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Foamed Cementing Solution in Shallow Wells of Argentina

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Abstract

This paper presents job design and results for two shallow wells that were cemented with foamed cement in the northeast platform portion of the Neuquén Basin of Argentina. The two example wells are typical of the 40 wells similarly drilled and cemented in the area.

Past efforts to drill and cement wells in the area were thwarted by severe loss of circulation. The lost circulation limited drilling and cementing, which resulted in a large amount of hydrocarbon reserves being left in place. The use of aerated drilling mud and foamed cementing has unlocked these reserves. This paper presents the lessons learned from the operating and service companies' experiences in the Jaguel Casa de Piedra and El Corcovo fields.

Background

The operator acquired 100% operating interest in the CN-VI A/B exploration concession in September 2005. The 38,880-acre concession is divided into two parcels, CN-VI A and B. The concession is located in the province of Mendoza (see **Fig. 1**).

In previous operations in the area, the operating company worked through lost-circulation problems by drilling with aerated mud and cementing with foamed slurries. If drilling mud density exceeded 5–6 lb/gal, lost circulation would result. Reservoirs being drilled are very high-permeability and produced high- viscosity oil. Temperatures were low, and top of cement (TOC) was 300 m from the surface.

Current Operations

Foamed cement has been used successfully in this environment of low fracture gradient to get cement near the surface. Beginning with a base slurry density of 15.8 lb/gal, nitrogen is used to create stable foamed slurries in a range of 10 to 11 lb/gal. In these shallow wells, the keys to success are maintaining a constant rate of nitrogen injection and stepping the slurry rate to obtain the desired density of foam on the bottom.

Proprietary software is used to simulate the proposed job and simulate slurry performance in the fracture gradient exhibited by the reservoir. The software also monitors the job to help ensure that the job is proceeding as planned. For simplicity and ease of operation, the foamed cement jobs are calculated and designed based on constant nitrogen-feed rates and constant density. The slurry rate and foaming agent are varied during the job to make necessary adjustments. Wells cemented in this manner can maintain relatively constant downhole foamed cement properties, as displayed in **Tables 1** and **2**.

Introduction

Initially these wells were drilled using large volumes of nonaerated conventional mud, without circulation or even partial returns, because of severe lost-circulation problems.

In an attempt to maintain circulation, the operator began using aerated mud, reducing the density of the drilling mud. This change made it possible to circulate the well throughout the entire drilling process. Without lost-circulation issues, better cuttings removal was achieved, allowing better penetration rates. An increase in daily drilling costs was observed, but this was negated by a reduction in the total days spent drilling.

The aerated mud was created by injecting 800 scfm of air into 330 gal/min base mud, which resulted in an equivalent circulating density (ECD) of 4.7 lb/gal at (total depth) TD. The layout of equipment used for this operation can be reviewed in **Fig. 2**. The main components were: the air compressors, a booster pump, a rotating head, and the gas/liquid separator.

Fig. 3 shows a stratigraphic column identifying the typical formations from the Neuquén and Rayoso groups and the Centenario Superior, Centenario Inferior, Lotena, and Montosa formations.

Before logs were run, a mud pill with loss circulation materials (LCM) and calcium carbonate #200 was spotted; after which the well was filled with conventional mud.

Hole Conditioning

To remove as much of the gelled mud as possible, before cementing, the well was circulated with conventional, nonaerated mud with improved rheological properties. Mud with low rheology and a flat gel-strength profile works very well in these shallow wells.

This mud conditioning phase resulted in from normal-to-partial circulation to total lost circulation, depending on the area and the severity of the fractures. The cementing jobs often displayed similar results.

Centralizer simulation programs were run to determine the required number and optimal spacing to achieve a 75% standoff. Proper standoff helps ensure good displacement efficiency. Without proper centralization there could be a wide side and a narrow side of the annulus. If the annulus is eccentric, the laws of fluid dynamics dictate that the flow will differentially favor the wide side. If the narrow side is substantially tighter than the wide side, flow may not occur at all on the narrow side. Without flow, the mud will not be replaced with cement.

The base mud used on these very shallow wells had a density of 1080 g/L. Water, bentonite, and fluid-loss control additives are the main components. Typical properties of the mud are:

- Fluid loss: 5 mL
- Yield point: 18
- Pore volume: 12
- 10-sec Gel strength: 13
- 10-min Gel strength: 25
- 30-min Gel strength: 34
- Methylene blue test (MBT): 52 lbm/bbl
- Density: 1080 g/L

Fracture gradient values used in the cementing design are 0.47 to 0.50 psi/ft in the pay zone. Typical pore pressures for the reservoirs are 0.2 to 0.3 psi/ft

Lightweight Cement Options

When setting casing across weak formations and cement is required to circulate above these zones, normal-density cements will often exert too much pressure, fracturing the formation and result in lost circulation. To reduce the affective downhole forces, cement slurry density is decreased. Three methods are currently available to the industry for reducing cement slurry density: addition of extra water, addition of ultra-low-density particles, and nitrogen foaming.[1,2]

The oldest method for reducing cement density uses extra water. Because the slurry water in this study was only 8.33 lb/gal, each extra unit of water added would reduce its density until it approached water-weight slurry. To prevent slurry instability, a bulk gelling or water-extending material is added to the additional water to tie it up. This water-extending method for reducing cement slurry density is the most popular because it creates the most economical slurries being used in the industry. Unfortunately, as additional water is added to any cement slurry, the set properties start to degrade. If too much water is added to the slurry, initial set may be delayed to the point that the slurry will not be useable.

A second method for cement slurry density reduction is via the addition of ultra-low-density particles. While plastic beads have been used, the most common materials are hollow glass or pozzolanic spheres. The advantages of this method emanate from the fact that normal water ratios can be used, which means the initial-set times can be similar to conventional cement systems even when mixed at much lower densities. These systems are typically high-cost, lightweight cementing options and can require special blending techniques with potential equipment modifications and special mixing systems. However, when very lightweight, quick-setting, ultra-strong cement is required, microsphere systems are worth the cost and the special care required to execute the job properly.[3,4]

The third and final technique is foaming the cement slurry with nitrogen. In this technique, nitrogen is injected into the cement slurry in the high-pressure line between the cementing unit and the rig floor. Done properly, small well dispersed bubbles that will not coalesce and migrate are created. To create a stable foam, a surfactant/stabilizer package is required along with a choke to deliver a pressure drop.

Although operationally, foamed cement is the most complex method from a design-and-execution point of view; however, it has a number of benefits not inherently present in the other two systems.

- In the set state, foam cements are more elastic than conventional cements.[5,6] This increased elasticity allows the cement to better handle downhole stresses, increasing the likelihood that an initial annular seal will be maintained for the life of the well.
- In the liquid state, foamed cement is more compressible than other cement systems, meaning that a foamed cement slurry is better suited to avoid the formation of an annular gas channel up through the unset cement.
- Foamed cement slurries have high yield points. This equates to higher wall shear stresses, which means good displacement efficiency or a better ability to get the mud out of the well.[7] Effective mud removal is needed for good zonal isolation.
- Foam cements exert self-diverting characteristics, which means they are more likely to maintain circulation throughout the job.

All of these advantages went into the decision to use foamed cement on the sample wells discussed in this paper.

Job Design/Execution

In Well ECN10, a conventional 15.8-lb/gal cement was foamed down to 11 lb/gal. In Well ECN18, a conventional 15.8-lb/gal cement was foamed down to 11.5 lb/gal (see **Table 3**).

Foamed cement jobs are traditionally designed as constant-gas or constant-density designs. With constant gas, as the name implies, the nitrogen is injected at a single rate. The primary advantage of constant gas is that it simplifies job execution. On the other hand, this generates a variable-density cement column. If the column is very long, leading to a substantial pressure difference from top to bottom, there is a chance the upper portion of the cement can have too much gas (by volume). Remember the gas will be expanding as the slurry is being pumped up the annulus. If the volume percent gas becomes too high, permeability goes up and strength goes down. This density gradient also means the cement at the shoe will be the heaviest, meaning the best strength, which is where the better strengths are required. An additional benefit of constant gas is the planned slurry-density profile will be achieved when cementing to the surface regardless of excess volume. This feature can be important when hole size is unknown. The final hydrostatic pressure will not change regardless of how much cement is circulated out of the well. When cementing back to the surface is a must, large volumes of excess can be pumped and the amount circulated will not affect the bottomhole pressure.

With constant-density jobs, normally the nitrogen rate will be ramped from some lower volume up to a higher final volume as the job proceeds. If the hole size is well-known and suitably sophisticated design software is used, this method can result in the placement of a foamed cement column with uniform properties from top to bottom. The advantage is obviously the resulting uniform column of cement. The disadvantages associated with constant density are: (1) the job is operationally more complex, as not only does the nitrogen rate require continual modification, but the changes must correctly correspond to a certain volume of cement pumped, and (2) if the hole size is not correctly known, each portion of foam cement will end up at a depth either higher or lower than expected in the annulus. Because the volume of gas is directly related to the pressure and the density is directly related to the volume of gas, the cement column will be heavier or lighter than planned if the design hole size is different than the actual hole size.

To eliminate one more variable, the same crew and equipment were used to perform as many of the foamed cementing jobs as possible during this campaign. In an effort to achieve a uniform cement column as well as maintain cement competency at the top of the column without over-complicating the job, these foamed cement jobs were calculated and designed based on a constant nitrogen feed rate and a constant cement slurry density using a variable cement slurry pump rate (see **Figs. 4** and **5**). In both of these job charts one can see that the nitrogen rate was essentially constant (light blue line) during the foam cementing portion of the job and that both charts demonstrate a slowly decreasing slurry rate (dark blue line). If the gas is injected at a constant rate and the slurry rate is decreasing, an increasing concentration of gas will be added to the slurry. This translates to a lower concentration at the top of the column and a higher concentration at the bottom. Because the pressure increases with depth, this higher mass concentration of gas can compress to a uniform volume of gas or a uniform foamed slurry density. In these wells, hole caliper information was available so that accurate foam placement prediction was possible. Remember, with the constant-density design scenario, substantial errors in downhole pressures are possible when actual washout factors are not accurately known.

Also visible from the density curves (pink lines) on both charts (Figs. 4 and 5), are the seven stages of low-cost flush that were pumped This package was designed to both help with the lost-circulation issues and to remove the mud from the wellbore. The best designed cement slurry will not be capable of providing zonal isolation unless the mud is effectively displaced out of the annulus.

Conclusions

The two case histories provided, Wells ECN10 and ECN18, are representative of the other jobs performed in the CN-VI A/B exploration concession that used foamed cement. As can be seen from Table 3 and Fig. 3, cement was effectively circulated well into the Grupo Neuquen, surpassing required minimum height of cement by 50 and 110 m respectively. Not only was the required fill achieved, but the mud was effectively displaced, providing long-term zonal isolation as exhibited by the bond logs displayed as **Figs. 6** and **7**. To summarize:

- Foamed cement can be effectively delivered at low densities.
- Foamed cement can provide effective zonal isolation when careful planning is performed and best practices are followed.
- Techniques from the standard constant-gas and constant-density options can be combined, yielding simpler jobs and uniform columns of cement, when accurate hole size data is available

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Table 1—Final Annular Fluid Density/ECN-10

Measured Depth, m	Density, lb/gal	Quality, %	Optimum Stress Protection (Quality of 18–38%)	Hydrostatic Gradient, lb/gal
0	10	0	—	10
25.8	10	0	—	10
50.5	8.34	0	—	9.39
75.2	9	0	—	9.15
106.1	9	0	—	9.1
137	9	0	—	9.08
161.8	8.34	0	—	9.05
187	10	0	—	8.96
203.6	10	0	—	9.04
220.4	10	0	—	9.11
236.5	10	0	—	9.17
249.3	8.34	0	—	9.17
268.8	8.34	0	—	9.11
284.5	8.34	0	—	9.07
293.9	8.34	0	—	9.05
303.9	8.34	0	—	9.02
322.2	10.75	32.62	X	9.09
352	11.11	30.39	X	9.25
359.7	11.19	29.86	X	9.29
373.5	11.34	28.94	X	9.37
399.1	11.59	27.36	X	9.5
410.3	11	31.26	X	9.56
428.1	11.16	30.26	X	9.62
455.6	11.39	38.8	X	9.73
465.7	11.47	28.3	X	9.76
489.7	11.65	27.17	X	9.85
508.5	11.21	30.14	X	9.92
526.1	11.4	28.95	X	9.99
554.6	11.52	28.2	X	10.04
589	11.73	26.9	X	10.14
609	11.15	30.73	X	10.19
652.9	11.4	29.23	X	10.26
698.2	11.62	27.81	X	10.35
724.8	11.75	27.29	X	10.4

Table 2—Final Annular Fluid Density/ECN-18

Measured Depth, m	Density, lb/gal	Quality, %	Optimum Stress Protection (Quality of 18–38%)	Hydrostatic Gradient, lb/gal
0	9	0	—	9
29	9	0	—	9
59.9	9	0	—	9
90.8	8.34	0	—	9
115.5	8.34	0	—	8.86
140.3	10	0	—	8.99
171.2	10	0	—	9.17
195.9	8.34	0	—	9.17
206.1	9	0	—	9.13
217	9	0	—	9.12
230.5	9	0	—	9.11
244.1	9	0	—	9.11
252.4	8.34	0	—	9.09
257.6	8.34	0	—	9.08
266.8	8.34	0	—	9.05
273.9	10	0	—	9.07
280.4	10	0	—	9.09
293.7	10	0	—	9.13
297	10	0	—	9.14
314.4	10	0	—	9.19
327.2	10	0	—	9.22
343.8	8.34	0	—	9.18
359.9	8.34	0	—	9.14
380	8.34	0	—	9.1
396	10.51	34.32	X	9.08
417.6	10.73	32.97	X	9.16
437.7	10.92	31.79	X	9.24
463.4	11.14	30.39	X	9.34
492.3	10.94	31.79	X	9.45
509.9	11.07	30.95	X	9.51
537.5	11.27	29.7	X	9.59
566	11.47	28.5	X	9.68
588	11.24	30.03	X	9.75
624.1	11.46	28.68	X	9.84
649.4	11.6	27.8	X	9.91
675.8	11.48	28.68	X	9.98
711.1	11.65	27.58	X	10.06
719.8	11.7	27.57	X	10.08

Table 3—Well Statistics

Well Name	Total Depth, m	Casing, in.	Fracture Gradient, lb/gal	Base Slurry, lb/gal	Foamed Slurry, lb/gal	TOC (Design), m	TOC (From CBL), m
ECN-10	725	5.5	10.7	15.8	11	300	250
ECN-18	720	5.5	10.6	15.8	11.5	400	290

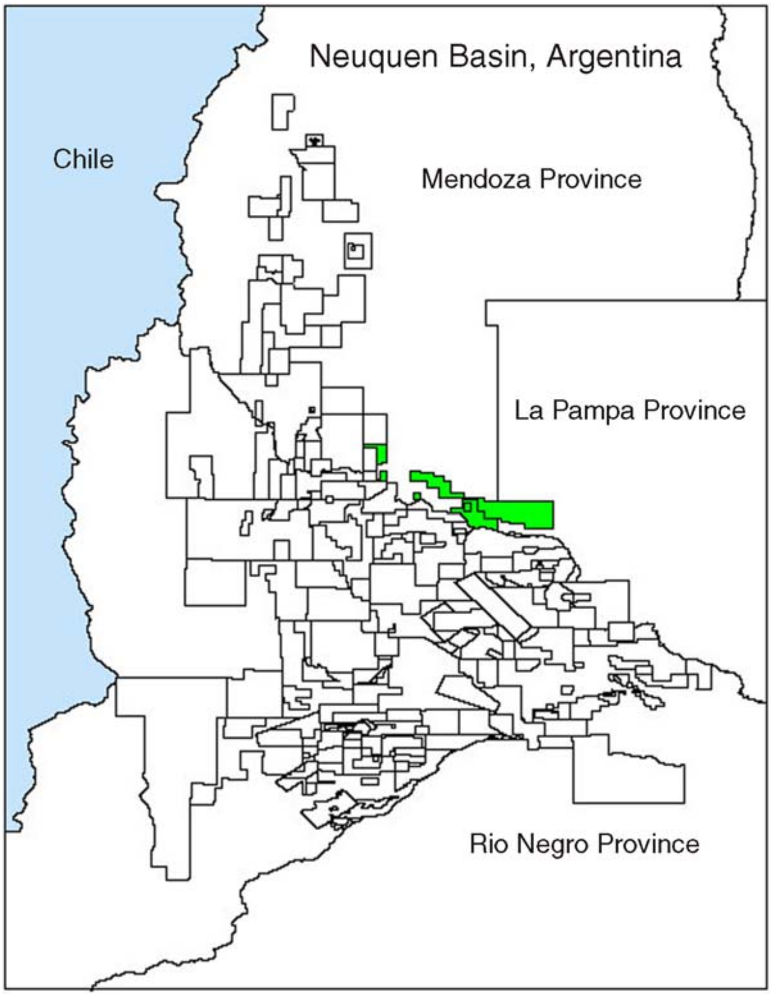

Fig. 1—Map of the subject area.

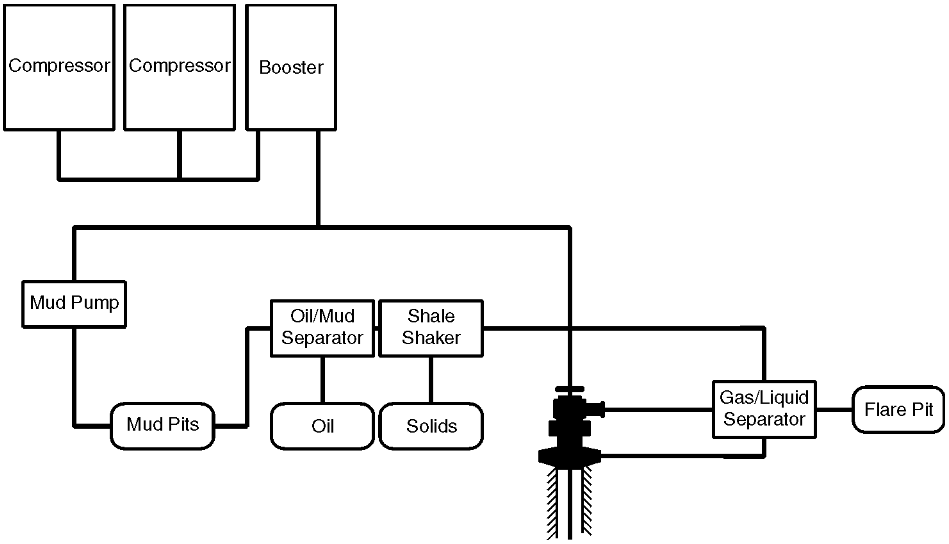

Fig. 2—Air drilling layout.

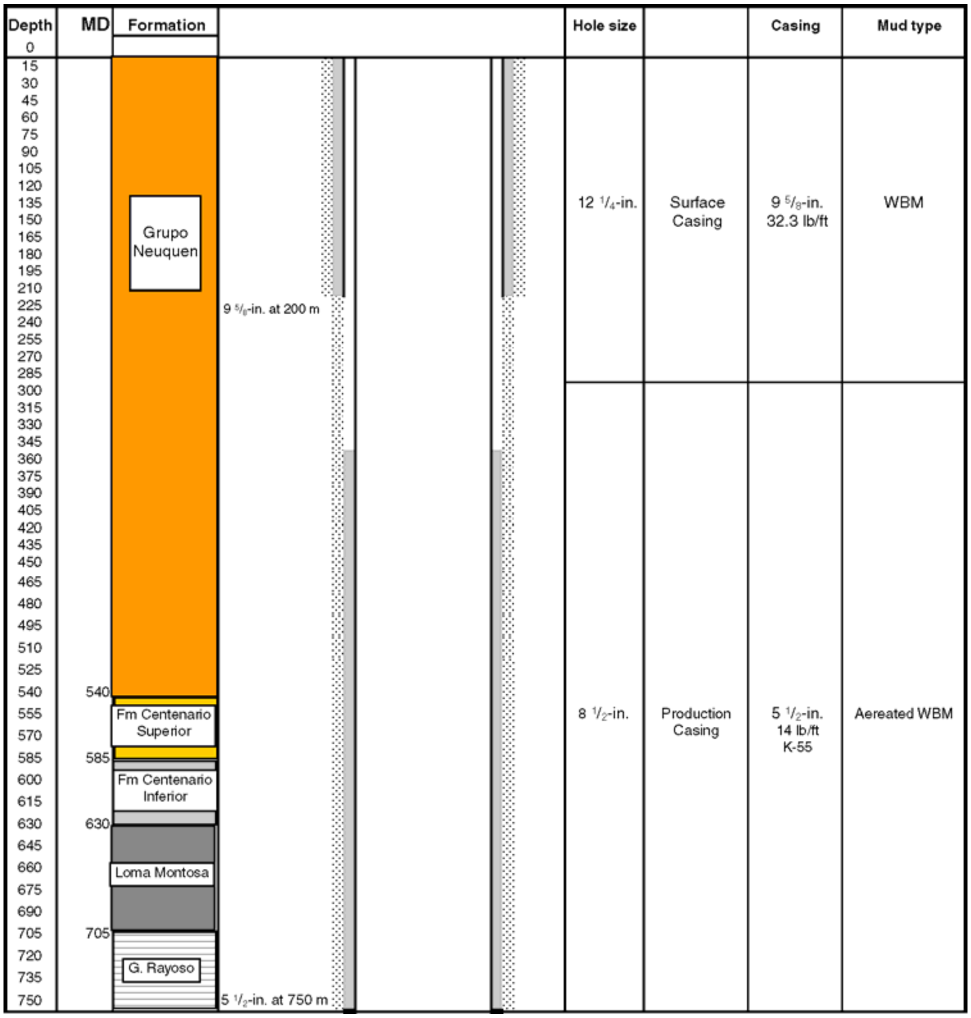

Fig. 3—Casing design for a typical well.

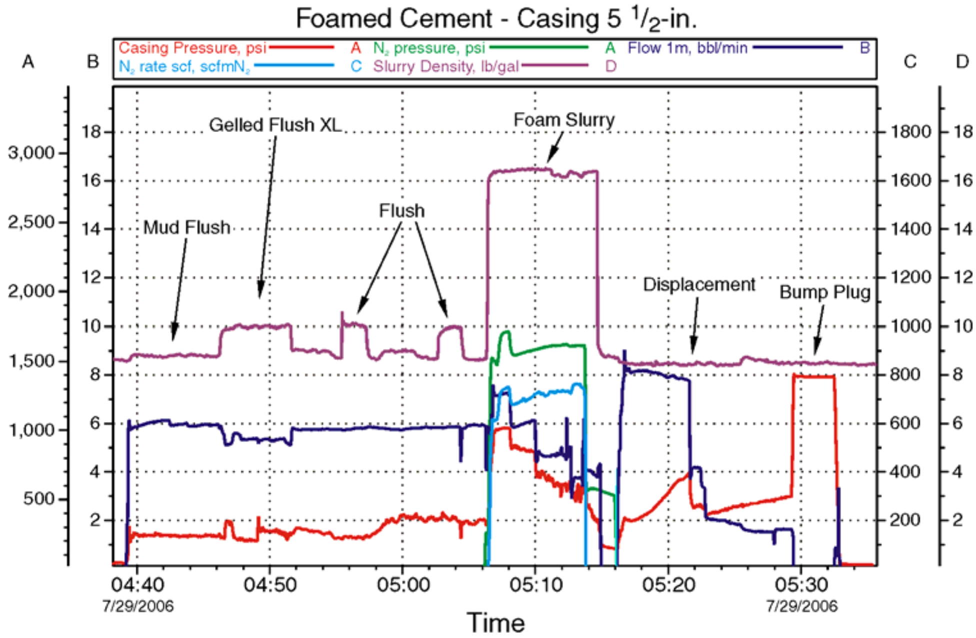

Fig. 4—ECN-10 pumping log.

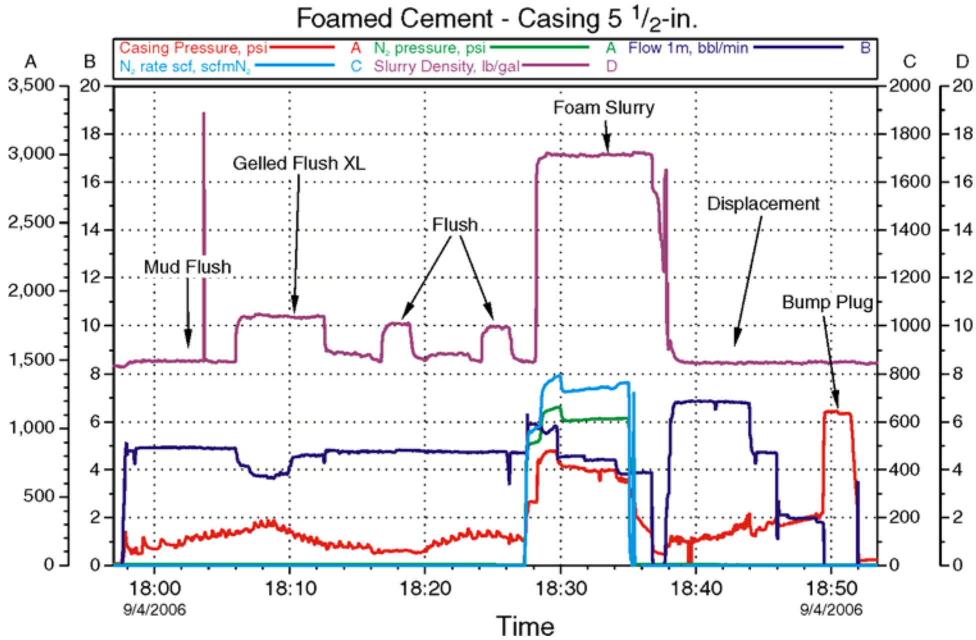

Fig. 5—ECN-18 pumping log.

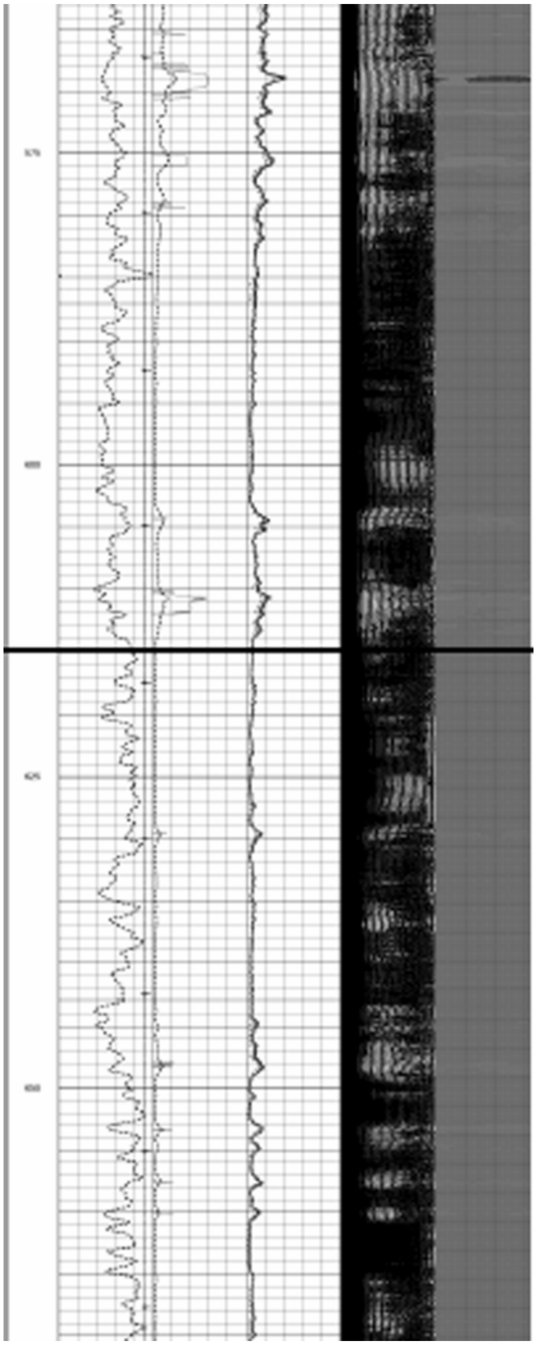

Fig. 6—ECN-10 cement bond log.

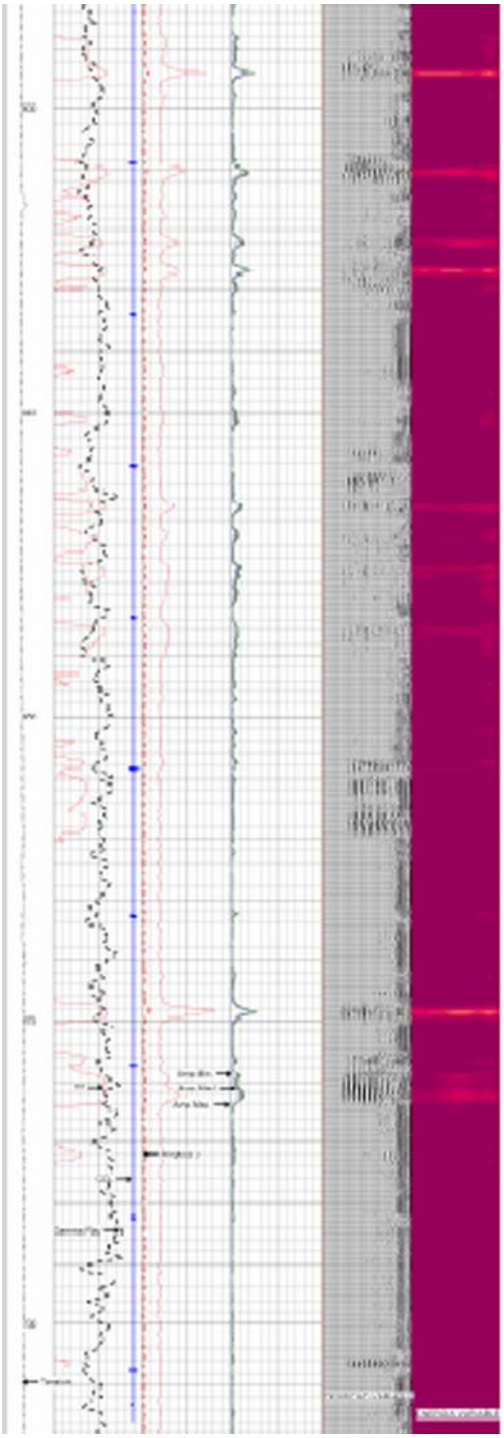

Fig. 7—ECN-18 cement bond log.