PROCEEDINGS, 42nd Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 13-15, 2017
SGP-TR-212

Problem Mitigation in Geothermal Drilling,

Case Studies of Stuck Pipe and Lost Circulation

Wisnu A. Nugroho, Satria Hermawan, Brian H. Lazuardi

Graha PDSI, Jl. Matraman Raya No. 86 Jakarta, Indonesia

Wisnu.nugroho@pertamina.com, satria.hermawan@pertamina.com, brian.lazuardi@pertamina.com

Keywords: Geothermal, Stuck Pipe, Lost Circulation, Aerated drilling

ABSTRACT

Geothermal energy is one of fast growing renewables resource in the world. Demand for renewable resources leads to increase of geothermal drilling activities. Well cost contributes up to 40 % of total geothermal project cost. Drilling in geothermal faced many challenges due to its natural characteristics. The most common problems are lost circulation and pipe stuck. Highly fractured zone is the ideal spot for geothermal production. Lost circulation is common in highly fractured formation. Stuck pipe is another problem. Stuck pipe can lead to extra cost of lost-in-hole and fishing operation. Water played an important role in geothermal drilling, not only to keep the wellbore pressure but also to cool down the temperature.

This paper shows some severe cases of lost circulation and pipe stuck in geothermal drilling. All of the data are taken from geothermal drilling projects in Indonesia. The cases of lost circulation can be divided into two major type based on the location, shallow and deep lost circulation. Each has different technique to overcome lost circulation. Two cases in pipe stuck presented in this paper are the most severe incidents in geothermal project in Indonesia. Underbalanced drilling was a common application in highly fractured and subnormal pressured formation as found in geothermal. Both cases performed underbalanced drilling prior to stuck pipe incident. This paper evaluates gas-liquid flow rate based on Guo and Ghalambor (2002) criterion.

1. INTRODUCTION

1.1. Geothermal Resources

Geothermal Energy is one of renewable source of energy. Geothermal resources are widely found in Circum-Pacific and Northern Atlantic region. According to US Code Title 30 Chapter 23 Section 1001, the definition of Geothermal Resources are: (i). All products of geothermal processes, embracing indigenous steam, hot water and hot brines; (ii) steam and other gases, hot water and hot brines resulting from water, gas, or other fluids artificially introduced into geothermal formations; (iii) heat or other associated energy found in geothermal formations; and (iv) any byproduct derived from them.

Based on latest report by Purnomo et al. (2015), Indonesia have 40% of world geothermal potential with total 28 GWe potential from 44 prospect spots. The main application of geothermal is for electricity generation. Currently, the total installed capacity of geothermal power in Indonesia plant is 1281 MW.

1.2. Geothermal Well Drilling

The main objective of oil and gas drilling is to reach hydrocarbon reservoir. It is normally in an abnormally pressure zone or kick zone. In geothermal drilling, the main objective is to reach the fracture zone or loss zone with a high-temperature gradient. Geothermal well can be either producing steam or injecting water through the fracture. The presence of special alteration mineral caused by excessive heat marked the zone with constant and continuous heating.

Zuhro et al. (2015) describe common casing design in geothermal project in Indonesia. Several slim hole is usually drilled prior to an exploration well. It is a temperature gradient survey well. Temperature gradient well usually drilled up to 800 ft. The standard-hole casing design are implemented in exploration well. Figure 1 shows typical standard hole and big hole design in geothermal drilling in Indonesia. Big hole design is the common for development well. Big hole well is needed to produce a high flow rate of steam or hot water. Common techniques for completion stages are perforated casing and open hole.

The main challenge of geothermal project is to maintain cost. To be competitive with other alternative energy, project cost should be pushed as low as possible. Drilling activity contributes up to 40% to the project cost. Drilling problem can cause additional cost the whole project. Combating loss circulation, Rough drilling condition with slow ROP, secondary cementing and many other problems need additional operation time. The material used to overcome the problem also increasing cost. Mitigating the drilling problems could save the entire project.

1.3. Drilling Problem in Geothermal Well

Natural condition and properties of formation can cause drilling problem. Geothermal resource is usually present in the volcanic area. Hard and abrasive rock can lead to slow ROP and BHA failure. Hard formation in seismically active region creates highly fractured zone. Loss circulation is the most common problem when entering fractured zone. Abnormal temperature gradient zone present in the production zone. High temperature can lead to equipment failure and cementing problem

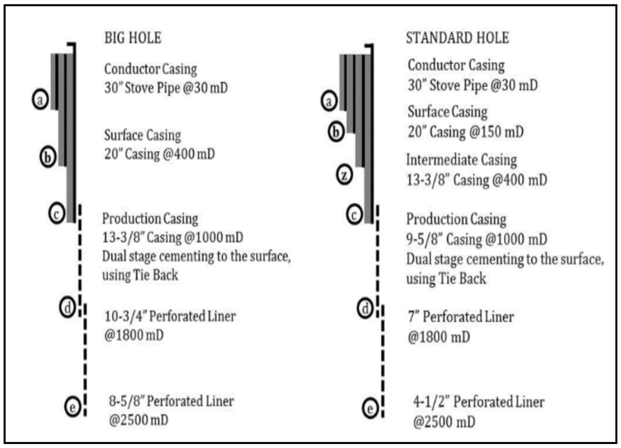

Figure 1.Typical casing design for geothermal exploration and production well in Indonesia (after Zuhro et al. 2015)

2. METHOD

2.1. Lost Circulation

The most common drilling problem in geothermal well is lost circulation. Lost circulation can create additional cost due to combating time, material, and creating another hole problem. Finger and Blankenship (2010) describe common problems that present with lost circulation as follows:

1. Stuck Pipe is common problem after loss ciculation, drilling fluids fails to lift the cuttings from the bottom hole during drilling in lost zone.
2. Loss also can lead to well stability issue, decreasing mud column can lead to low wellbore pressure.
3. The cost of drilling fluid. Loss of drilling fluid to the formation are unrecoverable.
4. Well Control. Drop in annulus fluid level decrease hydrostatic pressure, which can lead to steam/formation fluid influx into the wellbore.
5. Formation damage. Most of the loss zone are in the production zone. Drilling fluid can create formation damage in that area.
6. Difficult cementing Job, lost cement slurry to fractures can lead to a poor cementing result. For example, lost of cement slurry during cementing create poor sealing in the annulus between casing and wellbore. Un-cemented casing can lead to other problem in the lifetime of the well.

Combating loss circulation depends on many factors, one of the most important factors is location/depth. Treatment of loss in shallow depth did not affect production zone. While in the production zone, formation damage should be considered when dealing with lost circulation. Based on paper by Finger and Blankenship (2010), there are several way to overcome loss circulation. Drilling with lost circulation is the first way. Drill with lost circulation means drill without return. Common field term is “blind drilling”. Water are constantly pumped down the annulus and the drill pipe. Cuttings being pushed back to the fractured formation. This technique requires plenty of water. ROP should be maintained to ensure enough cutting loading. Hi-viscosity fluid swept are needed for several meter of drilling interval to ensure hole cleaning.

Drill with lightweight fluid. There are three categories of lightweight fluid: air, foam and aerated. They are diversified based on liquid – gas phase concentration. Air can only be used where liquid production does not exist. Foam can be used to lift bigger/ heavier cuttings. Aerated fluid is the solution to provide hydrostatic pressure slightly below the formation pressure. In geothermal well where temperature is a big issue, surfactant needs to be added to the fluid to overcome heat effect. Hi-viscosity fluid swept are needed for several meter of drilling interval to ensure hole cleaning.

Lost Circulating Material (LCM) is the material used to seal and block the loss zone. There are three types of lost circulating material: fibrous, flaky and granular. Fibrous and flaky material lay in the fracture create layer to catch solid from mud. Accumulation of solid on that layer conducts sealing mechanism. Granular materials seal the tip of the fracture and prevent fracture to builds further. Solid build up inside the fracture then seal the fracture itself. Fibrous and flaky materials are the best option to seal natural fracture in geothermal drilling.

LCM cannot handle big fracture where it allows them to pass through. A sealing mechanism that can be pumped into the fracture then solidify to seal the fracture is needed. This sealing mechanism can be done with cement slurry. Plug back cementing is applied by pump some cement in loss zone. Cement slurry fills the fracture and seals it as it hardens.

Geothermal loss formation mostly caused by fluid loss into fracture rather than matrix pore space. From the fracture perspective, lost circulation can be divided into two types. The first type is when the fracture is bigger than bit nozzle diameter and the second one is smaller. For smaller fracture, the loss zone can theoretically be sealed with LCM mixed with the fluid. The bigger one needs more treatment. The multiple spots of LCM along with drilling fluid can be costly and time consuming. The result is also questionable since LCM cannot effectively seal the fracture.

Plug back cementing is the most common solution in the geothermal application. It needs a round trip to change BHA to open-end. The result depends on the LCM foundation beneath the slurry. Research was conducted by Sandia National Lab to overcome this problem. They developed cementitious mud. Cementitious mud is drilling fluid that contain cement and other materials to satisfy certain criteria. It has the ability of rapid setting, temperature driven, provide permeability less than ten mili-darcies and the volume expand as it curing. This cement could be formulated by mixing conventional bentonite mud with ammonium polyphosphate, borax, and magnesium oxide. The proper operation should be managed to prevent it set up inside drill string.

Most of geothermal wells experience deep lost circulation when drilling trough the production zone. Severe partial loss or even total lost circulation is common while drilling this zone. The highly fractured formation is the main target of geothermal drilling. Fracture condition needs to be preserved to ensure enough flow capacity for steam to be produced.

2.2. Stuck Pipe

There are two kinds of stuck pipe while drilling; mechanically stuck pipe and differential pressure sticking. The major causes for mechanical stuck pipe are cutting accumulation, formation instability, unconsolidated formation, fracture or faulted formation, and cement blocks. Differential pressure sticking is caused by the pressure difference between formations and wellbore. Natural characteristics of geothermal prospect create a high chance for both mechanical and differential pressure to occur during drilling.

Cutting excavated from the formation can accumulated in the annulus of string and hole. To prevent that, cuttings should be transported properly. Accumulation of cuttings usually presents in the area where mud velocity reduced. Top of drill collar where annulus between string and wellbore change from drill collar-open hole to drill pipe-open hole creates a low-velocity zone. Enlarged hole also creates a low-velocity zone. In deviated or horizontal well, cuttings dragged to the bottom by the gravity. Cutting accumulates in the wellbore bed. When trip-out, accumulated cuttings in the top of drill collar may lead stuck pipe.

In vertical wells factor that affect hole cleaning are mud weight, annular velocity, mud rheology, cuttings morphology, ROP, pipe rotation, and time. Mud weight provides buoyancy to lift the cuttings. Annular velocity provides lifting force to the cuttings. Mud rheology related to flow regime when the mud pumped in certain pump rate. Cutting morphology affects slip velocity. The shape and nature of cuttings also affect shear thinning qualities of mud. The amount of cutting excavated by the bit depends on ROP. Pipe rotation improves hole cleaning by sweeping cuttings from low-velocity zone near the wall to the faster-moving stream. Time is an important parameter. Proper hole cleaning reached when mud circulates bottom-up in a certain amount of time.

All of the factors affecting hole cleaning in vertical well also influence hole cleaning in directional well. Additional factors are hole inclination and formation of cutting beds. The hole inclination differs hole cleaning in a horizontal well than in a vertical well. This is due to formation of cutting bed in the lower part of the borehole. In a vertical well, the effectiveness of hole cleaning is monitored by relating torque and visual inspection in the shakers. In a horizontal well, moderate torque might present while the cuttings in shakers are clean or normal. Good hole cleaning can be achieved when the cuttings dragged from cutting bed into the flowing area.

In naturally fractured formation, large chunks of formation can break from the wall into the wellbore. A Large quantity of rock falling into the wellbore can cause bridging and potentially cause a stuck pipe. Doglegs and drill string vibration exacerbate this problem. If the pipe has become stuck, the first action is applied jar and rotate. If possible, apply circulation in a maximum rate. This type of stuck pipe can be prevented by managing vibration to damp the severity and pump viscous pill whenever high torque occurs.

Wellbore instability is responsible for the most serious type of stuck pipe. When pipe stuck due to wellbore instability, we often lose our wells. Determining the required pressure to overcome hole collapse is not an easy task. It needs a robust and sophisticated model of geomechanics. Recording the hole caliper can be the best and easiest estimation.

Naturally fractured formation and low-pressure zone are common in geothermal drilling. Wellbore instability causes cave-in. The pressure difference between wellbore and formation cause differential sticking. Most of formation drilled in geothermal wells are subnormal pressure formation. Formation pressure lower than drilling fluid hydrostatic pressure can cause differential stuck pipe.

2.3. Criteria for Volumetric Gas Flow Rate in Aerated Mud and Foam Drilling.

Underbalanced condition are required while drilling trough fractured and low-pressure formation. Several issue needs to be accounted while drilling underbalance. Inadequate air and liquid flow rate combination can lead to other hole problem that can cause stuck pipe. Guo et al. (2002) present criterions for underbalanced drilling with foam and aerated drilling.

2.3.1. Criteria for Foam Drilling

Minimum velocity is the first criterion. In foam drilling, the mixture of foam and cuttings cannot be treated as a homogeneous mixture. It makes the minimum kinetic energy criterion for air drilling cannot be applied in foam drilling. The cutting transport requirements for foam drilling are presented below:

$$v_{sl} = 1.56\frac{D_s\left(\rho_s - \rho_{fm}\right)^{0.667}}{\rho_{fm}^{0.333} - \mu_e^{0.333}} \tag{1}$$

Where v_{sl}, D_s, ρ_s, ρ_{fm}, μ_e are slip velocity, cutting equivalent diameter, solid density, foam density and effective viscosity, respectively.

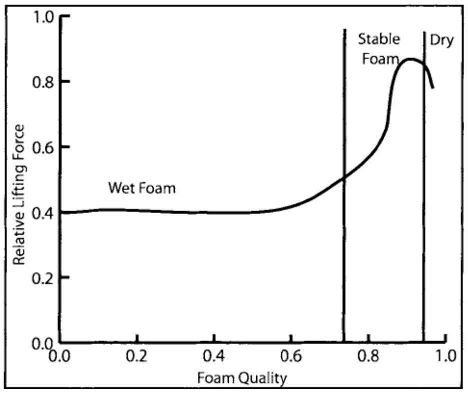

Figure 2. Foam lifting capacity (after Bayer et al., 1972)

Foam stability is the second criterion. Foam is stable when volumetric gas content is 0.55-0.975. When the gas phase is greater than 0.975, the continuous cellular foam structure that entraps gaseous phase become unstable, and the foam turns into mist. When the gas phase is less than 0.55, the foam structure tends to break down.

Foam quality also related to cutting lifting capacity. Figure 2 shows the relation between foam quality and relative lifting force. The lifting capacity starts to increase at foam quality of 0.6. The best lifting capacity achieved with foam quality ranges from 0.72 – 0.97. It declines after reach 0.97 as the foam begin to unstable.

Foam quality index is defined as

$$\mathit{\Gamma}=\frac{V_g}{V_g+V_l} \tag{2}$$

Where V_g and V_l are gas volume and liquid volume.

The pressure ratio between bottom hole pressures to surface pressure should be maintained to keep the foam quality as desired. Pressure ratio is defined as

$$\frac{P_{bh}}{P_s}=\frac{T_{bh}\mathit{\Gamma}_s(1-\mathit{\Gamma}_{bh})}{T_s\mathit{\Gamma}_{bh}(1-\mathit{\Gamma}_s)} \tag{3}$$

Where P_{bh}, P_s, T_{bh}, T_s, Γ_{bh}, Γ_s are bottomhole pressure, surface choke pressure, bottomhole temperature, surface temperature, bottomhole foam quality and surface foam quality, respectively.

2.3.2. Criteria for Aerated Mud

In aerated mud drilling, cuttings are large and move up the annulus at velocities significantly less than the in situ fluid velocity. Generally, flow of aerated water falls into a turbulent flow and flow in oil falls into a transitional regime between turbulent and laminar. It is safe to consider the flow as turbulent flow region. For turbulent flow (Re>2000) the cuttings terminal settling velocity can be estimated using the following equations

$$v_{sl}=5.35\sqrt{\frac{D_s(\rho_s-\rho_f)}{\rho_f}} \tag{4}$$

$$v_m=v_{sl}+v_{tr} \tag{5}$$

$$v_{tr}=\frac{\pi d_b^2}{4AC_p}\left(\frac{R_p}{3600}\right) \tag{6}$$

Where v_{sl}, v_m, v_{tr}, D_s, ρ_s, ρ_{fm}, db, Cp are slip velocity, mixture velocity, transport velocity, cutting diameter, solid density, foam density, bit diameter, and particle concentration in the flow path.

Flowing bottom hole pressure is an important parameter in aerated drilling. Mixture of air and liquids are generating flowing bottom hole pressure while pressure drop occurs in the annulus. Liquids are combinations of drilling mud and any formation fluid presence.

For vertical hole, flowing borehole pressure can be formulated as follow

$$dP=\gamma_m\left(1+\frac{fv^3}{2gD_H}\right)dh \tag{7}$$

Where

$$\gamma_m = \frac{9.45 * 10^{-5} {d_b}^2 S_s R_p + 1.667 * 10^{-2} W_m Q_m + 9.7327 * 10^{-2} S_l Q_f + 1.275 * 10^{-3} S_g Q_{go} P}{6.7846 * 10^{-2} T Q_{go} \left[\frac{2.2283 * 10^{-3} Q_m + 1.5597 * 10^{-3} Q_f}{6.7846 * 10^{-2} T Q_{go}} P + 1 \right]}$$

and

$$f = \left[\frac{1}{1.74 - 2 log\left(\frac{2e}{d_H}\right)} \right]^2$$

Where dP, γm, f, v, dh, g, d_H, S_s, R_p, W_m, Q_m, S_l,Q_f, S_g, Q_{go}, T and e are borehole pressure, specific weight of mixture, Moody's friction factor, fluid velocity, depth incremental, gravity constant, hydraulic diameter, bit diameter, specific gravity of cuttings relative to water, rate of penetration, mud weight, mud flow, specific gravity of influx relative to water, formation fluid influx rate, specific gravity of injection gas relative to air, gas flow rate, average temperature, material roughness, respectively.

Guo et al., 2002 describe the liquid gas rate window as combinations of liquid flow rate that meets a certain requirements. The gas injection rate should be carefully designed, so the flowing bottom-hole pressure is less than formation pore pressure under drilling condition, and bottom hole pressure is greater than formation collapse pressure. In this paper, the formation collapse pressure is measured at the weakest point of open hole, which is pressure at the casing shoe. Other limits in designing liquid and gas rate include cutting-carrying capacity and wellbore washout or equipment limit.

Right Boundary. The right boundary of LGRW is the curve of liquid gas rate combination that yield casing shoe pressure. This pressure should be maintained to be higher than formation collapse pressure. Since both liquid and gas should be constantly pumped into the well during drilling, this boundary counts the limit as circulating pressure. During circulation-break such as during connection, liquid and gas was replaced by high viscosity mud and original mud. Both has higher hydrostatic pressure relative to aerated drilling. Determining formation collapse pressure is complex tasks of geo-mechanics. This paper did not cover this task.

Left Boundary. The left boundary of LGWR is determined by the curve of combination of liquid and gas rate that meets the requirements for an underbalanced condition. Both needs to be maintained below formation pressure at the bottom hole. The combination of liquid and gas rate that equal to formation pressure can be determined based on Guo's model. For the same mud rate, higher gas injection rate result in lower bottom hole pressure.

Lower Boundary. The lower boundary of LGRW can be determined based on carrying capacity of the fluid and gas mixture under bottom hole condition. This can be determined by plot the maximum allowable cutting diameter under certain mud flow rate and air injection rate.

Upper boundary. Guo's determined the upper limit as a combination of liquid and gas rate that achieved wellbore washout pressure. The wellbore washout is not a common in geothermal formation. This paper will use equipment's technical limit as the upper limit of LGRW.

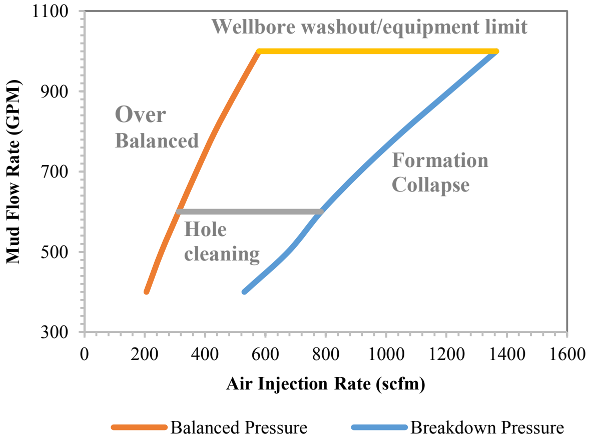

Figure 4. Liquid-Gas Rate Window (Guo and Ghalambor (2002). Field application should be inside the window to prevent over balanced, provide proper hole cleaning, prevent formation collapse and below equipment limit.

7. CASE STUDIES

3.1. Lost Circulation

Case #1,well X-1 is designed for an injection well

Target depth : 2500 mMD, Target days : 38 days

Actual depth : 2180 mMD, Actual days : 52 days

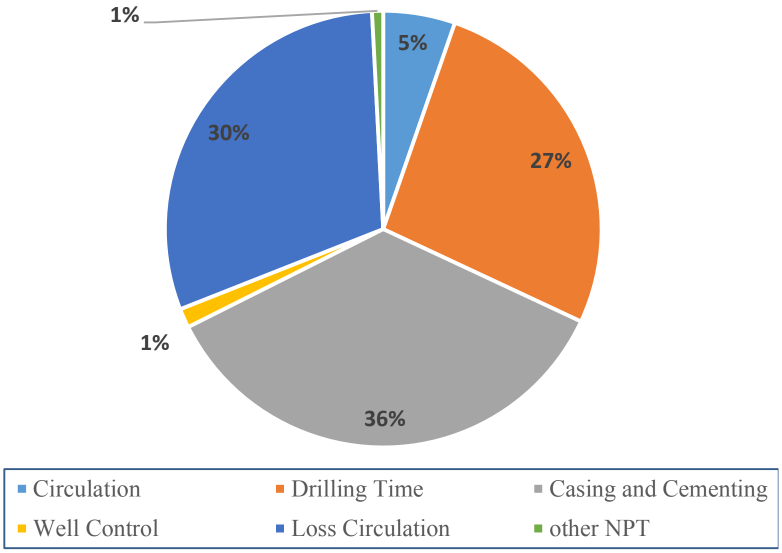

Figure 5. Operation Time Distribution of Well X-1

Well A-1 is a geothermal well located in Indonesia. Severe lost circulations present during drilling. Figure 5 shows operation breakdown of well A-1. The total time to combat loss in this well is 194 hours or 30% of total operation time. Lost circulation time presented in the chart is based on non-productive-time calculations. It means only time without drilling and time with limited drilling recorded in this chart. Another lost circulation event where normal drilling is possible, recorded as drilling time. As described in Chapter 2, lost circulation also creates trouble in casing and cementing. Total time to casing and cementing operation is 36% of total operation time.

Another option to drill ahead in lost circulation condition is drilling with lightweight fluid. In high cutting condition, foam drilling could be the best option. That option cannot be established since 29½" diverter was installed in the stack. The available rotating head is only suitable for 20" flange or smaller. After many considerations, it was decided to set the casing 20" at the last depth. Unsealed fracture zone creates a problem in cementing. Some of the cement slurries went into the fractures. Top job cementing was performed to ensure good cement bond.

The next section is drilled with 17 ½ "bit. Total Lost Circulation still occurred during drilling. The partial lost circulations were treated with LCM spots or drill ahead with air or water. During drill ahead, numerous high torque condition present. This is one of the signs of poor hole cleaning. In air drilling, proper injection rate are needed to ensure proper hole cleaning. Based on

In total loss condition, a decision should be made to drill ahead or seal the loss zone. They usually deceive to drill ahead as far as possible along with spotting LCM then seal the fracture zone with plug back cement. LCM are needed prior to plug back. It provides foundations to the slurry. Cement will accumulate on the LCM layer, and then it seal the fracture as it thickens. There were totally 8 x plug back cementing in this section.

The success of plug back cement depends on the LCM layer prior to cementing. There was one success in cementing with plugging material being pushed down prior to cementing. This plugging material called bentonite ball. They mixed bentonite, chopped straws, chopped banana trees and chip of bricks and form a golf-ball-size plugging material. This plugging material cannot be pumped down the string. It should be pushed down with the bit. The result the bentonite ball was remarkable. There was only one plug back cementing needed to seal the loss zone. Even though it has a remarkable result. This operation needs many considerations, especially during push down with bit that can lead to pipe stuck.

Water or mud lost into the location for this well is more than 650.0000 barrels. It is the typical amount of water needed in the drilling of a single geothermal well in this area. From that fact, water supply needs to be planned and designed properly. Especially because most of the geothermal prospect are located in a mountainous area which water supply is limited. In most cases, water needs to be constantly pumped into the annulus to provide adequate hydrostatic pressure in the well. It creates enough pressure to hold formation pressure and provide well stability during drilling. The water not only create water column in the well but also to cool downhole temperature. The need of water can be devastating when combating lost circulation.

Case #3, well X 3 is designed for a production well.

Target depth : 2800 mMD, Target days : 52 days

Actual depth : 2362 mMD, Actual Days : 170 days

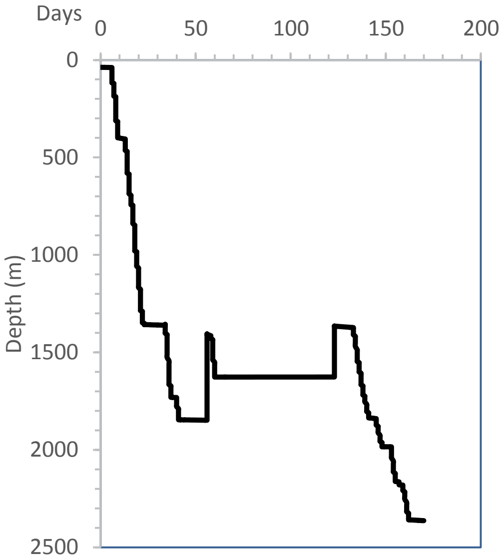

Figure 6. Time vs Depth Chart of Well X-3

Well X-3 is a geothermal production well located in Indonesia. Figure 6 shows drilling days of Well X-3. There are 13 stuck pipe incident in this well. Two of them ended in back-off and lost in hole string. Identification of the stuck pipe is done by applying stuck pipe identification technique proposed by John Mitchell (2011). The Mitchell technique was meant for trouble shooting during operation, so the parameter can be determined on-location during the stuck pipe. There are 5 stuck pipe incidents caused by pack-off bridging, 2 incidents by differential sticking, 2 Incidents by wellbore geometry, and 4 Incidents are caused possibly by either Pack-off/bridge or wellbore geometry.

To identify stuck pipe causal, we need to observe the event prior to the stuck pipe. Most of the mechanically stuck pipe incidents in this well are preceding by high torque condition. High torque during drilling or reaming can be related to hole cleaning or wellbore geometry. Based on field engineering analysis stuck pipe are caused by poor hole cleaning. Hole cleaning can be an important issue when drilling with air, foam or aerated drilling. All parameters should meet the minimum volumetric requirement for hole cleaning. The minimum volumetric requirements for air, foam, and aerated drilling are presented in simulation. Simulation are based on model as described in figure 7.

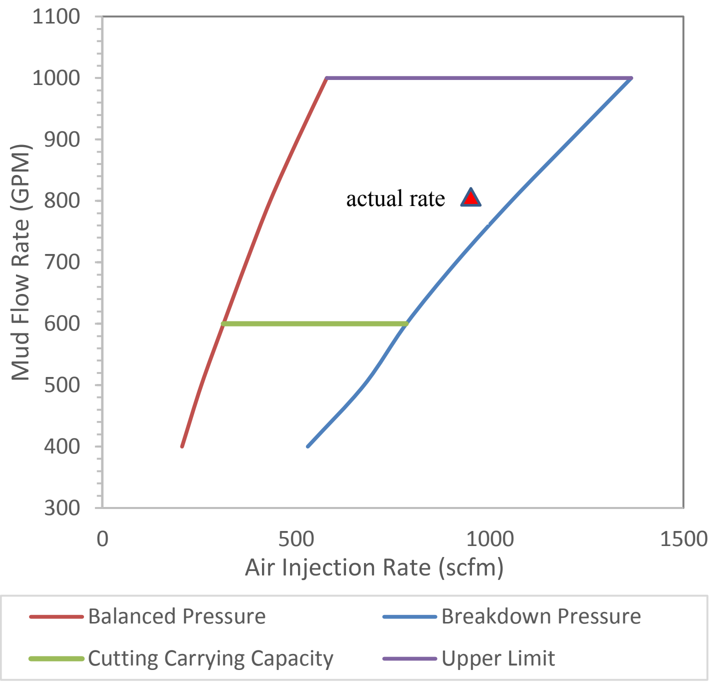

Figure 7. Liquid-Gas Rate Window in Well X-3

Figure 7 shows the final result of LGRW of Well X-3. This LGWR is based on assumptions of formation pressure equals 2000 psi, formation collapse pressure 1400 psi and desired cutting diameter 1 inch. The actual combination of air and mud flow rate is inside the window. It means actual flow rate is adequate to overcome formation collapse pressure, to achieve underbalanced conditions, adequate to lift 1-inch cuttings, and below the maximum capacity of the mud pump.

Lesson learned from this case, minimize static pipe. When pumping high viscosity fluid, driller tend to leave the pipe static. During the circulation, driller should work on pipe (pull out and back in with slow rotation) to prevent static pipe. Minimize static time when preparing hi-viscosity spot. Differential stick can happen seconds after stop drilling. Another takeaway is that filter cake control should be considered to apply in the permeable and low-pressure zone.

Drilling the next section was very challenging. Several stuck pipe due to both differential pressure and cave in. Mud cake dispersant and oil were used to overcome differential pressure stuck. Pumping and jarring were used to free the pipe from the hole cave-in stuck pipe. The high torque condition exacerbates the problem, then decided to set final depth above the original target depth.

Key takeaways, high torque condition often occur in geothermal drilling. Hard formation could be the main cause of torque. Since the bit used in geothermal is rotary drilling bit, the high torque should not occur. Even more when operating in low weight on bit and rpm. The nest suspect is the dogleg severity. From MWD data, dogleg severity is considerably low. Most of the time the DLS is lower than 1, only a few area reach up to 3.2. Vibration might be the cause of high torque. Further research is needed to conclude the vibration effect on geothermal drilling

Case #4, Well C-1 is a production well. It is a side-track well from old drilled well. Well C-1 expected to be drilled in 24 days, actual drilling days expand to 28 days without reaching target depth. The final result from the drilling activities was an abandoned well and lost-in-hole equipment.

The severe problem happened at 9-7/8” Hole section. There were 5 stuck pipe incidents in well C-1. From the event analysis, there are one wellbore geometry suck pipe and four pack-off/bridge stuck pipe. The last stuck pipe leads to lost-in-hole with 1396 meter of fish. This well then abandoned with the top of fish at 353m. All of the stuck pipe incidents happened in the 1721-1749 interval. High torque is the warning sign in this area. We can treat the first four as warning sign to a bigger problem in the last incident. Stuck pipe in the same interval over and over can be related to wellbore stability issue. Vibration problem can also lead to high torque during drilling.

In 9-7/8” section of well C-1, foam drilling was performed to create underbalanced condition. This is the section where trouble encountered. In foam drilling, foam quality is the most important parameter. To achieve stable foam, foam quality should be maintained between 0.65-0.97. Foam quality will change as temperature and pressure change. This simulation based on assumption that desired foam quality at the bottom of the hole is 0.65 and foam quality at the surface 0.97. Another parameter that related to foam quality is

GLR. GLR should be maintained at calculated ranges to achieve desired foam quality at certain pressure and temperature. Figure 7 shows required GLR vs. actual GLR.

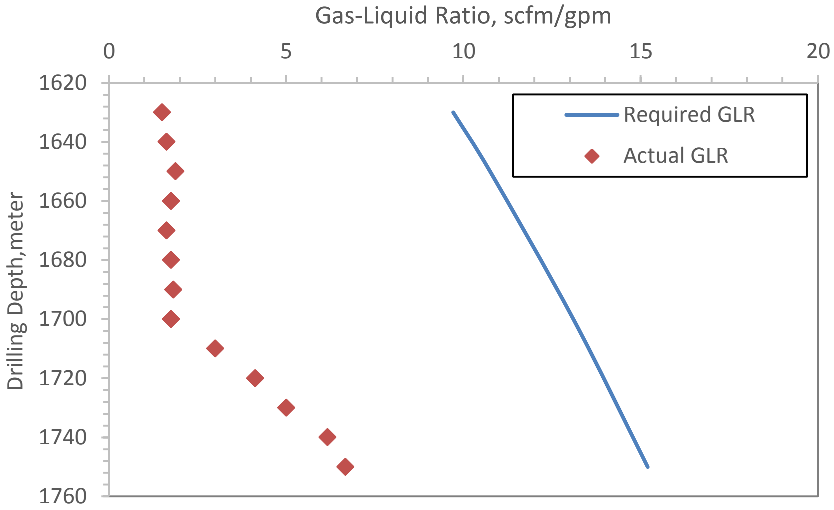

Figure 7. Required vs. Actual Gas-Liquid Ratio to achieve Γ_{bh}= 0.65

As shown in figure 7, actual GLR are lower than required GLR. It means, foam are not in stable condition and has actual foam quality less than 0.65. Unstable foam quality will result in improper hole cleaning. One of the reasons of foam drilling is to ensure hole cleaning in underbraced condition. The liquid phase of foam in well C-1 is water. Without proper additives, water does not perform good quality hole cleaning.

Guo et al., 2002 describe that under surface conditions, GLR should be maintained below 4.32 scfm/gpm. When required GLR for bottom hole condition is higher than 4.32 scfm/gpm, surface backpressure should be applied to the choke. Figure 8 shows required surface back pressure to maintain surface foam quality index above 0.97. No back pressure were applied during foam drilling in this well. Thus, foam quality under bottomhole condition was below 0.65.

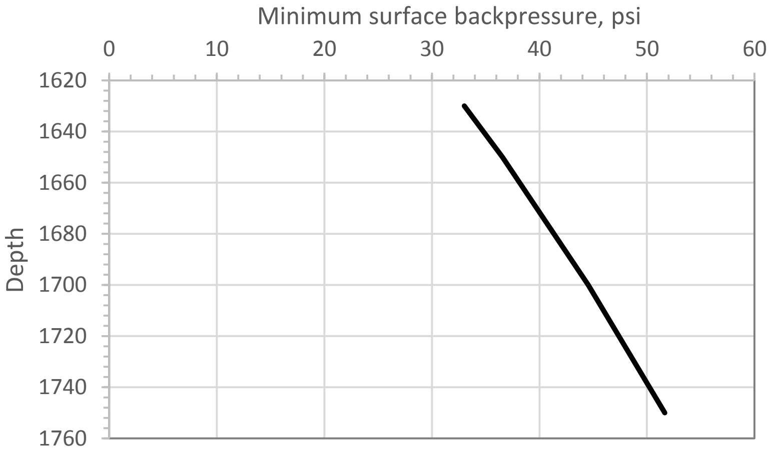

Figure 8. Minimum surface backpressure

Simulation was conducted to determine the required combination of liquid and gas. Several assumption were made, those are Γsurface : 0.97, Γ bottom-hole: 0.65, Foam velocity: 2.2 fps. Simulation results are: Gas injection rate: 2567 scfm, Water rate: 161 gpm, Gas-Liquid Ratio: 16 scfm/gpm, Bottomhole pressure: 1223 psi.Based on simulations, actual gas and liquid injection rate in well C-1 is not adequate to form a stable foam.

CONCLUSION

1. For lost circulation problem several factors should be design and planned properly. Location of loss zone is important factor to overcome lost circulation, In shallow depth/far from production zone : spotting lost circulating material, cement plug and lightweight fluid, In production zone, drill ahead with light weight fluid is the best option. In plug back cementing, Spot LCM prior to plug back cementing is necessary to create foundation for slurries. Water supply in geothermal drilling is important, typical well with depth 2000-2500 mMD can consume up to 650,000 barrels of water.
2. For Stuck pipe with loss circulation prior to stuck, air and liquid combination shoud be properly designed. Actual liquid and gas combination should be maintained inside the LGRW window and considering safety factor. For Foam Drilling, surface back pressure should be applied when liquid and gas combination was below required.

REFERENCES

Poernomo A., Satar S., Effendi P., Kusuma A., Azimudin T., Sudarwo S., “An Overview of Indonesia Geothermal Development-Current Status and Its Challenges”. Proceeding World Geothermal Congress 2015, Melbourne, Australia.

Aromaharmuzi A., Arif G.R.,”Pertamina Geothermal Energy Drilling Campaign”. Proceeding World Geothermal Congress 2015, Melbourne, Australia

D.A. Glowka, 1990, Lost Circulation Technology Development Projects, DOE Geothermal Program Review VIII, San Francisco, California.

Finger J. and Blankenship D., Handbook of Best Practices for Geothermal Drilling, 2010, Sandia National Laboratories, New Mexico.

Carson C.C., Geothermal Drilling Problem and their Impact on Cost. 1982, Sandia National Laboratories, New Mexico

REN21, 2015. Renewables 2015 Global Status Report, Renewable Energy Policy Network for 21st Century.

US Department of Energy, “A History of Geothermal Energy Research and Development in the United States”, 2006.

Guo B., Ghalambor A., “Gas Volume Requirements for Underbalanced Drilling-Deviated Holes”, 2002. Penn Well Corporation, Tulsa, Oklahoma.

Guo B., Sun K., Ghalambor A., “A Closed Form Hydraulic Equation for Predicting Bottomhole Pressure in UBD with Foam”, 2003. Proceeding IADC/SPE Underbalanced Technology Conference, Houston, Texas.

Mitchell J., “Trouble Free Drilling, Stuck Pipe Prevention” 2009. Dilbert Engineering Inc.

Beyer A.H., Millhone R.S., Foote R.W., “Flow behavior of Foam as Well Circulating Fluid”, 1972. SPE 3986

LMB A-1-End of Well Report. 2012. PT. Pertamina Geothermal Energy. Indonesia.

KRH 6-1-End of Well Report. 2013. PT. Pertamina Geothermal Energy. Indonesia

HLS A-1-End of Well Report. 2013. PT. Pertamina Geothermal Energy. Indonesia

KRH 5-3-End of Well Report. 2014. PT. Pertamina Geothermal Energy. Indonesia