Evaluation of Applicability of Reverse Circulation Primary Cementing method in Supercritical Geothermal Wells

Ryo Shimomura and Shigemi Naganawa

School of International Resources Sciences, Akita University, Japan

Keywords

Supercritical geothermal well, drilling technology, cementing method, reverse circulation cementing, wellbore temperature simulation

ABSTRACT

Supercritical geothermal resources are expected as a next generation geothermal resource that are located at depths between 4000 and 6000 m with formation temperatures of over 400° and formation pressures between 30 and 60 MPa. To maintain wellbore integrity for a sufficiently long period of time in such a harsh environment, it is necessary to select an appropriate primary cementing method that considers the geological environment and the wellbore geometry. The reverse circulation cementing method, in which the cement slurry is pumped down the casing annulus directly from the surface and is returned through the casing pipe, is considered to have some advantages for geothermal wells. In this study, the effectiveness of reverse circulation cementing in reducing the cement slurry pumping time was evaluated for supercritical geothermal wells for which the cementing interval is long and the cement slurry is exposed to high formation temperatures during cementing.

1. Introduction

For a supercritical geothermal well, the formation temperature is over 400° and the pressure is 30 to 60 MPa. This harsh environment is due to the origin of supercritical fluids. **Figure 1** shows a schematic diagram of a supercritical geothermal system. Supercritical geothermal resources are located in areas close to magma, where water from seawater drawn underground by plate tectonics exists at high temperature and pressure conditions.

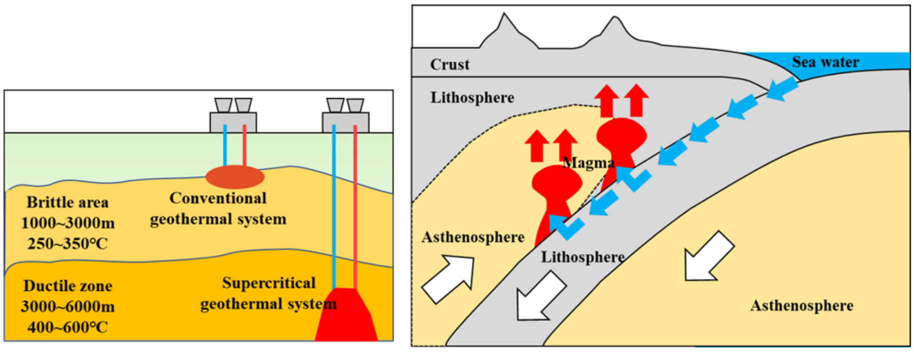

Figure 1: Schematic diagram of a supercritical geothermal system.

Table 1 compares formation properties for oil and gas fields, and geothermal fields. In typical oil and gas fields, the formation temperature is at most approximately 200° at a depth of 5000 m. On the other hand, in typical geothermal fields, the formation temperature reaches approximately 250° to 300° at shallow depths of 1000 to 2000 m. In supercritical geothermal systems, the formation temperature reaches approximately 400° to 600°. In addition, formation pressure in a geothermal field is typically low or subnormal because the reservoir fluid has a low density due to high formation temperatures. Therefore, the combination of the low-pressure conditions and naturally fractured formations found in geothermal systems commonly result in severe lost circulation during drilling or cementing operations.

Table 1: Comparison of formation properties among oil and gas fields, conventional geothermal systems, and supercritical geothermal systems.

	Oil and Gas	Geothermal	
		Conventional	Supercritical
Temperature	200°C at depth of 5000 m	250°C to 350°C	400°C to 600°C
Pressure	High Formation Pressure	Low Formation Pressure	
Rock	Sedimentary Rock	Sedimentary/Base Rock (Hard)	
Fluids	HC (CO_2 and/or H_2S)	CO_2 and/or H_2S, Low pH	
Target depth		1 km to 3 km	3 km to 6 km
Origin	Organic material	Rain water / Snow	Sea water

Cementing operation is an important factor in drilling to maintain the wellbore integrity for a certain long period of time in such a high temperature and pressure environment. It is necessary to select an appropriate primary cementing method that considers the geological environment and the wellbore geometry.

In this study, the reverse circulation cementing method is considered to have some advantages for geothermal wells, when taking into consideration cementing operation time. Thus, the wellbore temperature distributions for the reverse circulation cementing method were simulated based on the data from the Kakkonda WD-1a well drilled in Japan. In addition, considering the low formation pressures found in geothermal wells, we calculated and analyzed the lift pressure during cementing operation.

2. Cementing Operation

2.1 Objective of Cementing in Well

Cementing operation is conducted to prevent flow to surface and to fix the casing pipe in the well. In oil and gas wells, production fluids flow through the tubing and are transported to the surface. Hence, cementing is conducted to prevent fluid from non-producing formations from entering the annulus. At depths shallower than the production layer, cementing is not conducted in the annulus and drilling mud is often left in the section that does not need to be intercepted by other layers.

In geothermal wells, production fluids flow through the casing and are transported to the surface. In this situation, full-hole cementing is needed to protect hot water and steam in the production zone from being vented to the surface. If the casing pipe is damaged due to corrosion, thermal fluids can easily jet to the surface trough the annulus if there is no or insufficient cementing on the outside of the casing. Full-hole cementing in a geothermal well is also intended to secure the casing and minimize vertical movement of the wellhead equipment due to thermal expansion and contraction. **Figure 2** shows how cement column height differs between a geothermal well and an oil and gas well.

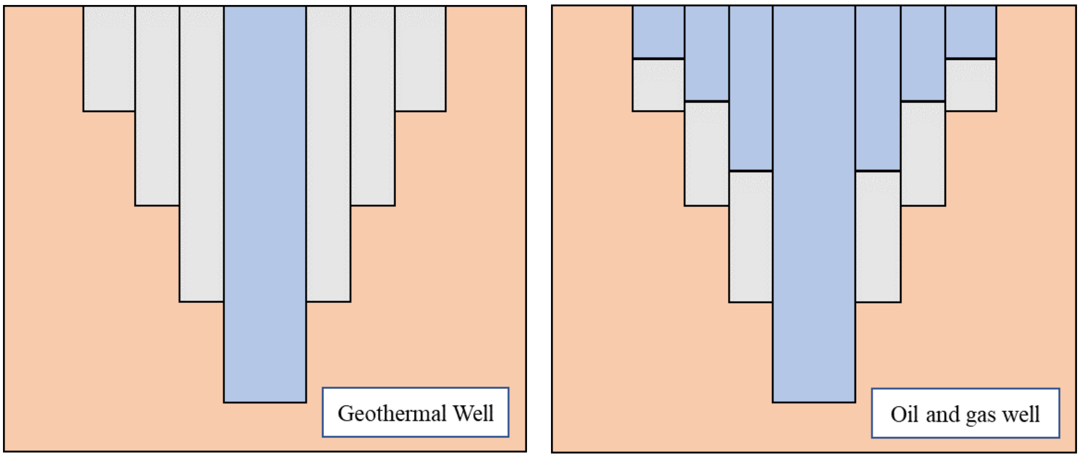

Figure 2: Cement column height difference between a geothermal well and an oil and gas well.

2.2 Reverse Circulation Cementing

Figure 3 shows the direction of two types of cementing methods. The conventional circulation cementing method, in which the cement slurry is pumped down the casing pipe from surface and is returned through the casing annulus, is commonly used in drilling. However, the reverse circulation cementing method, in which the cement slurry is pumped down the casing annulus directly from the surface and is returned through inside the casing pipe, is considered to have some advantages in geothermal wells as follows.

- Cementing time including pump time is reduced.
- Increased pump rate of cement slurry compared to conventional cementing.
- A long section can be cemented at a time.
- Improved compressive strength.

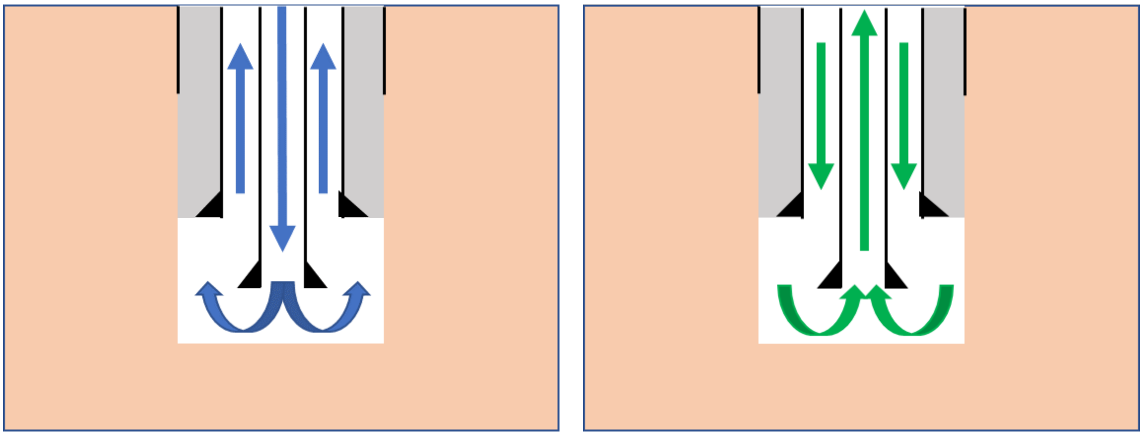

Figure 3: Flow direction of the cementing methods. (Left: conventional circulation cementing method. Right: reverse circulation cementing method).

3. Simulation Study

3.1 Simulation Conditions

The temperature distributions in the casing annulus during pumping of cement slurry, just after pumping started and after pumping finished, were simulated using a wellbore temperature simulation program “GEOTEMP2” originally developed at Sandia National Laboratory (Mondy and Duda, 1984). The wellbore geometry and formation temperature gradient data were based on the Kakkonda WD-1a well formerly drilled in Japan. The downhole temperature in the Kakkonda WD-1a well reached over 500° at a depth of 4000 m **(Figure 4)**.

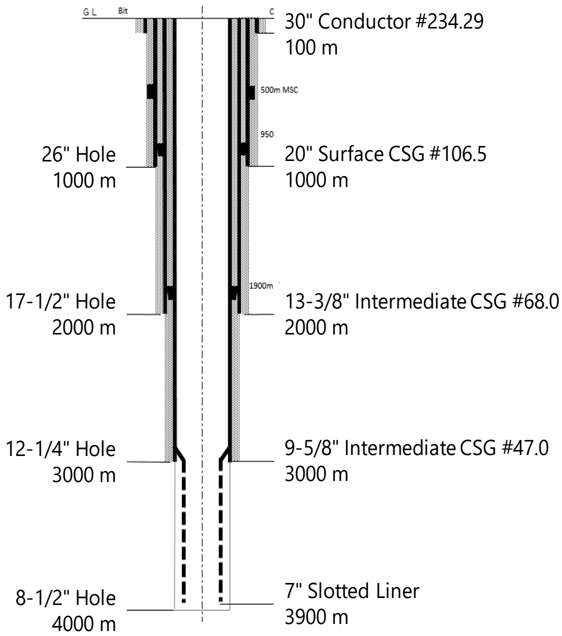

Figure 4: Casing program of the simulated supercritical geothermal well.

The simulation parameters in this study were set as shown in **Table 2.** The pump rate for the cement slurry and the mud water were initially set to 500 L/min and 2000 L/min, respectively. We also considered different pump rates for the cement slurry.

Table 2: Parameters used in the simulation.

	Density (kg/m³)	Viscosity (cP)	Yield point (lbf/100ft²)	Pump rate (L/min)
Mud water	1200	15.0	5.0	2000
Cement slurry	1750	30.0	50.0	500

3.2 Result and Discussion of Simulation

3.2.1 Temperature Inside the Casing

Figure 5 shows the simulated wellbore temperature distribution inside the casing pipe just after cement slurry inserted in the annulus for both types of cementing methods. The temperature of the mud water inside the casing pipe was higher for the reverse circulation cementing method. For reverse circulation cementing, the fluid in the annulus, which is affected by the formation temperature, flows into the casing pipe. For the conventional cementing method, the direct effect of formation temperature on the fluid is small.

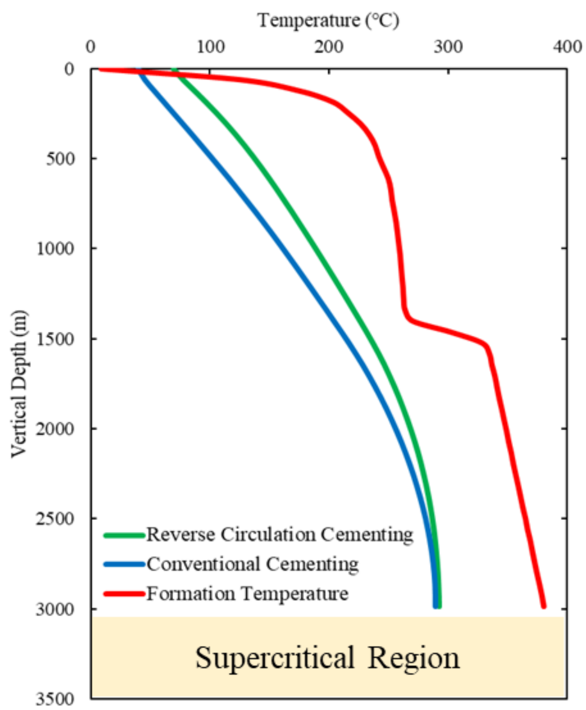

Figure 5: The simulated wellbore temperature distribution in the casing pipe just after cement slurry inserted in the annulus.

3.2.2 Temperature at Annulus

Figure 6 shows, for different flow rates, the simulated wellbore temperature distribution in the casing annulus just after the cement slurry front reached the bottom of the well in conventional cementing and just after the cement slurry front returned to the surface in reverse circulation cementing. The annulus temperature at most depths (especially shallow depths) is lower when using the reverse circulation cementing method. Close to the bottom of the well, the annulus temperature is slightly lower for conventional cementing.

The right image in **Figure 6** shows for a different pump rate the simulated casing annulus temperature distribution just after cement slurry inserted in the annulus. Because the pump rate of cement slurry can generally be set higher in reverse circulation cementing than in conventional cementing, the maximum pump rate in the simulation study was set to 750 L/min for the conventional cementing and 1500 L/min for the reverse circulation cementing. It was found that the downhole annulus temperatures just after cement slurry inserted in the annulus were lower at all well depths for the reverse circulation case than for the conventional circulation case. However, as the depth of the cement slurry front increased, the temperature difference between the two methods became smaller. This may be due to the difference in cooling effect between the annulus and casing pipe, which is caused by the difference in the cross-sectional area which the cement slurry passes. The cross-sectional area of 9 5/8-inch casing pipe is 0.037 m^2 and cross-sectional area of annulus is 0.031 m^2. The conventional cementing method that injects cement into the casing pipe (that has a larger cross-sectional area than the annulus) showed a greater cooling effect.

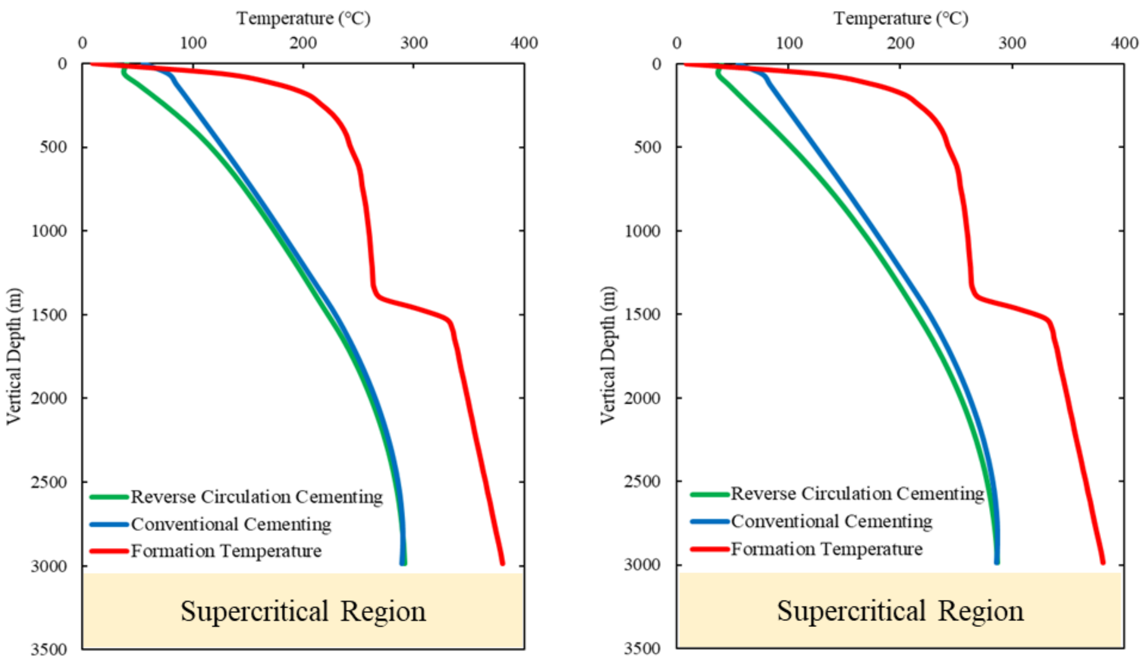

Figure 6: The simulated wellbore temperature distribution in the casing annulus just after cement slurry inserted in the annulus. (Left: 500 L/min of cement slurry in conventional cementing and reverse circulation cementing. Right: 750 L/min in conventional cementing and 1500 L/min in reverse circulation cementing.)

3.2.3 Change of Temperature

The cementing operation time of the two cementing methods were compared. **Figure 7** shows the front temperature of cement slurry during pumping into the well. In the case of reverse circulation cementing, the cementing time can be reduced by 3.57 hours. This may prevent the problem of early thickening of the slurry due to high temperature conditions and reduce the possibility of cementing failure.

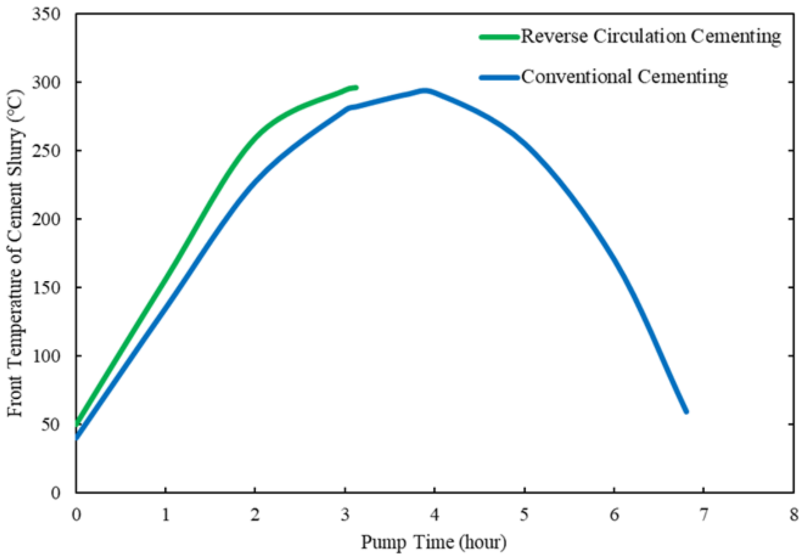

Figure 7: The front temperature of cement slurry during pumping into the well.

4. Pressure Calculation

Formation pressure in geothermal wells is low since the density of reservoir fluids is low at the high temperature conditions found in geothermal systems. This environment may cause lost circulation or blowout. Hence, pressure gauging during cementing operation is an important factor. For conventional cementing, the lift pressure is defined as the difference between the pressure in the casing ($p_{casing\ pipe}$) and the pressure in the casing annulus ($p_{annulus}$) as below.

$$p_{conventional\ cementing} = p_{annulus} - p_{casing\ pipe} \quad (1)$$

Similarly, the lift pressure for reverse circulation cementing is given as follows.

$$p_{reverse\ circulation\ cementing} = p_{casing\ pipe} - p_{annulus} \quad (2)$$

Figure 8 shows the result of lift pressure during cementing operation. In the figure, section (A) highlights the period where mud water is circulated. Section (B) indicates the interval where cement slurry is pumped down through the inside of the casing pipe in conventional cementing and through the casing annulus in reverse circulation cementing. Section (C) indicates the period where cement slurry is returned to the surface in conventional cementing. In reverse circulation cementing, cement slurry does not need to return to the surface. Based on the above results, the lift pressure of reverse circulation cementing method is lower than that of conventional cementing.

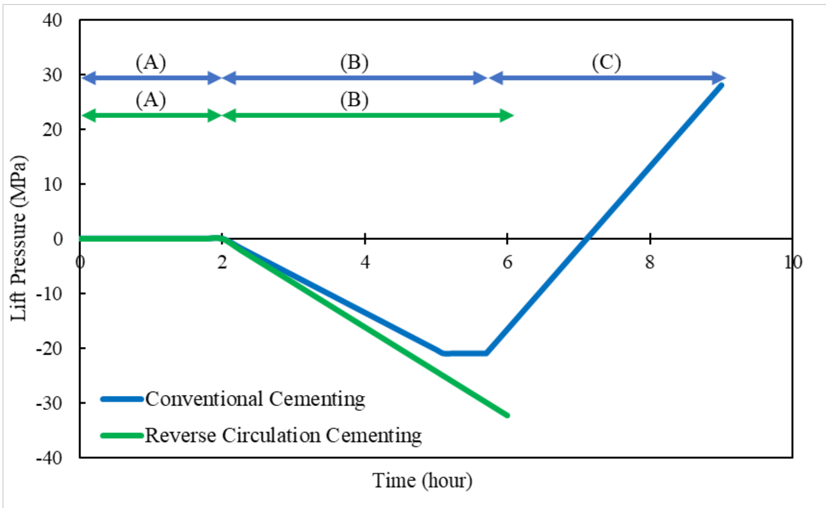

Figure 8: Calculated lift pressure during cementing operation.

5. Conclusions

In this study, wellbore temperature distributions and lift pressure during cementing was calculated to evaluate the effectiveness of the reverse circulation cementing method in supercritical geothermal wells.

- The temperature distribution in the casing annulus just after cement slurry inserted in the annulus is similar for the two cementing methods.
- If the cement slurry flow rate during the reverse circulation cementing method is sufficient, the temperature in the casing annulus can be reduced compared to that of the conventional cementing method.
- In supercritical geothermal wells, cementing failure may occur because the cement slurry is affected by high temperature conditions for a long time in conventional cementing.
- By using the reverse circulation cementing method, the temperature of the cement slurry can be lowered and proper cementing can be performed in a short time.
- In geothermal wells that commonly have low formation pressures and permeable zones that can result in lost circulation, the pressure during cementing operation is important.
- For the reverse circulation cementing method, lift pressure is always negative because the cement slurry does not need to return to the surface.

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