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Evaluation of Lost Circulation Mechanisms and Solutions in Geothermal Drilling Field Ulubelu Hole Traject 17.5”

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ABSTRACT

Ulubelu field geothermal system is water dominated with reservoir temperature ranges from 250°C to 260°C. The main drilling target is reservoir target with depth respectively 1250 mMD / 1250 mTVD; 1500 mMD / 1500 mTVD dan 1800 mMD / 1800 mTVD. Typical rock types in geothermal reservoirs include granite, granodiorite, quartzite, greywacke, basalt, and volcanic tuff. One of the problems that is often found in geothermal drilling is loss of circulation, where the drilling fluid is lost into the pores or fractures in the drilled rock formation. The material and rig operating costs caused by these problems often account for a quarter or more of the total drilling costs. At non produced intervals, the circulation lost zone must be closed so that the borehole can be casing and cemented to the surface. The placement of lost circulation material (LCM) is quite difficult because the depth of the top and bottom of the lost circulation zone is unknown. LCM or cement used to cover the lost circulation zone often moves from the targeted zone to another lost circulation zone as drilling continues. In the Ulubelu field, the most problematic zone was found on the 17.5 " hole route with depth intervals of 1117 m to 1239 m, and cementing was carried out eleven times to overcome this problem.in geothermal drilling, fractures occurred in the hole is unpredictable, whether it is continuous or limited. Diaseal-M represents high solid and high filtrate that is effective in a limited number of fractured, so as to give space for Diaseal-M forming such a plug cake in the fracture. However, in geothermal drilling, fractures occurred in the hole is unpredictable, whether it is continuous or limited. To find out big or small the fracture in the hole is, it can be indicated by the magnitude of rate loss occured. If partial loss found to be 0-2 bpm, the possibility of fracture found is small. So it is effective to spot Diaseal-MAt the time of pumping and squeezing Diaseal-M, it should be better to utilize cementing unit, because it is more effective in controlling pressure rate. In terms of cost consideration needed for Diaseal-M and cement plug activity, there is no significant difference. However, in terms of time, Diaseal-M is more effective, because it can be pumped using drilling bit assembly, so that it doesn’t spend so much time to replace BHA assembly with OEDP assembly.

1. INTRODUCTION

1.1. Background

Based on the analysis of surface and sub-surface geology data exist, the geothermal conceptual model in Ulubelu area can be described as follows. Geothermal prospect of Ulubelu area is geologically associated with graben pattern aiming to northwest-southeast, in line with a major geological fault of Sumatera island (Semangko fault pattern). Ulubelu field geothermal system is water dominated with reservoir temperature ranges from 250°C to 260°C. The main drilling target is reservoir target with depth respectively 1250 mMD / 1250 mTVD; 1500 mMD / 1500 mTVD dan 1800 mMD / 1800 mTVD.

Typical rock types in geothermal reservoirs include granite, granodiorite, quartzite, greywacke, basalt, and volcanic tuff. Compared to the sedimentary formations of most oil/gas reservoirs, geothermal formations are, by definition:

a. Hot (production intervals from 160°C to above 300°C)
b. Often hard (240+ mpa compressive strength), abrasive (quartz content above 50%)
c. Highly fractured (fracture apertures of centimeters)
d. Underpressured
e. Often contain corrosive fluids
f. Some formation fluids have very high solids content

From those conditions mean that drilling is usually difficult, with problems that include:

a. Rate of penetration and bit life are typically low.
b. Corrosion is often a problem.
c. Lost circulation is frequent and severe.
d. These problems are often compounded by high temperature.

Lost circulation and reservoir damage deserve special mention. Lost circulation is often massive and complete loss of returns at pumping rates of hundreds of barrels per hour is common. Geothermal wells have been abandoned because of the inability to drill through a loss zone and many more have needed an unplanned string of casing to seal off a problem interval. Lost circulation treatment is complicated by the requirement that the treatment not damage the producing formation, and this distinction is often difficult.

Lost circulation material (LCM) is sometimes effective, but often fails because losses are through fractures with apertures of several centimeters so that the LCM particles are not large enough to bridge the loss zone. If zones with fractures must be sealed, cement is usually the treatment of choice but is hard to place accurately. It is much more important to repair loss zones where casing will later be set than in production intervals. Time and materials for lost circulation treatment can represent 15% of well cost, and the underpressured formation aggravates pipe sticking, so these can be major impacts on drilling cost.

The magnitude of the problem prompted the initiation of an investigation of the various aspects of lost circulation. Combating lost circulation can be approached in different ways:

a. Drill ahead with lost circulation.

b. Drill with a lightweight drilling fluid that will have a static head less than pore pressure in the formation.

c. Mix the drilling fluid with fibrous material or particles that will plug the loss apertures in the formation.

d. Or pause in the drilling and try to seal the loss zones with some material that can be drilled out as the hole advances.

Combating lost circulation in Well X Ulubelu field is conducted by pumping lost circulation material, in this case utilizing diesel-M, and plug cementing. By evaluating the result, it can be compared which one is more optimum between pumping plug cement, or diesel-M. In addition, it is possible to decide when it is needed to use diesel-M or plug cementing. The objectives of this paper are to present the results of the investigation to stimulate interest and discussion. Limitation of this paper is focused only on lost circulation mechanism and solution encountered in 17.5" hole traject.

1.2. Lost Circulation

Modern drilling methods rely on drilling fluid, or mud to lubricate the cutting surface, cool the bit, return cuttings to the surface, and maintain proper hydrostatic pressure against the formation. In geothermal wells, drilling mud is typically used above reservoir formations, which are then cased. Once steam begins to enter the wellbore, drillers typically drill pneumatically (i.e., with air) rather than with fluid, which reduces bit life and slows drilling.

In areas above the reservoir where drilling fluids are used, this fluid may be lost in fractured, cavernous, or high-permeability formations; this is known as "lost circulation" or "lost returns." When a portion of the mud pumped down hole is returned to the surface, losses are said to be partial. The industry defines losses of less than 25 barrels per hour (BPH) as "seepage," losses of 25 to 100 BPH as "partial," and losses of more than 100 BPH as "severe."

When no mud returns to the surface through the annulus, losses are said to be "total." Typically, drilling cannot continue through total losses unless near the next casing point. If only 50 feet of depth must be attained before the next casing string is to be run, drilling will often continue while continuing to pump drilling fluids, even though the fluid will not return. The challenge is that there is no hydrostatic pressure control and cuttings are transported to an unknown downhole location. This acceptable length varies by driller and well. Circulation may also be lost through significantly overbalanced drilling (OBD). This is when the pressure of the drilling fluid in the wellbore (annular pressure) significantly exceeds the formation fluid pressure, causing fluid to be pushed into the formation. For this reason, mud characteristics (e.g., density, viscosity) must be closely monitored and adjusted as formation pressure changes.

When circulation losses are encountered, drillers have used several responsive actions. Primarily, the driller focuses on maintaining downhole pressure by continuing to pump fluid down the hole. If this is unsuccessful and the annular pressure drops below the formation pressure, a "kick" could occur, where formation fluid enters the wellbore uncontrollably. If left uncorrected, a kick may lead to a dangerous blowout. Other actions include attempting to seal the LC zone or altering mud parameters to drill under-balanced. Underbalanced drilling is using a mud weight lower than formation pressure to minimize the risk of fracture propagation and circulation loss. Although this may tend to decreases ROP, this technique saves time if used in appropriate situations.

1.3. Importance of Lost Circulation Miti-gation Success in Geothermal Drilling

Two important distinctions between geothermal drilling and oil and gas drilling relevant to the LC discussion are the difference in formations begin drilled and the completion of the wells. First, oil and gas wells are typically drilled in sedimentary rocks where lost circulation can be mitigated more easily than in the cavernous hard rocks typical of geothermal systems. Second, oil and gas wells are typically only cemented in the top and bottom portions of the well, and produce through tubing rather than the well casing. Therefore, the zones of lost circulation encountered while drilling do not need to be cemented during well construction. Drilling through LC zones can be done without later ramifications.

Geothermal wells, however, are cemented the entire length of the well because the hot geothermal fluids will heat the casing during production. If only the top and bottom portions of a geothermal well were cemented, the hot production fluids could cause the middle section of the casing to expand and buckle. Alternatively, if mud is trapped in the annulus, it too could heat and expand, causing the internal casing to collapse. Thus, to prevent casing failure during production, geothermal wells are typically cased for the entire length of the well.

Therefore, addressing LC events during geothermal drilling becomes much more important than in oil and gas drilling. Trying to cement a well with LC zones becomes difficult because cement will be lost in these zones. Rather than completing cement jobs through the bottom shoe, drillers may have to resort to "top jobs"—placing cement from the top down—and/or perforating the well and squeezing cement into the annulus through the wellbore to fill open zones. Both of these methods add cost and are less successful at completing a solid cement job than the traditional bottom-hole cementing method. Addressing LC during geothermal drilling becomes critical to reducing the cost of well construction and cementing and to increasing the integrity of the well.

1.4. Lost Circulation Mitigation

To solve partial losses, LC material (LCM) may be mixed into the circulating drilling fluid. The purpose of LCM is to block pores and fractures in the formation, sealing the wellbore and preventing fluids from flowing into the formation. For this purpose, LC materials often contain platelets, fibers, or polymers (Brandl, 2011). LCMs are relatively inexpensive and can be circulated and applied quickly (in under an hour). Wells analyzed for this study used paper, cottonseed hulls, nutshells, and calcium carbonate among other materials as LCM. LCM may also be mixed into the mud as a preventative measure if a fractured or highly permeable formation is predicted. This technique, known as wellbore strengthening, can prevent or reduce losses while drilling and allows a wider range of mud weights. While drilling, mud weight must remain in a particular "window" above the pore pressure and below the fracture pressure. If the mud weight dips below the pore pressure, the driller risks a kick, where formation fluid flows into the wellbore. Conversely, if the mud weight is above the fracture pressure, known as overbalanced drilling, the hydrostatic pressure of the formation is not high enough to prevent fluid infiltration and circulation losses. The purpose of wellbore strengthening is to increase the fracture pressure of the formation, allowing for a greater range of mud weights and reducing the risk of fracture propagation. However, wellbore strengthening allows higher mud weights to be used in zones of suspected fluid loss.

Alternatively, LCM "pills" are applicable for larger fractures or more severe losses. These pills, which consist of specialized LCM intended to expand once placed in a fractured zone, ideally result in bridged/sealed fractures within two hours of placement. Pills are not intended to be suspended material in the drilling fluid, but are spotted downhole through the drill string and then squeezed into a severe loss zone, where they must be allowed to expand and set.

When the formation is cavernous rather than fractured, or when total losses are encountered, a more time-consuming cement plug is usually placed to mitigate losses. Balanced cement plugs are the most commonly placed type of plug. The balanced nature of the plug requires that calculations be made to assure that the cement level inside of the drill string is equal in height to that in the annulus. The drill string must be pulled from the hole and a cement-plug-specific bottom-hole assembly must be connected. Once set up, the drill string and bottom-hole assembly is tripped back into the hole and the cement plug is set across the LC zone until fluid levels are equal and hydrostatically balanced. The drill string is then slowly pulled out once more and the cement is allowed to set. This technique is shown in figure 1. The height of cement column outside the drill string is equal with the height of the cement column inside of the string. Once set, the plug is drilled through and wiped clean to prepare for further drilling. Plugs are usually in the range of 50 to 150 feet in length and take around 20 hours from the start of tripping out the drill string to the completion of drilling through the plug. If the formation causing losses is continuous beyond this length, cement plugs may be set consecutively.

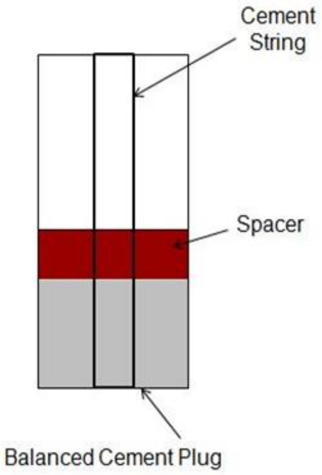

Figure 1: A balanced cement plug

The goal of LCM, pills, and cement plugs is to either reduce or mitigate LC while drilling. These strategies are typically employed for partial, severe, and total losses and are considered "successful" if losses are reduced to less than 25 BPH (i.e., if losses are reduced to seepage losses). If losses are initially only seepage, then success is considered mitigating all losses. If losses are initially minimal, drillers may try to "drill through" or mitigate using less-expensive LCMs. Drilling through the zone is possible because cuttings help to seal loss zones caused by pores or small fractures. If unsuccessful, or for severe or total losses, drillers will then typically use cement plugs. Generally, these mitigation methods are only seen in the surface and intermediate drill sections because circulation loss in the production zone is required. LCM, pills, and cement are rarely used below a depth of 8,000 feet.

2. METHODOLOGY

2.1. Data Collection

To evaluate the mechanism of lost circulation occurred in the 17.5" hole traject and the solution taken to overcome the problems, several of drilling prognosis and drilling report of the observed well must be known, especially when drilling 17.5" hole traject, such as rock lithology of previous well, lost circulation zone prediction based from offset well, plug cement job program, mud loss summary, diesel-M standard operating procedure and resume. From rock lithology, the potential and hazard zone can be recognized. In addition, well correlation information will be needed to detect which interval zone that suffered problem the most. Operation summary could be so much help to decide what action should be taken to deal with problems. According to some data collected, the most troublesome zone was encountered in the 17.5" hole traject, which dominantly is major loss circulation zone, and pipe stuck area. Some previous wells must be sidetracked to reach total depth, and even abandoned. So the only ways practicable motsly in all geothermal field to deal with the problems were accomplished through plug cementing job and pumping LCM. Somehow, there are some conditions which one is effectively performed against the problem, and it can be achieved through field experiences. The evaluation performed in this study was based upon the data taken from well X which is a vertical injection well. A flow chart is modelled to explain the workflow of lost circulation evaluation in simple form as follows.

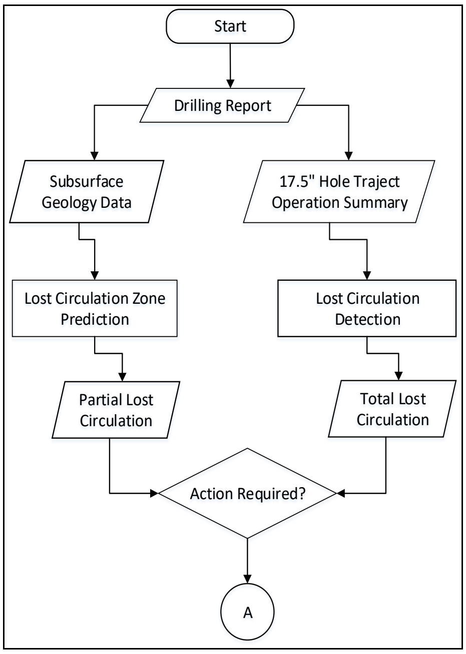

Figure 2: Lost Circulation Evaluation

Flowchart Part 1

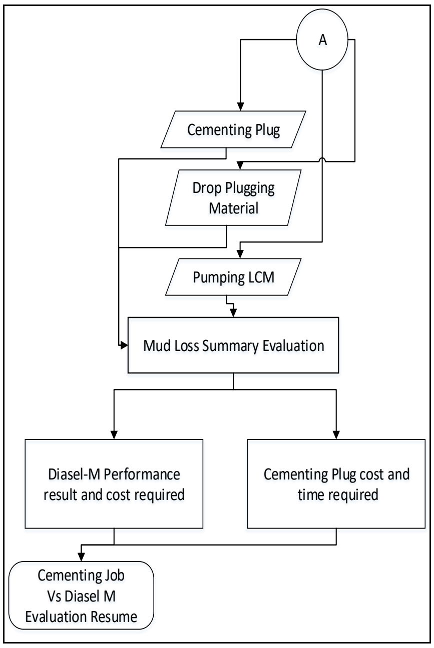

Figure 3: Lost Circulation Evaluation Flowchart Part 2

2.2. Data Analysis

Total drilling time required to drill 17.5” hole traject is 868.5 hours with total productive time is 112 hours and the rest is nonproductive time (NPT). For the purpose of this study, NPT was defined as any activity that did not show progress progress in well depth (any activity other than drilling). Conversely, productive time was a sum of the time periods for which actual drilling occurred. The distribution time of drilling activity is presented by a pie chart in figure 4.

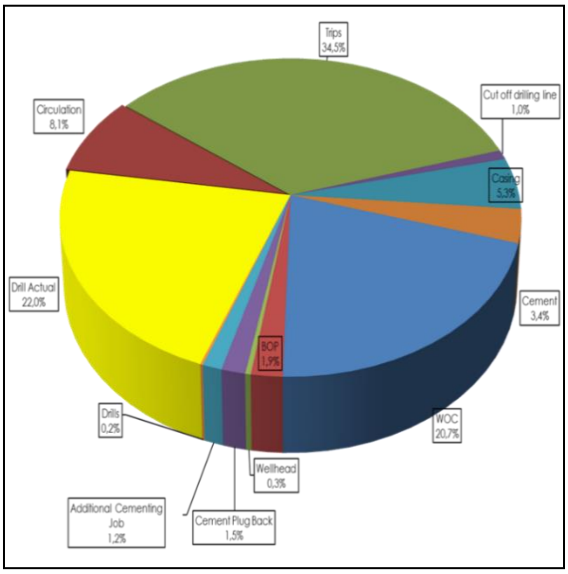

Figure 4: Drilling Time Activity Distribution

Cementing plug job sequences contribute to the most of non-productive time. It consumed 13 hours for cement plug job, 104.5 hours for tripping open end, running tool and running stinger, and 182.5 hours for waiting on cement which is the most consuming time. Therefore, lost circulation problem should be mitigated successfully and effectively.

Based on subsurface geology data and well correlation with offset well, lithology prediction found in the well X is as shown in the table 1. In addition, lost circulation zones which were predicted based on offset wells in a single cluster are presented in the table 2. According to those data, 17.5” hole interval traject is dominated with breccia rock, pyroclastic breccia rock and andesit with black clay interbed. Drilling hazard that potentially found is partial lost circulation, collapse formation, and stuck pipe. Moreover, indication of lost circulation problem can be observed through drilling parameters. The most accurate indication of lost circulation are mud level in the tanks and stand pipe pressure. Both of them would be dropped if lost circulation was occurred. Figure 5 shows the drilling parameter when drilling 17.5” depth interval. It can be figured out that there is a correlation between lost circulation prediction and drilling parameters as penetrating the potential interval, stand pipe pressure decreased.

Table 1. Lithology Prediction of Well X

Measure Depth (m)	Litholgy	Hardness
0-500	predominant pyroclastic breccia (tuff and andesit)	Moderate
500-1200	predominant pyroclastic breccia and andesit with black clay interbed	soft-hard
1200-2000	predominant pyroclastic breccia	Moderate-hard

Table 2. Lost Circulation Zone Prediction of Well X

Depth Prediction		Loss Type	Loss Rate (bpm)
Measure Depth (m)	TVD (m)		
800-1100	800-1100	PLC	0.1-1
1100-1200	1100-1200	PLC	1-10
1200-2000	1200-2000	TLC	>20

Table 3. Drilling Hazard Prediction of Well X

Depth Prediction		Permea-bility Control	Drilling Problem
Measure Depth (m)	TVD (m)		
800-1100	800-1100	Fractured andesit and pyroclastic	Black clay, stuck pipe
1100-1200	1100-1200	Fractured andesit and pyroclastic	Collapse Formation and pipe stuck
1200-2000	1200-2000	Fault zone	Collapse formation and pipe stuck

Drilling hazards that are probably encountered when drilling 17.5” hole traject interval are collapse formation and pipe stuck. Based upon drilling history of two previous offset wells, one of them must be sidetracked twice because of partial lost circulation and pipe stuck problem that got worse. Beside lost circulation, pipe stuck problem may be developed, so the mitigation of lost circulation problem is critical in the geothermal drilling operation.

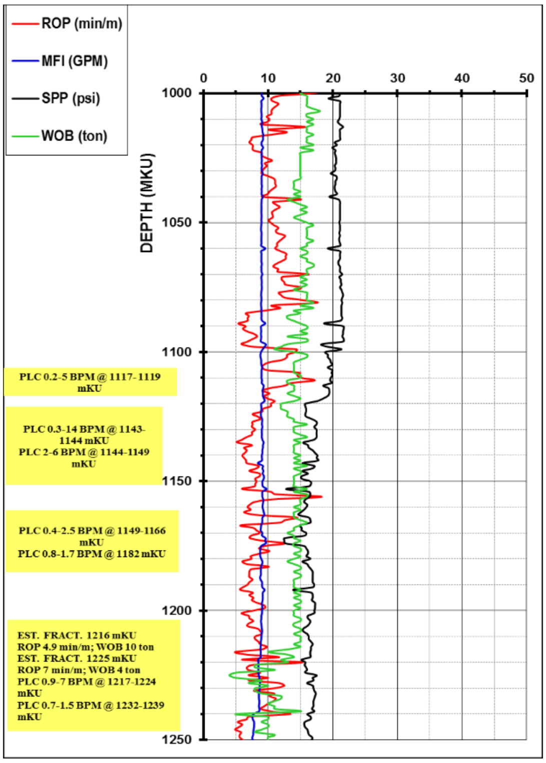

Figure 5: Drilling Parameter 17.5” Hole Traject Depth Interval 1000-1250 m

2.3. Diaseal-M SOP and Spot Job

Diasel M LCM is a highly effective, high-solids, high-fluid-loss lost circulation squeeze material. A solid plug is formed in the thief formation when water or oil is squeezed from the slurry. Diaseal M LCM creates a seal in the loss zone, not in the wellbore like conventional LCM. The seal cannot be easily disrupted by circulation or drill pipe movement. The illustration of how diaseal-M works can be seen in the figure 6.

Diaseal-M differs from other types of lost circulation materials (LCM), in that it forms a solid plug within the loss zone, rather than remaining at or near the face of the wellbore. This minimizes the possibility of the seal being removed during drilling operations, and thereby necessitating repeated remedial loss treatments of the same zone. Solving the loss problem as soon as possible after its occurrence, prevents excessive volumes of mud from entering the formation, and further propagation of fractures which may compound the loss problem. There are two key factors to obtaining a successful Diaseal M squeeze: First, a slurry with an extremely high solids content and high fluid loss must be prepared. Then, it must be placed at the proper location in the wellbore so that it can do its job.

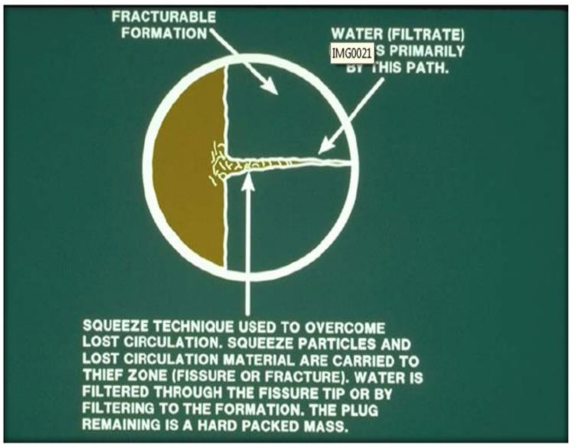

Figure 6: Diaseal-M Workings Illustration

Diaseal-M squeeze procedure are as follows.

a. Mix twice the open hole volume, or a minimum of 100 bbls. (16 m3) slurry for longer open hole intervals. Ideally enough slurry should be available to cover all potential loss zones, as well as to have excess volume available for squeezing operations.

b. No special equipment is needed to pump unweighted Diaseal M® slurries. The unweighted slurry can be mixed in a clean, uncontaminated mud pit and pumped with rig pumps. The operators should consider using a cement company blender and pump truck to place weighted Diaseal M® slurries of over 12 ppg. This gives better control of squeeze pressure and avoids contamination.

c. Begin with approximately 80% of the prescribed.volume of fluid, (oil or water as per Table 1 or 2). To the fluid, add Diaseal- M barite, and then the remainder of fluid. Follow this with additional LCM as required or desired.

d. lf building a weighted slurry, it should be weighted to the same density as the drilling mud in use.

e. Some additional LCM in the slurry will often be beneficial. From 5-20 ppb (14-57 kg/m3) total LCM can be added depending upon conditions. Place slurry openended if possible. If placing through bit, avoid excessive concentrations, and use LCM smaller than nozzle sizes to avoid plugging. Use combination of fine-medium LCM, and avoid too much fibrous materials.

f. Place bottom of drill pipe or bit at depth that will allow an equivalent of the calculated open-hole volume to remain inside the casing above the casing shoe.

g. Pump slurry at 2 bbls./min. (bpm) until it reaches the end of the pipe. Before beginning the hesitation squeeze, check the annulus. If no fluid can be seen, use the fill-up line and fill the hole.

h. Close annular bop, and pump slurry at 1 bpm. This will direct the Diaseal M slurry downhole to the point of loss. Pump the full open hole volume, plus an additional 20-30 bbls. (3-5 m3), leaving remainder of slurry in the casing.

i. Begin pumping again at 1/4 to 1/2 bpm. When a pressure of 50 psi is obtained, discontinue pumping for 10-15 minutes. Repeat this procedure until 50 psi can be maintained, and then attempt at progressively higher pressures in 25-50 psi increments. With this hesitation squeeze" method, (see Figure 7), there will be a pressure bleedoff each time the pump is stopped. However, with each successive squeeze, the pressure should stabilize at a higher level.

j. A 200-600 psi squeeze is generally considered to be very good, but it may be advisable to squeeze to a higher equivalent mud weight if it is known that a higher fluid density will be needed in this hole interval. When maximum holding pressure is obtained, shut down for two hours.

k. Bleed the pressure from the annulus slowly, and then circulate the water, and remaining Diaseal M® out of the hole

l. Run the drill pipe back into the hole slowly, monitoring the weight indicator, and checking for bridges. Wash to bottom, drilling any Diaseal M® plug if encountered. The Diaseal M® will not set up like cement, so there is no danger of sidetracking the hole. Any remaining Diaseal M® may be retained in the drilling fluid.

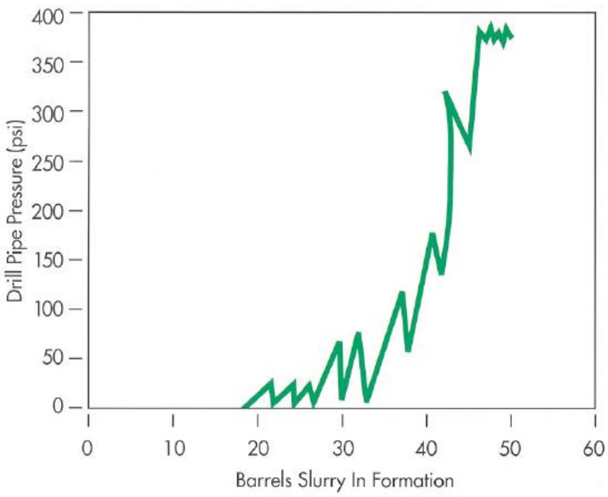

Figure 7: Hesitation Squeeze Profile6

FOMULA FOR PREPAIRING ONE BARREL DIASEAL M® LCM SLURRY WITH FRESH OR SEA WATER

Density lb/gal	Diaseal M® LCM lb	Diaseal M® LCM sacks	Barite sacks	Water bbl
9.0 ppg	50 ppb	1.25 sacks	0.0 sacks	0.93 bbl
10.0 ppg	50 ppb	1.25 sacks	0.6 sacks	0.89 bbl
11.0 ppg	47 ppb	1.18 sacks	1.2 sacks	0.86 bbl
12.0 ppg	42 ppb	1.05 sacks	1.8 sacks	0.82 bbl
13.0 ppg	39 ppb	0.98 sacks	2.3 sacks	0.79 bbl
14.0 ppg	35 ppb	0.88 sacks	2.9 sacks	0.76 bbl
15.0 ppg	31 ppb	0.78 sacks	3.5 sacks	0.72 bbl
16.0 ppg	28 ppb	0.70 sacks	4.0 sacks	0.69 bbl
17.0 ppg	25 ppb	0.63 sacks	4.6 sacks	0.66 bbl
18.0 ppg	22 ppb	0.55 sacks	5.2 sacks	0.62 bbl
19.0 ppg	17 ppb	0.43 sacks	5.8 sacks	0.59 bbl

Note: If saturated salt water is used, decrease barite by 0.6 sacks per barrel
If nut plug is used, subtract 0.12 bbl of water from table for each sack used

Figure 8: Diaseal-M Slurry Formulations6

2.4. Cementing Plug Job Program

Cementing plug method has been discussed in previous chapter. However, evaluating cementing plug job needs more brief explanation and concept to calculate cementing plug program. Type of cementing plug usually used to overcome lost circulation problem is balanced cement plug. Somehow, to perform balanced cement plug, every service company has their own standard job sequences procedure as follows.

a. Rig up cementing line at the rig floor
b. Hold-pre-job safety meeting (PJSM) and perform job safety analysis (JSA)
c. Flush cement lines 2 bbl
d. Pressure test cement line up to 2000 psi and hold for 5 minutes.
e. Pump water ahead with slow pump rate
f. Mix and pump cement slurry
g. Pump water behind
h. Displace with mud
i. Bleed off the line and check return to the cementing unit
j. Squeeze job with maximum pressure 300 psi
k. End of cement and wait on cement (WOC).

Mixing cement slurry would require the concentration of each additive and fresh water. Those data are provided by service company from test laboratory. For cementing plug 17.5” open hole, the slurry recipe is presented in table 4. The slurry composition is as follows.

- Slurry density is 14 ppg
- Yield of cement is 2.32 ft3/sack/sk
- Mixxing fluid is 12.172 gal/sk
- Slurry type is conventional
- Sack reference is 94 lb of cement

In addition, identification of lost zone depth should be detected and the height of cement must be estimated to calculate cement slurry volume that should be pumped. In this case, illustration is given to better understanding in figure 9. Mixing order for 17.5” hole traject cement slurry is water + D047 + D153 + D155 + D145A + D081 + Blend (G Cement + D066). Explanation for each code of additives will be mentioned in table 4.

Table 4. 17.5” OH Cementing Plug Recipe

Code	Concentration	Component
Fresh Water	8.789 gal/sk	Base Fluid
D047	0.010 gal/sk	Antifoam
D153	0.3% BWOC	Antisettling
D155	3 gal/sk	Extender
D193	0.2 gal/sk	Fluid Loss
D145A	0.02 gal/sk	Dispersant
D081	0.140 gal/sk	Retarder

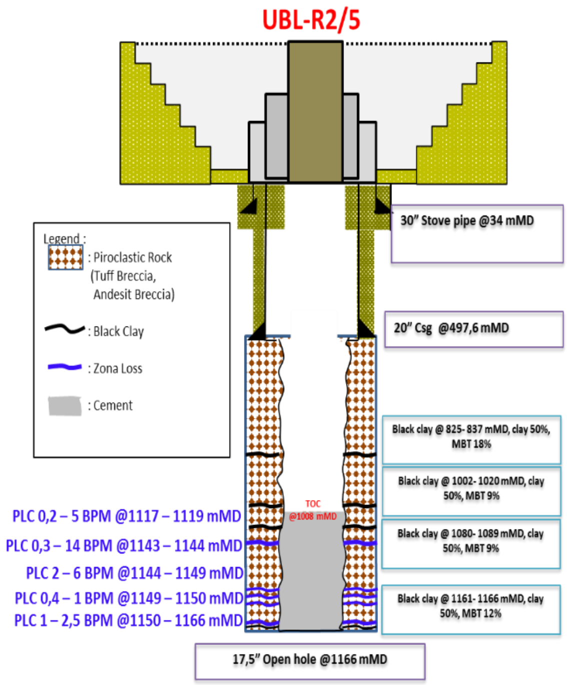

Figure 9: Cement Plug Job Illustration7

The steps to calculate cement slurry needed is as follows.
1. Determine volume of cement that is needed.

$OHc = OHd^2 : 1029.4$ (1)

$Vc = Lc \times OHc$ (2)

2. Determine height of cement and spacer when pipe in hole.

$OEDPc = IDdp^2 : 1029.4$ (3)

$Ac = OHd^2 – ODdp^2$ (4)

$Lc\ w/pipe = Vc : (DPc + Ac)$ (5)

$TOC = MD – Lc\ w/pipe$ (6)

3. Determine displace volume to balance the hydrostatic both sides. When the displacement is completed, it should have equal height of cement/spacer/mud.

$Vs_1 = Ac \times La_1$ (7)

$Ls_1 = Vs_1 : Ac$ (8)

$Vs_2 = DPc \times Ls_1$ (9)

4. Determine volume of mud displacement

$Vds = DPc \times L_d$ (10)

5. Calculate initial sack of cement required

$Sc = Vi \times 5.6146 / Sv$ (11)

6. Calculate volume of mixing fluid

$Vm = (Si \times \text{mixing fluid} / 42) + Vd$ (12)

7. Calculate total sack of cement required

$St = (Vm \times 42) / \text{mixing fluid}$ (13)

8. Calculate volume of additives required

Volume of each additive = component of additive x prepared cement (14)

4. RESULTS

4.1. Spot Diaseal-M Job Procedure

1. Position the end of ROEDP inside casing to the top of slurry volume, where LCM volume is between bit and casing shoe. This is to prevent the string being stuck. If it is required to position in open hole, then the position of ROEDP is above loss zone.
2. Pump Diaseal-M slurry with rate 2-3 bpm, until the fluid is in the end of ROEDP (make sure the calculation of pump stroke). Before squeezing, check fluid level in the annulus. If the top of fluid is not found, pump until the annulus fully loaded.
3. Close BOP (pipe ram) and squeeze by pumping Diaseal-M with rate 1 bpm. So that it will lead Diaseal-M enter the loss zone. If the unweighted slurry is pumped, add 20-30 bbls.
4. Stop pumping and wait 2-3 hours for Diaseal-M getting dried. Pump again with rate 0.25 atau 0.5 bpm. After pressure reaches 50 psi, continue to pump 10-15 minutes. Repeat the procedure until pressure stable at 50 psi. Then, increase pressure 25-50 psi gradually.
5. 200-600 psi is enough for squeezing. If using pressure exceeds those value, it is required to know the highest density permitted (fracture gradient of formation) that can be used at interval depths (the limits of highest pressure before formation fracture). If maximum pressure has been reached and stable, stop pumping and wait reaction for 4-6 hours to convince that the slurry has been dried.

Note: 4 hours for unweighted slurry and 6 hours for weighted slurry.

6. After the reaction is done, bleed of pressure slowly from annulus and circulate Diaseal-M left in the hole.
7. Run in back the string slowly, check the fill, wash down or drill if seat found due to Diaseal-M plug. In drilling mud, it would likely be found the remains of Diaseal-M in drilling mud and act as seepage loss material.

4.2. Spot Diaseal-M Resume

- **Chronology**

Drill cement from 1203 m to 1218 m, circulate for hole conditioning. Drill formation from depth 1218 m to 1224 m and PLC 7-15 bpm occurred intermittent. Pull out string to 1095 m. Mixing 100 bbls Diaseal 50 ppb. Run in hole string to 1223 m and spot 100 bbls Diaseal-M 50 ppb, then displace with 66 ppb of mud. When pull out bit 17.5" over pull occurred until 11 T at 1214 m depth.

- **Spot Diaseal-M Job**

1. Pull out 17.5" bit RR#5 + BHA#9 steerable assembly from 1224 m to 1095 m (off bottom 129 m)
2. Mixing Diaseal-M 100 bbls with concentration 50 ppb, equivalent with 125 sack of Diaseal-M
3. Ream down 17.5" bit RR#5 + BHA#9 from 1095 m to 1224 mMD, flow 570 gpm, SPP 250 psi, RPM 61, torque 3 klbft, no return.
4. Spot 100 bbls Diaseal-M with 50 ppb at 1223 m, no return
5. Pull out bit RR#5 17.5" + BHA#9 from 1223 m to 1066 m. Normal pull 1223 – 1214 mMD, overpull 11T at 1214 mMD. Back ream from 1214 – 1066 mMD.
6. Wait reaction of Diaseal-M while observing static loss at 1066 m, after filling the hole 126 bbls.

- **Spot Diaseal-M Job Results**

1. 1 hour after pulling the string and Diaseal-M in place, fill the hole for observing static loss and static loss 0.19 bpm is found and after 2 hours counted from Diaseal-M in place, static loss 0.08 bpm.
2. Run in hole string from 1076 m, observe dynamic loss flow 800 gpm, SPP 1360 psi, normal return flow (no loss).
3. Squeeze with rig pump (hesitate) with maximum pressure 300 psi, observe again for dynamic loss with flow 800 gpm, SPP 1360 psi, no loss.

4. Run in hole string 17.5” bit RR#5 + BHA#9 from depth 1076 – 1217 mMD, WOB 5 T, fill 7 m, circulate 800 gpm, SPP 1360 psi, RPM 51, torque 2 klbft. PLC 9 bpm was found again.

4.3. Cement Plug Resume

- **Capacities and Annular Data**

Table 5. Well Information

Data	Size	Unit
OD casing	20	inch
ID casing	18 3/4	inch
drill pipe OD	5	Inch
Drill pipe ID	4 2/7	Inch
Hole diameter	17 ½	Inch
Excess	-	%
Stick up	1	meter
Cap 20”csg – 5” DP	0.3165	bbl/ft
Cap 17.5” OH – 5”DP	0.2732	bbl/ft
Cap 20” csg	0.3408	bbl/ft
Cap 17.5” OH	0.2975	bbl/ft
Cap DP 5”	0.01776	bbl/ft

- **Cement Plug Job Program**

Tablel 6.1. Additives Concentration

Additive	Cement Plug #1	Cement Plug #2	Cement plug #3	cement plug #4
Water	8.763	8.742	8.742	8.742
Antifoam	0.010	0.010	0.010	0.010
Antisettling	0.150%	0.150%	0.150%	0.150%
Extender	3	3	3	3
Fluid loss	0.2	0.2	0.2	0.2
Dispersant	0.150	0.150	0.15	0.15
Retarder	0.080	0.060	0.06	0.05
Silica flour	40%	40%	40%	40%
accelerator	-	-	-	-
cement	-	-	-	-

Table 6.2. Additeves Concentration

Additive	Cement Plug #5	Cement Plug#6	Cement Plug #7	Cement Plug#8
Water	8.742	8.742	10.262	10.262
Antifoam	0.010	0.010	0.010	0.010
Antisettling	0.150%	0.150%	-	
Extender	3	3	0.05	0.05
Fluid loss	0.2	0,2	-	
Dispersant	0.150	0.150	-	
Retarder	0.50	0.50	0.05	0.05
Silica flour	40%	40%	40%	40%
accelerator	-	-	-	1%
cement	-	-	80	

Table 6.3. Additives Concentration

Additive	Cement Plug#9	Cement plug#10	Cement Plug#11
Water	10.262	10.262	10.262
Antifoam	0.010	0.01	0.01
Antisettling	-	-	-
Extender	0.05	0.05	0.05
Fluid loss	-	-	-
Dispersant	-	-	-
Retarder	0.05	0.05	0.05
Silica flour	40%	40%	40%
accelerator	1%	1%	1%
cement	80	80	-

Table 7. Spot Job Placement Program

Job	Depth (m)	OEDP (m)	Length of cement (m)	Length of water ahead (m)	Length of water behind (m)
Plug#1	1119	1118	52.38	33.47	33.47
Plug#2	1166	1165	83.80	33.47	33.47
Plug#3	1218	1217	83.80	33.47	33.47
Plug#4	1182-1199	1198	83.80	22.31	22.31
Plug#5	1187.3	1185	83.80	22.31	22.31
Plug#6	1218	1217	104.75	22.31	22.31
Plug#7	1224	1223	104.75	22.31	22.31
Plug#8	1239	1238	104.75	22.31	22.31
Plug#9	1222	1220	104.75	22.31	22.31
Plug#10	1220	1219	125.70	22.31	22.31
Plug#11	1215	1214	83.80	22.31	22.31

Table 8.1. Cement Slurry Mixing Requirements

Job	Density (ppg)	Yield (cuft/ sack)	Water needed (gps)	Mix fluid (gps)	Sack of cement
Plug#1	14	2.32	8.763	12.160	121
Plug#2	14	2.33	8.742	12.173	192.8
Plug#3	14	2.33	8.742	12.173	192.8
Plug#4	14	2.32	8.742	12.167	121

Table 8.2. Cement Slurry Mixing Requirements

Job	Density (ppg)	Yield (cuft/ sack)	Water Needed (gps)	Mix Fluid (gps)	Sack of cement
Plug#5	14	2.32	8.742	12.167	193.6
Plug#6	14	2.32	8.742	12.167	242
Plug#7	14	2.09	10.262	10.423	268.6
Plug#8	14	2.09	10.262	10.423	268.6
Plug#9	14	2.09	10.262	10.423	268.6
Plug#10	14	2.09	10.262	10.423	322.4
Plug#11	14	2.09	10.262	10.423	214.9

Table 9. Volume Required for Plug Job

Job	Mix Fluid vol (bbls)	Water ahead Vol (bbls)	Water Behind Vol (bbls)	Cement Vol (bbls)	Displace Vol (bbls)
Plug#1	40.03	30	2	50	60.5
Plug#2	65.9	30	2	80	61.4
Plug#3	65.9	30	2	80	64.4
Plug#4	40.01	20	1.3	50	65.3
Plug#5	66.1	20	1.3	80	62.7
Plug#6	70.1	20	1.3	100	63.4
Plug#7	66.7	20	1.3	100	65
Plug#8	76.7	20	1.3	100	64.6
Plug#9	76.7	20	1.3	100	64.8
Plug#10	90	20	1.3	120	64.5
Plug#11	63.3	20	1.3	80	64.2

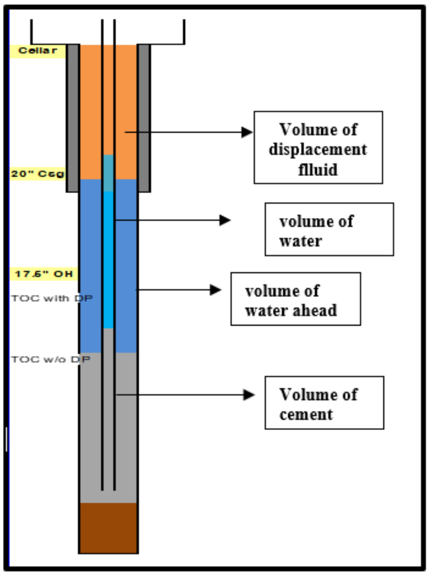

Figure 10. Illustration of Plug Cement

Table 10.1 Mud Lost Summary

Cement Plug 17.5" UBL-X			
Describtion	Depth (mMD)	Volume (bbls)	TOC Theory (mMD)
Plug#1	1119	50	1069
Plug#2	1166	80	1068
Plug#3	1218	80	1138
Plug#4	1198	50	1148
Plug#5	1187	80	1107
Plug#6	1218	100	1118
Plug#7	1224	80	1144
Plug#8	1239	100	1139
Plug#9	1221	80	1141
Plug#10	1220	80	1140
Plug#11	1214	80	1163

Table 10.2. Mud Lost Summary

Describtion	TOC Actual (mMD)	Volume in Hole (bbls)	Volume lost into formation (bbls)
Plug#1	1079	39.4	10.6
Plug#2	1108	59	21
Plug#3	1146	72	8
Plug#4	1187	12	38
Plug#5	1143	44	36
Plug#6	1208	10	90
Plug#7	1150	74	6
Plug#8	1221	18	82
Plug#9	1163	58	22
Plug#10	1215	5	75
Plug#11	1151	63	17

5. CONCLUSIONS

1. Diaseal-M represents high solid and high filtrate that is effective in a limited number of fractured, so as to give space for Diaseal-M forming such a plug cake in the fracture. However, in geothermal drilling, fractures occurred in the hole is unpredictable, whether it is continuous or limited. To find out big or small the fracture in the hole is, it can be indicated by the magnitude of rate lossoccured. If partial loss found to be 0-2 bpm, the possibility of fracture found is small. So it is effective to spot Diaseal-M
2. The procedure of spoting Diaseal-M conducted in ulubelu well X was not optimum because standard operating procedure used is not accordance with SOP from manufacture, which spot is done by way of spot LCM in common ways and the time for reaction to be done is quite short. Spot Diaseal-M as recommended is pumping slowly with rate 2-3 bpm, until fluid reaches at

the end of OEDP , and wait reaction for 2-3 hours. After that fill the annular until full and do hesitation squeeze with rate 0.5 bpm until stable pressure reached between 200-600 psi. Then wait for reaction again for about 4 hours. Position of string when pumping is only 1 meter above loss zone so that cause an over pull when pull out string of hole because of Diaseal-M which already started to dewatere or dehydrate. Recommendation from literature is that it should be positioned above loss or above top of Diaseal-M fluid according to calculation.

3. At the time of pumping and squeezing Diaseal-M, it should be better to utilize cementing unit, because it is more effective in controlling pressure rate.
4. In terms of cost consideration needed for Diaseal-M and cement plug activity, there is no significant difference. However, in terms of time, Diaseal-M is more effective, because it can be pumped using drilling bit assembly, so that it doesn't spend so much time to replace BHA assembly with OEDP assembly.

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Symbol List

OHc = open hole capacity (bbl/ft)
OHd = open hole diameter (inch)
Vc = volume of cement (bbl)
Lc = length of cement (ft)
OEDPc =nopen end dril pipe capacity (bbl/ft)
IDdp = inside diameter of drill pipe (inch)
Ac = annulus capacity (bbl/ft)
ODdp = outside diameter of drill pipe (inch)
DPc = drill pipe capacity (bbl/ft)
TOC = top of cement (ft)
MD = measure depth (ft)
Vs1 = volume of spacer ahead (bbl)
Vs2 = volume of spacer behind (bbl)
La1 = length of annulus filled with spacer ahead (ft)
Vds = volume of displacement fluid (bbl)
Ld = length of displacement fluid
Sc = initial sack of cement (sack)
Vi = volume of cement initial (bbl)
Sv = slurry volume (cuft/sack)
Vm = mixing volume (bbl)
Vd = dead volume (bbl)
St = total sack of cemen required (sack)