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An Integrated Management of Drilling Design and Operational of Geothermal Wells

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ABSTRACT

As energy demand increase, people started to seek and develop new alternative energy sources. One of those is geothermal energy. Although drilling for geothermal energy is quite similar to drilling for oil and gas, there are some aspects of it that are unique. The main challenges associated with geothermal drilling are related mostly to the hardness of igneous and metamorphic rocks being drilled, the high temperature of the formation (Marbun et al., 2012). Also, there are other challenges encountered in drilling operations including total loss of circulation, low penetration rate, high temperature damage of directional drilling steering tools and mud motors, breakdown of drilling foam structure at high temperatures, high drill string torque, loss of cement slurry and others (Zhang et al., 2012). As the well has been drilled, evaluation is a critical step to improve the next drilling operations. To obtain great learning and convert it into better operations, requires experiences from previous operations. The most important is analyzing problems that occurred during the drilling process. Good management of drilling operation has to apply well planning, execution and evaluation continuously in order to achieve maximum result.

The methodology used in this study is integrated drilling management. An improvement towards drilling design and operation is achieved by considering the geological conditions and production target. Well planning data are collected and compared with real condition. The goal is to find the compatibility between the design and the well condition such as in lithology and formation temperature. Properties analyzed include hole cleaning, bit selection and casing design.

The methodology of this study was implemented in a geothermal field resulting in analysis of the causes of drilling problems, proper design to avoid the problems, and recommendations of procedural operations for next drilling activity. Implementation of the method would lead to great cost saving for the operation by overcoming the problems encountered while drilling.

1. INTRODUCTION

The objective of drilling a geothermal well is to make the hole as quickly as possible subject to technological, operational, quality and safety constraints associated with the process. The objective is frequently conflicting and depends on factors that are interrelated, and vary with respect to time, location, and personnel, and are subject to intrinsic and other uncertainty. It is common practice for operators to rely on their well delivery personnel (i.e. drilling engineers and/or superintendents) to perform drilling evaluation and analysis to drilling tools and performances and wellbore-related failures. However, integrated and comprehensive evaluation into non-productive time (NPT) and other drilling variables requires additional time and effort which usually the well delivery personnel could not provide.

A successful construction of wells containing potential or encountered trouble zones depends on accurate analysis of all available well data to deliver the well and its objectives. Often, data and learning from previous well construction attempts within a project are ignored. The next well design is left unchanged and the well is drilled with the same mindset that was used on a previous failed attempt, expecting different results (York, et al., 2009). This approach has been frequently practiced in drilling planning and operational. The aim of this study is to generate a new improved methodology to evaluate a drilled geothermal well to avoid similar failure and over-cost for next drilling project.

2. WELL PLANNING AND WELL EVALUATION

2.1 Well Planning

Well planning is perhaps the most demanding aspect of drilling engineering. It requires integrated engineering principles, corporate or personal philosophies, and experience factors (Adams, 1985). Although well planning methods and practices may vary within the drilling industry, the final result should be a safely drilled, minimum-cost hole that satisfies the reservoir engineer's requirements for geothermal production (Figure 1).

2.2 Drilling Performance Evaluation

There are many factors and events which impact the time and cost to drill a well. Those factors can be classified as either observable or unobservable (Kaiser, 2007). Measurable factors include physical characteristics, geology, and drilling parameters of the well, while indirect characteristics, such as operator's experiences and wellbore quality, will be represented by proxy variables. Several factors such as well planning and execution, team communication, leadership, and project management skills will also impact drilling performance, but to capture and identify the influence of these variables are often beyond the scope of analysis. There is no way to identify all the relevant characteristics of drilling, but many factors can be identified and in practice it is necessary to identify only the set factors that describe the primary elements of the process.

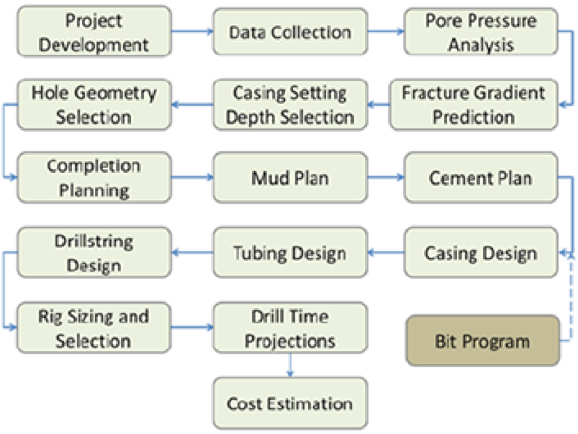

Figure 1: Flow diagram for well planning, Adams (1985).

3. METHODOLOGY

The methodology which is developed and used in this study is as shown by flowchart in Figure 2.

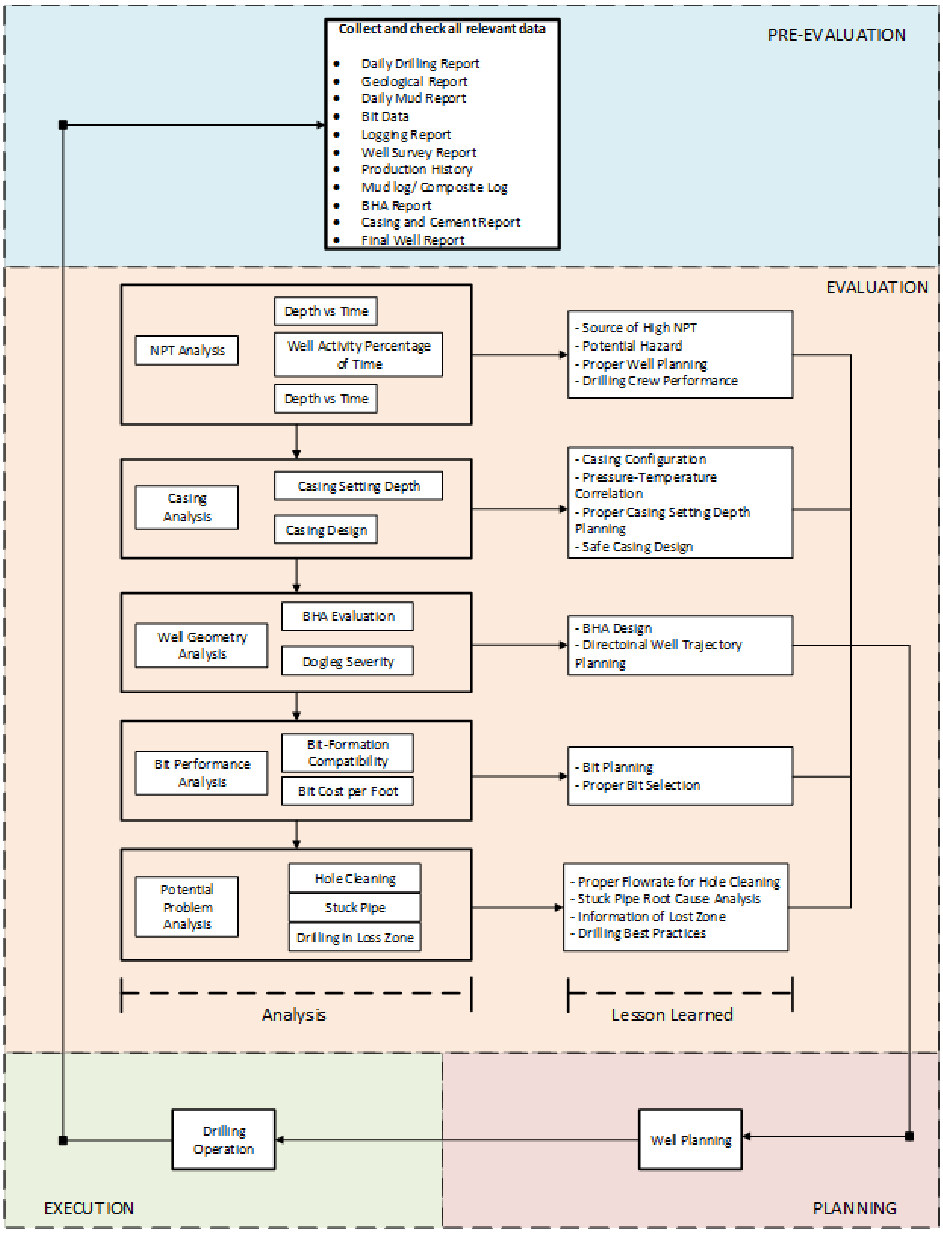

Figure 2: Flowchart of geothermal drilling evaluation.

4. CASE STUDY

4.1 Well Information

Well X-34 is located in X Field in Indonesia. The well's information is described as below:

Well Name : Well X-34

Classification : Development Well

Total Measured Depth : 1782 m

See Figure 3 for detail of X-34 well schematic.

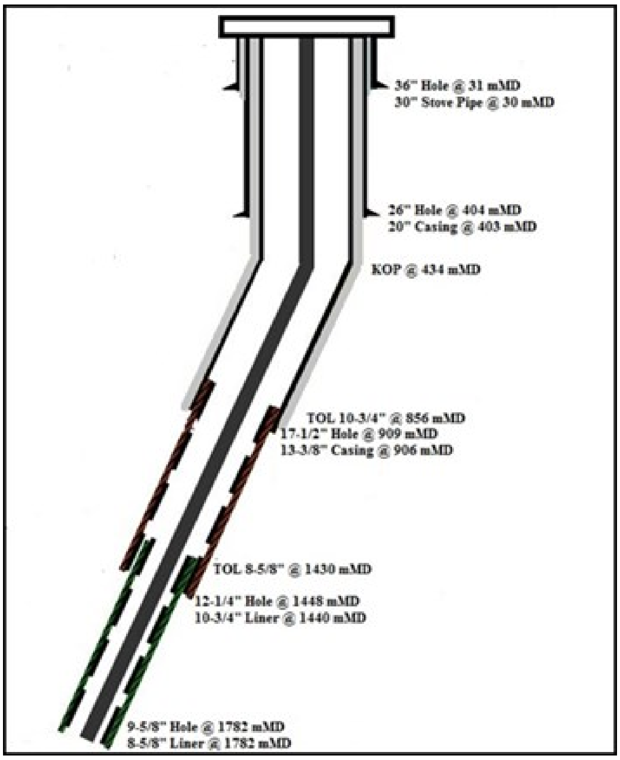

Figure 3: Well diagram.

4.2 Non-productive Time Analysis

Figure 4b shows a comparison of planned and actual drilling operation time for X-34 well. The planned drilling operation time was 42 days, whereas the actual time took 55 days to finish. It is also shown in this figure that the actual drilling did not reach the planned target depth. Most of the lost time occurred during the drilling of 17-1/2" hole section, as shown in Figure 4a, where there were more than 10 days of NPT. The NPT occurred due to stuck pipe problem that the drilling crew faced and also the efforts needed to release the pipe. After the drill string was released, a decision to make a sidetracked hole was taken. The process also contributes to the NPT. The other causes of the high NPT value are equipment failures such as top drive and water pump. This occurrence should not happen if the equipment were properly prepared and checked. The equipment issue, related to availability, conditions, and performance should be more emphasized to prevent big loss time or to reduce NPT, especially in a remote area. The percentage of NPT versus Productive Time (PT) for well X-34 is shown in Figure 4c where the total PT is 85% and the total NPT is 15%.

4.3 Casing Setting Depth

Figure 5 shows casing setting depth of well X-34 and also the top of the high temperature reservoir where temperature of 220^{o}C is noted.

Casing setting depth of well X-34 is evaluated using Philippine Method (Figure 6). From the graphic plot of pore pressure and overburden pressure with addition of temperature of formation, production casing shoe (13-3/8") should be set of 935mTVD and surface casing shoe at 410mTVD. Actual casing shoe, as shown in Figure 5, was at 860mTVD for production casing (13-3/8" casing) and 403mTVD for surface casing (20" casing). Compared to the correct setting depth for this well, the actual shoe was 75 m shallower. The effect of inappropriate casing depth as done in this well is influx of cooler formation fluid into the well. It will lead to reduction of enthalpy and production of the well.

4.4 Casing Design

Casing design is also evaluated to obtain information about casing performance. The importance of this evaluation is to know whether the casing set for the wells were able to hold several loads while drilling or production operations. Evaluation for burst load, collapse load, biaxial load and tension load for the production casing is performed by using maximum load method. However, evaluation for production load cannot be performed because production data such as erosion rate, corrosion rate and steam velocity are not available.

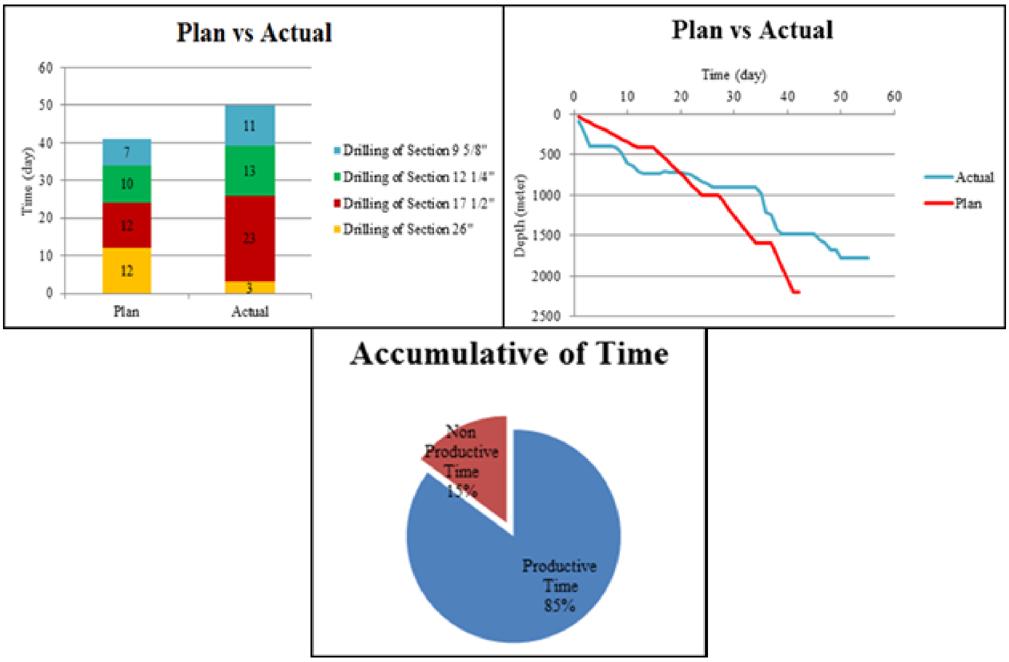

Figure 4: Graphs a, b, and c is arranged clockwise starting from top left and are described as follows: a) Comparison of planned versus actual time of each section in well X-34; b) Graph of planned and actual day versus depth of well X-34; c) Comparison of productive time versus non-productive time of well X-34.

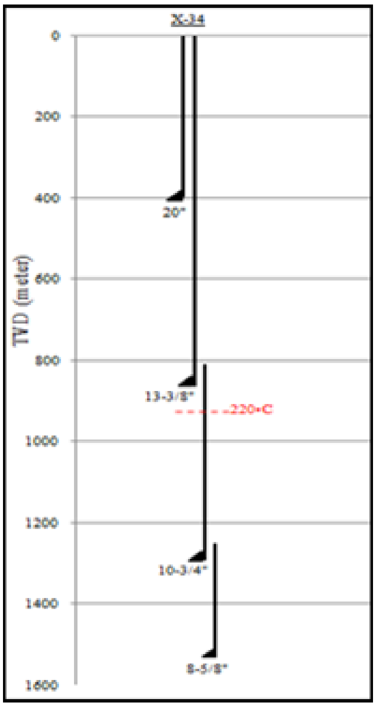

Figure 5: Casing shoe depth of well X-34.

Casing rating especially for burst, tension and collapse generally found in API table doesn't count the effect of temperature. In this paper, the casing rating is calculated with the correction to the temperature which impact to reduction of casing yield strength. Tension rating and burst rating from the table are then recalculated by multiply them with temperature correction factor. However, for the calculation of collapse rating, it is slightly different (Syarief, 2012). Parameters of collapse is calculated first, ratio of casing diameter and thickness is then used to determine the type of collapse experienced by the casing (elastic collapse, transitional collapse, plastic collapse).

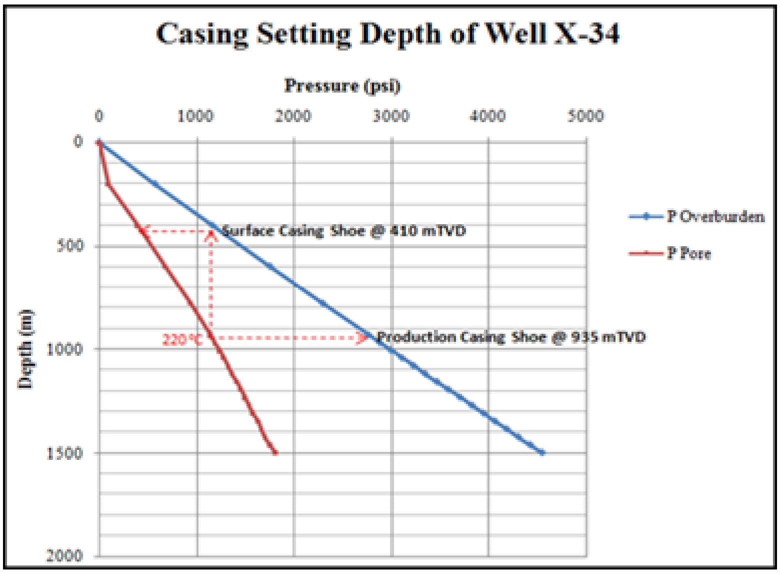

Figure 6: Casing setting depth of well X-34.

Figure 7 shows the burst load, collapse load and tension load experienced by L-80 68 ppf casing in well X-34. There are no problems for burst load and tension load which is indicated by separated design line and burst rating line in Figure 7a and tension rating line in Figure 7c. However, as shown in Figure7b, casing design of this well is not safe due to collapse load which is higher than collapse rating of the casing. Casing collapse would cause casing damage which lead to influx of formation fluid into the well. It is also confirmed by well inspection history that there was casing collapse and it lead to the reduction of the production. Production load evaluation is not performed for this well due to several data unavailability.

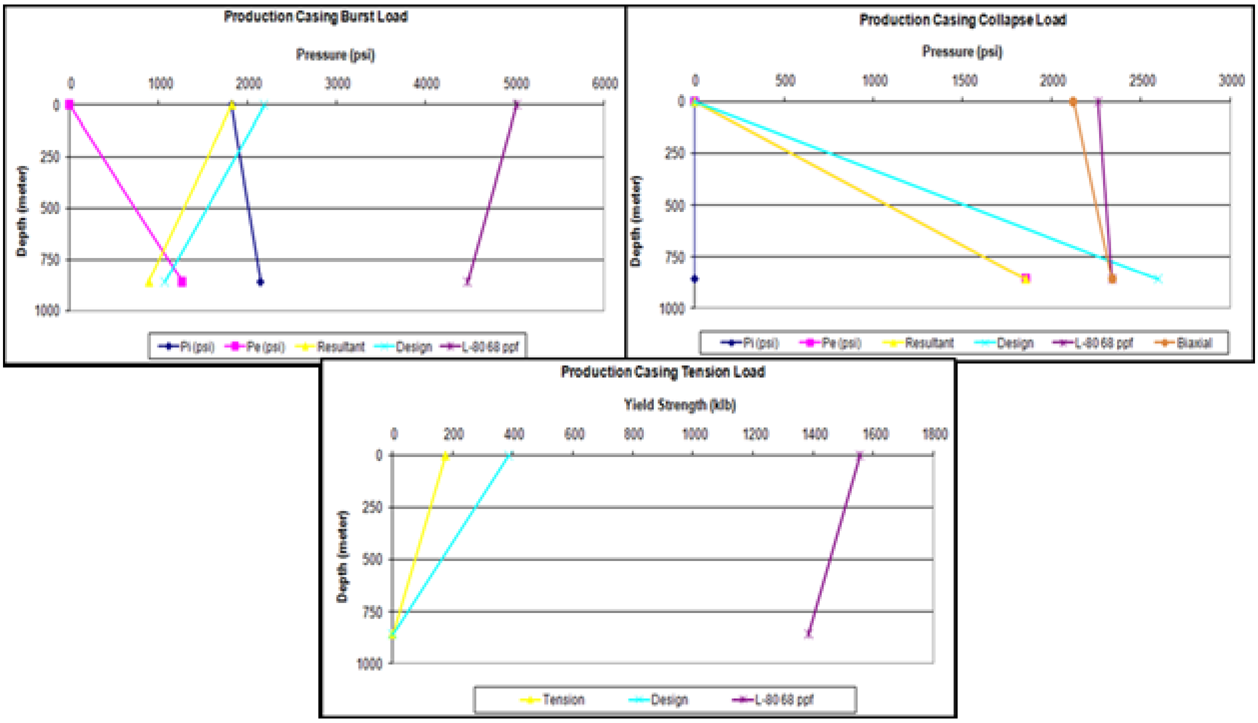

Figure 7: Graphs a, b and c is arranged clockwise starting from the top left and are described as follows a) Production casing burst load of well X-34; b) Production casing collapse load of well X-34; c) Production casing tension load of well X-34.

4.5 Well Geometry

During drilling operation, differences in rock characteristics would cause deviation in direction compared to planned drilling trajectory. It is also occurred while doing directional drilling with directional bottomhole assembly (BHA), sudden change in inclination or azimuth would cause deviation of the well direction. Drastic change in well direction is commonly called dogleg.

Well geometry analysis of well X-34 shows that the Dogleg Severity (DLS) measured in this well is quite extreme, higher than the maximum allowable value of DLS which is 2°/30 m for geothermal well. Consequently, on each point of casing with high DLS will experience a high pressure concentration and high temperature which will cause deformation of the casing around the area with high DLS.

There are also several additional factors affecting the deformation of well X-34 casing:

- Axial compressive strain along casing due to pressure stress and temperature. The decrease of axial compressive strain causes reduction of casing strength to restrain casing collapse. In a deviated well, compaction leads to the deformation of cross-section casing into an oval shape due to the decrease in lateral pressure support.
- Loss or reduction of lateral support.

Another impact of high DLS in a well is the occurrence of casing wear. Casing wear leads to several related problems, such as:

- Reducing casing strength to restrain loads experienced at the casing in the productive time of the well.
- Cavity or hole on the casing in a severe condition. This hole will expose formation as well as formation fluids to the well and give a big impact towards the performance of the well due to enthalpy reduction, scale buildup, or influx of formation fluids into the well.

Table 1: Dogleg severity of well X-34.

X-34					
Survey Depth (meter)	DLS(°/30m)	Survey Depth (meter)	DLS (°/30m)	Survey Depth (meter)	DLS (°/30m)
0		**757**	**3.17**	**1163**	**1.41**
377	**0.03**	**786**	**6.19**	**1191**	**2.33**
417	**0.13**	**815**	**4.3**	**1221**	**0.82**
446	**1.36**	**844**	**3.43**	**1247**	**1.35**
475	**5.16**	**874**	**2.03**	**1279**	**0.7**
504	**2.44**	**911**	**1.22**	**1308**	**1.55**
532	**2.1**	**940**	**1.11**	**1336**	**1.1**
561	**3.9**	**969**	**3.65**	**1365**	**0.94**
590	**3.89**	**998**	**1.33**	**1395**	**3.3**
618	**4.67**	**1027**	**1.55**	**1424**	**1.46**
645	**4.12**	**1056**	**1.45**	**1495**	**1.96**
649	**0.99**	**1075**	**2.75**	**1708**	**0.17**
700	**3.08**	**1104**	**2.61**	**1782**	**0.17**
726	**2.06**	**1133**	**2.43**		

Dogleg severity (0 < DLS < 1°/30m) is acceptable and safe for casing.

Dogleg severity (1 < DLS < 2°/30m) is risky and casing problems would probably occurred.

Dogleg severity (>2°/30m) is critical and would cause casing problems.

4.6 Bit Performance Analysis

A bit performance depends on several variables such as bit type, bit design, formation rock hardness and wear which are experienced by the bit. As for geothermal environment, where harder rock is commonly encountered and additional of high temperature formation, proper bit selection becomes critical issue. Improper bit selection will cause many problems including slow rate of penetration (ROP) and bit damage. These problems will influence drilling performance and operational, resulting for extra bit change which is not planned in drilling program and lead to a longer time of the drilling operational compared to the drilling plan.

Evaluation of bit performance is conducted to prevent previous unwanted incident occurred. Improvements on bit usage for the next drilling operation are expected following the evaluation on bit-formation compatibility based on formation penetrated by the bit. For more comprehensive analysis, rock strength and hardness level should be recorded with detailed scale while drilling in order to get objective comparison.

Table 2 shows summary of bit data for 17-1/2" hole section drilling of well X-34. This table simply shows comparison of bit quantity, bit penetration interval, average ROP and penetration interval per bit for each well. Simple comparison of average ROP will lead to a conclusion that bit selection in section 12-1/4" well is the most optimum bit, resulting in 12.1 m ROP and only 47 hours bit used. This is not valid because type of formation rock penetrated by each bit is not included in the calculation. In order to get a more detail analysis, composite log/mud log, daily drilling report and dull grading bit data need to be checked to assure whether the bit is compatible to the formation drilled or not.

The composite log of well X-34 is assessed and information related to the formation rock is extracted. The composite log shows tuff and andesite were dominantly found at depth 100 – 900 m where the 17-1/2" hole section was drilled. Hardness level is stated to be moderate up to hard without any clear scale. It can be seen from table 2 that the average of ROP for each well is very low in this section, resulting 2.6 m/hr. Bit data is checked to obtain information about profile of the bit used to drill this section. All of the bits used have IADC Code 435, means milled tooth bit for medium soft formation and sealed bearing-gauge protected. Dull grading for each bit is also assessed to know bit condition after the drilling activity. Worn teeth (WT) and broken teeth (BT) are the most common problem found. WT is a normal dulling characteristic of the tungsten carbide insert bits, for geothermal cases worn teeth become faster to occur caused by high temperature of formation drilled and abrasive rock penetrated. In some formations, BT is kind of a normal wear characteristic of tungsten carbide insert bits and is not necessarily an indicator of any problems in bit selection or operating practices. However, if the bit run was of uncommonly short duration as in those wells, broken teeth could indicate one or more of the following: the need for a shock sub, too much WOB and/or RPM, or improper bit application. Broken teeth is not considered to be a normal wear mode for steel tooth roller cone bits and may indicate improper bit application or operating practices. Several causes of BT are as follows:

- Bit run on junk.
- Bit hitting a ledge or hitting bottom suddenly.
- Excessive WOB for application. Indicated by broken teeth predominantly on the inner and middle row teeth.
- Excessive RPM for application. Indicated by broken teeth predominantly on the gauge row teeth.
- Improper break-in of bit when a major change in bottom hole pattern is made.
- Formation too hard for bit type.

From the previous explanation, it is highly possible that bit damage and slow ROP were caused by a very hard formation for such a bit type. This can be improved by the use of bit designed for harder rock classification. Also, WOB and RPM need to be controlled while drilling for next well because excessive WOB and RPM can be the critical factors of bit damage.

Table 2 also shows summary of bit data for 12-1/4" hole section. Average of ROP for this section is relatively higher than the previous section. Dominant lithology in this section is relatively the same as 17-1/2" section, andesite and tuff with hardness level soft-hard, also interbedded soft lithology is found in top part of the section based on composite log. This could be the cause of high ROP in this section. Bit Code 517 was used to drilled along this hole section.

From dull grading bit data, bit used was known to be had worn teeth dull characteristic. Reason of this problem probably because the bit was 517 Code, which is known to be bit used for soft formation. The bit damage is caused by penetration of harder rock. Drilling using hard type formation bit is recommended and if possible use higher classification than 517 IADC Code. Also, WOB and RPM need to be controlled during drilling for next well because excessive WOB and RPM can be the critical factors of bit damage.

Table 2 also contains summary of bit data for 9-5/8" hole section. Lithology penetrated in this section is similar to 12-1/4" hole section which is dominantly consisted of tuff and andesite. However hardness level of the rock in this section is relatively harder than previous ones. Bits used to drill in this section have IADC Code 517. Average ROP for this last section is relatively very slow compared to average ROP in 12-1/4" hole section. Incompatibility of the bit and drilled formation caused broken teeth occurred on some bits. It is recommended that the bit is designed for higher hardness classification.

Table 2: Summary of bit data of well X-34.

No	Hole Section	Bit quantity	Depth (m)	Bit penetration interval depth (m)	Bit hours (hrs)	Average ROP (m/hrs)	Penetration interval per bit (m)
1	17-1/2"	5	403 - 909	506	193	2.6	101
2	12-1/4"	1	909 - 1488	579	47	12.1	579
3	9-5/8"	2	1488 - 1782	294	66	4.4	147

4.7 Cutting Transport Analysis

Hole cleaning becomes more complicated for a slanted well and if it is not well controlled, problems will be encountered such as stuck pipe (fishing or plug), increasing in torque and drag, difficulty in set casing into target depth and difficulty while logging. Factors affecting hole cleaning are as follows: eccentricity, inclination, drill pipe rotation, drilling fluid flow rate (annular velocity and flow regime), rate of penetration, drilling fluid rheology, and cutting properties (size, shape and density).

In this analysis, actual flow rate used in the field is evaluated whether it comply with minimum flow rate from the calculation or not. As a result, the mechanism of cutting transport can be assessed. If the actual flow rate is above the minimum flow rate from calculation, the cutting is transported properly. Otherwise, the cutting is not transported properly and it would lead to stuck pipe problem. Cutting transport data for the well are shown in table 3.

Performance analysis of cutting circulation in well X-34 is classified into 3 sections: 17-1/2" hole, 12-1/4" hole and 9-5/8" hole.

Table 3: Cutting transport data of well X-34.

Section	Depth (meter)	Minimum Flow Rate (GPM)	Actual Flow Rate (GPM)	Remarks
17-1/2"	403 - 629	1595	600-800	Cutting is not transported properly
	629 - 731	1600	800-900	Cutting is not transported properly
	668 - 735	1580	850-925	Cutting is not transported properly
	735 - 866	1550	750-860	Cutting is not transported properly
	866 - 909	1600	750-860	Cutting is not transported properly
12-1/4"	909 - 1488	950	750-800	Cutting is not transported properly
9-5/8"	1488 - 1676	455	700-780	Cutting is transported properly
	1676 - 1782	675	700-950	Cutting is transported properly

4.7.1 17-1/2"Hole Section

The drilling of 17-1/2" hole section started after setting 20" casing. Well X-34 begins to slant in this section, however the inclination still can be classified into low inclination (less than 20^o). As shown in table 3 above, flow rate required to circulate cutting is very high, up to 1600 GPM. Meanwhile, actual flow rate for this section is 600 – 925 GPM. Drilling operation with pump rate below minimum flow rate would cause problems in cuttings circulation from bottomhole to the surface and it will also lead to other drilling problems such as stuck pipe and reduction in rate of penetration due to the regrinding of cuttings which are unsuccessfully circulated. The daily drilling report shows that at the drilling operation of 17-1/2" hole, stuck pipe problem was encountered.

4.7.2 12-1/4" Hole Section

Lower actual flow rate than minimum flow rate required was found during drilling this section as shown in table 3. The consequences of the inadequate hole cleaning are drilling problems such as stuck pipe and reduction in rate of penetration due to the regrinding of cuttings which are unsuccessfully circulated. Stuck pipe was encountered during drilling this section.

4.7.3 9-5/8" Hole Section

For the drilling 9-5/8" hole, inclination of the wells has to be considered due to high inclination (up to 44^o) Minimum flow rate required for drilling this section due to calculation is 450 – 675 GPM. Based on daily drilling report, well X-34 had higher flow rate than the minimum required flow rate. No stuck pipe was found during drilling this section.

4.8 Stuck Pipe Analysis

When the drill string is no longer free to move up, down, or rotates as the driller wants, the drill pipe is in term of stuck. Sticking can occur while drilling, making a connection, logging, testing, or during any kind of operation which involves leaving the equipment in the hole. During drilling a geothermal well, stuck pipe is one of the most common problems occurred as discussed in previous subsection and would cause major loss of time.

The consequences of a stuck pipe are very costly. They include lost drilling time when freeing the pipe, high wasting time and cost of fishing: trying to pull out of the hole the broken part of the BHA, and abandonment of the tool in the hole because it is very difficult or too expensive to remove it.

In order to prevent those problems to be occurred and to improve the drilling performance, evaluation towards stuck pipe incidents is performed. A few variables must be taken into account when dealing with stuck pipe including pore pressure of the formation, drilling parameters from daily drilling report, cutting information from daily mud report, and the depth versus time (the longer the pipe in the hole without action, the more likely the pipe to get stuck). Summary of stuck pipe incident is as shown in table 4.

Drilling parameters from daily operational is checked, information related to stuck pipe identification is as shown in table 4. Activity performed to free the string is also recorded and analyzed. Information related to cutting is not available due to unavailability of daily mud report.

Depth at where the pipe stuck is investigated. Dogleg severity and hole cleaning at the depth is checked to confirm what mechanism caused the stuck pipe. Mud weight is normal and overbalance pressure is acceptable, so the possibility of differential sticking can be neglected. Stuck pipe caused by key seating mechanism is also impossible since dogleg severity at depth of the incident is small, also as shown in table 4, stuck pipe is encountered while drilling activity, not tripping in as the key seating mechanism identification. Packoff is the most possible cause due to the signs and identifications of the incidents. Several signs and identifications of stuck pipe caused by packoff are as follows:

- Insufficient cuttings on shaker.
- Excessive overpull at connections and trips.
- Reduced overpull when pumping.
- Increase in pump pressure and pressure spikes when hole momentarily plugs up.

- Pump pressure much higher than predicted using hydraulics program.
- Encounter loss zone.
- Stuck occurred while drilling.

Packoff mechanism is occurred when drilling cuttings or avalanche of formation settled around drill string thus causing the pipe stucked. The conditions which affect pack-off mechanism are as follows:

- Drilling in a fault zone, so that it causes the formation to be easily collapse and settled around the drill string which cause stuck pipe. The effect of BHA vibration on the drill string also leads to the formation collapse. From all of the stuck pipe mechanisms, packoff mechanism is often occurred while drilling operation instead of tripping or making connection of the drill string. The indications of this stuck pipe are the possibility of loss circulation or increasing pit volume (gain), the existence of large size cuttings, and cuttings are filling the borehole.
- Poor hole cleaning will cause cuttings unable to be circulated to the surface and settle in the borehole. This condition often occurs at a deviated well with high inclination where the circulation is quite hard to be done efficiently due to tendency of the formation of cutting bed. Inadequate circulation rate and inappropriate drilling fluid properties are the main cause of cuttings unable to be transported to the surface.

Table 4: Summary of stuck pipe of well X-34.

Well	Section	Depth (mMD)	Indication	Activity on stuck pipe
X-34	17-1/2”	731	-Total Loss was occurred -High pump pressure -Sliding Drilling	-Pump 50 bbls spotting fluid -Pump LCM 50 bbls -Pump water into annulus periodically -Jar up and jar down
	12-1/4”	1478	-Total Loss was occurred -High pump pressure -Blind Drilling	-Jar up and jar down -Air drilling -Pump 40 bbls spotting fluid -Pump water into annulus

5. LESSONS LEARNED AND RECOMMENDATIONS

Lesson learned and recommendations are shown in Table 5.

6. CONCLUSIONS

- Well X-34 has been evaluated and analyzed based on developed methodology. Methodology used to evaluate well X-34 covers NPT analysis, casing analysis, bit analysis, well geometry analysis and potential problem analysis.
- The recommendations for well X-34 were obtained, comprise of drilling procedures, casing setting depth, casing design, hole cleaning, drill bit and rock formation analysis.

NOMENCLATURE

1 lb = 0.4536 kg;

1 feet = 0.3048 meters;

1 in = 0.0254 meters;

1 day = 86400 s;

1 cp = 1×10^{-3} Pas;

1 GPM = 6.3083×10^{-5} m^3/s

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Table 5: Summary of lessons learned and recommendation.

Evaluation	Lessons Learned	Recommendations
Non Productive Time	Analysis of NPT shows that well X-34 is not well drilled with NPT above 10%. The amount of NPT is dominantly caused by stuck pipe problem. Equipment failure is also contributed into NPT as found in every well.	Designing the well, particularly preparation in time, equipment and procedures are critical issue. Drilling tools and equipment should be maintained routinely to prevent sudden failure while drilling operation. Best practices for stuck pipe problem should be done when the incident occurred.
Casing Setting Depth	Improper casing setting depth was found at well X-34 design. Production casing shoe was set shallower than it should be. Thus, it would lead to influx of cooler formation fluid into the wellbore and decrease the production.	Integrative study of geology, geochemist and reservoir should be conducted to have a pressure-temperature profile for the X field, in purpose of determining the point depth of top of reservoir. Therefore, Philippine Method should be used to determine the casing point.
Casing Design	Analysis of casing design for production casing considers temperature as it would reduce casing yield strength in axial and radial direction. This well is not safe due to casing design calculation. However, the evaluation only considers loads experienced by the casing during drilling operation, complete evaluation should be calculate production load too.	Higher grade and pounder of casing than L-80 casing should be set for the next drilling operation to overcome the temperature problem. Using of anti-corrosion material for casing is recommended due to H_2S encountered while drilling
Bit Performance	Broken teeth were commonly found in drilling using 435 and 517 IADC Codes. It indicates incompatibility between bit and formation drilled.	Bits used for drilling in X field should be able to drilled very hard formation. 537 bit code should be good to be used to avoid broken teeth problem and to get higher ROP
Well Geometry	Dogleg severity more than 2^o/30 m is commonly found in well X-34. High DLS would cause casing wear and excessive stress to the casing	To avoid high DLS, a good planning trajectory should be performed. Also, survey has to be conducted as often as well to ensure there is no sudden change in azimuth or inclination while drilling.
Hole Cleaning	Hole cleaning problem is found in well X-34. Actual flow rate below minimum flow rate by calculation would cause slow ROP, cutting settling and stuck pipe problem.	Minimum flow rate to transport cutting should be calculated. Calculation should also consider high well inclination as found in well X-34. Pumping hi-vis routinely is recommended to clean the hole.
Stuck Pipe	All stuck pipe problems encountered in this well were caused by inadequate hole cleaning.	Stuck pipe can be avoided with proper planning of well trajectory and hole cleaning. If stuck pipe occurred, best practices to free the string should be done.