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Fracturing Plugs Drillout Experiences in Unconventional Applications

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Abstract

A drill-bit supplier provided mills and bits for drilling out fracturing plugs for a new project in the Vaca Muerta formation in Argentina; however, it was difficult to locate information on similar experiences elsewhere. This paper presents the experience gained during execution of a completions project that included fracturing plug drillouts.

Several technologies were used, and their performances are reviewed, including mills, roller-cone bits, and polycrystalline diamond compact (PDC) bits. Drillout times, size and shape of debris, hole cleaning, and tool dull grades are analyzed. All operations were performed with coiled tubing (CT) equipment. Other parameters considered in the analysis include drilling parameters, number of runs to complete a well, plugs per run drilled, and tolerances with respect to casing drift. Some problems that occurred during project execution are discussed, such as motor stall and casing deformation.

The operations were performed in a combination of horizontal and vertical wells. More than 500 fracturing plugs were drilled out in more than 60 wells, gaining sufficient experience to derive significant conclusions. To help reduce drilling time, improve economics, minimize risks, and reduce CT system fatigue, the five to six-blade PDC bit was verified as the best option in this context. This drill type has an acceptable rate of penetration (ROP), does not risk losing moving parts, and minimizes motor stall. When tolerance with respect to casing drift is correct, the five to six-blade PDC bit also minimizes debris size, which helps reduce stuck-in-hole risks and improves subsequent well production.

Several statistics, images, and resolved issues are presented to advise future CT and well intervention projects. Conclusions regarding various plug types, materials, and drillout procedures are also explained to aid similar projects.

Introduction

Vertical and horizontal wells are analyzed in this work **(Table 1).** The first wells included a 5-in., 20.8 lb/ft casing in the production section. The second wells included a combination of 5-in., 20.8-lb/ft × 4.5-in., 13.5-lb/ft casing in the production section, with the fracturing plugs located in the 4.5-in. casing. Because of a known casing deformation problem in the area, two diameters of bits/mills were developed; the larger diameter was designed for standard casing, and the smaller diameter was designed for contingencies of casing deformation. According to the plug manufacturer, the recommendation for the bit/mill diameter was 95 to 98% of the casing drift to help prevent issues and to minimize the size of debris.

Well Type	Casing	Drift (in.)	Comment	Bit/Mill Diameter (in.)		(mm)	% Drift
Vertical	5 in., 20.8 lb/ft	4.031	Larger diameter	3 7/8	3.875	98.43	96.1
			Smaller diameter	3 3/4	3.750	95.25	93.0
Horizontal	5 in., 20.8 lb/ft × 4.5 in., 13.5 lb/ft	3.795	Larger diameter	3 5/8	3.625	92.08	95.5
			Smaller diameter	3 1/2	3.500	88.90	92.2

Table 1—Well analysis.

As Table 1 shows, the smaller diameter for casing deformation contingencies was designed to be smaller than the minimum recommended range for typical applications, with the objective of bypassing a restriction.

There were two types of plugs to be drilled out, those used in vertical wells and those used in horizontal wells **(Figs. 1 and 2).**

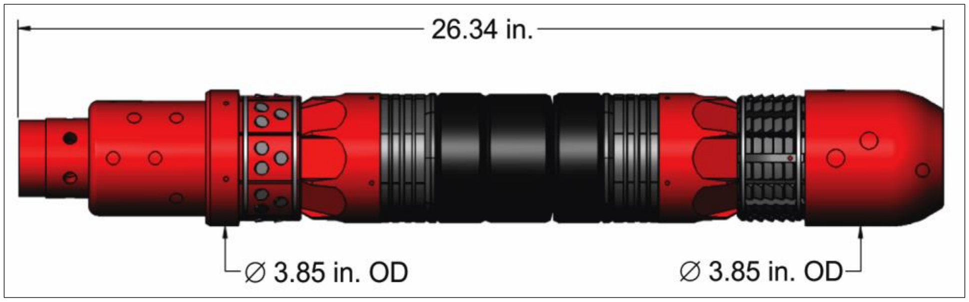

Fig. 1—Bridge plug assembly, 10 kpsi, 325°F, 5-in., used in vertical wells. (Model A)

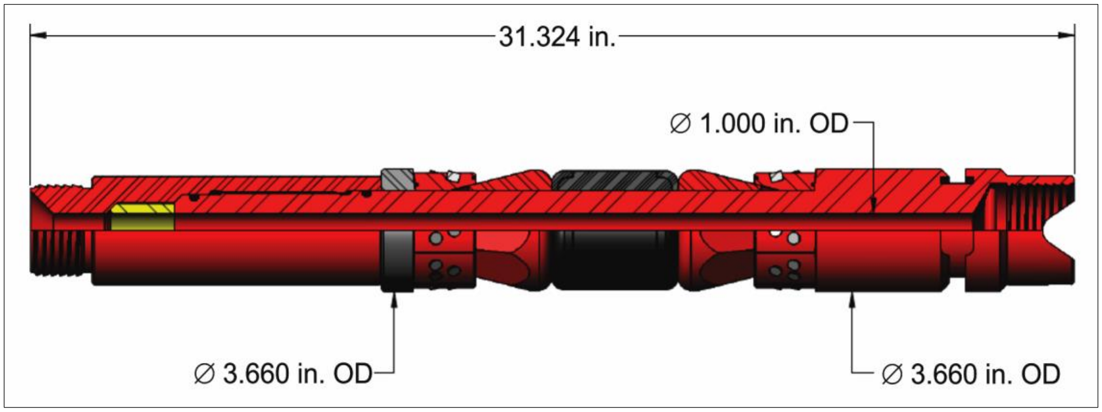

Fig. 2—Fracturing plug assembly, 10 kpsi, 325°F, 4 1/2-in. metallic-ceramic composite (MCC) button slips, used in horizontal wells. (Model B)

Three types of tools were considered for the fracturing plug drillout: mills, PDC bits, and roller-cone bits. A CT drive system was used in all cases, with the typical BHA shown in **Fig. 3**, independent of the tool in use.

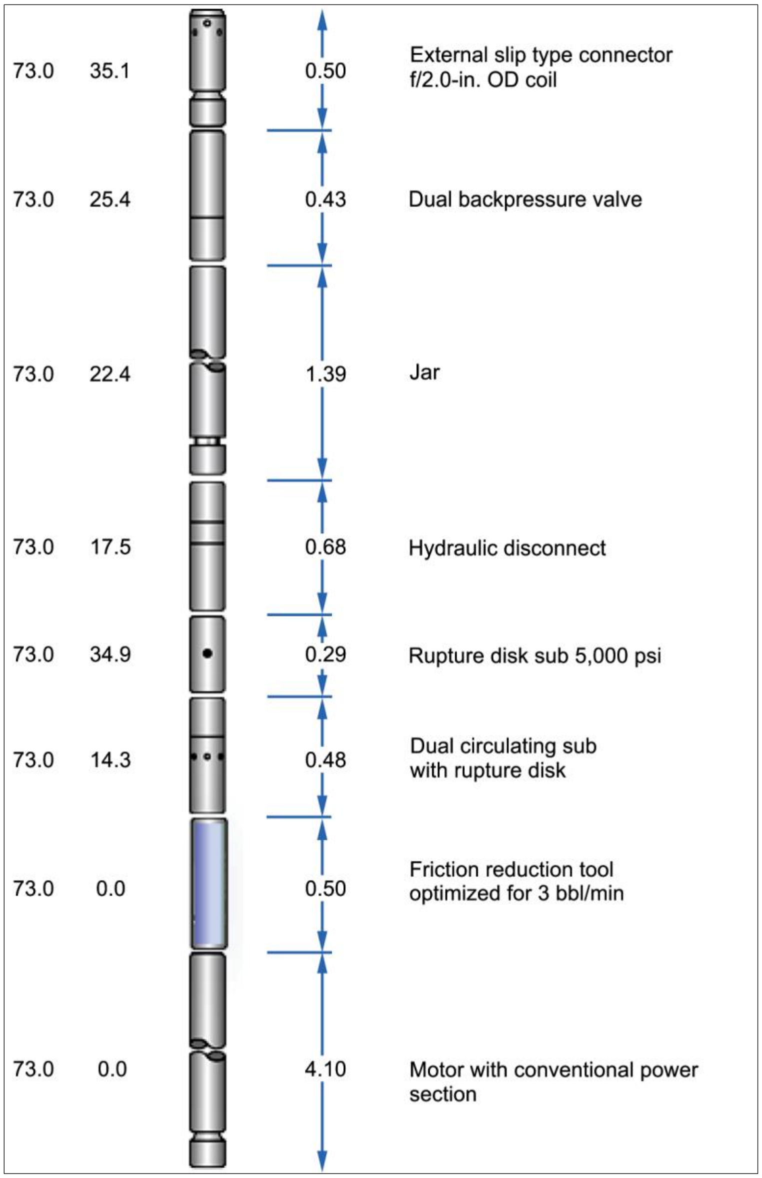

Fig. 3—Typical BHA used for drilling out fracturing plugs.

Field Experiences

Vertical Wells

In these types of wells, the production section is between 2700 and 3100 m. The first experience in a vertical well using a mill was unsuccessful. After drilling out four plugs in an average time of 67.25 minutes per plug, heavy dull grade was observed in the outer part of the mill **(Fig. 4).** The possible cause was the presence of cast iron slips in the fracturing plugs **(Figs. 1 and 5).**

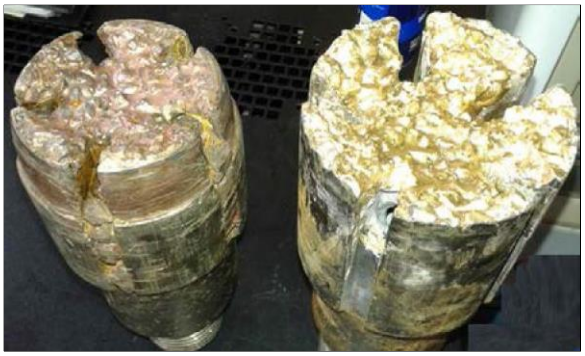

Fig. 4—(Left) Mill used in the first vertical well; (right) mill in new condition.

Fig. 5—Cast iron slips in 5-in. bridge plug assembly.

Fig. 4 shows junk slots of the mill completely plugged with pieces of cast iron slips. The width of the junk slot was 0.5 in. Also, there was no angle of attack in the blade, which could have contributed to the lack of success of the case. After this experience, modifications were introduced in the mill: (1) the junk slot was widened to 0.75 in.; (2) an angle was added alongside the junk slot to facilitate debris evacuation; and (3) an attack angle was created in the blade. **Fig. 6** shows the modifications.

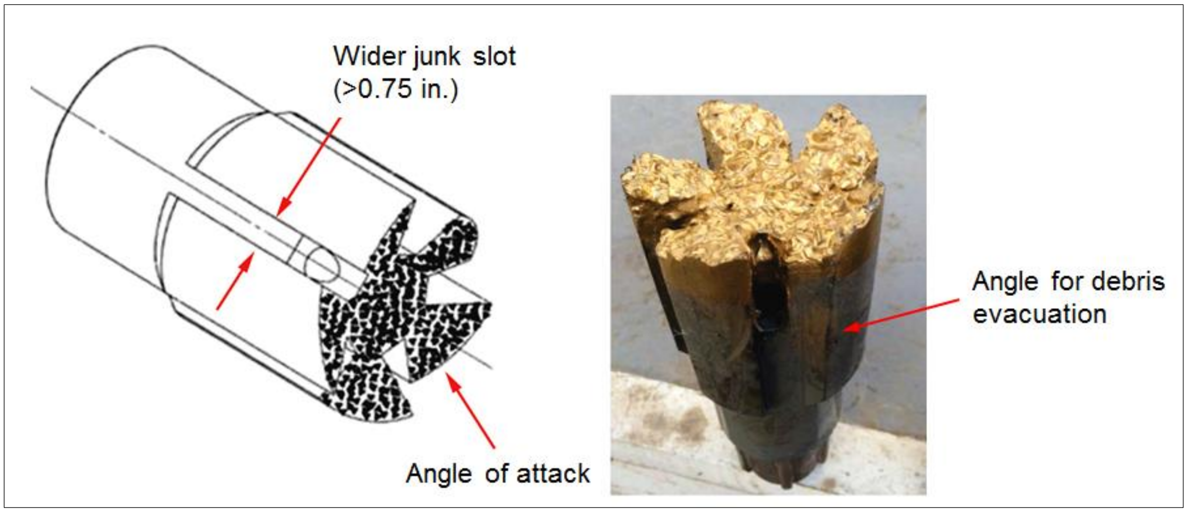

Fig. 6—Changes introduced in the mills.

The modified mills showed some improvements in the dull condition, and the average time per plug was 52.5 minutes **(Fig. 7).**

Fig. 7—Results of the mill changes.

The next step in the project was the introduction of PDC bits. In Well A-925, two 5-in barriers plugs were drilled out at 648 and 688 m depth. After an unsuccessful attempt with a mill, a PDC bit with five blades with 10-mm cutters was run, with an average time per plug of 41 minutes. A heavy dull grade condition was evidenced again in the cutting structure **(Fig. 8),** possibly resulting from the presence of cast iron slips discussed previously. This was the typical scenario while drilling out fracturing plugs in vertical wells. **Table 2** shows a summary of drillout operations in the vertical wells.

Fig. 8—Dull condition of PDC bit after drilling out two barrier plugs.

Vertical Wells			
Type of Tool	Number of Tools Used	Plugs Drilled Out	Avg. Plugs Per Tool
Mill	40	131	3.28
PDC	5	12	2.40
Roller Cone	0	0	—
Total	45	143	3.18

Table 2—Summary of drillout operations in the vertical wells.

Horizontal Wells

This type of well typically has a kick off point at approximately 2,700 m, the landing point at approximately 3,200 m measured depth (MD), and a total depth (TD) of approximately 4,800 m MD.

Drillout operations in the horizontal wells were different. Plug and perf along with a “zipper fracturing” technique was the technology selected by the operator to reduce completion times significantly (Domelen 2016). The fracturing plug used for this type of well was a 4.5-in. plug with MCC button slips instead of cast iron slips **(Figs. 2 and 9)** (i.e., Model B).

Fig. 9—MCC buttons in a 4.5-in. fracturing plug assembly.

The first PDC bit used in horizontal wells was 3 5/8 in. (95.5% of the drift) with three blades having 10-mm cutters. Two issues were observed with this type of tool—large pieces of debris and motor stalling **(Fig. 10).** The first issue was resolved using a bit diameter adjusted to the casing drift; the second issue was resolved with a less aggressive bit (e.g., increasing the number of blades).

Fig. 10—The three-blade, 10-mm cutter PDC bit usually showed motor stalling during drilling out.

Motor stalls required some additional maneuvers to free the tool, such as recovering the CT and running into the hole again with rotation. This sequence was repeated several times per plug, adding cycles and fatigue to the CT and increasing the operational costs.

Some six-blade PDC bits were run to resolve the motor stalling issue; however, the diameter was small because they were used in casing deformation instances at 92.2% of the casing drift **(Fig. 11).**

Fig. 11—Six-blade, 10-mm cutters used in casing deformation contingency cases.

Using a bit diameter less than 95% of the casing drift resulted in large debris sizes **(Fig. 12).** The fragments recovered in the plug catcher had a shell shape, increasing the risk of blocking the CT and also potentially generating subsequent production problems.

Fig. 12—Large debris sizes resulting from running PDC bits smaller than 95% of the casing drift.

To minimize debris size, higher-diameter PDC bits were run. The next step was to test five-blade, 10-mm cutter PDC bits at 98% of the casing drift. The results were successful in terms of debris size, reactive torque of the motor, and drillout time per plug. All 19 well plugs were drilled out in one run with an intermediate short trip. The average time per plug was 39 minutes, with a minimum of 25 minutes and a maximum of 55 minutes.

The pending step in the project was to test roller-cone bits to drillout fracturing plugs. The advantage was a lower coefficient of sliding friction produced by cone rotation, thus reducing reactive torque and motor stall tendencies; however, the movable parts of roller cones can cause cones to be lost in the hole.

Roller cones were used in Well A-1400h **(Fig. 13).** The first run drilled out 14 plugs, then the tool was pulled out of hole (POOH) because of problems with the bottom-hole assembly (BHA). The dull grade of the bit was heavy: 2-5-WT-A-F-2-NO-HP. As the dull grade classification indicated, all cones were pulled out in failed condition. A similar bit was run to drill out the remaining six well plugs. Again, the dull grade was heavy, and all cones were pulled out in failed condition: 2-3-WT-A-F-2-NO-TD.

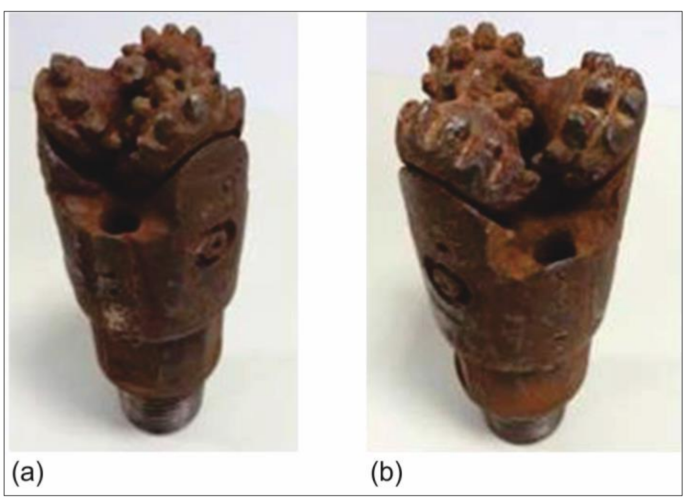

Fig. 13—Roller cones run in Well A-1400h. (a)The first bit drilled out 14 plugs, 2-5-WT-A-F-2-NO-HP; (b) the second bit drilled out six plugs, 2-3-WT-A-F-2-NO-TD.

Despite the logical improvements in reactive motor torque, issues regarding debris size were evident in this well. The bit diameter was 3 5/8 in., or 95.5% of casing drift. As **Fig. 13** shows, a complete shell of fiber was removed from the plug catcher.

Fig. 14—Debris of plugs from a roller-cone bit at 95.5% of casing drift.

The average drillout time per plug was 28 minutes, with a minimum of 5 minutes and a maximum of 1 hour and 25 minutes.

After investigation, it was discovered that the bits were run at 11 to 25% higher revolutions/minute than recommended by the bit manufacturer. Testing of a motor with lower revolutions/gallon is pending.

This type of technology cannot be discarded because improvements in seals and cutting structure could be made. Investigation showed that roller cones for 4 1/2-in. plugs are uncommon because the bearings are small; however, roller cones for 5 1/2-in. plugs typically produce good results.

In several cases using mills or PDC bits, it was necessary to POOH the BHA because of casing deformation. Possible causes of casing deformation in the Neuquina basin are explained by García et al. (2013). In such circumstances, a smaller-diameter mill or bit was used to attempt to bypass the restriction. Some attempts were successful, and some were not. Eccentric mills were developed, but they were not run in the project. **Table 3** shows a summary of drillout operations in the horizontal wells.

Horizontal Wells			
Type of Tool	Number of Tools Used	Plugs Drilled Out	Avg. Plugs Per Tool
Mill	12	115	9.58
PDC	10	167	16.70
Roller Cone	2	20	10.00
Total	24	302	12.58

Table 3—Summary of drillout operations in the horizontal wells.

Plug Selection

Composite fracturing plugs were developed to improve efficiency in completions, where previously inflatable packers or cast iron plugs were being used. Composite fracturing plugs can be easily drilled out, thus significantly reducing drilling times and drilling difficulties (Guoynes et al. 1998).

The plugs used in this project included the following:

- Model A: cast iron with wickers, used in vertical wells
- Model B: MCC/composite body, used in horizontal wells
- Model C: white ceramic/composite body, used in horizontal wells

After the experiences mentioned previously, a review of the criteria to select the suitable fracturing plug was performed in an ongoing effort to improve milling time and quality. Comparing pressure and temperature rating with actual wellbore values indicated that the 4 1/2-in. fracturing plug (Model B) was engineered for a significantly more demanding downhole environment than needed. The analysis resulted in changes to the fracturing plug selection.

The alternate composite fracturing plug (Model C) is manufactured in a different way to help enhance drillability, and utilizes a different button material in the slips—ceramic instead of MCC, **(Fig. 15)**. The ceramic buttons not only improved milling time but also helped preserve the drill bit and casing compared to MCC buttons. This type of plug has been successfully run in other areas (Halliburton 2016).

Fig. 15—Fracturing plug assembly used in horizontal wells (Model C): 10 kpsi, 250°F, 4 1/2-in. white ceramic button slips.

The change was tested in Well A-1307, where a deformed section forced the use of Model B fracturing plugs below the deformation (slim size, 3.44 in.) and Model C fracturing plugs above it. Two extra Model B (standard size, 3.66 in.) plugs were used in the vertical zone to provide barrier isolation **(Fig. 16).**

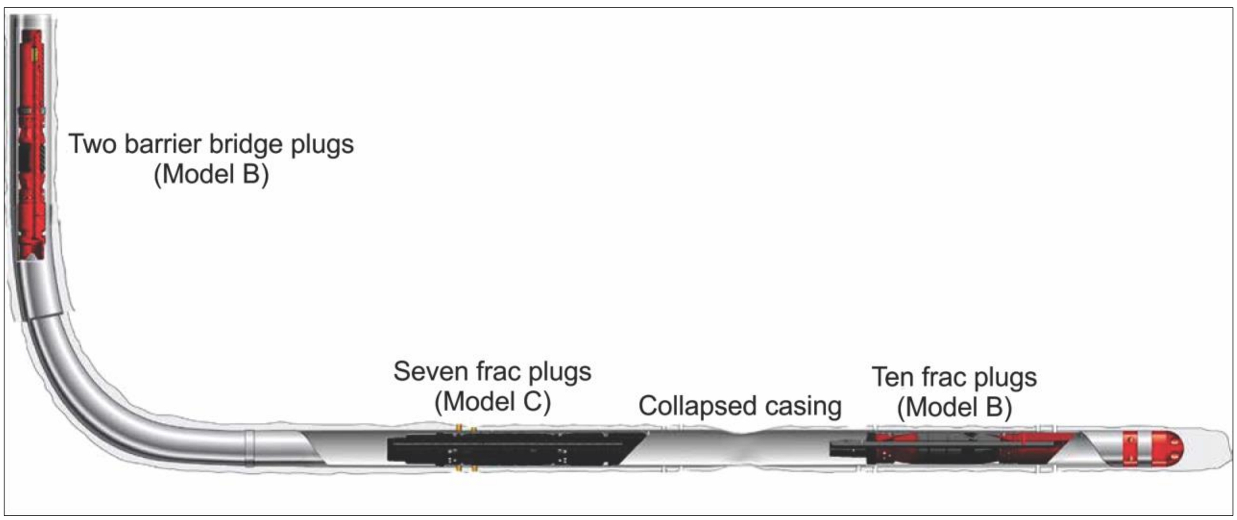

Fig. 16—Completion schematic of Well A-1307.

The casing diameter at the deformed section was measured at 3.701 in. (94 mm) with a casing drift of 3.795 in. (96.4 mm). A 3.625 in. (92 mm) five-blade PDC bit with 10-mm cutters was selected for the operation, which was performed with only one PDC bit in one run with a short trip at Plug 10 where the restriction was located. **Fig. 17** shows the time spent milling out the plugs in Well A-1307. The average time for each type of plug was the following:

- Model B (barrier): 45 minutes
- Model C: 27 minutes
- Model B: 76 minutes

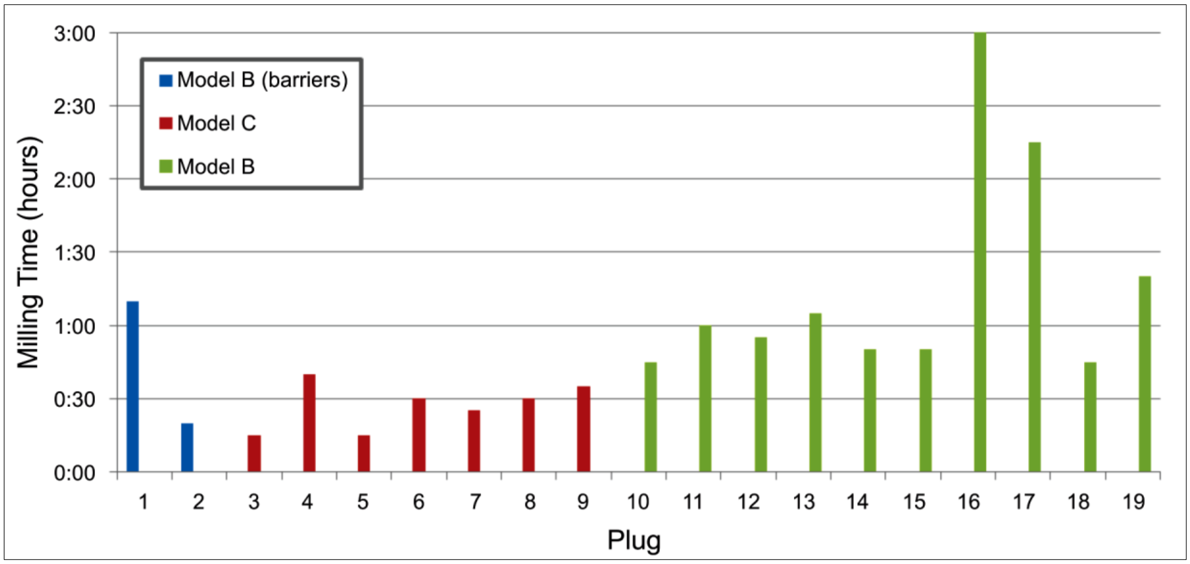

Fig. 17—Milling time in Well A-1307.

The longer time spent at Plug 16 resulted from a motor stall event after which a release maneuver was performed. The dull grade of the PDC bit was significant and most likely caused by casing deformation **(Fig.18).**

Fig. 18—Dull grade of PDC bit used in Well A-1307.

Statistics

Table 4 summarizes the project results. To obtain reliable conclusions, some particular cases were discarded (e.g., cases in which excessive drilling time resulted from casing deformation, drilling out remaining degradable plugs was necessary, and competitor mills were used). **Figs. 19 through 21** show wiper trips were reduced from four to one, resulting from the following changes: 1) changing from a standard mill to a PDC bit, creating a more robust cutting structure; 2) reduction of debris size reducing the risk of BHA sticking; and 3) changes in fluid positively impacting well cleaning (beyond the scope of this paper). **Fig. 22** summarizes the entire project. It shows the number of plugs drilled out, drilling time, and type of tool used for vertical and horizontal wells in chronological order.

Project Variable	Total	Total Included in Analysis
Wells	62	53
Runs	123	91
Plugs drilled out	506	445

Table 4—Summary of the project results.

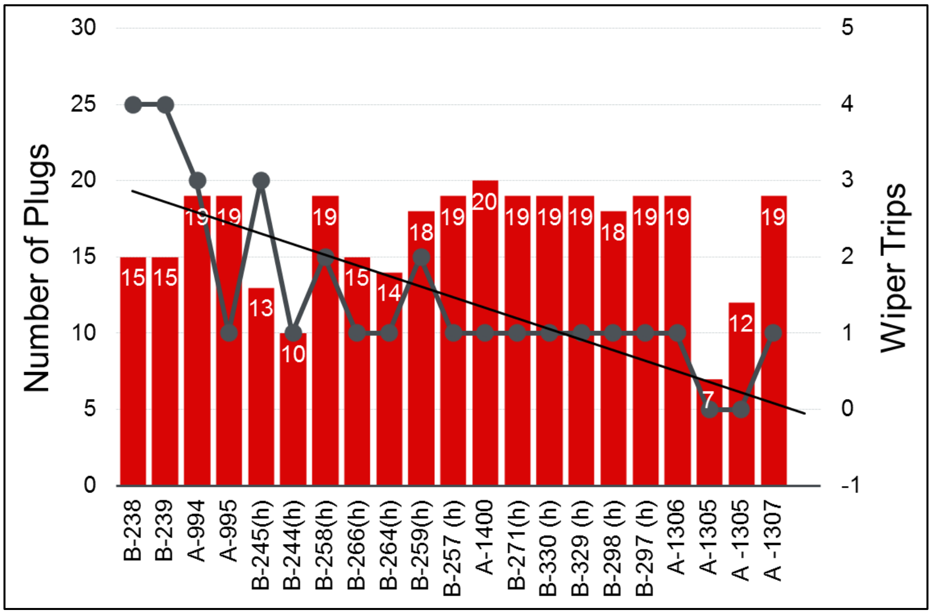

Fig. 19—Wiper trips trend during project, horizontal wells.

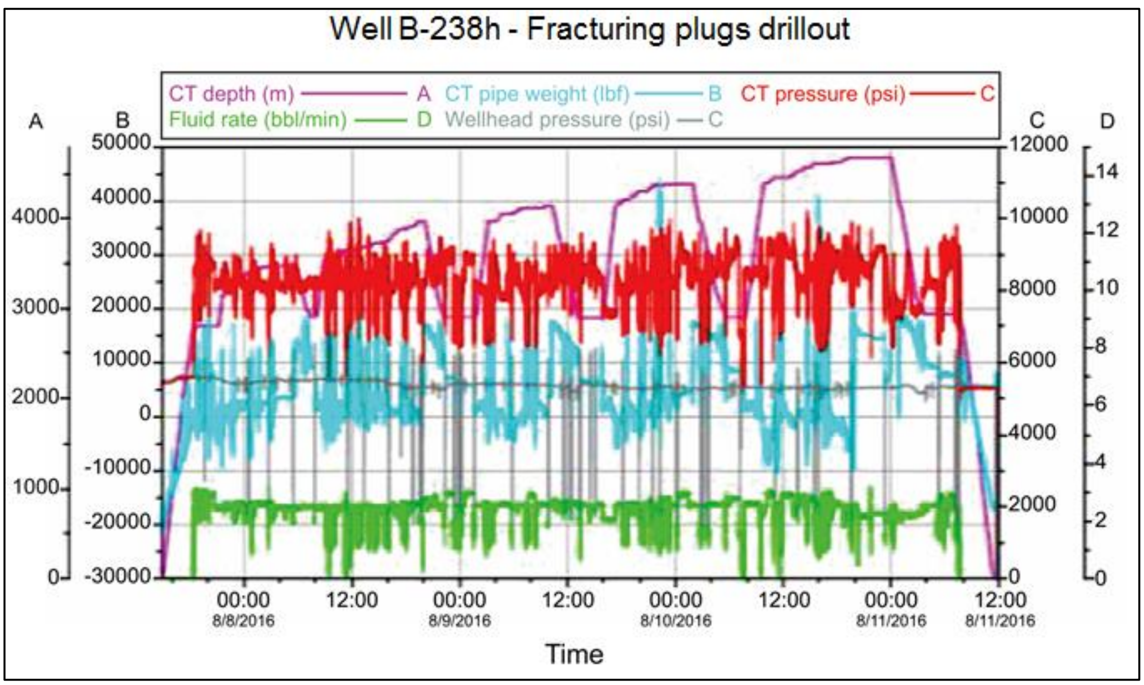

Fig. 20—Wiper trips (magenta) at the beginning of the project.

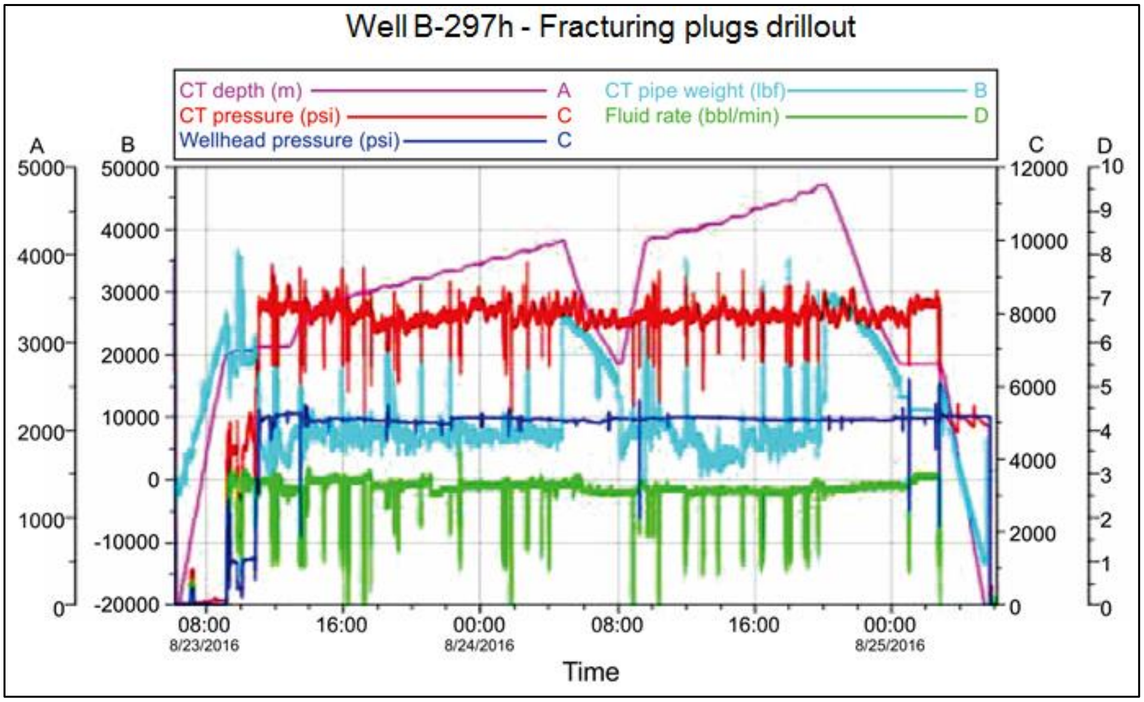

Fig. 21—Wiper trips (magenta) the end of the project.

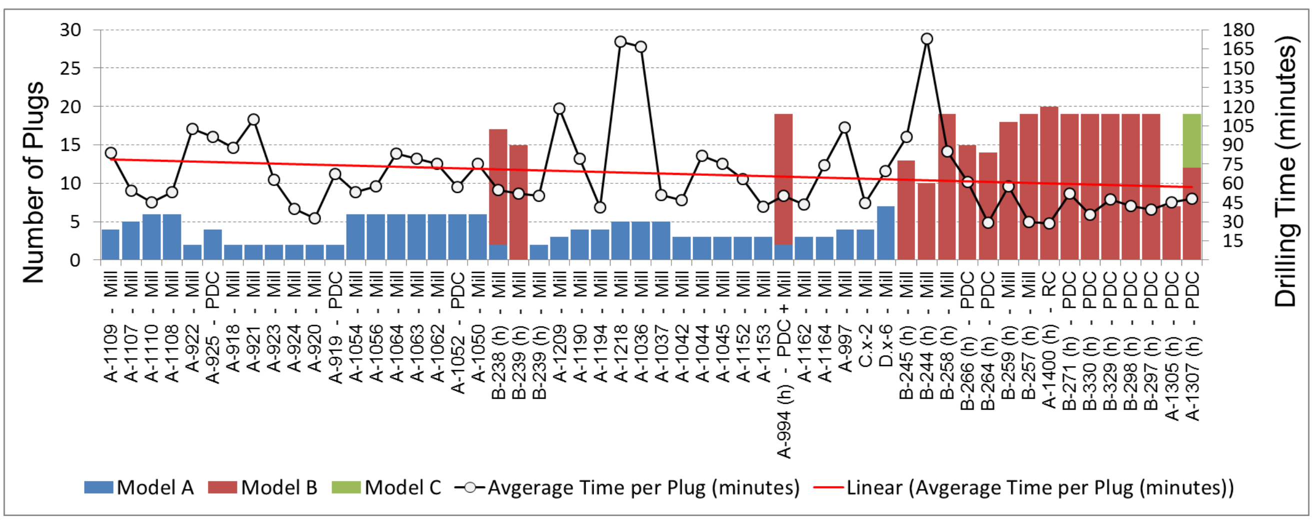

Fig. 22—Summary of the project results for vertical and horizontal wells: drilling time, quantity, type of plug drilled out, type of tool, type of well, and name of well shown in chronological order.

Figs. 23 and 24 show the same information in **Fig. 22** separated for vertical wells and horizontal wells, respectively. **Table 5** summarizes the statistics of the project for both vertical and horizontal wells, showing the number of plugs drilled out with each type of tool. Average drillout time is also presented. As shown, the average time is the same for vertical wells (approximately 73 minutes) independent of the tool used. All the drilled-out plugs were Model A. Note that this type of plug has cast iron slips, which could influence the PDC performance.

For horizontal wells, the average drillout time for mills was similar to the values of vertical wells (approximately 72 minutes). But for PDC bits, drillout time was reduced to 44 minutes. Again, drillout time was reduced to 28 minutes for roller cones. Note that this type of tool was used in just one well resulting in heavy dull grade and large-sized debris. Additional experiences are necessary for more reliable conclusions about this type of tool.

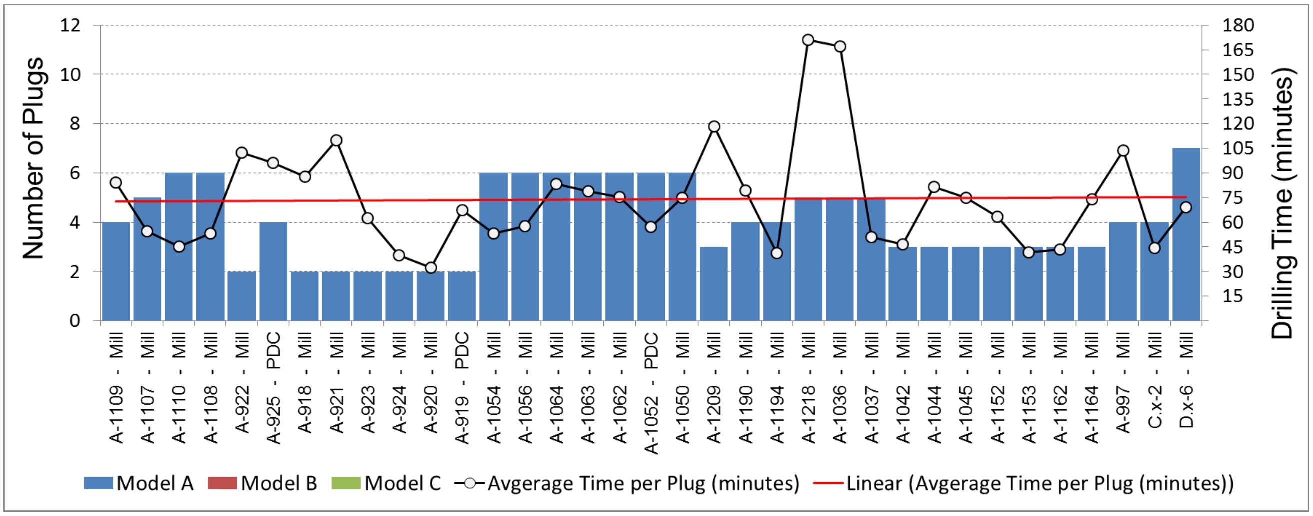

Fig. 23—Summary of the project for vertical wells: drilling time, quantity, type of plugs drilled out, type of tool, and name of well shown in chronological order.

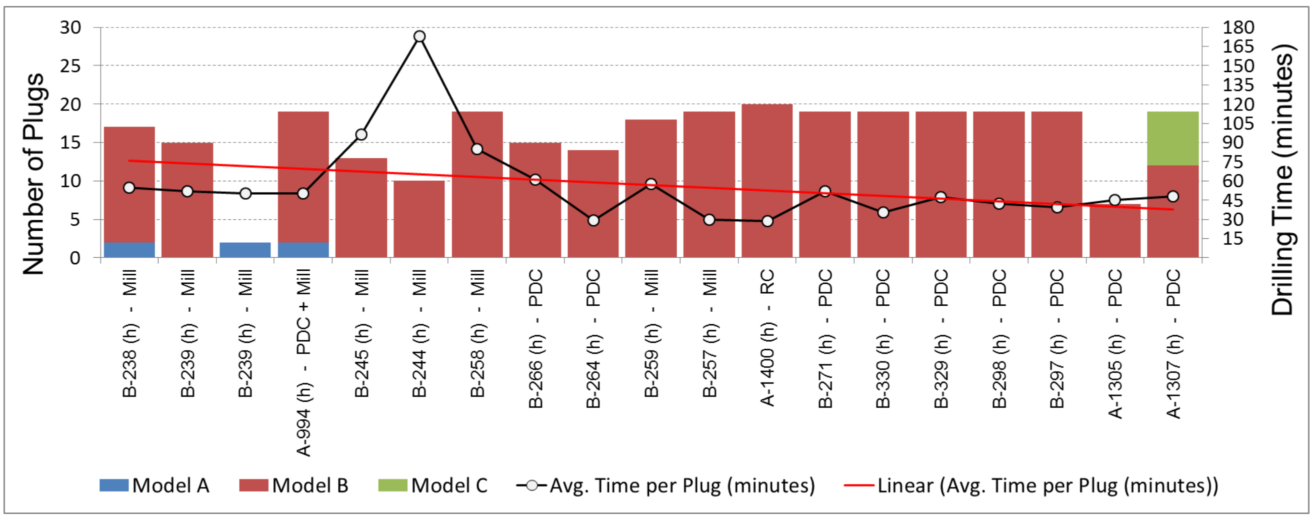

Fig. 24—Summary of the project for horizontal wells: drilling time, quantity and type of plugs drilled out, type of tool, and name of well shown in chronological order.

	Vertical Wells				Horizontal Wells			
Number of Plugs	Model A	Model B	Model C	Avg. Time (minutes)	Model A	Model B	Model C	Avg. Time (minutes)
Mill	131	0	0	73	6	109	0	72
PDC	12	0	0	73	0	160	7	44
Roller Cone	0	0	0	—	0	20	0	28
	143	0	0	73	6	289	7	56
Totals	143				302			
	445 (67 minutes average)							

Table 5—Summary of the project: number of plugs, type of tool ,and average drilling time.

Conclusions

As **Fig. 23** shows, the vertical wells included a maximum number of seven plugs per well. **Table 2**, then, does not produce reliable conclusions about the average number of plugs drilled out by type of tool. Regarding the presence of cast iron slips in plug Model A, PDC bits are not recommended for drilling out this type of plug. Because the horizontal wells included more than ten plugs per well, they provided better conclusions regarding average number of plugs drilled out by type of tool. As **Table 3** shows, the average number of plugs drilled out per PDC bit was 16.70, but it is important to note that this type of tool drilled out the entire quantity of plugs in every horizontal well. It was never necessary to POOH the tool because of cutting structure damage. With other tools, generally more than one mill was necessary to complete the drillout of all the plugs in horizontal wells; the number of plugs drilled out per mill was 9.58 in average. The PDC cutting structure performance exceeded that of a standard mill, which typically requires more than one run to complete the drillout of all well plugs. **Table 5** shows better drillout times for the PDC bit compared to a standard mill in horizontal wells.

The one case in which a roller cone was used required two tools to drillout all plugs. As mentioned previously, more experience and testing are necessary to draw conclusions about this tool.

Regarding the behavior of different types of PDC bits, increasing the number of blades generally reduced the tendency of motor stall. Five to six blades was preferable to three blades.

Regarding the diameter of the tool, a casing drift value of 98% was generally preferred to smaller values, but the risk of damaging the cutting structure in the gauge area was higher when casing deformation events were common in the area **(Figs. 25 through 27).** The reason for this diameter is that the debris was smaller, thus stuck-in-hole risks were reduced and also subsequent well production improved.

Fig. 25—Cutting structure of five-blade, 10-mm cutter PDC bit after drilling out 19 plugs. The bit diameter was 98% of casing drift. Heavy dull grade could be caused by casing deformation typical in the area.

Fig. 26—Size of debris of fracturing plugs drilled out by five-blade, 10-mm cutter PDC with a diameter of 98% of casing drift.

Fig. 27—Dull condition of five-blade, 10-mm cutters after drilling out the plugs in Well E-12. The bit diameter was 3.625 in. (95.5% of casing drift). Less damage was observed.

Some improvements were made in the PDC bit design, such as adding reinforcement in the shoulder area where more damage is typically observed. At the time of writing, the final test was pending **(Fig. 28).**

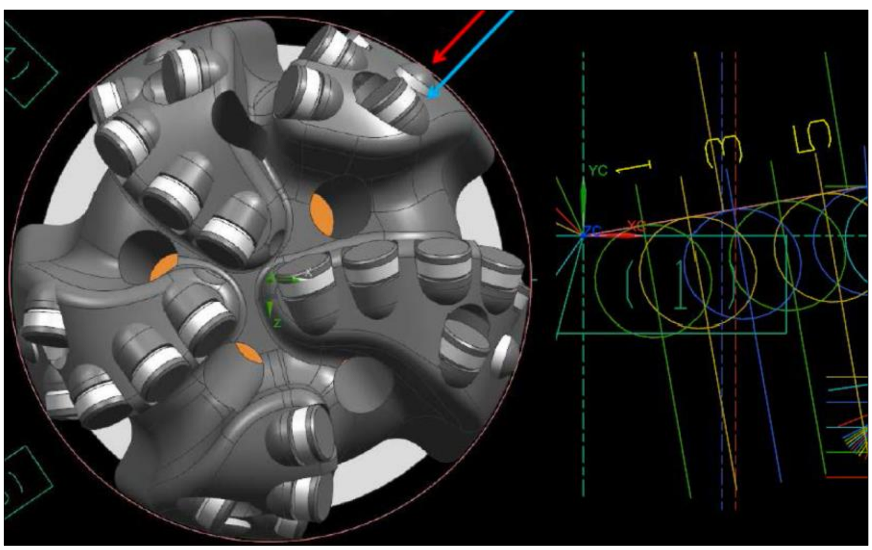

Fig. 28—New PDC bit design with dual rows added to the cutting structure (testing pending).

To try to resolve the casing deformation issue, the operator drilled the lateral sections of the wells at a lower depth (out of the kitchen) in the Vaca Muerta formation. However, the attempts were unsuccessful and the solution is still pending.

Results indicate that use of a fracturing plug that exceeds the necessary pressure and temperature ratings for the operation can affect drillout performance, which suggests that specific and detailed fracturing plug selection should be performed, taking into account all involved variables.

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