Study of Prevention and Mitigation of Stuck Pipe in Geothermal Drilling

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ABSTRACT

Stuck pipe of geothermal well drilling occurs when the pipe, for the likes of drill string and casing in the wellbore cannot be pulled out without exceeding its designed working load. This incident will result non-productive time and unnecessary additional cost. Historically, one out of three wells drilled in geothermal area in Indonesia experienced stuck pipe problems. Most cases of stuck pipe of geothermal well drilling in Indonesia can be avoided with good drilling design and operation. This paper shows the stuck pipe incidents from a plenty of geothermal wells throughout the Indonesian geothermal fields. The data of design and the execution of wellbore where the stuck pipe incidents have occur will be presented and explained. The analysis and evaluation based on the wellbore data will be carried out. The method of stuck pipe causes, prevention and mitigation will be build.

1. INTRODUCTION

Geothermal systems are widely produced from a hydrothermal system. Hydrothermal systems contain water in the pore and fracture inside the rock with large permeability that is enough to produced large volume of fluids. Geothermal formations have the following characteristics which are (1) relatively high temperature from 160 to above 300 C, (2) compressive strength 240^+ MPA (compared with the sediment reservoir 100^+ MPa), abrasive (quartz content above 50%), highly fractured, under pressured, contain corrosive fluids and formation fluids containing high solid content (Finger and Blankenship, 2010).

There are two classifications of rocks, brittle and ductile. A rock is brittle if, when subjected to stress, it breaks without significant deformation (strain). A rock is ductile if, when subjected to stress, it can deform under tensile stress. Rocks that are often encountered in geothermal reservoir are granite, granodiorite, quartzite, greywacke, basalt, rhyolite and volcanic tuff.

Geothermal reservoir rock which is brittle and highly fractured could lead to breakouts and results in caving. Caving is not desired during drilling operation because it causes lots of problems such as restricted circulation, borehole enlargement, and stuck pipe. Those problems can be avoided with good drilling design and operation.

The term of stuck pipe is when the drill string cannot longer free to move up, down, or rotates as the driller wants. In drilling operation of a geothermal well, stuck pipe is one of the most common problems occurred. Stuck pipe leads to loss of time and can be very costly, including lost drilling time during freeing the pipe, cost of fishing, and even it risks abandonment of tools inside the hole.

Concerning these problems and in order to improve the drilling operation performance, evaluation towards stuck pipe incidents in geothermal drilling is performed. Certain parameter are taken into account in handling stuck pipe and in order to perform a free-stuck-pipe drilling operation, such as rock strength (compressive and tensile), and cuttings information from daily mud report.

This paper will focus in analising the wellbore stability to ensure that the drilling operation in geothermal reservoir can be conducted safely and effectively to avoid drilling problem and non-productive time.

2. METHODOLOGY

Geothermal well instability is affected by lots of factor. Several factors which will be discussed in this paper are the mineralogy, clay support, natural fractures, and permeable formation. The mineralogy and clay support trigger the chemical activity in the formation which result in shale swelling. The shale swelling leads to tight hole problem which can be observed from Gumbo accumulation on drill string and small caliper log value.

The high productivity of geothermal system have characteristics of high porosity (natural fracture) and high permeability. The closely space and weak planes (based on natural fracture characteristic) lead to existing fracture enlargement and large caving. Meanwhile, high permeability causes lost circulation problem which can lead to inadequate hole cleaning and accumulation of cutting bed. On the other hand Fracture enlargement leads to borehole enlargement which can be observed from UBI and caliper log. Large caving and lost circulation can be detected from surface parameter resulted by restricted annulus. The indicators of restricted annulus are low weight-on-bit (DWOB), low rate of penetration (ROP), restricted circulation, and pump pressure spike.

The methodology which is used to identify the wellbore instability mechanism is shown in Figure 1
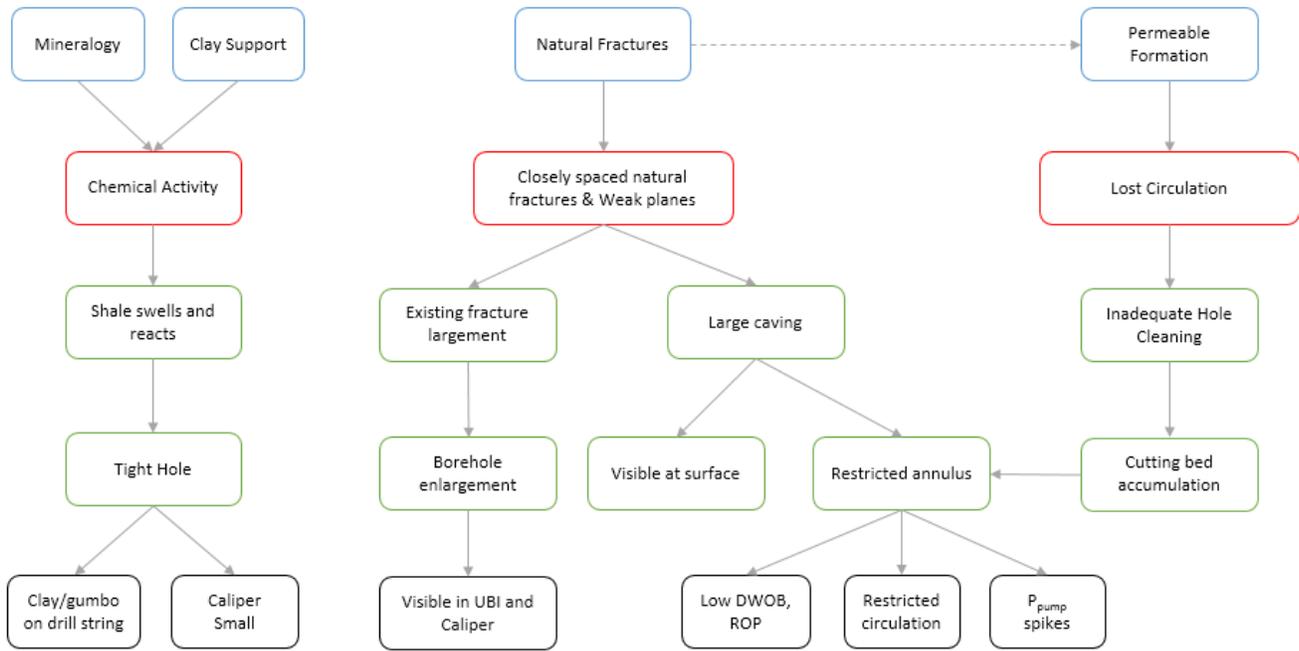
Figure 1. Methodology

2. ROCK MECHANICS

2.1 Rock Strength

Rock strength describes the maximum stress and minimum stress from Uniaxial Compressive Strength (UCS) and Triaxial Compressive Strength (TCS) tests. Based on these tests, there are two types of rock, brittle and ductile. Brittle and ductile deformation are described on the following figures. From the figures below, in brittle deformation the rock loses its strength suddenly while ductile acts the other way around.
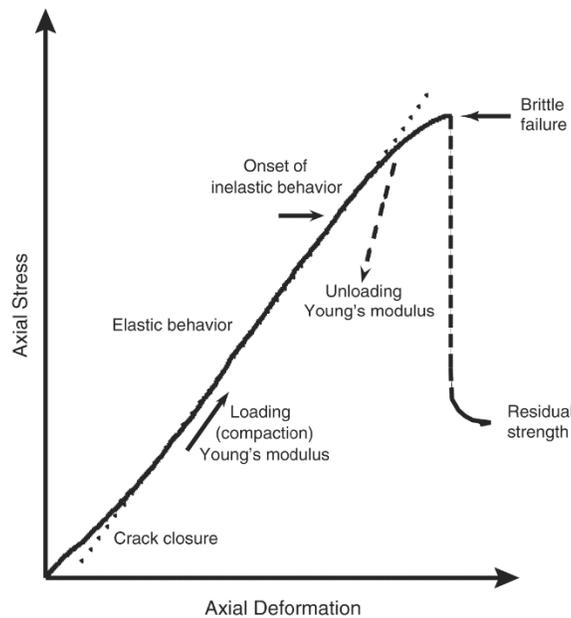

Figure 2. Axial stress vs. axial deformation during a triaxial strength test (GeoMechanics Intl. Inc.)
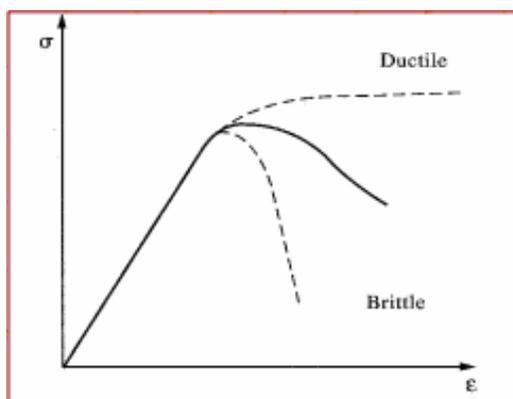
Figure 3. Brittle vs Ductile Deformation

As the rock is loaded, stress-strain behavior for quartzite is illustrated from the figure below.
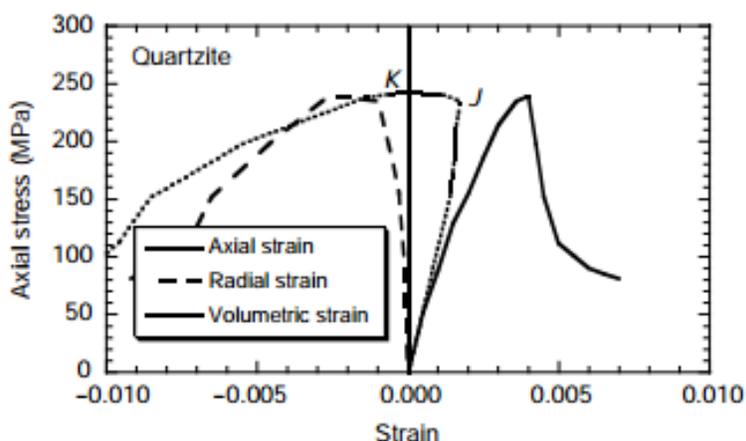

Figure 4. Axial strain of an argillaceous quartzite (Hojem et al., 1975).

Rocks under certain depths experience anisotropic pressure during drilling or production operation which cause enhance shear stress around the wellbore or at perforation zone. Effective principal stress is almost equal to zero around the wellbore and a little higher at the wall of the wellbore due to the presence of the mudcake ($p_w > p_f$). Unconfined compressive strength, C_o, is an important parameter to describe the wellbore stability (Marbun internal report, 2011).
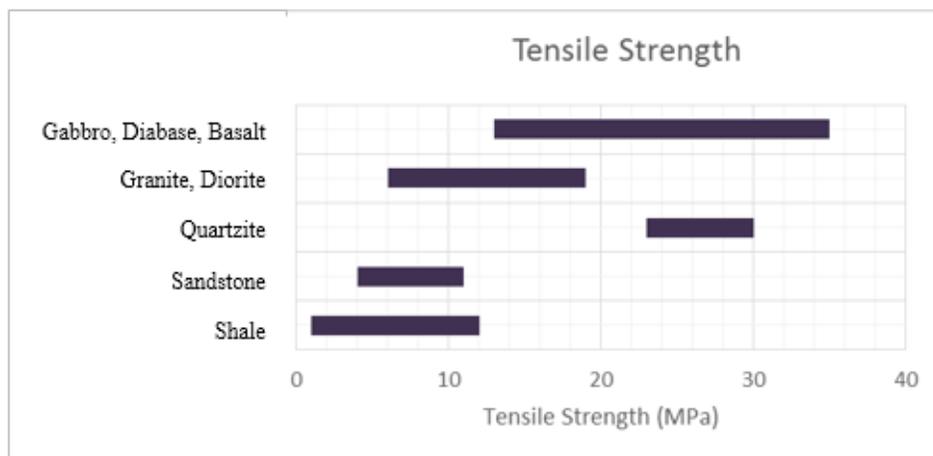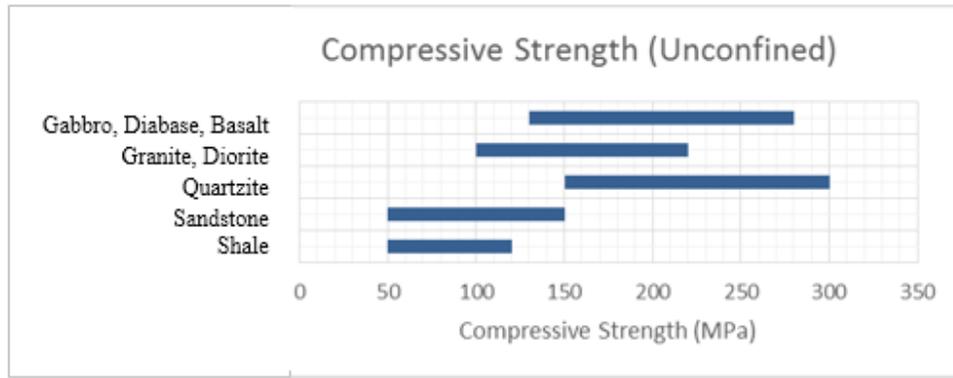

Figure 5. Tensile strength comparison

3

Figure 6. Unconfined compressive strength comparison

2.2 Wellbore Stability

According to criteria compressive shear failure that is combined with rock strength concept, stress value which can lead to breakout can be predicted. On the other hand, mud weight at tensional fracture or hydraulics can be estimated from tensile strength approximation.

Mud weight calculation is done based on geomechanics model where the main stress direction at the wellbore are taken into account. Equation that is used for mud weight calculation is:

$$P_{w,\min} = P_f + \frac{\sigma_v + 2|v_{fr}|(\sigma_H - \sigma_h) - P_f - C_o}{\tan^2 \beta}$$

(1)

where $P_{w,\min}, P_f, \sigma_v, |v_{fr}|, \sigma_H, \sigma_h, P_f, C_o, \beta$ are lower mud-weight value, pore pressure, absolute value of Poisson's ratio, maximum horizontal stress, minimum horizontal stress, unconfined compressive strength, and rupture angle of rocks respectively.

Wellbore instability indication can be seen through stuck pipe as the lost drilling time. Causes that can lead to wellbore instability that will be discussed further are breakouts and closely spaced natural fracture/weak planes.

3. FRACTURED ROCKS

More than a half of all known geothermal resources occur in fractured igneous formations (Sanyal, et al, 1979). Most commercial hydrothermal resources exist as dual porosity system. The high productivity of geothermal system is related to the highly fractured and abrasive rocks. The highly productive fracture system is required to make geothermal projects economically viable, but is also the basis of the endemic stuck pipe problems encountered when drilling geothermal wells. (Finger and Blankenship, 2010)

From what we have discussed before, fractured igneous rocks have a brittle and abrasive characteristics means the rocks have a high tendency to fall into pieces and are very loose. The rocks can fall into the wellbore and jam the string in the hole (Nguyen et al., 2009). Inadequate hole cleaning will also causing the rocks to pack-off
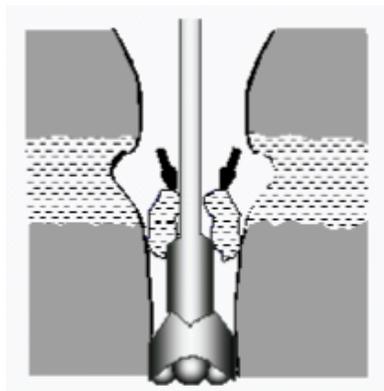
Figure 7. Pack-off mechanisms in fractured or mechanically incompetent rock (Rabia, Well Engineering and Construction)

When the well packs off, there is a sudden reduction or loss of the ability to circulate, and decrease pump pressures follow, which indicates the pipe is stuck caused by pack-off. Pack-off will also result squarish and high volume of cuttings in shale shaker. Pack-off causes borehole enlargement due to high tendency of the rocks to fall into pieces. Due to this borehole enlargement, the weight-on-bit

(DWOB) readings at surface will be decreased, and by small cuttings jamming under the bit, the rate of penetration (ROP) will also decrease while the torque will increase. From Logging While Drilling, gamma ray will show high value (Gamma Ray API > 60) and resistivity follows the fracture and bedding plane orientation. This event indicates pack-off during drilling. The inability to circulate due to pack-off is indicated by higher hookload due to the decrease of buoyancy force acting on the drill pipe.

Table 1. Wellbore Instability indicator due to fractured rocks at borehole condition

	ROP	DWOB	Caliper	Gamma Ray	Resistivity	UBI
Natural Fractures/Weak Planes	Decrease	Low	BoreholeEnlargement	GAPI >60	Fracture & bedding plane orientation	Borehole geometry

Table 2. Wellbore instability indicator due to fractured rocks at surface condition

	Pump Pressure	Circulation	Mud	Cutting and Cavings	Hookload	Surface Torque
Natural Fractures/Weak Planes	Decrease	Flow decrease	Loss at similar weights across field	Squarish, high volume	High	High

3.1. Prevention of Stuck Pipe Due to Fractured Rocks

1. Minimize drill string vibration during drilling operation.

2. Choose an alternative revolution per minute (RPM), lower preferably, or change the BHA configuration if high shock vibrations are observed.

2. Do proper hole cleaning practice (reaming, circulate before tripping out).

3. Slower tripping speed, especially before entering the fractured zone.

3.2 Mitigation of Stuck Pipe Due to Fractured Rocks

1. As soon as it is suspected there is pack-off (a sudden reduction or loss of the ability to circulate, and high pump pressures and torques), pump stoke must immediately reduce to half. This minimize the likelihood of pressure trap to occur (the higher the likelihood, the worse the pack-off will get).

2. If the pipe is already stuck, shut down the pump and bleed off the pressure in standpipe (do not do this if there is non-ported float valve). During the bleed off, flow rate of drilling fluid is maintained to prevent U-tube occur, where solid particles from cuttings plug the drill pipe.

3. Use minimum unbalance pressure (<500 psi) under the pack-off zone. This will be the indicator when pack-off is managed and the pressure should be bleed off.

4. Maintain standpipe pressure below 500 psi and give torque (just enough to be able to connect the drill string and joint). Do not move the drill pipe up and down.

5. Continue giving torque and monitor the bleed off pressure and flow circulation in shale shaker. If there is back flow to the surface, increase the pump stroke gradually to maintain standpipe pressure at 500 psi. If there is still back flow to the surface, increase the pump stroke immediately.

6. If there is no back flow to the surface, try to free the drill pipe by moving (at free points of drill pipe) up and down. Do not give excessive force to the drill pipe. During the effort to free the drill pipe, maintain the standpipe pressure at 500 psi.

7. Do not do jarring. If the back flow still occurring, increase the stand pipe pressure to 1500 psi and continue to free the drill pipe while keep giving torque.

8. If full back flow to the surface occurs, then it is allowed to do jarring. If pack off happened during tripping out, do jarring downwards. If pack off happened during the drill pipe is moving down, do jarring upwards.

4. LOST CIRCULATION

The most expensive problem routinely encountered in geothermal drilling is lost circulation, which is the loss of drilling fluid to pores or fractures in the rock formations being drilled. Lost circulation represents an average of 10% of total well costs in mature geothermal areas and often accounts for more than 20% of the costs in exploratory wells and developing fields. Well costs, in turn, represent 35-50% of the total capital costs of a typical geothermal project; therefore, roughly 3.5-10% of the total costs of a geothermal project can be attributable to lost circulation.
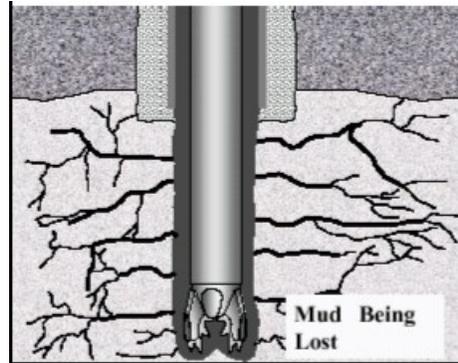

Figure 8. Lost circulation (Rabia, Well Engineering and Construction)

One of the best solution for loss circulation with if an adequate water supply is available, it is practical to drill without returns. If fresh water is not available, produced brine, which would normally be reinjected, can be used for drilling wells within a developed project. Drilling without returns is frequently used when core drilling, where the cuttings are very fine and where much of the rock comes out of the hole in the form of core. There have been many rotary drilled holes where intervals of many hundreds of meters have been drilled with complete lost circulation. There are special techniques required to prevent formation collapse and to keep from getting stuck. The highest risk is when only partial returns are obtained, as the low annular velocities above the loss zones may not be adequate to clean the hole. High viscosity sweeps are usually used to reduce this risk. Once total loss is encountered, pumping water at high rates down the annulus as well as down the drill pipe will flush the cuttings away from the wellbore, preventing any sticking problems, and provide positive wellbore pressure to hold up weak formations.

Conventional lost circulation material is not always successful in the cavernous and vugular low-pressure formations encountered in the geothermal reservoirs. Based on results from the survey of industry experience, geothermal operators are using conventional petroleum methods for fighting lost circulation problems.

When lost circulation occurs, it is important that causes be identified in order that proper remedial procedures can be implemented. Lost circulation causes can be grouped into one of the following four categories:

1. Surface Drilling – for surface hole drilling, formations are generally weak and hole diameter is large. Drill solids from the large hole can build up, generating relatively high downhole pressure that may break the formation.

2. Rapid Drilling – High equivalent circulating density can cause pressure that may exceed the closure stress. Fast penetrating rates can load the annulus with drill solids, creating rheology and hydraulic problems.

3. Abnormal Pressure - In drilling through high pressure zones, mud weight is normally increased for well control purposes, but lost circulation may result if a low or normally pressured zone is also encountered, General practice is to set casing through the high pressure interval and change back to normal mud weight for deeper drilling. This requires careful casing point selection. Otherwise, both the high pressure interval and the lost circulation zone will be exposed simultaneously in open hole.

4. Fractured Formations – When encountered, the general practices is to add Lost Circulation Material (LCM) to maintain returns or use a cement squeeze if LCM is unsuccessful. If necessary, the hole should be forced to desired depth, but the lost circulation problem must be solved at each interval before drilling deeper since, otherwise, problems can compound or occur later. Casing should be set as soon as possible and the casing shoe should always be tested. Deeper drilling should not commence unless the casing seat holds pressure.

The first two categories constitute drilling-induced problems related to hole cleaning capability and equivalent circulating densities.

When drilling is in progress, the presence of these fractures let the drilling fluid enter the formation easily which causes a loss circulation problem. Loss circulation in drilling operations is the loss of drilling fluid to pores of fractures in the rock formations. This loss is harmful for several reasons (Marbun et al., 2015):

1. When the drilling fluid is loss to the formation, it will not bring cuttings to the surface and stick the drilling assembly.

2. Loss of drilling fluid to formation will be very costly.

3. Production zone in geothermal field is usually a loss zone, so it will be difficult to solve the lost circulation problems while preserve the production ability.

4.1 Prevention of Stuck Pipe Due to Permeable Formation

1. Maintain the correct drilling fluid properties

2. Mix the drilling fluid with fibrous material that will plug the loss apertures in the formation

4.2 Mitigation of Stuck Pipe Due to Permeable Formation

1. Use low density fluid such air/gas, foam, aerated fluid

2. Move drill pipe up and down (at the free point) but do not overpull since it makes the condition worse

3. Do not do jarring during this condition, do the jarring process when full circulation return to the surface

Table 3. Wellbore Instability indicator due to permeable formation at borehole condition

	DWOB	Caliper	Gamma Ray
Permeable Formation	Decrease	Thick Filter Cake	GAPI <= 60

Table 4. Wellbore Instability indicator due to permeable formation at surface condition

	Pump Pressure	Circulation	Mud	Hookload	Surface Torque
Permeable Formation	Gradual decrease	Flow decrease	Water loss, high solids	Increase	Higher

5. UNDERGAUGE HOLE

In Geology, interbedding occurs when beds (layer of rock) of a particular lithology lie between or alternate with beds of a different lithology. (UCMP glossary 2008). Good penetration rates can be expected in interbedded sand and shale formations. However rocks that are often encountered in geothermal reservoir are granite, granodiorite, quartzite, greywacke, basalt, rhyolite and volcanic tuff (Figure 5 and Figure 6) shows the tensile and compressive strength of rocks which often encountered in geothermal reservoir. This extremely hard, abrasive, or fractured formations require a bit set with small diamonds and a crowsfoot fluid course to permit a high concentration of diamonds.

Undergauge hole condition could occur when drilling hard formation (abrasive) zone which result in bit wear and smaller hole diameter that the bit diameter. This condition could lead to stuck pipe especially at the section which have the same diameter with the bit. When the wear out bit is pulled out and the new bit is run the drillsting is likely to get stucked, especially if the hole is not reamed when the drillstring is run in hole. This mechanism could also occur when run in hole the drillstring rapidly without reaming. Usually the coring tools size are smaller than the bit size, consequently the hole will be smaller and caused the drillstring to stuck. This stuck pipe mechanism only occurs during tripping in operation. Indications of undergauge hole stuck pipe mechanism are decrease in hook load in a sudden, slightly/full unrestricted circulation and bit could not reach the bottom of the well or the previous zone after coring operation. (Marbun et al., 2011)

5.1. Prevention of Stuck Pipe Due to Undergauge Hole

1. Identify the abrasive formation (quartzite, granite, etc)

2. Selects bit with good gauge protection

3. Never force a new bit to bottom

4. Ream the hole regularly

5.2 Mitigation of Stuck Pipe Due to Undergauge Hole

1. Keep circulating in borehole

2. If the drill sting is stuck when moving up the drill string then do the jarring operation downward and giving torque

3. If the drill string is stuck when moving down the drill sting the do the jarring operation upward but do not giving torque

4. Jarring operation starts by giving low load (50,000 lbs) and increase the load gradually in an hour. When jarring downward, the circulation should be stopped or reduced. On the other hand, when jarring upward pump pressure could help to release the drill string so the circulation is recommended to be increased

Marbun et al.

6. TIGHT HOLE

Tight hole is a phenomena that happened in the wellbore that caused by shale or clay formation that leads to wellbore hole enlargement. The wellbore wall, which has clay formation become weakened by adsorption of water into the clay of the wellbore rock. (Marbun et.al, 2011)

Clay minerals can be divided into two broad groups. They are hydrophilic clays, which readily and easily absorb water, such as montmorillonite. The other group is hydrophobic clays, which not readily and easily absorb water, such as illite. Clay minerals have a sandwich-like structure usually consisting of three layers. The alternate layers are of silica and alumina. A clay particle usually consists of several sandwiches stacked together like a pack of cards. (Heriot Watt Drilling Engineering).

The main study of clay support is clay that has special characteristic that high reactivity. Reactivity of the clay formation is known as chemical activity. Chemical activity of the shale can be resulted to mud diffuses and mud will reacted especially using water as the drilling fluid, mud chemistry changes, and time changes. Consequently, shall swells and reacts. In fresh water, the clay layers will absorb water. The chemical bonds which holding them together are weakened and the stack of layers disintegrates. (Heriot-Watt Drilling Engineering)

As the results of the swelling phenomena, tight hole incident was happened. Tight hole can be observed at the borehole and surface indicators. Indicators that are used to detect tight hole in the borehole are using MWD, LWD and wireline. ROP that was observed was decreased and DWOB that observed was decreasing. Tight hole can be analyzed from caliper log, which indicates that hole tightens with time or dissolves. Using GR log, clay formation that caused tight hole can identified by GAPI>40. UBI can also detect swelling which leads to tight hole.

In summarize for detecting tight hole at the borehole condition, Table 5 will summarize below.

Table 5. Wellbore Instability indicator due to tight hole at borehole condition

	ROP	DWOB	Caliper	Gamma Ray	UBI
Chemical Activity	Decrease	Decrease	Borehole reduction	GAPI > 60	Swelling Detected

At the surface, tight hole condition can be observed by some indicators. Pump pressure was increased because of the tight hole will make it harder to pump the mud. Mud flow is decreasing because shale will interact with the drilling mud that cause mud weight and solids is increasing due to shale swelling. Cuttings and cavings that observed at the surface has special characteristics, for instance soft and Gumbo cutting. Hookload has large overpull at connections, and the surface torque is increasing.

Indicators at the surface will be summarized at the Table 6 below.

Table 6. Wellbore instability indicator due to tight hole at surface condition

	Pump Pressure	Circulation	Mud	Cutting and Cavings	Hookload	Surface Torque
Chemical activity	Increase	Flow decrease	MW & solids increase	Soft water soluble, Gumbo	Large overpull at connections	Increases

For preventing and mitigating the tight hole phenomena, some drilling actions can suppress the instability whereas some actions has no influence on instability or makes it worse. Drilling actions that can suppress the instability are infrequent wiper trips and use inhibitive mud. Drilling actions that has no influence on instability or makes the wellbore instability worse are frequent wiper trips, decrease ROP, increase Mud Gel Strength, increase mud circulation rate, limit outer diameter (OD) size/drill collars, increasing mud weight, decreasing mud weight, use minimum overbalance (200 psi), ensure overbalance exceeds 200 psi, add fluid loss agents, and minimize swab and surge affects.

Drilling actions that can worsen wellbore instability and suppress wellbore instability can be summarized at the Table 7 and Table 8 below.

Table 7. Drilling Action Suppress Wellbore Instability

	Infrequent Wiper Trips	Use Inhibited Mud
Chemical Activities	√	√

Table 8. Drilling Actions Worsen Wellbore Instability

	Frequent Wiper Trips	Decrease ROP	Increase Mud Gel Strength	Increase Mud Circulation Rate	Limit OD size/ DC	Increase MW	Decrease MW	Use Minimum Overbalance Pressure (200 psi)	Ensure Overbalance exceeds 200 psi	Add Fluid Loss Agents	Use Inhibited Mud
Chemical Activities	√	√	√	√	√	√	√	√	√	√	√

7. CASE STUDY

Field X is located in Indonesia. It has producing wells which are used to produce geothermal products such as steam and hot water from the reservoir. It also has injection wells which are used to inject producing fluids back to the reservoir.

This paper will study stuck pipe problems which was occurred during drilling in Field X. Examples for the studies will be taken from well X-1, which has produced geothermal products and well X-2, which has known and used for injecting producing fluids.

7.1 Well X-1

Well X-1 is a directional well with kick-off point (KOP) 700 m and reach true depth (TD) at 2,366 m. This well has been plug at 1,596 m until 1,617 m depths and sidetrack was done to correct the well trajectory. Due to stuck pipe problem, plug back was done at 1,561 m until 1,651 m depth and sidetrack was done again at 1,615 m depth.

Dogleg severity at well X-1 is high enough at depth interval 1,100 m to 1,129 m, which approximately measured at 2.9°/100 ft and at depth interval 1,129-1,157 m with dog leg severity (DLS) measured is 3.25°/ft. Consequently, casing failure/casing was torn down was observed.

During drilling, problems that were encountered was mainly caused by tight hole which led to stuck pipe phenomena. When drilled 17-1/2" hole, tight hole and stuck pipe incident was observed and identified at 637 m, 650 m, and 882 m. Drilling operation was continued to 1,688 m TD and tight hole and stuck pipe also happened when 17-1/2" hole was drilled. As a result, using 175 klbs over-pulled, drill pipe can be freed.

Tight hole and stuck pipe happened again at 1,717 m when drilling 12-1/4" hole. Overcoming this problem jars and air drilling was used, and successfully freed the drill pipe. Stuck pipe phenomena was also taken place at 1,750 m depths when drill string was tripped in, but this problem can be countered. Stuck pipe problems also happened again when drilling 12-1/4" during making connection at the wellbore.

After 5 times back-off operation was done, back-off happened at 1,724 m with top of fish was at 1,694 m. As the result, fish was cemented from 1,617 m – 1,596 m and sidetracked operation was done at 1,617 m.

Stuck pipe incident also happened at 12-1/4" sidetracked hole at 1,664 m when survey operation was done. Lost circulation phenomenon was also followed this incident. During drilling 12-1/4" sidetracked hole, fish was also occurred at 1,638 m, so plug back cementing was done at 1,651 m until 1,561 m. Sidetrack#2 hole was drilled at 1,615 m depths. When drilling 8-1/2" hole at the sidetrack#2 hole, stuck pipe occurred at 1,988 m while survey was being done. Aerated mud solution was used to work on pipe and it can freed the drill pipe.

The drilling problems that were happened during drilling well X-1, can be simplified in the table below.

Table 9. Drilling Problems at Well X-1

Case	Remarks
Tight Hole and Stuck Pipe (17-1/2" Hole)	Found at 637 m, 650 m, and 882 m when drilled 17-1/2" hole.
Tight Hole and Stuck Pipe (17-1/2" Hole)	Tight hole was happened at 1,688 m. Overpulled with 175 klbs. Succeeded
Tight Hole and Stuck Pipe (12-1/4" Hole)	Stuck pipe at 1,717 m depths. Work on stuck pipe using jars and air drilling. Succeeded
Stuck Pipe (12-1/4" Hole)	Stuck pipe happened at 1,750 m. when pipes were tripped in. Stuck pipe was mitigated.
Stuck Pipe, Back-Off, Fishing, and Plug (12-1/4"	Stuck pipe happened at making connection at the wellbore. After 5 times back-off were done, back-off happened at 1,724 m with top of fish at 1,694

Hole)	m. Fish was cemented from 1,617 m – 1,596 m.
Sidetracked #1	Side tracked from depth 1,617 m.
Stuck pipe (12-1/4" ST#1)	Stuck pipe happened at 1,664 m depths when survey was done with followed by lost circulation.
Back-Off (12-1/4" ST#1)	Back-off was done using jars and piston top of jars were left at the wellbore. Top of fish at 1,570 m (3xHWDP, 4xDC, monel, stabilizer, MWD, mud motor, 12-1/4" bit). Second back-off was done with free point at 1,647 m.
Fishing and Cement Plug Back (12-1/4" ST#1)	Fish that was obtained has 58.91 m length, but was not fully obtained (35.5 m length left in the wellbore). Overshot was run above fish and jar was done at 1,629 m. Top of fish at 1,638 m. Cement plug back was done at 1,651 m until 1,561 m.
Sidetracked #2	Side tracked from 1,615 m depths.
Stuck pipe (8-1/2" hole ST#2)	Stuck pipe at depth 1,988 m when survey was done. Work on pipe as done using aerated mud. Succeeded

7.2 Well X-2

Well X-2 was a directional well with KOP at 523 m and TD at 2,366m MD.

Dogleg severity at well X-2 is high enough at interval depth 530 m – 617 m, which approximately reached at 2.77 – 4.59^o/100 ft, 886 m – 906 m with DLS equals to 2.78^o/ft, 1,862 m – 1,910 m with DLS equals to 3.04^o/ft, and interval depth 2,334 m – 2,381 m with DLS equals to 2.93^o/ft. Casing failure or casing was torn down was probably happened due to high DLS.

During drilling operations, problems that were encountered was mainly caused by stuck pipe and tight hole. Tight hole was faced at 1,095 m depths that led to stuck pipe. Drilling jar was malfunctioned and Pipe-Lax was pumped. As the result, fish was occurred in the wellbore. In order to mitigate the fish, back-off operation was done at 1,040 m and fishing job was done in 64 hours. Next, when drilling at interval depth 1,041 m – 1,176 m, tight hole was observed. Penetrations that was done were failed. Due to this cause, cement plug was done but the results was nothing as the wellbore instability.

Problems that countered that were caused by stuck pipe was, when drilled interval depth 2,205 m – 2,220 m, stuck pipe was taken place at the wellbore. Wash and reaming operation was done due to this operation. Fish which was has 55.46 m length was observed, so back-off operation was done at 2,160 m. At the next drilling operation, stuck pipe was happened again at 2,602 m. The operation that was done was work on pipe. Finally, the pipe can be released from the stuck condition.

The drilling problems that were happened during drilling well X-2, can be simplified in the table below.

Table 10. Drilling Problems at Well X-2

Case	Remarks
Stuck Pipe, Back-Off, and Fishing	Tight hole was analyzed and faced at 1,095 m depth that cause stuck pipe. Drilling jar was malfunctioned and Pipe-Lax was pumped. Back-off operation was done at 1,040 m and fishing job was done (64 hours)
Tight Hole	Happened at interval depth 1,176 m – 1,041 m. Penetrations were failed. Cement plug was done but wellbore instability could not be encountered.
Stuck Pipe, Back-Off, and Fishing	Stuck pipe at 2,205 m – 2,220 m. Wash and reaming was done. At 2,160 m back-off was done. Fishing was observed and fishing operation mitigation was done.
Stuck Pipe	Stuck pipe at 2,602 m. Work on pipe and pipe can be released.

CONCLUSION AND RECOMMENDATION

1. Wellbore instability are the main problem which leads to many other drilling problems, such as pack-off, lost circulation, undergauge hole, and restricted annulus causing stuck pipe.

2. Stuck pipe leads to loss of time and can be very costly, including lost drilling time during freeing the pipe, cost of fishing, and even it risks abandonment of tools inside the hole.

3. Prevention and mitigation method have been explained in each cause of stuck pipe in this study.

4. From the study case that is happened in Field "X" in Indonesia, stuck pipe problem is the main drilling problem for drilling in geothermal operation. This was due to tight hole indication in the Field "X".

NOMENCLATURE

BHA = Bottom Hole Assembly

DC = Drill Collar

DLS = Dog Leg Severity

DWOB = Drilling Weight on Bit

GR = Gamma-Ray

GAPI = Gamma-API scale

hrs = hours

HWDP = Heavy Weight Drill Pipe

KOP = Kick of Point

LCM = Lost Circulation Material

m = meters

MD = Measured Depth

MWD = Measurement While Drilling

OD = Outer Diameter

psi = pound per square inch

ROP = Rate of Penetration

RPM = Rotation per Minute

ST = Sidetrack

TD = True Depth

UBI = Ultrasonic Borehole Imager

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