONTAL CONFIGURATIONS: DYNAMIC CEMENT PLACEMENT APPROACH

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Abstract

The increasing energy demand has led shale unconventional reservoirs to become a focal point for operators worldwide. Over the past decades, several technological advances conveyed to drilling and completing horizontal geometry wells in which ulterior massive hydraulic fracture treatments are deployed to improve production of these reservoirs, technically but not economically recoverable. Argentina, which counts with one of the largest shale-stored hydrocarbon reserves in the world, has become one of the leading countries in unconventional reservoirs completions, having horizontally-drilled wells number increased over the past decade.

This fact has generated the need to find solutions operationally and economically viable to successfully cement horizontal wells, achieving proper zonal isolation. Since the difficulties encountered in Neuquén's wells, such as channeling, differential fluid velocities, among others, most of them not possible to overcome, the need to implement casing movement while cementing as a practical solution had arisen. Studies have shown that displacement efficiency can top as much as 50 % when there is no pipe movement to increasing up to 100 % with movement, in which rotation shows to be the preferred pipe movement because of the azimuthal forces exerted on the fluid that cause it to be completely swept away around the annulus.

The challenge is to incorporate previous experience in the field and introduce casing rotation for dynamic cementing. This mechanical method, although proven to be the most cost effective, has remained as one of the least accepted solutions, due in large part to the misconceptions and the fear that the high torques during the cement pumping/displacement will cause casing failures.

In a recent campaign, the last well considered rotation in the production section-cementing job. Rotation was enabled from circulating mud prior cementing until displacement and bumping the plug. A rotation speed sensitivity was analyzed to determine the optimum angular speed and according to the torque capabilities (connections and surface equipment) an optimum rate of 30 rpm was proposed. This well was cemented obtaining congruent results from comparing bond logs and fluid placement simulations.

This project focuses on the definition of the factors contributing to a successful cementing job in an horizontal geometry, the aspects that need to be analyzed from the cementing perspective when rotating casing to aid in mud displacement, and the evaluation related to the wells cemented under these circumstances compared to the simulated results predicted during the design phase of the well.

Introduction

The potential of Argentina unconventional resources is within the most important in the world, having Argentina the 2nd and the 4th place for the largest technically recoverable shale gas and shale oil resources respectively, putting almost all the attention on the Neuquén basin, located in the center-west of the country covering an area of more than 200.000 km^2.

During the last years, different Operators, increasing significantly the production of unconventional gas and oil, have drilled hundreds of wells. A large percentage of the activity has been directed to the shale oil and gas in the Vaca Muerta formation and due to the particular characteristics of this type of reservoir, horizontal wells are proved the most cost-effective ones for production.

The usual objective of a horizontal well is to provide improved production relative to that obtained with a less deviated well. This is primarily because of the greater productive formation surface area exposed to the wellbore, improving the contact with the reservoir; thus, not only the productivity but also the total production is increased.

A typical horizontal well configuration present in the region corresponds to the medium to long-radius type, used to develop reservoirs whose depth and thickness require accurate well placement.

The horizontal section length (lateral) can range from1000 m to 2500 m (landed at the Vaca Muerta shale), and has open hole diameters from 15.56 cm [6 1/8 in] to 21.59 cm [8.5 in]. The well is usually cased off with a tapered 12.70 x 11.43 cm [5 x 4 ½ in] or 13.97 x 11.43 cm [5 ½ x 4 ½ in] production string, and cemented up to the previous (intermediate) casing string. Some of the main advantages of the cemented completions are listed below, hence the importance of obtaining a good cement coverage:

- The possibility to perform multi-stage fracturing.
- Isolation of productive zones in the horizontal section
- Ability to perform effective remedial treatment with a workover rig or coiled tubing during the life of the well. It is almost impossible to shut off an unwanted water-producing zone in an open-hole completion.
- Provides borehole stability
- 9 5/8 production casing acts as secondary barrier (compared to liner design)
- Eliminates liner hanger as potential failure point

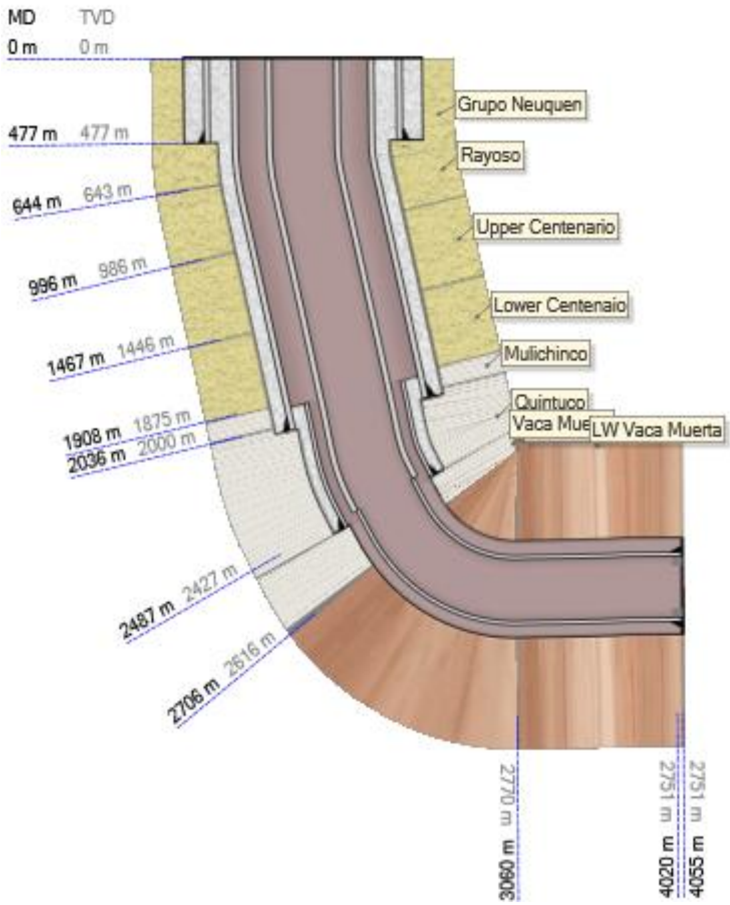

Figure 1. *Typical Horizontal well design for the zone.*

Problem Identification

Effective zonal isolation is critical to avoid communication between zones and essential to mitigate risks and non-productive time associated with leaks, corrosion and contamination. Even though well integrity for the stimulation load case is the critical concern, a bad zonal isolation can result in a lower quality Frac job and well completion, which can generate lost production consequently. A good cement job is a key factor to be able to perform the stimulation per program.

In terms of cementing horizontal wells, the most common cause of not achieving zonal isolation is the ineffective mud removal. The presence of mud pockets, thin films or channels, prevent cement from forming an effective bond to casing and formation walls. Conventional cementing good practices, such as the use of pre-flushes or the centralization of the string, may not be sufficient for an effective mud displacement on horizontal wells.

- In the horizontal section, friction (rheology) hierarchy mainly drives mud removal, while the density hierarchy has little effect.
- The casing is never perfectly centralized in the open hole (even when using several centralizers), contrarily to a vertical well where a few centralizers can provide

a good standoff of 75% or higher. Fluids will always take the path of least resistance through the wide side of the annulus, and the fluid velocity will be higher than in the narrow side.

As the deviation angle increases, casing centralization becomes more difficult because of the increasing load on the centralizers. The optimum number and spacing of centralizers could be determined using a cementing software, but sometimes the resulting centralization schedule is not practically achievable, thus, the cement job design had to be optimized in another way to avoid any annular communication and provide good cement isolation.

For those wells drilled with water-base mud (WBM), the borehole geometry is negatively affected, making centralization more challenging (need to increase number of centralizers) and worsening the well cleaning. Under this scenario, and to avoid increasing the drag while RIH casing string, the number of centralizers was limited to a minimum.

In addition, well conditions conveyed to high mud density and rheology, this fact along with the presence of a narrow operative window, limited the ideal flow regime for optimum hole cleaning and the fluids friction hierarchy optimization.

Advanced 3D Annular Displacement Simulator (3D-ADS) predicted major fluids channeling and poor cement coverage because of the bad centralization (Figure 2) and difficulties to adjust the friction hierarchies considering the narrow operating margins. Mud pockets and channels left in the annulus will prevent the cement from bonding to the casing and formation wall forming a hydraulic seal. In addition, these channels are preferential paths for gas migration. Mud channels are one of the most common causes of primary cementing failure.

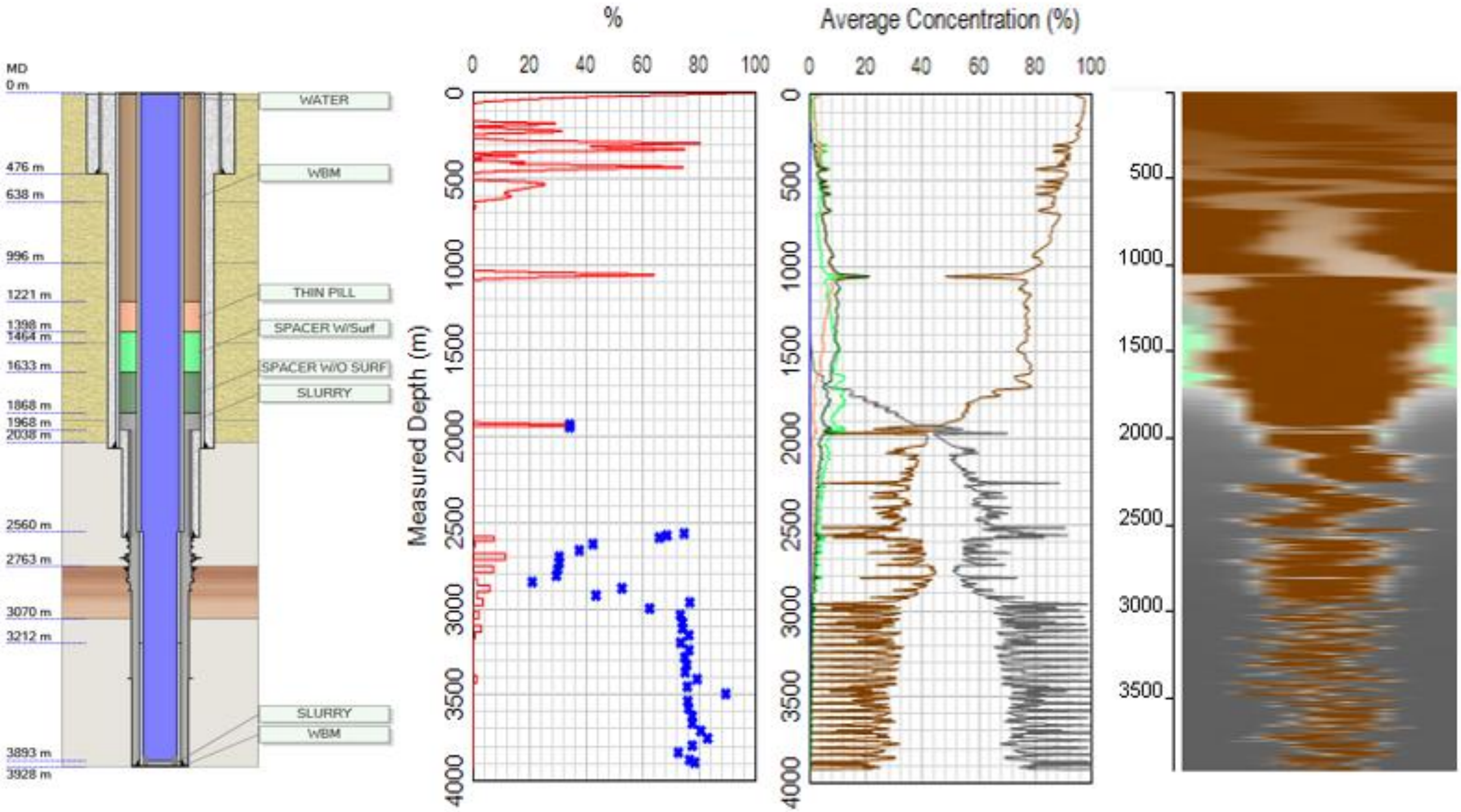

Figure 2. *Centralization and Average fluid concentration in annulus, 3D Aperture result.*

Solution

Because neither the standoff nor the fluids design could be improved as to make a difference in the mud removal results, the casing rotation while cementing seemed to be the only practical solution to improve cement coverage.

As it was mentioned before, studies have shown that displacement efficiency (mud removal) can increase from 25-50 % when there is no pipe movement to as much as 100 % with movement. Movement of the pipe will have several beneficial effects, improving the cement bond quality:

- Aid in cuttings removal.
- Break gel strength.
- Change the annular flow profile.

Dynamic cementing refers to the rotation the casing string during the execution of the job, from the time the operation starts - or since the well is conditioned prior the job - until the cement placement in the annulus is completed, as long as the well conditions allow and torque permits. Pipe movement increases the effective volume of drilling fluid that is actually moving in the annulus and supplies a mechanical aid for breaking up the gelled structure of immobilized mud.

Rotation during cement placement helps to remove mud that would otherwise be trapped on the narrow side of eccentric annuli, or inside washed-out areas. In static mode, the casing's standoff is determined, and the quality of the cement coverage relies mainly on fluid rheology and centralization itself. When casing rotation is introduced, the conventional definition of standoff is no longer valid, since the shortest distance between the pipe and wellbore wall is changing constantly as the pipe rotates, creating a pseudo-dynamic standoff effect.

As the standoff changes dynamically with time due to the pipe movement, the area of highest and lowest flow will change accordingly. These pressure fluctuations will break up gel strengths and eventually allow the cement to displace the trapped, static mud around the wellbore. Additionally, when the pipe is rotated, fluid will flow in an azimuthal velocity vector, enabling a mass transfer from narrow to wide side and vice versa.

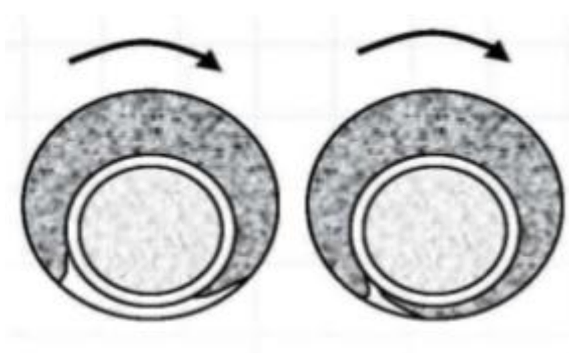

Figure 3. *Flowing cement with rotation*

Dynamic Cementing Design Considerations

Rotation is the preferred pipe movement method, because the rotational forces exerted on the fluid will cause it to be completely swept around the annuli.

The correct combination of cementing fluids (friction hierarchy) and rotation speed can make the gelled mud to be thinned and displaced completely from the annuli. A following sensitivity analysis of the rotation speed serves to determine the optimum value for a certain job. Figure 4 shows the simulation results for rotational speeds of 0, 10, 20 and 30 rpm.

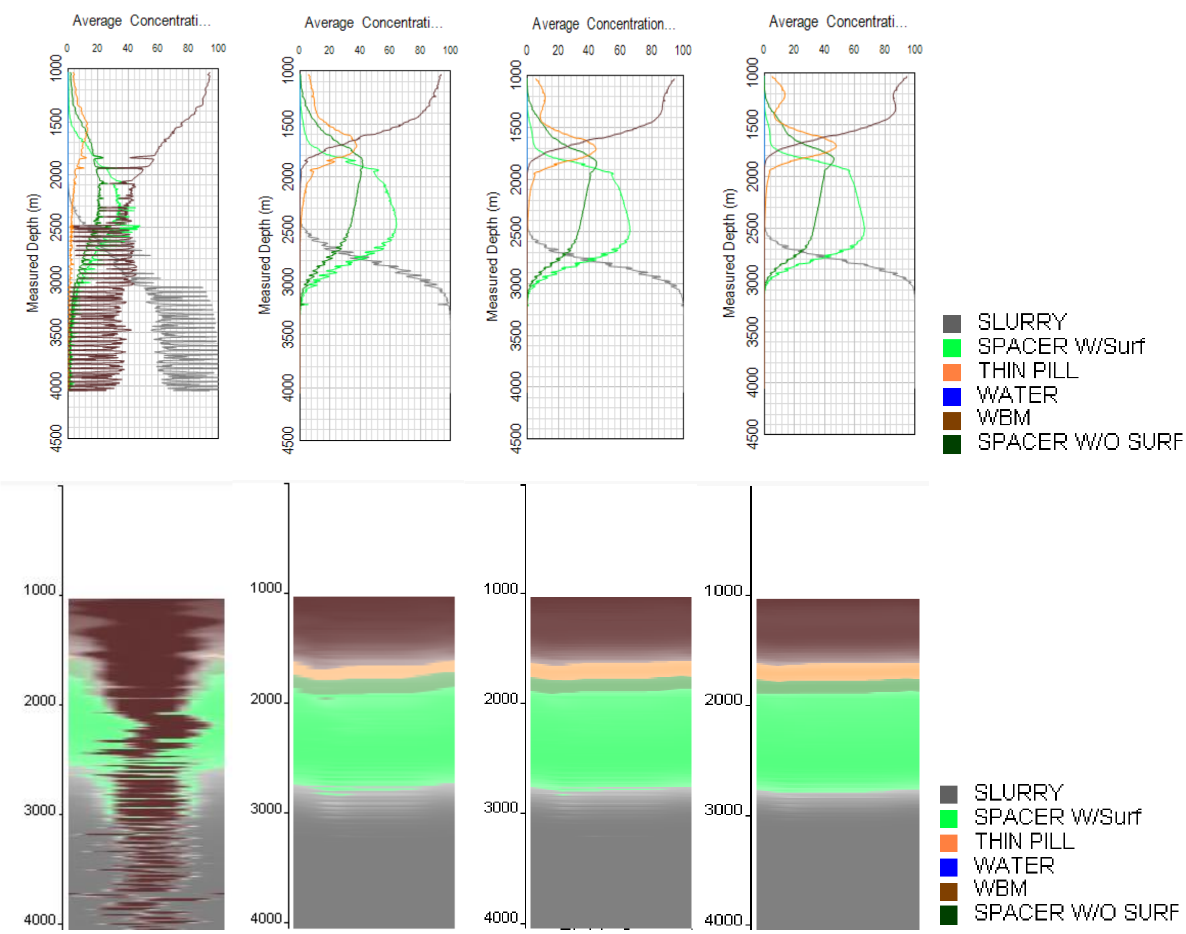

Figure 4. *Sensitivity to rotational speed: average fluids concentration in annulus for no rotation, 10 rpm, 20 rpm and 30 rpm rotation-cementing job.*

It is evident that implementing rotation, even at low speeds, improves substantially cement concentration in annulus. Increasing angular (rotational) speed has a less significant effect, but a more uniform cement top can be found, hence; as consistent flow velocity throughout the annulus prevents lower cement levels in the narrow side.

Another benefit of increasing rotational speed is the increase on azimuthal flow, which is directly proportional to having less risk of gelled up mud on the wall.

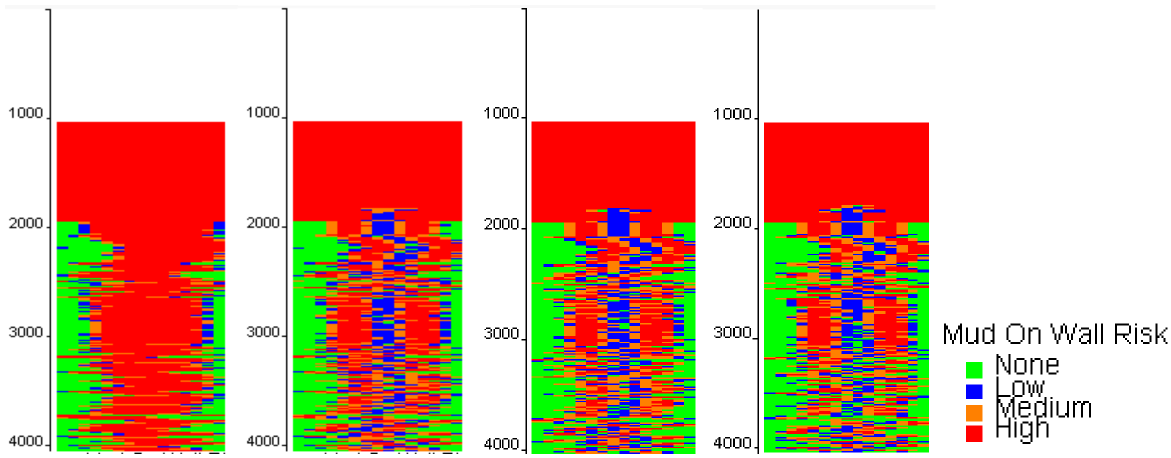

Figure 5. *Mud on the wall risk for no rotation, 10 rpm, 20 rpm and 30 rpm rotation cementing job.*

Rotating Equipment Required

In order to rotate casing during cementing, a side entry swivel sub is made up to the top of the casing drive system (CDS). This provides an entry port for the cement below the top drive, so no cement is pumped through it [top drive]. A chicksan line is rigged-up to the swivel sub. This line goes directly to cement unit. The swivel is then locked during cement operation to keep line steady as casing is rotated.

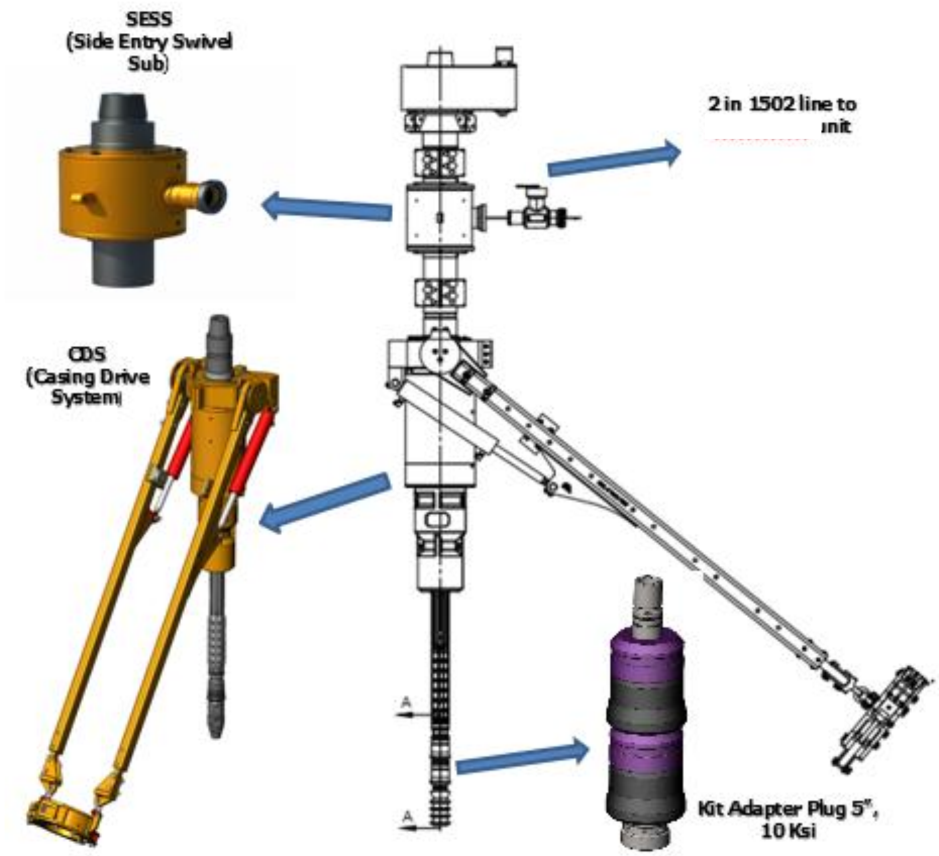

Figure 6. *Principal components*

The main components used to rotate the casing during the operations are:

- Rotating casing hanger
- External Casing Drive System (CDS)
- Rotating Cement Head (Side Entry Swivel Sub - SSES)
- Kit Adapter Plug 12.70 cm [5"], 68.95 MPa [10 Kpsi], 26.8-31.8 kg/m [18-21.4 lbs/ft]
- Wireless Torque Turn Sub (WTTS).
- Torque Ring
- Reduction 7.62 cm x 5.08 cm [3" x 2"] Fig. 1502.
- Wellhead properly designed for casing rotation

Dynamic Cementing Field Application

Once the well was defined as a candidate for dynamic cementing a thorough analysis of the risks involved, necessary equipment and tension/torque and compression limits was carried out. Joint with the sensitivity analysis shown before, a 30 rpm angular speed was chosen for the job.

After casing was on bottom, rotation was applied while circulating the mud for 45 minutes with a maximum torque achieved of 10.84 kN-m [8 klbf-ft].

During cement placement, rotation started at 30 rpm while spacers were pumped into the casing, and the torque was closely monitored reaching to a maximum of 12.07 kN-m [8.9 klbf-ft]. Pumping and rotation was stopped to load and drop bottom plug. Rotation later reassumed at 30 rpm while pumping cement slurry and torque values decreased as expected; being the maximum torque reached during cement pumping 10.17 kN-m [7.5 klbf-ft]. Pumping and rotation was stopped once again to load and drop top plug. Rotation was reassumed at 30 rpm with a maximum torque of 11.66 kN-m [8.6 klbf-ft] that decreased while cement entered the shoe track and inside the annuli. The rotation speed was maintained at 30 rpm until the plug was bumped and operation concluded.

Cement Bond Log Comparison

The results of the post job analysis derived by the cementing software are validated with the Cement Bond Logs.

Figure 7 shows examples of jobs where there was no rotation while cementing. The displacement simulator shows a poor cement coverage and mud channeling due to low standoff and minimum pressure gradient not overachieved. In comparison, the bond logs show a strong channel of mud present with significant arrivals of cement bonded to casing.

Example 1: Well A **Example 2: Well B**

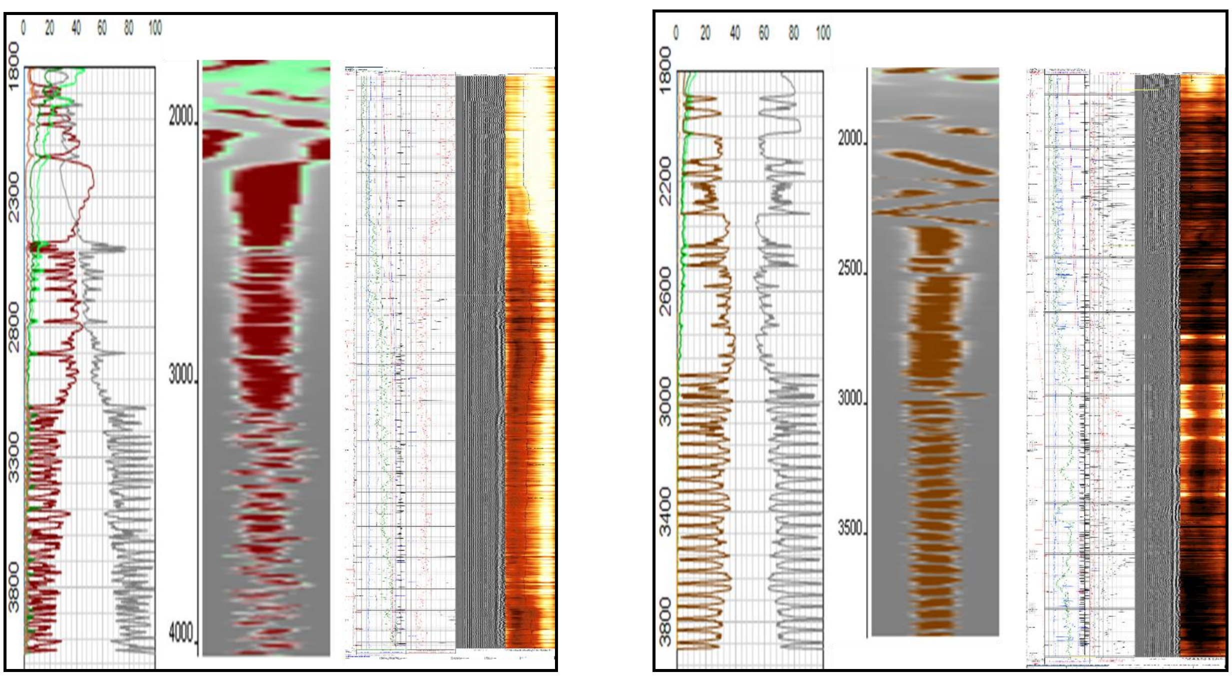

Figure 7. *Cement evaluation logs compared to cementing software simulations for cementing jobs on horizontal wells without casing movement.*

On figure 8, Cement Bond Logs readings are matching with displacement simulation concentration map. The top of cement is found at the simulated depth. Along the cement coverage annuli, the acoustic amplitude is less than 5 mV.

Example 3: Well C

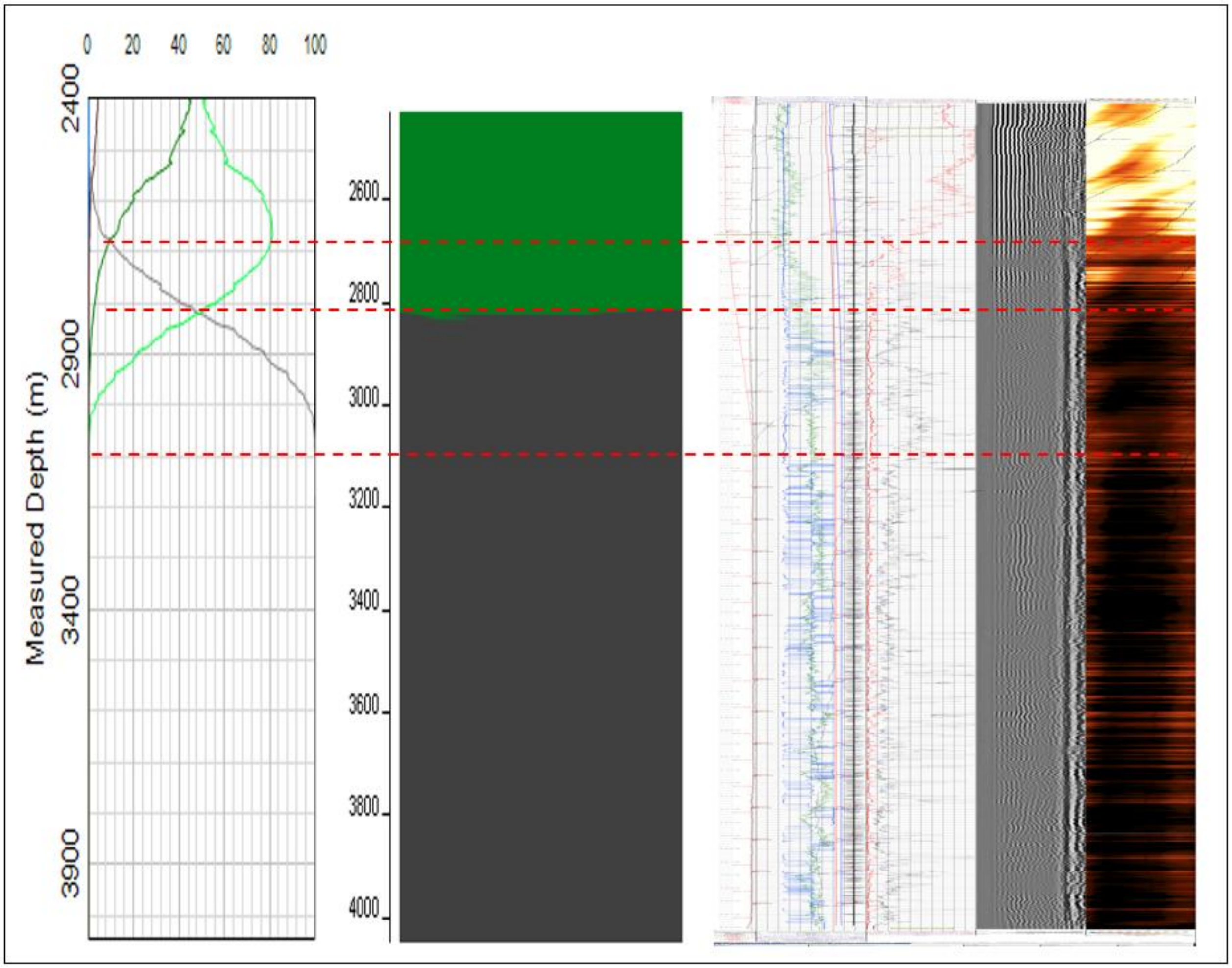

Figure 8. Well C: *Dynamic Cementing Job's Cement evaluation logs compared to cementing software simulations.*

Conventional vs. Dynamic Cementing

The following comparative table (Table 1) shows the design condition of the 3 cases of study included in this paper. Most of the design variables remain roughly constant: depths, OH and casing diameters, temperatures, volumes and densities of cementing fluids, pumping rates, etc., the main difference relies on whether the casing string was rotated or not during the operation. You can see for the **Well A** (the first horizontal well of this project) that the cementing results were poor (Figure 7, Example 1), observing strong cement fingering and static mud channels left behind in the annular, as predicted by the 3D-ADS.

In the **Well B**, the well conditioning was improved and the friction hierarchies were optimized to the maximum extent allowed by the well conditions and - even less centralizers were used compared to well A - the results in terms of cement bond were better (Figure 7, Example 2), but still observing intervals with presence of mud channels. Finally, the **Well C** had a more challenging condition, with a higher mud density and with more restrictions to adjust friction hierarchies (operative window). Although this well had the least number of centralizers, the casing string was rotated (at 30 rpm) during mud circulation / hole conditioning and along the entire cementing operation. The final cement quality was excellent (Figure 8), with no channeling and presenting low CBL amplitudes of 1-5 mV in average. In all the 3 cases, the results matched with the outputs of the 3D-ADS; this software has proven to be very accurate in predicting mud displacement in different scenarios, even in complex well geometries and horizontal drains.

	UOM	**Well A**	**Well B**	**Well C**
Total Depth	m	4060 m	3970	4060
Casing Size	in	5 x 4 1/2	5 x 4 1/2	5 x 4 1/2
Bit Size	in	6 1/8	6 1/8	6 1/8
Well Type		Horizontal	Horizontal	Horizontal
Lateral Length	m	1000	1000	1000
BHST / BHCT	°C	106 / 95	102 / 93	110 / 104
Mud Density	ppg	15	15	15.6
Spacer Density	ppg	15.4	15.4	16
Spacer Volume	bbl	80	80	80
Slurry Type		Gas-Tight	Gas-Tight	Gas-Tight
Slurry Density	ppg	15.8	15.8	16.3
Slurry Volume	bbl	160	150	170
Max. Displacement Rate	bpm	5	5	5
Centralizers Quantity		47	42	41
Casing Rotation		NO	NO	YES
Rotational Speed	rpm	-	-	30
CBL		Bad	Regular	Very Good
Average Amplitude	mV	30 - 40	20	< 5
Mud Channels		YES	YES	NO

Table 1. *Conventional vs. Dynamic Cementing comparative table.*

It is worth mentioning that to be able to reproduce (with the 3D-ADS) the cement bond results obtained in the **Well C**, but without applying casing rotation, it is necessary to increase the number of centralizers to at least 120 units (3 times more units required) to obtain a decent standoff (at the centralizers) in the horizontal leg, and still the results are not as good as with casing rotation, observing mud pockets in the annular.

Regarding the benefits of this technique, in addition to the savings in centralizers, the actual value of obtaining an excellent cement quality and zonal isolation in unconventional wells is immeasurable, allowing operator to stick to the completion plan that involves multi-stage fracturing, critical to produce the shale-reservoirs. A bad cement quality and lack of zonal isolation is very difficult to repair under this scenario, since conventional squeeze techniques are incompatible with unconventional completions where the high-pressure, massive fracturing treatments are pumped through casing; therefore, the perforations would become a week point and a potential path for communication of the casing with the annular.

Conclusion

Depending on the final well conditions, Dynamic Cementing can eliminate the need for additional centralizers, since rotating the casing will make standoff dependent on time and the azimuthal forces exerted on the fluid will cause it to be completely swept away around the annuli.

These results were validated in practice through operations in which a coherent cement coverage is evidenced in Cement Bond Logs noting the effectiveness of the technique and highlighting its clear remark as a mud removal aid.

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