Cementing and Aerated Drilling Solutions for Curing Shallow Loss Circulation

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ABSTRACT

Performing cement plugs in the top-hole section due to shallow losses is expected in any geothermal drilling project. In fact, around 10-20% of the well's budget is allocated for this purpose. Many factors contribute to this high cost, but the most significant are the long turn-around time in between cementing jobs and the high number of plugs needed to seal the losses. This results in significant lost rig time and thus presents a big opportunity for cost reduction measures.

PGPC executed an 11-well campaign in known locations, with offset wells which showed that >20 plugs were required to be able to drill and case off the top-hole section. The primary objective of the team was to reduce the non-productive time associated with these losses. The initial approach was to develop a thick, viscous, fast-set cement plug with a lost circulation material (LCM) pre-flush to create a bridge near the wellbore to improve cement plug performance and also reduce waiting-on-cement (WOC) time. Further improvement led to a shift from an LCM-centric approach to cement gelation so the slurry would quickly gel up after pumping was stopped. At this point, the number of cement plugs was already reduced by 88% and the cement turn-around time decreased by 61%.

However, the team pushed further to eliminate shallow cement plugs by employing aerated drilling in the shallow sections. The cement plugs were successfully eliminated by the third well and the campaign was finished without any cement plug operations in the shallow loss zones.

1. INTRODUCTION

Lost circulation is defined as the partial or total loss of fluid to sub-surface formations, which occur in naturally faulted and fractured formations. Sometimes, it can also be induced by excessive hydraulic pressures when drilling through weak, loose, or highly permeability formations – both common in geothermal systems. Geothermal losses are typically common in two areas; (1) in the shallow section where there are unconsolidated boulders and (2) in the deep section where there is high permeability due to porous rocks or natural fractures as is shown in Figure 1.

Drilling ahead with losses is not preferred especially in the top-hole section because it results in a lot of issues like potential cuttings pack-off or worse, hole collapse from loss of a hydrostatic column. It can also lead to casing integrity issues due to poor cement consistency in the loss zones. Furthermore, deciding to drill ahead with losses in big diameter wells like 26" and 17 ½" holes requires a lot of mud chemicals, assuming mud mixing is able to cope up with the drilling rate, which is commonly not the case.

Traditional methods used to control lost circulation, particularly in the top-hole section is by means of lost circulation material (LCM), which are typically fibrous bridging materials of different sizes that plug cracks or create a barrier through interlocking fibres. LCMs are usually mixed into the mud system or pumped downhole as a lost circulation pill in order to plug the formation interval that is losing the fluid, and they are reasonably successful in controlling partial losses, but are not so effective on total losses within geothermal conditions. In total-loss conditions due to formation or fault fractures, which is common for geothermal wells, no amount of lost circulation material, regardless of size, is very successful. Placing cement plugs is often the most effective method for curing these types of losses. The cost to cure these heavy losses can be significant due to the consumption of large volumes of cement chemicals and mostly due to the additional rig time. Reviews of geothermal wells circulation loss costs have indicated that such costs can range from 10–20% of the overall drilling costs (Mansure et al., 2002).

The PGPC drilling team challenged itself to identify and develop a solution to minimize both the number of cement plugs and placement turnaround to plug the shallow loss zones using only placement techniques and formulations consisting of local materials as costs and logistics are a significant barrier to bringing specialty cement systems to geographically isolated locations like the Philippines.

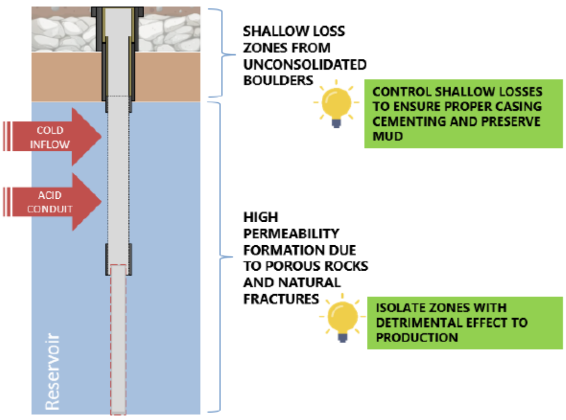

Figure 1 Typical losses in geothermal well come from both shallow and deep sections (Aspiras et al, 2022)

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2. PGPC BASELINE CEMENTING PRACTICES

Eleven (11) wells were approved to be drilled for this campaign, all at existing well-pad locations. Presented below are the estimated number of cement plugs (CP) based on the well offset information and the average CPs conducted in similar wells. It is assumed that without any intervention, the new set of wells are expected deliver similar results as in adjacent wells, losing the company an estimated >$500k per well or more than $5.5M in rig time alone for the whole project due to shallow loss zone isolation issues.

For the purpose of estimating the cement job time (hours per job), the recent performance of the rig and crew in conducting cement plugs was averaged, as this next campaign was scheduled to utilize the same people and contractors. The cement job time includes all activities from the rig-up of the cementing string until tagging of hard TOC.

Table 1 summarizes the baseline data from which the performance of the technology initiatives would be measured. It shows that on current practices, the rig operations can only perform two cement plugs a day at best and together with the estimated number of cement plugs, on the average the rig will lose 108.8hrs per well.

Table 1 Offset Wells: Cement plugs in Shallow Loss Zones result in ~106 hrs lost per well.

Well	No. of Cement Plugs
Well 1	8
Well 2	8
Well 3	8
Well 4	22
Well 5	3
Well 6	3
Well 7	3
Well 8	3
Well 9	18
Well 10	5
Well 11	5
Ave. #CP per well	**~ 8**
Job Time per CP, hrs	13.6
Rig time lost per well, hrs	108.8

3. CEMENT SLURRY DESIGNS

The main objectives of the project can be summarized in two parts: (1) decrease the cement turnaround time in between plugs and (2) reduce the number of cement plugs, if possible. The most obvious approach is to revise the current slurry designs such that it will set fast and hard enough to isolate loss zones but still be safe enough to pump. However, with the Philippines being geographically isolated from the rest of the world and having very strict regulations for importing chemicals, it is a challenge to bring in specialty additives that may address the issues mentioned. Thus, the project team needed to come up with innovations in the slurry designs using chemicals typically used in a cementing job, and already available in the inventory.

3.1 Fast-set cement slurry design

3.1.1 Laboratory design development

For the first objective, a chemical additive known as an accelerator was added to the system to shorten the time for the cement to develop gel strength and compressive strength, thereby reducing the waiting on cement (WOC) time. The chosen accelerator was calcium chloride, ($CaCl_2$) as it is the most efficient, and cost-effective available accelerator. Depending on the wellbore depth and temperatures, the concentrations used for $CaCl_2$ can be between 0.5% and 3.0%. For shallow casing strings where temperatures are low (90°F-120°F), a concentration of 1.5%-2% by weight of cement (BWOC) is typically used. A high concentration or improper mixing of an accelerator into the system runs the risk of causing a pre-mature set of cement. Thus, a proper mixing and placement technique should be used when executing fast-set cement slurries. In addition, the slurry must be designed to be thick and viscous in order to slow down the flow of the slurry into the loss zone, thereby allowing more heat transfer to occur, effectively inducing the hardening of the cement so that it forms a bridge and is not just lost into the formation.

3.1.2 Fast Set Cement Plug Field Results

Presented in Table 2 are the results of the application of the fast-set cement slurry design. It did not give much improvement in reducing the number of cement plugs but it had the impact of shortening the turn-around time between cement plug jobs from greater than 13 hours to about 9 hours, thus reducing the lost rig time by 42% for this well. Though the efficiency of shorter WOC saved rig time, the methodology was still not able to address the significant number of CPs required to shut off the lost circulation.

Table 2 Fast-Set: Cement Plug Design results in a 42% improvement.

Particular	Base Offset Well	Actual Fast Set	% Improvement
No. of CP	8.00	7	13% ↑
Hrs/Job	13.6	9.04	34% ↑
Rig hours lost	108.8	63.28	42% ↑

3.2 Pseudo-thixotropic cement slurry design

3.2.1 Laboratory design

Learnings from the first well showed that the shallow loss zones are so aggressive that the flow restriction resulting from the thick, viscous slurry was still not enough to effectively create the initial bridge, and thus reduce the number of plugs. The next challenge was to design a system that would not only set fast but would develop gel strength even faster. This rapid gel-strength development enables the slurry to become self-supporting only minutes after cement placement, meaning that it should help form the initial bridging of the loss zone faster, thereby continuously narrowing the area to be cemented.

The pseudo-thixotropy properties cement slurry was developed using a solution of $CaCl_2$ and a Sodium Silicate (Na_2SiO_3) solution, both typically available at the field. The cement slurry was formulated to be thin while being mixed

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and pumped, but after pumping has stopped, the cement rapidly begins to form a gel structure and become self-supporting. The base-case temperature used for the thixotropic cement system Bottom Hole Static Temperature (BHST) and Bottom Hole Circulating Temperature (BHCT) is 90-100°F. The relatively low geothermal temperature results from the continuous pumping during losses, thus quenching the formation.

Depending on the loss rates, the pseudo-thixotropic cement plugs could be pumped and after sufficient WOC, the loss rate checked before pumping a subsequent cement plug or two thixotropic cement plugs could be pumped back-to-back (at least 30 min apart) without attempting the filling of the hole in-between.

Figure 2 shows the actual pictures of the laboratory set up when designing the system. Figure 3 shows that the thickening time to 70 Bc is designed to be greater than 90 mins to cover for pumping time with a safety factor. Figure 4 presents the compressive strength results, and it shows an initial set of 50 psi reached within 1-1/2 hrs and 500 psi is achieved in 4-6 hours.

Figure 2 Pseudo Thixo Cement Slurry - Laboratory Test pictures after 10min and after 20min

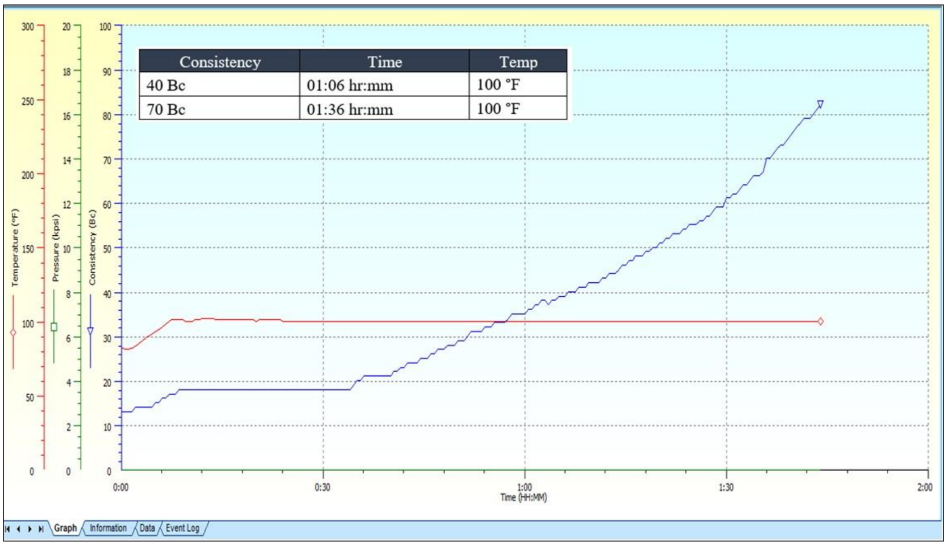

Figure 3 Pseudo-Thixo Thickening Time Chart showing 40BC design of 1:06 hrs

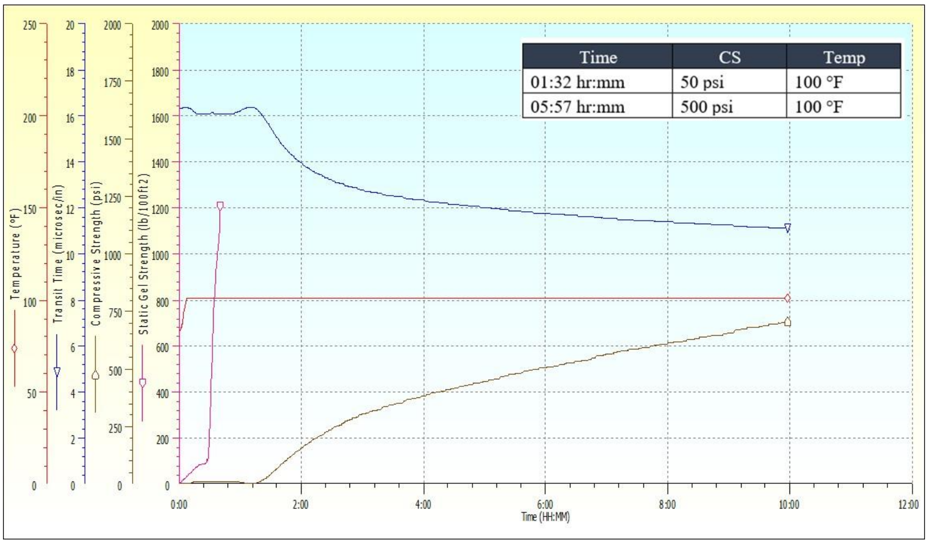

Figure 4 Pseudo-Thixo UCA Chart showing initial set in 1:32 hrs

<u>3.2.2 Pseudo-thixo Cement Plug Field Results</u>

Table 3 Pseudo Thixo: Cement Plug Design Results

Particular	Base Offset Well	Actual Pseudo Thixo	% Improvement
No. of CP	8.00	1	88% ↑
Hrs/Job	13.6	5.25	61% ↑
Rig hours lost	108.8	5.25	95% ↑

The slurry design was implemented with the high risk of potential pre-mature setting in mind and thus this slurry design is applicable for a total-loss scenario only. It assumes that the cement completely falls back into the loss zone after pumping. Adequate field personnel training and experience are necessary to pump this kind of slurry. Proper placement technique is required to ensure optimum effectivity. In this case, a mechanism to wipe the drill-pipe was put in place to prevent the occurrence of cement stringers inside drill-pipe.

Actual field reports show it takes samples about 30min to fully set and about 1 ½ - 2 hrs to completely harden. This had the impact of further shortening turnaround time between cement plug jobs from about 9 hours (from Well1) to about 5 hours due to the efficiency of a shorter WOC time. Also due to the behavior of the slurry, the number of cement plugs was greatly reduced since the cement is now setting near the wellbore only, just enough of a plug to combat losses while drilling ahead. Lost rig time dropped from 108.8 hrs to 5.25 hrs. Given the success in the cement slurry design, the team is now able to pursue other solutions not only to reduce CP but now to eliminate the need for one.

6. AERATED DRILLING IN SHALLOW SECTION

6.1 Aerated Drilling Technology and Its Uses

Aerated drilling is used in the geothermal industry for various reasons but with one overarching generic goal, that is to improve the overall cost performance of the well through cost reduction, drilling efficiency, or production improvement. As noted by Russell (1987), "the use of aerated fluids as the drilling medium for geothermal wells is one of the more successful techniques for overcoming drilling problems and improving production". The principal objective of the system is to lower the density of the drilling fluid through the introduction of air into the mud, such that the pressures in the annulus are reduced until they "balance" formation pressures at potential loss zones (Nas and Toralde, 2010). This gives the system the ability to induce or encourage returns and maintain circulation at the surface, which is beneficial for hole cleaning, and eliminates hole pack-offs due to intersection of additional loss zones while drilling. Other advantages include improving the rate of penetration, elimination of differential sticking, prevention of formation damage, and reduction in mud and water requirements from the reduction of losses (Russell, 1987; Rehm, 2002; UNU-GTP, 1992; Rizo and Cuenca 1984).

In PGPC, aerated drilling is employed in drilling the deep reservoir (depths >11,000ft) to aid in lifting cuttings at depth and distribute them to the upper loss zones. In the past 10 well campaign, 41 stuck-pipe events occurred with 6 of them not freed – the majority of which were associated with poor hole cleaning. In the present campaign where 9 were drilled in the same area as the previous one, only 3 minor stuck-pipe events occurred as of writing, all of which were freed immediately. The aerated drilling equipment package are all hooked up and personnel are on standby from the spud-in of well. There is little to no additional investment required and so this set-up presents an opportunity to potentially address shallow loss zones.

6.2. Application to Shallow Loss zones

A proper mud system is critical in ensuring the success of the drilling of a well – properties such as cuttings carrying index, proper hydraulics, filter cake formation, and others depend on the proper mixing of mud. The main viscosifier of the mud system is bentonite and it requires a certain amount of time to properly hydrate. This, coupled with the limited space capacity of mud tanks, dictate the amount of loss that the system can accept in order to keep up with mixing new mud. If losses are greater than the mixing mud capacity, cement plugs are necessary to control the losses and allow the operations to build up a new mud volume. Thus, in order to proceed with drilling and not stop for cement plugs, it is only necessary to reduce the losses to a level that is acceptable in terms of the rate of mixing of new mud, and this is where aerated drilling system can play a significant role. The primary objective of aerating the shallow sections is not to regain full circulation, but only to keep the losses to less than 500bph to keep up with mud mixing.

Aerating the shallow section does have some minor disadvantages such as low chance of having cement slurry returns during the primary cementing, performing top jobs although these can be done offline, and compromised casing cement integrity. So it should not be conducted for pressure containment casings without adequate planning for back up. On top of that, there are very few examples of the success of the method and it should be regarded as purely experimental at this stage.

6.2.1 Air injection Parameters

To properly identify the parameters needed to reduce losses and not pump so much air as to scour the formation, which could result to more pressing issues, the team modeled the system using aerated drilling software which was customised to be usable for geothermal applications. Among the more critical parameters considered in the simulation were:

- Mud properties
- Hole Temperature
- BHA and bit assembly
- Formation pressure
- Lithology

From this study, the team came up with recommended parameters for the rig operations to employ on the 26” and 17 ½” hole sections when losses are encountered. Parameters were monitored closely during execution. The models were subsequently calibrated based on actual pressure data obtained from drilling.

6.2.2. Aerated Drilling Tophole Section Actual Field Results

The team eliminated the need for cement plugs in the shallow section at the first attempt. The success was also repeated in various pads for the next eight (8) wells, even in areas where more than 20 plugs had been needed to arrest shallow loss zones. Tables 4 and 5 show the actual performance in combating the shallow loss zones for the 11-well campaign. Table 5 also shows the number of top jobs conducted per well.

Table 4 Aerated Top hole Actual Field Result

Particular	Base Offset Well	Actual Aerated	% Improvement
No. of CP	8.00	-	100% ↑
Hrs/Job	13.6	-	100% ↑
Rig hours lost	108.8	-	100% ↑

Table 5 Eleven Well Campaign Actual Plug results

Well	CP Technology	Offset Wells	Actual CPs	Actual TJs
Well 1	Fast Set	8	7	0
Well 2	Pseudo-Thixo	8	1	1
Well 3	Aerated	8	0	2
Well 4	Aerated	22	0	4
Well 5	Aerated	3	0	6
Well 6	Aerated	3	0	3
Well 7	Aerated	3	0	4
Well 8	Aerated	3	0	3
Well 9	Aerated	18	0	12
Well 10	Aerated	5	0	1
Well 11	Aerated	5	0	1

7. RESULTS, SENSITIVITY ANALYSIS, AND CONCLUSION

7.1 Cement Plug Performance of the Campaign

Figure 5 graphs the cement plug performance for this campaign. By the third well, all CPs were eliminated and more importantly, the success was repeated in all the subsequent wells. All in all, the team reduced the expected number of CPs from 86 to 8, accelerating the commercial online date for steam by 46 days giving the company additional revenue on top of the avoided cost due to cement plug operations. Table 6 summarizes all the computed savings. Sensitivity analysis on the foregone opportunity had the team stopped at different levels along the journey is presented in the next section. The biggest impact was felt with the introduction of the Pseudo-thixo cement slurry design, but air wiped out the NPT due to these surface losses and fast-tracked the online date for the wells.

7.2 Conclusion

Cement plugging in the shallow section was thought to be inevitable in any geothermal drilling project, but technological innovations and human creativity showed that this can be successfully eliminated. The team took this challenge with no expectations in mind, but to always take the solution process to the next level until the objective of eliminating the cement plugs was met. The initial objective was to develop a thicker and fast-set cement plug with refined temperature assumptions in order to improve on the cement job turnaround time. LCM was also added to the pre-flush to further slow the movement of the slurry by forming a preliminary bridge in the cracks – in an effort to reduce the number of cement plugs. Unfortunately, the LCM – fast-set design combination was only able to address the former but not so much the latter, and thus the mindset needed to be shifted to a more unconventional solution. The new mindset shifted from LCM-centric approach to accelerating cement gelation by developing a slurry with pseudo-thixotropic properties that quickly gelled up after pumping was stopped and also developed compressive strength quickly to further reduce waiting-on-cement time. Still, lost rig time is still lost investment, not to mention the delay due to requiring a cement plug is a delay on the online date of the production well. Together, they form an important reason to further push to eliminate the need for cement plugs and the opportunity presented itself by utilizing aeration, a technology that is readily available at the rig site.

One of the key findings in this project is that though one can improve current practices by tightening requirements, ensuring proper execution, and refining assumptions, technology still provides the highest improvement opportunity.

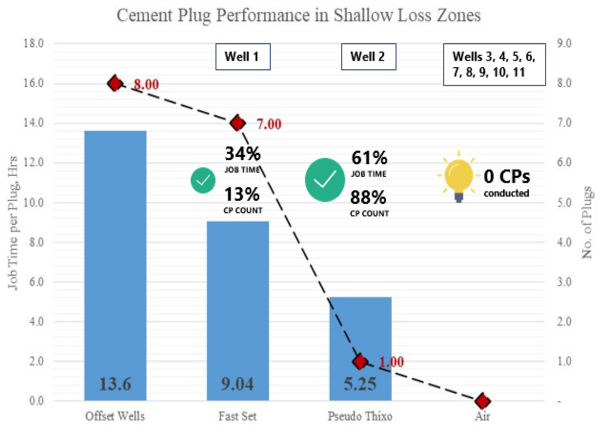

Figure 5 Cement Plug was completely eliminated by Well 3 and was sustained for the whole campaign

Table 6 Actual Cement Performance

Well	CP Technology	Offset Wells	Actual CPs
Well 1	Fast Set	8	7
Well 2	Pseudo-Thixo	8	1
Well 3	Aerated	8	0
Well 4	Aerated	22	0
Well 5	Aerated	3	0
Well 6	Aerated	3	0
Well 7	Aerated	3	0
Well 8	Aerated	3	0
Well 9	Aerated	18	0
Well 10	Aerated	5	0
Well 11	Aerated	4	0
		Baseline	Actual
	Cement Plug Count	86	8
	Lost rig time, days	49 days	2.9 days

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