Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Reverse-Circulation Cementing and Foamed Latex Cement Enable Drilling in Lost-Circulation Zones

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Keywords: Reverse circulation, Latex, lower ECDs, foamed cement, lost circulation

ABSTRACT

Drilling in geothermal locations can pose significant challenges for conventional cement systems and circulation methods. To overcome these challenges in a geothermal well in California, a special cement system and circulation method was used. Because conventional Portland cement systems are vulnerable to chemical attack and mechanical stress typical in geothermal wells, a specially formulated foamed latex-cement blend was developed to provide good zonal isolation under these conditions.

In addition, a geothermal well often experiences lost-circulation problems that require the reduction of circulation pressures while circulating cement in place. To help minimize these circulation pressures, cement was pumped in reverse. Reverse circulation significantly reduced placement pressures and allowed placement of the cement with no apparent losses. This paper details how these technologies and techniques were successfully used in the cementation of one casing string in a geothermal well.

1. INTRODUCTION

Cementing of a casing string is often accomplished by pumping a cement slurry down the inside of a tubing or a casing, and then back up the annular space around the casing. In this way, a cement slurry may be pumped into the annular space between the casing to be cemented and the openhole or outer casing to which the casing is to be cemented. Such method often is referred to as conventional circulation cementing. Conventional circulation cementing is the most commonly used method for pumping cement slurries into the wellbore.

Conventional circulation cementing method may not be advantageous in certain circumstances. For instance, a well bore may have one or more weak formations that may be unable to withstand the pressure commonly associated with conventional circulation cementing operations. The formation may breakdown under the pressure applied by the cement, causing the cement to be lost into the formation. The loss of cement into the formation is undesirable, among other things, because of the expense associated with the cement lost into the formation. Lost circulation that occurs during a cement job can lead to incomplete sealing of the annulus, which could possibly require remedial cementing in an attempt to fill the annulus. Bour and Hernández (2003). Likewise, high pumping pressures can cause the undesirable effect of inadvertently "floating" the casing string. That is, exposing the bottom hole of the well bore to high pump pressures can, in some cases, cause the casing string to "float" upward. Moreover, the equivalent circulating density of the cement may be to high, which may lead to problems, especially in formations with known weak or lost circulation zones.

Another method of cementing casing, referred to as reverse circulation cementing, involves pumping the cement slurry directly from the surface into the annular space rather than pumping the cement slurry down the casing string itself **(Fig. 1)**. In particular, reverse circulation cementing avoids the higher pressures necessary to lift the cement slurry up the annulus. Other disadvantages of having to pump the cement slurry all the way down the casing string and then up the annulus are that it requires a much longer duration of time than reverse circulation cementing. This increased job time is disadvantageous because of the additional costs associated with a longer duration cementing job. Moreover, the additional time required often needs a longer slurry pump time, which may require additional retarders or other chemicals to be added to the cement slurry. Typically, when cementing geothermal strings of casing in California, the calculated excess volume may be doubled in some instances. Conventional circulation cementing causes excessive cement waste and costs associated with the volume of cement used.

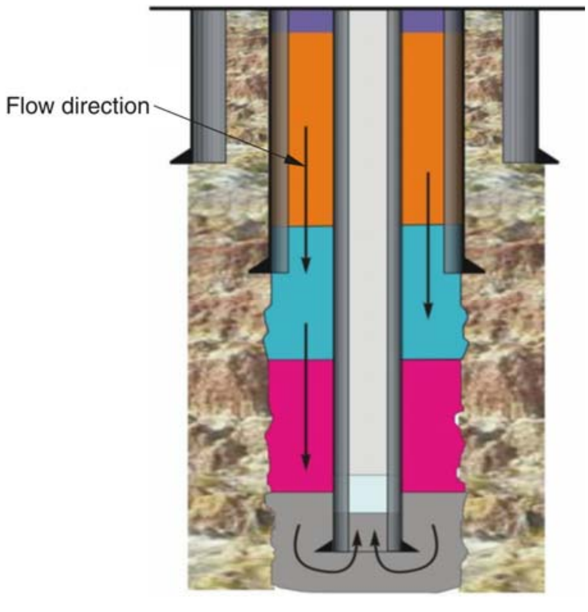

Fig 1: Reverse circulation cementing flow direction.

To help deal with other problems often associated with geothermal wells, a special latex based Portland cement was utilized for this operation. This specialized cement is designed to improve acid resistance, fluid-loss control, and solids suspension at high-temperature conditions. Treating cement with Latex yields slurries with excellent wetting properties, low base slurry viscosities, and increased resiliency. These properties help increase bonding strength, resulting in a tighter annular seal and superior zonal isolation.

To help prevent cement sheath failure that can occur as a result of stresses induced from thermal cycling, and to help minimize the pressure on the formation during placement, the latex cement was foamed to a density of approximately 11.5 lb/gal. Foam cements at low densities allow the placement of cement across weak formations, which may prevent lost circulation problems. The use of foamed cement offers a low-density material that develops relatively high compressive strength and low permeabilities and enhanced protection against annular gas invasion.

2. Reverse Circulation Cementing RCC

Reverse circulation cementing consists of pumping fluids down the annular space of the wellbore and taking returns from inside the casing string to be cemented. In certain cases, reverse circulation may be an advantageous choice.

2.1 Advantages of Reverse Circulation Cementing

RCC can provide the following advantages:

- Reduced Hydraulic Horsepower
- Reduced ECDs
- Shorter slurry thickening times
- Improved compressive strength development
- Improved safety and environmental management

2.1.1 Reduced Hydraulic Horsepower:

The gravity force is working in favor of the slurry flow; therefore, the hydraulic horsepower required to place the cement slurry is greatly reduced.

2.1.2 Reduced ECDs.

In reverse circulation cementing the Equivalent Circulating Density ECD is the effective density that combines casing fluid density and casing pressure drop. Since the cement slurry is not circulated back to surface, the equivalent circulating densities ECDs can be significantly reduced **(Fig. 2)** in RCC in comparison to conventional circulation cementing **(Fig. 3)**.

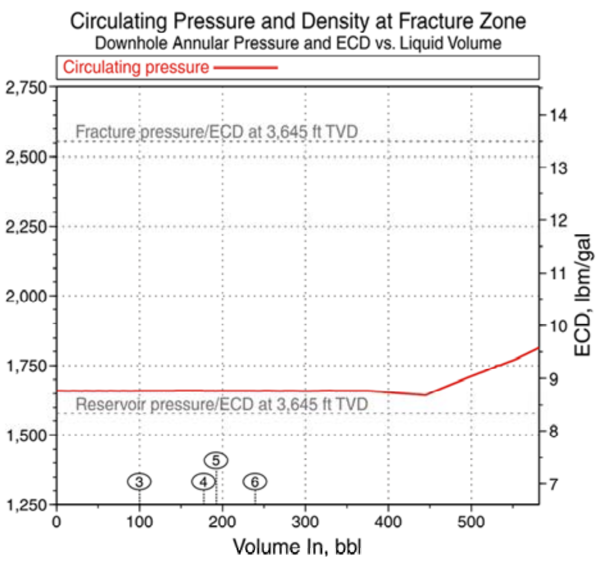

Figure 2: Reverse Circulation ECDs.

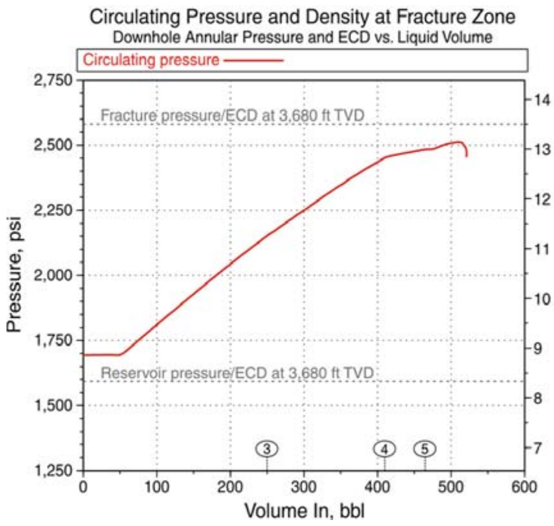

Figure 3: Conventional Circulation ECDs.

2.1.3 Shorter Slurry Thickening Times.

The concentration of retarder used in these slurries can significantly be reduced, staged, or even eliminated because of shorter transit times of filler slurries that will not go around the casing shoe at TD. Moreover, if necessary, sections of filler cement blends may be accelerated where the shoe cement and the deeper parts of the filler contain retarders. In addition to the engineered design of cement blends based on interval temperatures that they will be exposed to, the minimized displacement volume can provide a shorter pumping time. On most RCC jobs, the displacement volumes is a calculated small volume that is pumped behind the filler cement to clear the surface lines and well head equipment. In Addition, when using the RCC method, the need for wiper plugs is eliminated because the cement slurries are pumped down the annulus.

2.1.4 Improved Compressive Strength Development.

Compressive strength development of filler slurries has always been an area of concern when dealing with cooler temperatures in the upper hole sections. In conventional cementing, filler cement is retarded to provide enough pumping time to pass around the casing shoe. However, the retarded filler slurries may take excessive time to setup and develop compressive strength. Because in the RCC process, the filler cement will not see the shoe bottomhole temperatures, a faster setting cement can be designed that could develop compressive strength more rapidly.

2.1.5 Improved Safety and Environmental Management.

RCC can be a safer method of cementing geothermal wells. Placement and displacement pressures are much lower than pressures observed on conventional cement jobs. RCC is also a more environmentally friendly process. Primarily because no excess cement is pumped back to surface that will have to be disposed of. In addition, less time and equipment is used on location.

2.2 Challenges of Reverse Circulation Cementing.

While the reverse circulation is an appropriate choice for some cementing applications, a few challenges remain in RRC method. Moore et al (2003):

- Determining cement location
- Rigup.
- Job design and execution
- Experience
- Float equipment

2.2.1 Determining Cement Location

Accurately determining the location of the leading edge of the cement slurry can be challenging. Knowing when competent cement is at the shoe; however this can be easier if a logging tool and radioactive tracer are used.

2.2.2 Rigup. Rigging up to perform a RCC job is not complex; however, more iron is required to rig up for the RCC technique. Part of the rig up is designed to handle contingency situations. Davies et al (2004).

2.2.3 Job Design and Execution

Specialized cementing simulation software capable of aiding in the design of RRC jobs is highly recommended, However, such software is not standard in the industry . Every job should be carefully designed, monitored and executed. All parameters in this process should be studied in detail before and during every job. Cooperation and communication between al parties should be continuous.

2.2.4 Experience

Having experienced staff and crew is important for performing each job from design to execution. Davies et al (2004).

2.2.5 Float Equipment

Conventional float equipment is not suitable for RRC jobs. Float equipment that allows RRC must be used and is normally specially ordered . Three main types of RCC float equipment are commonly used **(Fig. 4)**: (1) Float and Stinger assembly that enables job execution similar to an inner-string cementing procedure, and (2) The Pump-out-valve assembly that can be activated by landing a ball on the valve and shearing the valve from the float collar allowing reverse circulation. Alternatively, in some applications, a (3) guide shoe and can be used. However, with (2) and (3) once cement placement is complete, surface pressure must be held on the casing while the cement sets.

Figure 4: Schematics of Float equipment used in RRC: (a) Float and Stinger assembly; (b) Pump-out-valve assembly and collar; (c) conventional guide shoe. (drawings not to scale)

3. Case History

The job consisted of cementing an intermediate casing string using the RRC method. The following parameters applied:

- Casing size—13 $^{3}/_{8}$-in.
- Casing depth—3,645 ft
- Gamma- ray tool depth—3,045 ft
- Previous casing size—20-in.
- Previous casing shoe—798 ft
- Openhole size—17 $^{1}/_{2}$-in.
- Job excess—+20%

3.1 Equipment Layout

Performing the reverse foamed-cementing job required specialized equipment and computer design programs. A foam generator that creates an adequate pressure drop was needed to provide the required shear energy to promote stable foam. An automated nitrogen unit slaved to the cement-slurry rate provided consistent target slurry densities. In addition, an automated surfactant unit slaved to the cement slurry rate provided a consistent surfactant-to-cement ratio. The reverse foamed-cementing process fully integrated the automation for all parts of the cementing job. All equipment was linked together and operated according to the cement-slurry rate. Spielman et al (2006). **(Fig. 5)** illustrates the required instrumentation and overall layout of the operational rig up.

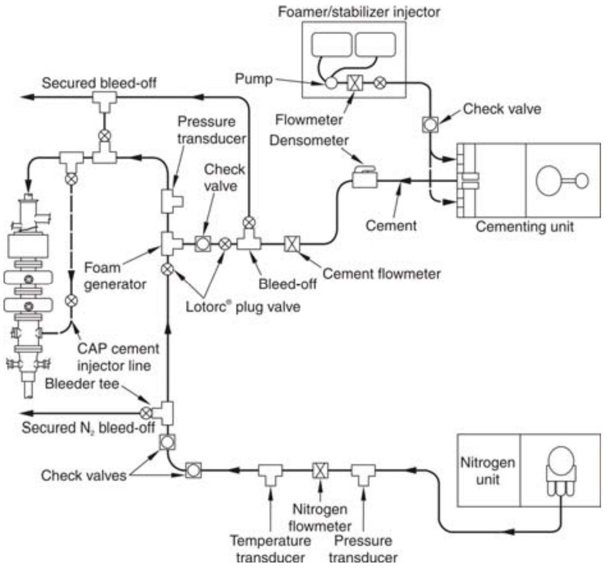

Figure 5: Foamed-cement operation equipment layout.

3.2 Pumping Regime

Careful monitoring of pressures and accurate control of mixing ratios of nitrogen, base slurry, and surfactant were recommended for a successful operation. Designing a reverse foamed-cement job and executing the plan accordingly required accurate quality control during the pumping sequence. Base-slurry density was controlled using an automatic density control mixer. Both the surfactant and nitrogen units were slaved to the base-slurry rate so that any changes in base-slurry rate also changed the surfactant and nitrogen rates accordingly. Pumping data was recorded in real time to enable control of the process **(Fig. 6)**.

3.3 Slurry selection

Latex cement. Latex cement was designed as a preventive measure to help resist corrosion from naturally occurring brines and carbon dioxide. Latex cement can improve corrosion resistance, has good fluid-loss control, and high-temperature solid suspension properties. Treating cement with latex yields slurries with excellent wetting properties, low viscosities, and increased resiliency. These properties help increase bonding strength, resulting in a tighter annular seal and superior zonal isolation. The Latex cement was foamed for three primary reasons: (1) Foamed cements at low densities allow the placement of cement across weak formations. (2) Foamed cements at low densities develop relatively high compressive strength and enhance protection against annular gas invasion. (3) Foamed cement is more ductile and can tolerate expansion and shrinking without losing its sealing capabilities Spielman et al (2006). Stresses caused by temperature changes that occur in a geothermal well can crack a conventional cement sheath because of heat-induced changes in casing diameter. Bour and Hernández (2003).

Foam cement sheaths are more ductile and can tolerate expansion and shrinking without losing their sealing capabilities.

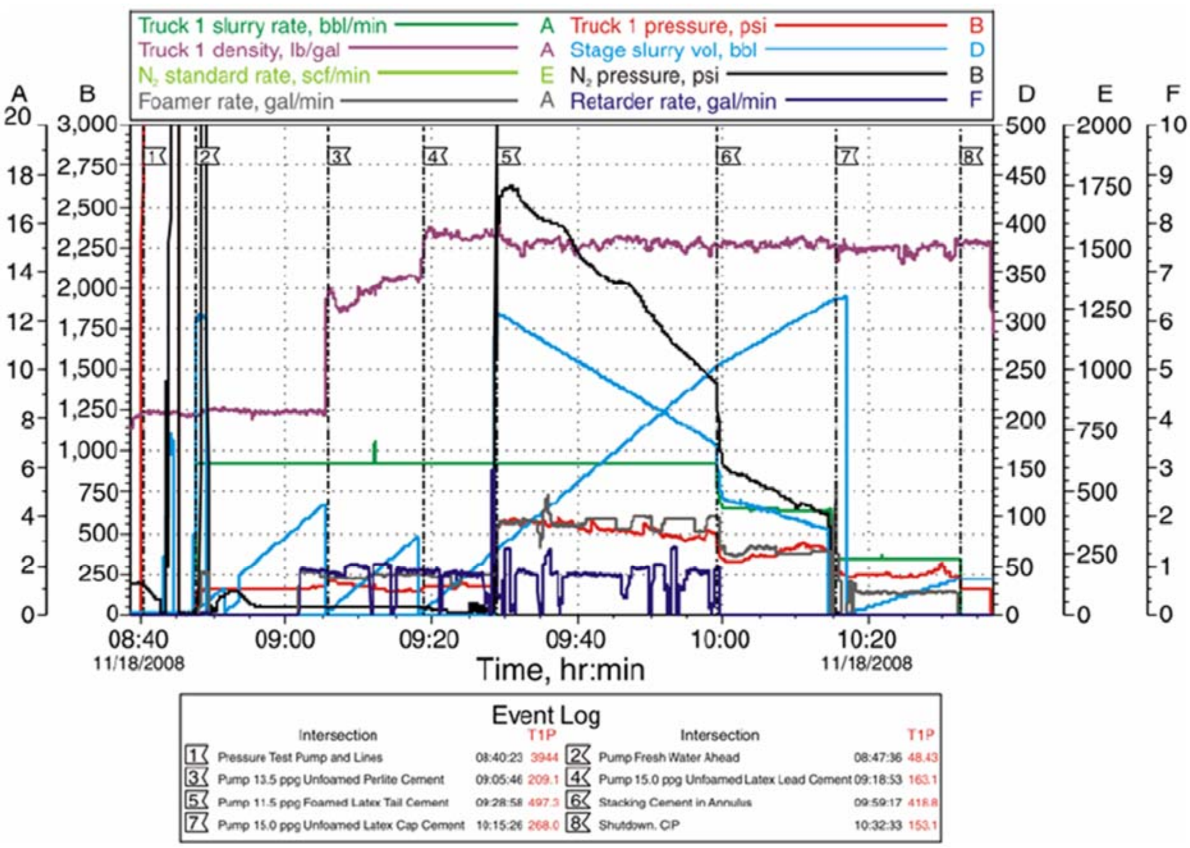

Figure 6: Real-time job execution data.

3.4 Job execution

Following the running of the casing, the well was circulated by the rig mud pumps in the conventional manner. During this initial circulation stage , the casing was reciprocated to abrade the wall of the bore hole as well as to remove any accumulated mud cake, which was carried out along with cuttings and debris by the circulating drilling mud. When the mud at the pit was substantially clean, the circulation of mud was then reversed. Once the well was reverse circulated without any problems, the well was ready for cementing. After a pre-job safety meeting was conducted, pumping equipment and surface lines were pressure tested and the equipment was prepared for the cementing operation. 100 bbl of unfoamed freshwater spacer was pumped ahead to cool down, followed by 80 bbls of 13.5 ppg unfoamed scavenger slurry. The main cement stage consisted of 62 bbl of 15.0 ppg unfoamed Latex cement, 205 bbl of 11.5 ppg foamed Latex cement with retarder and 65 bbl of 11.5 ppg foamed latex cement without retarder, and finally 35 bbls of 15.0 ppg unfoamed latex cement with accelerator. The cement slurries were mixed and pumped on-the-fly into the annulus driving the mud ahead of it so that it circulated back to surface from the upper end of the casing back to the mud pit.

A Radioactive tracer was injected once the scavenger cement was started downhole. A gamma-ray tool located inside the casing at 600 ft from the casing shoe, picked up the radioactive tracer the first time –in the annulus- at 355 bbl into the cement job corresponding to a near-gauge hole. The actual second detection of the radioactive tracer happened at ~455 bbl into the job as expected. At this point, the returns at surface were shut-in and the gamma tool was pulled 500 ft above detection point without interrupting the pumping stage. Good circulation was observed throughout the entire job. After finalizing the cementing operation 340 psi were left inside the casing until the cement setup.

CONCLUSIONS

The following conclusions are a result of this work.

- RCC is a viable option available to the geothermal industry
- RCC is becoming a common and acceptable cementing technique because of its advantages.
- The reverse circulation process yields lower annular pressures than the conventional circulation method.
- RCC provide quicker cement jobs because the cement slurry is pumped down the annulus directly, instead of being pumped down the casing and up the annulus.
- Because of the way the cement slurry is pumped, not all of the cement slurry is exposed to the high well temperatures. This simplifies the cement slurry design.
- The concentration of retarder used in RCC slurries can be significantly reduced or even eliminated because fill slurries will not be required to go around the shoe.
- Conditioning the well by circulating in conventional and reverse fashion is important to minimize the potential of mud solids falling back and bridging off inside the casing.
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- The reverse-circulation technique significantly reduces the ECDs, therefore, reducing the pressure exerted on the formation that can induce unwanted fractures.
- A radioactive tracer and gamma-ray tool can provide an indication of the position of the leading edge of the cement inside the casing and identify where the top of cement would be on completion of the job.

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