Bit Performance Evaluation in Geothermal Well Drilling

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ABSTRACT
Geothermal, as a new potential renewable source of energy, has been developing in all over the world rapidly. One of the ways in developing geothermal energy is by increasing the number of exploration and exploitation drilling wells. However, the need of appropriate and careful design is very important in geothermal well drilling operation due to harsh environment generally encountered. The design need to consider the holes condition, the well geometry, production rate, well lifetime and also other economic factors. In addition to that, one of the crucial factor is the bit selection method which will contribute to effective and low cost drilling operations.

An appropriate bit design will result in an effective penetration rate, since it is common in geothermal field that the formation is consist of igneous or metamorphic rock, which has high compressive strength and not easy to penetrate by using normal bit. Therefore, the bit performance analysis of a geothermal well is very important because it gives information, evaluation, and recommendation in selecting suitable bit for the next operations. This study will cover cost per foot (CPF) method which are very common used to evaluate the bit. Nevertheless, some modifications will be used to adjust evaluation methods toward geothermal conditions.

The aim of this study is to analyze and to compare bit performance from geothermal drilling data in a field. Analysis of the factors affecting the bit performance in geothermal wells drilling will be discussed as well. As a result, performance analysis can be made for various kinds of bit in geothermal wells which will lead to suggestions and recommendations in selecting bit effectively and efficiently for future geothermal well drilling operation.

1. INTRODUCTION
1.1 Geothermal Field
Geothermal field is different from oil and gas field. The basic differences are on three major factors which are rock type, temperature and pressure. Common rock types in geothermal reservoirs are igneous rocks and metamorphic rocks which include granite, granodiorite, quartzite, greywacke, basalt, rhyolite and volcanic tuff. Compared to the sedimentary formations of most oil and gas reservoirs, geothermal formations are, by definition, hot (production intervals from 160°C to above 300°C) and are often hard (240+MPa compressive strength), abrasive (quartz content above 50%), highly fractured (fracture apertures of centimeters), and under-pressured. They often contain corrosive fluids, and some formation fluids have very high solids content. These conditions mean that drilling is usually difficult, rate of penetration and bit life are typically low, corrosion is often a problem, lost circulation is frequent and severe, and most of these problems are aggravated by high temperature.

Geothermal systems can contain dissolved or free carbon dioxide (CO₂) and/or hydrogen sulfide (H₂S) gases. While these gases contribute to the corrosion problem, H₂S in particular limits the materials that can be used for drilling equipment and for casing to the lower strength steels, because higher strength steels will fail by sulfide stress cracking. H₂S can also present a substantial safety hazard during the drilling process. Also, the abrasive nature of many geothermal reservoir formations accelerates the wear on downhole tools. All of these limitation increase the cost of drilling geothermal wells.

1.2 Bit Description
Bit is one of the most important components that must be exist in the drilling process. The main role of this tool is to crush or cut the rock. It is assembled on the bottom of the drill string and must be changed when it becomes excessively dull or stops making progress in depth. Most of bits work by scraping or crushing the rock, or both, usually as part of a rotational motion. Everything on a drilling rig directly or indirectly assist the bit in crushing or cutting the rock.

Three main factors that affect most bit performance and bit lifetime are lithology, drilling parameters, and bottom-hole assembly design. The drilling engineer has little or no control over lithology, but significant improvements can sometimes be made by changing the latter two factors. The latter two factors is composed of three parameters that can be easily changed for any bit/formation combination. They are rotary speed, weight on bit (WOB), and hydraulics (combination of jet size and flow rate). It often takes some experimentation to determine the best combination of these values which is called drill-off test.

Bit selection and utilization is merely small part of the drilling process, but any errors in bit selection can lead to a big mistake such as longer drilling time, hole problems, etc. These problems will ultimately increase drilling cost.
1.3 Bit Evaluation Method
In this study, evaluation of bit depends on provided drilling data. Highly complex drilling data is simplified to obtain a comparison Cost per Foot (CPF) from each bit brand as linear function of engineering and cost. This simple model is not intended to compare overall drilling cost, but to compare relative cost of bit brand that have been used in Indonesia by many drilling company at many fields.

Several parameters for evaluation are bit cost, bit lifetime, rate of penetration, and operational cost. All of these parameters are divided into two zones with linear constraint. The purpose of this model is to analyze and to evaluate the efficiency of bit. Then, the evaluation is used for further optimization of brand selection and specification bit to improve the cost effectiveness of drilling.

1.4 Bit Performance in Geothermal
The main problem of geothermal drilling is low penetration rate of bit because of high torque friction, which is caused by subsurface condition comprises of hard formation and high temperature affecting performance of bit. The performance of bit can be checked in history data usage of bit. By evaluating the data, bit performance analysis can be made. The bit performance analysis depends on several variables such as bit type, bit design, formation characteristics, bit durability and drilling condition. If bit is not used in accordance with the subsurface condition and formation, it will lead to an escalation of bit cost and ineffectiveness in geothermal well drilling.

2. METHODOLOGY
In the end of drilling process, sets of evaluations are required in order to make references for the next drilling process. One example of the evaluation is bit performance evaluation that will show the bit utilization evaluation in the drilling process. In general, one of the methods used for bit evaluation is Cost per Foot method. The method has been generally used in oil and gas field application. However, in this study, this method is applied for geothermal field. Because of that, the main idea of this study is to validate the CPF method suitability in geothermal field.

2.1 Cost per Foot
Cost per Foot (CPF) method is a common method that is carried out to determine the performance parameters of a bit in drilling operation which include parameters such as the price of drilling bit, bit life, rate of penetration, equipment rental costs, operating time and cumulative depth obtained.

The formula applied in the method of Cost per Foot (CPF) is:

\[
CPF = \frac{C_B + (t_T+t_E)C_E}{f}
\]  

(1)

The basic assumption used in this method is that the difficulties in a particular well’s section compare to other well’s section in the same field remain the same. However, in practice, the Cost per Foot method still has several drawbacks. The drawbacks may come from different conditions experienced by the bit in the formation being penetrated. Thus, in an effort to analyze the performance of a bit relative to other types of bit, their conditions must first be adjusted. In other words, corrections will be necessary to this method when applied for the bit performance analysis.

The condition that must be obtained in the bit performance comparison is that the use of cost per foot method must be in a balanced comparison. It means that in comparing the bits performance, these bits must be in the same and balanced condition. It is important because it is the correct way to check the optimum performance given by each bit in the term of cost and technical parameters.

For geothermal conditions, there are also some corrections made before this method applied. The basic equation is:

\[ C_F = C_D + C_F \]  

(2)

Time parameter divided into three types:

\[ t = t_D + t_T + t_E \]  

(3)

Constant cost divided into two types:

\[ C_E = \sum C_{T_i} N_{T_i} + C_E \]  

(4)

Then, the interval cost become:

\[ C_F = C_D (t_D + t_T + t_E + \sum C_{T_i} N_{T_i}) + C_E \]  

(5)

In order to make a new bit compete with old bit economically, interval cost new bit must be less or the same with the old bit cost.

\[ C_{EN} \leq C_{EO} \]

\[ C_D (t_D + t_T + t_E) + \sum C_{T_i} N_{T_i} + C_{EN} \leq C_D (t_D + t_T + t_E) + \sum C_{T_i} N_{T_i} + C_{EO} \]  

(6)
The assumptions applied in this method are:

- The time and cost of end-of-interval does not change with a new bit,
- The costs of methods do not change,
- The daily cost do not changed,
- Drilling time is greater than tripping time and bottom hole assembly (BHA) \( t_D >> t_T \).

With the assumption above, the equations become:

\[
C_D (t_D + t_{EN}) + C_{BN} N_{BN} \leq C_D (t_{DO} + t_{EO}) + C_{BO} N_{BO} \tag{7}
\]

The relationship between the number of bits and the drilling time is as follows:

\[
t_{DK} = \frac{L_D}{ROP_k}
\]
\[
N_{DK} = \frac{L_D}{ROP_k + t_{SK}}
\]

Therefore, the condition of new bit, which can compete with the old bit economically, is as follows:

\[
C_D \left( \frac{L_D}{ROP_n} \right) + C_{BN} \frac{L_D}{ROP_n + t_{BN}} \leq C_D \left( \frac{L_D}{ROP_0} \right) + C_{BO} \frac{L_D}{ROP_0 + t_{BO}}
\]

\[
\frac{1}{ROP_n} \left\{ C_D + \frac{C_{BN} t_{BN}}{C_{BO} t_{BO}} \right\} \leq \frac{1}{ROP_0} \left\{ C_D + \frac{C_{BO} t_{BO}}{C_{BO} t_{BO}} \right\}
\]

\[
\frac{ROP_n}{ROP_0} \left\{ C_D + \frac{C_{BN} t_{BN}}{C_{BO} t_{BO}} \right\} \geq \left\{ C_D + \frac{C_{BO} t_{BO}}{C_{BO} t_{BO}} \right\}
\]

\[
C_D \left( \frac{ROP_n}{ROP_0} - 1 \right) \geq \frac{C_{BN} t_{BN}}{C_{BO} t_{BO}} - \frac{ROP_n}{ROP_0} \frac{C_{BO} t_{BO}}{C_{BO} t_{BO}}
\]

\[
C_D \left( \frac{ROP_n}{ROP_0} - 1 \right) \geq \frac{C_{BO} t_{BO}}{C_{BO} t_{BO}} \left( \frac{ROP_n}{ROP_0} \frac{C_{BO} t_{BO}}{C_{BO} t_{BO}} \right)
\]

\[
\frac{ROP_n}{ROP_0} \left\{ C_D + \frac{C_{BN} t_{BN}}{C_{BO} t_{BO}} \right\} \geq \frac{C_{BO} t_{BO}}{C_{BO} t_{BO}} \left( \frac{ROP_n}{ROP_0} \frac{C_{BO} t_{BO}}{C_{BO} t_{BO}} \right) + C_D
\]

\[
\frac{ROP_n}{ROP_0} \geq \frac{C_{BO} t_{BO}}{C_D + C_{BO} t_{BO}} \left( \frac{C_{BN} t_{BN}}{C_{BO} t_{BO}} \right) + \frac{C_D}{C_D + C_{BO} t_{BO}}
\]

Inequality linear relationship passes through the point \((0,1)\) on the dimensionless variables \( \{ROP_n/ROP_o\} \) and \( \{C_{BN}/t_{BN}\}/\{C_{BO}/t_{BO}\} \) (Figure 1). This line divides the space into two operational areas. The region above the line is cost effective area for the new technologies and region below the line indicates the cost-ineffective area.

![Figure 1: Inequality relationship to evaluate cost-effective bit](image-url)
3. FIELD STUDY
In this study, several field data have been prepared regarding bit performance evaluation. The data reviewed is obtained from geothermal field “L” in Indonesia. The field is located in a volcanic depression which has an area of 12 km$^2$. The depression is surrounded by complex volcanic chain system creating an immense potential source of geothermal energy.

The geothermal field “L” is counted as productive field in Indonesia and still in the process of further development. In its development, geothermal field “L” already has several wells consist of injection and production wells.

3.1 Rock Characteristics
Judging from the characteristics of the reservoir rock, as mentioned previously, geothermal reservoir is often consist of igneous or metamorphic rock which is harder than sandstone or limestone in a normal oil and gas field. The statement is also valid for reservoir characteristic in geothermal field “L”.

Regionally, rock distribution in this area is dominated by young volcanoes rock formation consist of lava, bomb, lapilli and ash from quarter age. Tufa formation which is consist of coarse clastic volcano mainly composed of andesite, composed of angular component and semi-angular component identified as many limestone fraction, lapilli pumice, breccia, dense ignimbrite from quarter age. The rock formation of geothermal field “L” consists of breccia, lava and tuff from Miocene age.

In addition to the conditions mentioned above, faults condition which is exist in geothermal field “L” are also well identified. From geological and geophysical data, these faults are identified as normal faults with slope or inclination near to vertical.

3.2 Bit Evaluation Method
The data is obtained from several adjacent wells of geothermal field “L” with relatively same formation being penetrated. Using the corrected CPF method above, the data is tabulated and the bit performance is compared for each section wells drilled and for each brand of bits used in the drilling process.

3.3 Bit Performance Result
3.3.1 Well Section 26”:
The lowest CPF comes from bit with brand “V” with the value of US$ 363. The highest CPF also comes from the same brand with the value of US$ 2939. The differences of CPF value between bit brand “V” and bit brand “S” is relatively not too far.

![Figure 2: Bit Performance Result Well Section 26”](image)

3.3.2 Well Section 17 1/2”:
The lowest CPF comes from bit with brand “S” with the value of US$ 408. The highest CPF also comes from the same brand with the value of US$ 2295. The broad distinction of CPF value of bit brand “V” in each well shows that there are other drilling variables affecting CPF other than variable in CPF equation mentioned above. Further analysis and evaluation is required in drilling design and operational in well section 17 1/2” of geothermal field “L”.

Bit brand “R” has CPF value that is relatively close to the bit brand “S”.
3.3.3 Well Section 17 1/2”:
The lowest CPF comes from bit with brand “V” with the value of US$ 274. The highest CPF also comes from the same brand with the value of US$ 1148.

The broad distinction of CPF value of bit brand “V” in each well shows that there are other drilling variables affecting CPF other than variable in CPF equation mentioned above. Further analysis and evaluation is required in drilling design and operational in well section 12 1/4” of geothermal field “L”.

3.3.4 Well Section 9 7/8”:
The lowest CPF comes from bit with brand “V” with the value of US$ 197. The highest CPF also comes from the same brand with the value of US$ 892.

The broad distinction of CPF value of bit brand “V” in each well shows that there are other drilling variables affecting CPF other than variable in CPF equation mentioned above. Further analysis and evaluation is required in drilling design and operational in well section 9 7/8” of geothermal field “L”.

In this section, there is no other brand of bit used in the drilling process, thereby; comparison among the bit brand cannot be done.
3.3.5 Well Section 8 1/2".
The lowest CPF comes from bit with brand “V” with the value of US$ 191. The highest CPF also comes from the same brand with the value of US$ 816.

The broad distinction of CPF value of bit brand “V” in each well shows that there are other drilling variables affecting CPF other than variable in CPF equation mentioned above. Further analysis and evaluation is required in drilling design and operational in well section 8 1/2” of geothermal field “L”.

In this section, there is no other brand of bit used in the drilling process, thereby; comparison among the bit brand can’t be done.

4. CONCLUSION
1. In this study, the bits have been evaluated in each section wells in that mentioned Field.

2. The concept of Cost per Foot (CPF), to evaluate various brands of bits, is a linear function of engineering and cost parameters. The parameters used are bit cost, bit lifespan, rate of penetration, and operational cost.

3. In this study, the data which have been evaluated are merely drilling operational data from wells in a field which has relatively similar level of difficulty and non-productive time.

4. Highly extreme drilling data, such as when the incidence of pipe sticking happened, non-productive time is very high, etc., are not used.

5. CPF calculation method in this study is relative. Therefore, CPF calculation results in this study shows that the conclusion number 3 should be considered more critical.
6. The results of calculation and evaluation are shown below.

<table>
<thead>
<tr>
<th>Field</th>
<th>Section (&quot;)</th>
<th>The most effective bit brand</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;L&quot;</td>
<td>26</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>17 ½</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>12 ¼</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>9 7/8</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>8 ½</td>
<td>V</td>
</tr>
</tbody>
</table>

7. By simply referring to the calculation of the value of CPF sorted from the smallest to the largest, bit selection for each section in each field can be done.

8. To obtain the results of the calculation and analysis more precise, it takes a more in-depth analysis and evaluation. The flow diagram below describes the parameters of what is not in the CPF calculation but greatly affect the value of CPF. This flow diagram (Figure 7) shows that the effectiveness of a bit is strongly influenced by other parameters, such as mud design, drill string and BHA design, and others.

9. Data collection and reporting system of the drilling operation can be made better in the future so that the analysis and evaluation of the tool can be done in an integrated and comprehensive, not only as a function of the economic effectiveness of the drilling, but also as a function of engineering effectiveness of casing, mud, drill string and BHA, etc.

![Flow Diagram](image)

**Figure 7: Well Program, Adams (1985)**

**NOMENCLATURE**

- CPF = Cost per Foot ($/ft)
- CB = Bit cost ($)
- CR = Rig cost ($)
- ti = Tripping time (hour)
- tr = Rotating time (hour)
- F = Footage (feet)
- Ct = Interval cost
- CD = Daily operating cost
- t = Time for drilling and completion in some interval
- CF = Cost depend on time (remain constant)
- tD = Drilling time
- tT = Tripping time and BHA
- tE = Other time (especially end-of-interval)
- CtM = Method cost
- NTi = Number of method
\( C_E = \) Other constant cost (especially end-of-interval)

\( L_i = \) Length of drilling interval

\( t_{bk} = \) Lifetime of bit type K

REFERENCES


