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Reverse-Circulation Method and Durable Cements Provide Effective Well Construction: A Proven Technology

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ABSTRACT

Construction of geothermal wells that are effectively cemented and durable poses a significant operational challenge. Typically, lost circulation while drilling and cementing can make it seemingly impossible to place a complete column of cement behind casing strings. Incomplete cementation can lead to well failure caused by cyclic temperature loading on the casing that occurs throughout the life of a well. Because cement systems are typically heavier than mud systems, operators in the past ruled out the possibility of successfully circulating cement from the bottom of the well all the way back to the surface. However, during the last several years, the process of reverse-circulation cementing (RCC) has proven effective, even in some of the most difficult circumstances encountered in geothermal fields.

The type of cement system used is critical to the long-term durability of a geothermal well. Conventional cement systems are high in strength but are often brittle. When cyclic temperature-stress loading is applied to the brittle cement systems, they typically fail. More ductile cement systems have been introduced and applied in geothermal-well applications. These systems are designed to be more ductile and can help the cement flex, rather than fail, when a well experiences temperature-induced stress loading on the casing and cement.

A broad overview of the successful application of RCC operations in geothermal applications is provided as well as a discussion of chemically and mechanically enhanced cement systems.

1. INTRODUCTION

Conventional cementing techniques involve displacing cement slurry down through the bore of the casing and out the shoe on the bottom of the casing so that the cement fills the annulus between the casing and the wellbore to the desired level. One or more float valves are installed in the casing to prevent backflow of the cement into the casing from the annulus if pressure in the casing is reduced, and because the density of the cement slurry is normally higher than the density of the displacing mud in the casing.

Although conventional cementing techniques have been used for many years, there can be a number of shortcomings. The process can be time-consuming because the cement is pumped all the way to the bottom of the casing and then back up into the annulus. Conventional-circulation cementing can cause excessive cement waste and costs associated with the volume of cement used, and expensive chemicals are often used to retard setting of the cement. This often results in the use of large concentrations of cement retarder. These conditions can be aggravated by high temperatures in the borehole and the water loss from the cement to the formation. In extreme cases, the cement can even set before reaching its destination or remain unset for excessive periods of time at near surface-temperature conditions. These factors potentially make conventional cementing a costly process, which can add considerably to the total completion cost of a well.

Another drawback of conventional cementing is the weight of the cement, which is typically heavier than the drilling mud. As the cement travels down the casing, considerable weight is placed on the casing string. A further problem in conventional cementing is in pumping the cement upward through the annulus from the bottom of the casing. In conventional cementing, the pump pressure must be sufficient not only to overcome the resistance to flow of the cement slurry, but also to overcome the pressure differential between the cement slurry outside of the casing and the fluids inside. These excessive pressures can contribute to failure in obtaining an annular cement column of adequate height as a consequence of the loss of cement to the formation (Hernández and Nguyen 2009).

It is important for the cement to form a competent, continuous annular sheath that bonds the casing to the wellbore. The cement should completely surround the circumference of the casing and should extend uniformly through the length of the annular interval cemented. If the cement is weak, or if any voids remain in the annular space, several undesirable consequences can result. A poor cementing job might not effectively isolate the formations penetrated by the wellbore, and unwanted communication between the formations can occur.

In RCC, cement is pumped downward into the annulus between the casing and the wellbore without pumping the cement into the bore of the casing, as compared to conventional-circulation cementing (**Fig. 1**). In particular, RCC avoids the higher pressures necessary to lift the cement slurry up the annulus.

To help prevent other cementing problems often associated with geothermal wells, such as cement-sheath failure caused by carbonation and mechanical stresses, cement properties can be enhanced to maintain sheath integrity.

Table 1 and **Fig. 2** represent proven successful cases of RCC jobs performed on the west coast of the United States at various depths, dating back to 2002. As a result of these documented successful applications, the RCC job count continues to increase and become a common practice.

Table 1: Successful RCC Jobs Completed on the West Coast Since 2002

Date	Depth, ft	Pipe Size, in.	Slurry Type	Slurry Volume, bbl
10/3/2009	5,012	8 5/8	Conventional	135
1/13/2009	3,774	13 3/8	Latex	721
2/14/2009	5,012	13 3/8	Conventional	731
2/20/2009	1,700	9 5/8	Conventional	130
12/2/2008	3,180	9 5/8	Conventional	232
10/26/2008	1,802	13 3/8	Conventional	230
11/18/2008	3,645	13 3/8	Foam Latex	548 (base)
4/4/2008	—	13 3/8	Conventional	140
2/5/2008	1,989	13 3/8	Conventional	450
4/6/2006	3,675	13 3/8	Foam	635 (base)
3/5/2006	1,450	7	Conventional	80
10/16/2005	5,000	11 3/4	Foam	995 (base)
10/11/2005	16,593	7	Conventional	506
8/1/2005	5,000	11 3/4	Foam	440 (base)
4/25/2005	9,900	7	Conventional	1200
3/3/2005	7,902	7	Conventional	325
12/30/2004	3,608	13 3/8	Conventional	370
10/3/2004	3,350	13 3/8	Latex	665
5/21/2004	3,290	9 5/8	Latex	100
11/29/2003	1,868	13 3/8	Conventional	370
4/7/2003	3,800	13 3/8	Foam	560 (base)
12/17/2002	2,065	2 7/8	Foam	60 (base)
11/4/2002	3,719	13 3/8	Foam Thermalock	440 (base)
8/19/2002	14,007	7 5/8	Conventional	207
4/2/2002	11,170	10 3/4	Conventional	426
—	2,250	7	Conventional	160

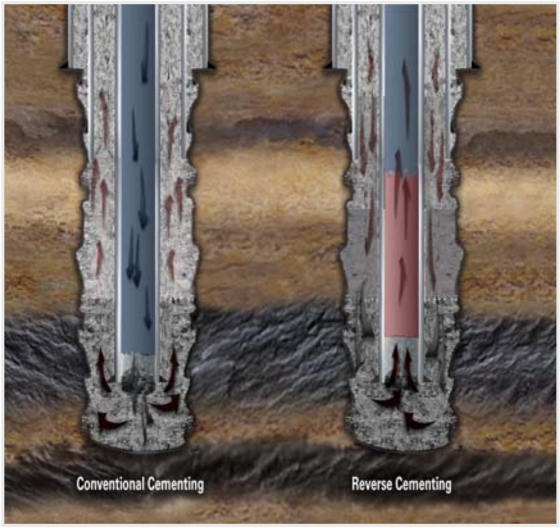

Fig 1: Conventional- and reverse-circulation cementing flow direction.

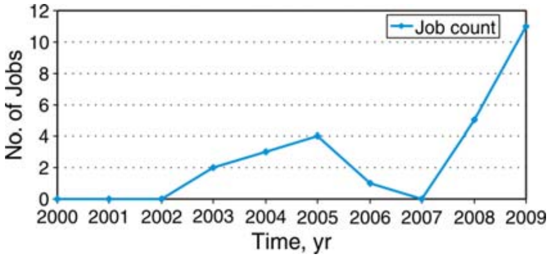

Fig 2: Job chart of successful cases of RCC jobs performed on the west coast of the United States, dating back to 2002.

2. RCC

RCC 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 can be an advantageous choice.

2.1 Advantages of RCC

RCC can provide the following advantages:

- Reduced hydraulic horsepower.
- Reduced equivalent circulating density (ECD).
- Shorter slurry-thickening times.
- Improved compressive-strength development.
- Improved safety and environmental management.

2.1.1 Reduced Hydraulic Horsepower

The gravitational 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 fluid pressure (often reported as an equivalent circulating density or ECD) at the shoe can be calculated by combining the effects of hydrostatic pressure and frictional fluid-induced pressures in the casing. Because the heavier and more viscous cement slurry is not circulated back to surface through the casing, the ECDs can be significantly reduced in RCC in comparison to conventional-circulation cementing (**Fig. 3**).

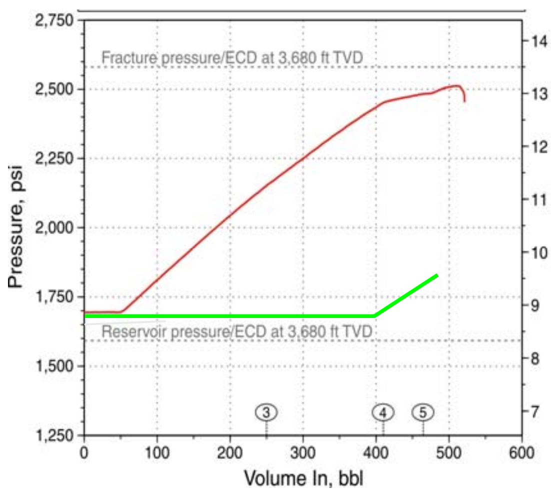

Figure 3: Conventional circulation vs. reverse-circulation ECDs.

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 can 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 volume is a calculated small volume that is pumped behind the filler cement to clear the surface lines and wellhead 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 can take excessive time to set up and develop compressive strength. Because in the RCC process the filler cement will not see the shoe bottomhole temperatures, a quicker-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 acceptable process. This is 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 RCC

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

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

2.2.1 Determining Cement Location

Accurately determining the location of the leading edge of the cement slurry can be challenging. However, knowing when competent cement is at the shoe can be easier if a logging tool and radioactive tracers 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 rigup 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 RCC 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 all parties should be continuous.

2.2.4 Float Equipment

Conventional float equipment is not suitable for RCC jobs. Float equipment that allows RCC must be used and is normally specially ordered. Three main types of RCC float equipment are commonly used and are shown in **Fig. 4**: (a) A float and stinger assembly enables job execution similar to an inner-string cementing procedure and (b) the pump out-valve assembly 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 (c) guide shoe can be used. However, with (b) and (c), once cement placement is complete, surface pressure must be held on the casing while the cement sets.

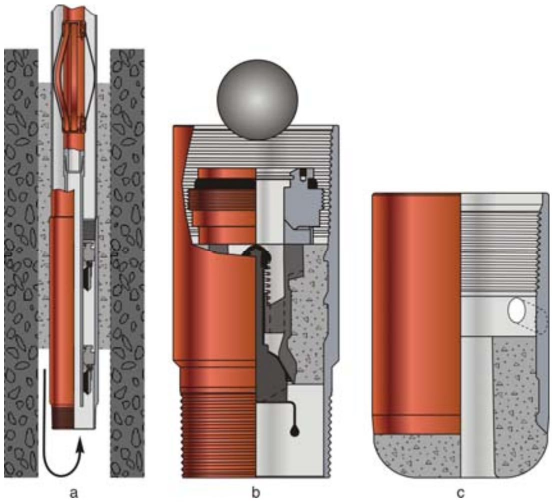

Figure 4: Schematics of float equipment used in RCC: (a) float and stinger assembly, (b) pump out-valve assembly and collar, (c) conventional guide shoe (drawings not to scale).

3. Durable cements

To help prevent cement-sheath failure that can occur as a result of stresses induced from thermal cycling and carbon-dioxide (CO_2) attack, which is common in geothermal environments, specialized cements can be designed with (1) enhanced chemical properties and (2) enhanced mechanical properties to aid in maintaining long-term wellbore integrity.

3.1 Chemically Enhanced Cements

To help reduce CO_2 attack in Portland-based cements, the surface area of the cement sheath that is exposed to CO_2 should be minimized to help prevent carbonation. This can be achieved by reducing the permeability of the cement sheath and reducing the components in the cement sheath prone to CO_2 attack. Slurry designs with a low water-to-solids ratio, high percentages of fly ash, silica, the use of latex additives and ultimately, non-Portland cements, such as calcium-aluminate cements and epoxy cements, constitute examples of chemically enhanced cements for CO_2 environments.

3.2 Mechanically Enhanced Cements

As the induced mechanical stresses from well operations increase, the chance of cement failure also increases. Temperature changes in the wellbore result in thermally induced stresses, while pressure changes in the formation and wellbore directly stress the cement.

To help maintain set-cement integrity, it is important for the cement sheath to be capable of deforming with stress without causing permanent damage and to be resistant to shrinkage, which can lead to debonding or tensile failure. Non-elastic cement and shrinking cement can result in microannuli or cracking.

Several additives can be used to achieve the desired cement-sheath properties. Such additives include: elastomers, fibers, foam bubbles, and expansion aids (Darbe et al. 2008).

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 provides 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.
- The reverse-circulation technique can significantly reduce the ECDs and therefore reduce the pressure exerted on the formation that can induce unwanted fractures.

REFERENCES

Bour, D. and Hernández, R. 2003. “CO2 Resistance, Improved Mechanical Durability, and Successful Placement in a Problematic Lost-Circulation Interval Achieved: Reverse Circulation of Foamed Calcium Aluminate Cement in a Geothermal Well.” *Paper presented at the Geothermal Resources Council annual meeting; Morelia, Michoacán, México 10-12 October*

Darbe, R., Gordon, C., Morgan, R., 2008. “Slurry Design Considerations for Mechanically Enhanced Cement Systems”. *Paper AADE-08-DF-HO-06 presented at the AADE Fluids Conference, Houston, Texass 8-9 April.*

Davies, J., Parenteau, K., Schappert, G., Tahmourpour, F., and J. Griffith, J. 2004. “Reverse Circulation of Primary Cementing Jobs—Evaluation and Case History.” *Paper IADC/SPE 87197 presented at the IADC/SPE Drilling Conference, Dallas, Texas 2–4 March.*

Moore, R. Bour, D., Reed, S., and Hernández, R. 2003. “High Temperature Wells with Lost Circulation Demands and Reverse Circulation Placement Technique Using Foamed Cement Systems: Two Case Histories.” *Paper SPE 84563 presented at the SPE Annual Technical Conference and Exhibition, Denver, Colorado 5–8 October.*

Spielman, P., Hernández, R., and Nguyen, H.. 2006. “Reverse Circulation of Foamed Cement in Geothermal Wells.” *Paper presented at the Geothermal Resources Council Annual Meeting; San Diego, California, September 12.*