Selection of Drilling Bit for the 12 ¼" Holes in the Geothermal Wells at the Company of XYZ

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Abstract- The selection of drilling bits properly can reduce the drilling process cost per day. In the real case, a company of XYZ has drilled 12 ¼" holes in geothermal wells having quartz formation using three different types of drilling bits, namely tungsten carbide insert (TCI) bit, polycrystalline diamond compact (PDC) bit, and Kymera hybrid bit. The purpose of this study was to determine the most suitable drilling bit type for the 12 ¼" holes based on four parameters including rate of penetration (ROP), evaluation of dull grading, cost per foot (CPF), and mechanical-specific energy (MSE). The data of twelve wells having 12 ¼" holes were collected from the company. The results showed that PDC had a higher ROP (11.5 m/hour) than Kymera (10.5 m/hour) and TCI (7.5 m/hour). Furthermore, Kymera had a better dull grade than PDC and TCI. Based on CPF analysis, the costs required for PDC, TCI, and Kymera were 122, 152, and 157 USD/ft, respectively. Based on MSE analysis, the energy needed for PDC, Kymera, and TCI was 295, 363, and 560 kpsi. In the scoring step (score scale of 1-3), PDC, TCI, and Kymera had average scores of 1.25, 2.75, and 2, respectively. Therefore, the most suitable bit type for 12 ¼" holes was the PDC drilling bit. These findings are important because they can be used as references by the company of XYZ. In addition, other geothermal companies can follow the method presented in this study for selecting the most suitable drilling bit.

Keywords *Kymera bit, Selection of drilling bit, Polycrystalline diamond compact bit, Geothermal well, Tungsten carbide insert bit*

1. Introduction

One of the renewable energy sources in Indonesia is geothermal energy. This energy is generated from the subsurface of the Earth. This energy can only be produced at a given time, needs to be reserved, and is not available everywhere [1]. However, geothermal energy is a replenished source and can be utilised all year round [2]. Therefore, the potential of geothermal energy is necessary to be investigated and discovered [3]. In addition, geothermal energy establishes an opportunity to fulfil the needs of future generations [4]. One of the greatest geothermal energy deposits in the world, located in Indonesia, has the capacity to produce 28.61 Gigawatts of electric energy (GWe) [5]. Currently, only 4.5% of Indonesia's geothermal energy has been utilised. Increasing energy consumption and demand can be caused by changes in population growth and lifestyle [6]. Thus, the production of geothermal energy as an alternative energy needs to be increased to meet Indonesia's energy targets in the year 2025. Therefore, the exploration of geothermal wells is important to be carried out.

Drilling is the activity of making holes starting from the surface until reaching the target point where geothermal heat can be produced safely [7]. In the process of geothermal drilling, good and appropriate equipment is needed so accidents and failures do not occur during the drilling process.

Therefore, it is necessary to select equipment properly before the drilling process is carried out.

A limited liability company (LLC) of XYZ is one of the Indonesian companies, which is conducting the drilling process for the development of several wells to meet Indonesia's electricity demand target of 240 kW. In practice, this company has developed several well pads which are already in production.

Most of the types of wells at the company of XYZ are wells with big holes. This well type is chosen by the company because if during the drilling process, there is a disturbance in the problem zone resulting in the termination of the drilling process on that hole, then the drilling process can be continued for the next hole. The common profile for wells with big holes is shown in Fig. 1 [8]. Therefore, as in Fig. 1, the 12 ¼" holes in wells at the company of XYZ have a depth range of 1200 – 2200 mMD which is then followed by the installation of a casing that has K-55 specifications with a connection type of butter thread coupling (BTC) [9].

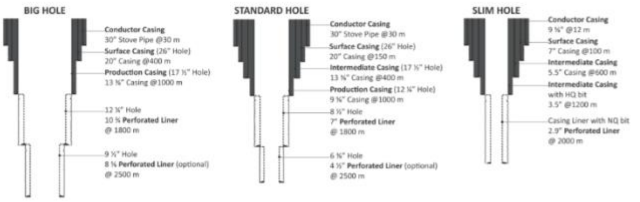

Fig. 1. Common well classifications according to the well diameter with typical casing depth [8]

There are twelve wells at the company of XYZ, which are Wells X-1, X-2, X-3, X-4, Y-1, Y-2, Y-3, Y-4, Z-1, Z-2, Z-3, and Z-4. The twelve wells have similar profiles, but different depths. The lithology of the rock formations of the 12 ¼" holes from the twelve wells has insignificant differences. This is because the twelve wells are located in two adjacent well pads. Most of the rock types exposed in the formations in the fields are volcanic rocks which tend to have very high rock hardness values. The different rock hardness of each rock type is a major factor affecting the performance and lifetime of the drilling bits used by the company. In Fig. 2, it can be seen that the characteristics of the rocks arranged to form formations in the 12 ¼" hole are very different from those of the rocks in the other holes. The type of rock having the highest hardness value is a metasedimentary rock with low to moderate alteration levels. Apart from these metasediments, volcanic rhyolite tuff with very strong alteration levels is also a type of rock that is hard to drill.

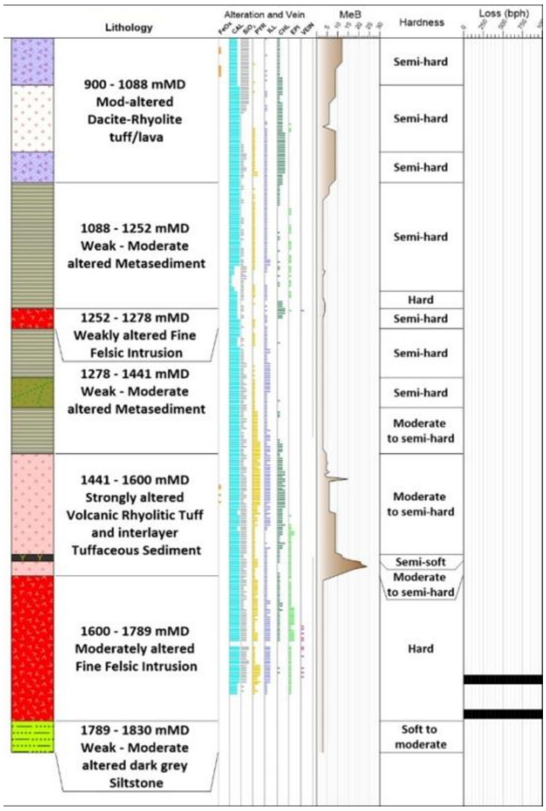

Fig. 2. Lithological formation (source: The company of XYZ)

At the company of XYZ, the drilling process for the 12 ¼" holes was conducted using three types of drilling bits, namely tungsten carbide insert (TCI) bit, polycrystalline diamond compact (PDC) bit, and Kymera hybrid bit. The TCI bit was used for the 12 ¼" holes in the Wells X-1, X-2, X-3, and X-4. The TCI bit was used early in the 12 ¼" hole drilling process. This drilling bit is used because it is related to drilling on the casing of the previous hole. The casing on the previous hole (13 3/8") has several accessories attached to the casing itself such as a float valve. For destructing these accessories, TCI is very suitable to be used. This is evidenced by the raised cuttings not containing cuttings from the casing itself. The appearance of the TCI bit is shown in Fig. 3.

Fig. 3. Tungsten Carbide Insert (TCI) Bit [10]

Furthermore, the PDC bit was used for the 12 ¼" holes in the Wells Y-1, Y-2, Y-3, and Y-4. The PDC bit is often used because of its durability in drilling rock formations in the 12 ¼" holes and without the presence of "Krev" on the PDC, which allows drilling one route without replacing another drilling bit. The appearance of PDC is shown in Fig. 4.

Fig. 4. Polycrystalline Diamond Compact (PDC) Bit [11]

Moreover, the Kymera hybrid bit was used for the 12 ¼" holes in the Wells Z-1, Z-2, Z-3, and Z-4. The Kymera hybrid bit with the model KMX525T is newer than the two previous types (TCI and PDC bits). The Kymera hybrid bit is designed by combining TCI and PDC designs so it can withstand all types of rock formations quickly. However, the Kymera has a very expensive price and results in a "Krev" value which can limit the use of this drilling bit in the drilling process. The appearance of the Kymera hybrid bit is shown in Fig. 5.

Fig. 5. Kymera Hybrid Bit [12]

According to [13], the method for selecting the suitable drilling bit needs to be developed by considering the characteristics of the formations. A previous study [14] reported that analysing the formation characteristics while drilling directly on cuttings can obtain substantial information that leads to the determination of the most suitable cutting structure for any specific hole section, leading to the identification of the most suitable drilling bit and saving valuable time and money. Furthermore, a previous study [15] described a method to optimise roller-cone bit selection and operation by achieving the highest rate of penetration and bit life in a given formation, resulting in the lowest total cost for the hole. Post-well analysis showed that when the expert system recommendations were followed by the operator, increases in the rate of penetration (ROP) and run length over the local pacesetter well were experienced in each hole section [16]. A previous study [17] showed a systematic approach on how to select PDC bits based on quantitative measurement by using a simple scorecard. Furthermore, a previous study [18] conducted database development for drilling bit selection. A database holding field data is designed, a computer program calculating necessary parameters is built, and a related Microsoft Excel file holding output is prepared. A previous study designed a new drilling optimisation procedure to improve the drilling efficiency with positive displacement motors (PDMs) and PDC bits [19]. A previous study [20] explored the effect of drill bit selection parameters on enhanced oil and gas recovery in Iranian oil and gas fields. A previous study [21] conducted rock-strength analysis and integrated FEA (finite element analysis) modelling to optimise the bit selection for deepwater exploration drilling. A previous study [22] posed a trial to obtain the compressive strength profile of the oilfield's formation from a sonic log.

Based on the information above, it is important to develop a method for selecting the most suitable drilling bit of the three drilling bits (TCI, PDC, and Kymera hybrid bits) used in 12 ¼" holes in twelve wells at the company of XYZ. This study used a method by considering four parameters, including the rate of penetrations (ROP), dull grading, cost per foot (CPF), and mechanical specific energies (MSE). The required data for calculating the four parameters was collected from the company of XYZ. Then, the ROP, dull grading, CPF, and MSE values for the three drilling bits were calculated and analysed. A good drilling bit has high ROP, high dull grading, low CPF, and low MSE values. Therefore, the purposes of this study were (1) to calculate the parameters (ROP, dull grading, CPF, and MSE) used in the selection of drilling bits and (2) to analyse the parameters and provide a decision on the most suitable type of drilling bit in the 12 ¼" holes in geothermal wells at the company of XYZ so that it can be used as a reference for drilling further wells. This study is original and has not been carried out by other authors.

2. Methods

In the selection of drilling bits, some data were collected and then analysed. The data needed in this study were offset well data in the form of drilling bit specifications, rate of penetrations (ROP), rock lithologies, drilled depth intervals in the 12 ¼" holes, dull grading results of the drilling bits, drilling parameters, selling prices of the drilling bit, daily rig operating costs, and specific mechanical energy (MSE) values of drilling bits. These data were obtained from the company of XYZ and approved by the responsible parties in the company of XYZ. In this study, four parameters were analysed, namely (1) the rate of penetrations (ROP), (2) the dull grading results, (3) the cost per foot (CPF), and (4) the value of mechanical-specific energies (MSE) of three drilling bits types used for drilling the same formation, namely quartz formation (quartzite).

2.1. *Rate of Penetration* (ROP)

The rate of penetration (ROP) indicates an increase in the depth of the well per unit of time. In other words, the ROP indicates the speed of drilling. It was assumed that the normal ROP value is in the range of 11 – 13 m/hour [9]. Therefore, it can be concluded that the higher the ROP value, the better the drilling bit performance.

2.2. *Evaluation of Dull Grading*

The effectiveness of a drilling bit in drilling a formation can be seen from the dull grading of each drilling bit after pulling out of a hole (POOH). In the dull grading analysis of each drilling bit, this study referred to the system created by IADC (Fig. 6).

IADC DULL GRADING SYSTEM

CUTTING STRUCTURE				BEARINGS/ SEALS	GAUGE	OTHER DULL CHAR.	REASON PULLED
INNER	OUTER	DULL CHAR.	LOCATION				
I	O	D	L	B	G	O	R

I — INNER CUTTING STRUCTURE (All inner rows)

O — OUTER CUTTING STRUCTURE (Gauge row only)
In columns 1 and 2 a linear scale from 0 to 8 is used to describe the condition of the cutting structure according to the following:

STEEL TOOTH BITS
A measure of lost tooth height due to abrasion and / or damage.
0 — NO LOSS OF TOOTH HEIGHT
8 — TOTAL LOSS OF TOOTH HEIGHT

INSERT BITS
A measure of total cutting structure reduction due to lost, worn and / or broken inserts.
0 — NO LOST, WORN AND / OR BROKEN INSERTS
8 — ALL INSERTS LOST, WORN AND / OR BROKEN

FIXED CUTTER BITS
A measure of lost, worn and / or broken cutting structure
0 — NO LOST, WORN AND / OR BROKEN CUTTING STRUCTURE
8 — ALL OF CUTTING STRUCTURE LOST, WORN AND / OR BROKEN

D — DULL CHARACTERISTICS
(Use only cutting structure related codes)
*BC — Broken Cone
BF — Bond Failure
BT — Broken Teeth / Cutters
BU — Balled Up Bit
*CC — Cracked Cone
*CD — Cone Dragged
CI — Cone Interference
CR — Cored
CT — Chipped Teeth / Cutters
ER — Erosion
FC — Flat Crested Wear
HC — Heat Checking
JD — Junk Damage
*LC — Lost Cone
LN — Lost Nozzle
LT — Lost Teeth / Cutters
OC — Off-Center Wear
PB — Pinched Bit
PN — Plugged Nozzle / Flow Passage
RG — Rounded Gauge
RO — Ring Out
SD — Shirttail Damage
SS — Self-Sharpening Wear
TR — Tracking
WO — Washed Out Bit
WT — Worn Teeth / Cutters
NO — No Dull Characteristic
*Show cone # or #'s under location 4.

L — LOCATION
ROLLER CONE
N — Nose Row, Cone # 1
M — Middle Row, 2
G — Gauge Row, 3
A — All Rows
FIXED CUTTER
C — Cone
N — Nose
T — Taper
S — Shoulder
G — Gauge
A — All Areas

B — BEARING SEALS
NON SEALED BEARINGS
A linear scale estimating bearing life used. (0 - No life used, 8 - All life used, ie. no bearing life remaining.)
SEALED BEARINGS
E — seals effective
F — seals failed
N — not able to grade
X — fixed cutter bit

G — GAUGE
1 — in gauge
1/16 — 1/16" out of gauge
2/16 — 1/8" out of gauge
4/16 — 1/4" out of gauge

O — OTHER DULL CHARACTERISTIC
Refer to column 3 codes

R — REASON PULLED OR RUN TERMINATED
BHA — Change Bottom Hole Assembly
CM — Condition Mud
DMF — Downhole Motor Failure
DP — Drill Plug
DSF — Drill String Failure
DST — Drill Stem Testing
DTF — Downhole Tool Failure
FM — Formation Change
HP — Hole Problems
HR — Hours on Bit
LIH — Left in Hole
LOG — Run Logs
PP — Pump Pressure
RIG — Rig Repair
TD — Total Depth / Casing Depth
TQ — Torque
TW — Twist Off
WC — Weather Conditions

Fig. 6. IADC Dull Grading System [23]

Evaluation of dull grading was carried out when the drilling bit had been removed from the surface. There are eight digits in the dull grading (see Fig. 6) including I-O-D-L-B-G-O-R. The first digit (I) describes the condition of the inner cutting structure of the drilling bit. The damage level of the inner cutting structure (I) is indicated by a number on a scale of 1 – 8. The second digit (O) describes the condition of the outer cutting structure which is also described by a number on a scale of 1 – 8. The third digit (D) describes the dull characteristics, so the third digit shows the damage experienced by the drilling bit. The fourth digit (L) describes the location of the damaged drilling bit. The fifth digit (B) describes the condition of the bearing seals on the drilling bit. If the drilling bit used is a drag bit, the fifth digit will be indicated by the letter "X". The condition of the bearing seal on the roller cone bit is indicated by the letter "E" if the bearing seal is still in good condition, and then it is indicated by the letter "F" if it has failed. The sixth digit (G) describes the gauge of the drilling bit. Additional damage notes to the drilling bit will be listed at the seventh digit (O). Finally, the eighth digit (R) explains the reason why the drilling bit is pulled [23].

2.3. Cost Per Foot (CPF)

Cost per foot (CPF) is one of the parameters used in the selection of drilling bits. The CPF shows the cost required per foot. The cost per foot (CPF) can be used to evaluate the efficiency of bit running in a well. The CPF value can be determined using the equation (1) [24].

$$CPF = \frac{B + (Drilling\ Time + Tripping\ Time) \times R}{\Delta D} \quad (1)$$

Where:

CPF	= Cost Per Foot (USD/ft)
B	= Bit Cost (USD)
Drilling Time	= Bit on the bottom (hours)
Tripping Time	= Bit while roundtrip (hours)
R	= Daily rig cost (USD/hour)
ΔD	= Drilling Depth (ft)

2.4. Mechanical-Specific Energy (MSE)

Mechanical-specific energy (MSE) is the energy required to reduce and destroy the volume of a rock formation [25]. The efficiency of the drilling process can be increased by minimizing the mechanical-specific energy (MSE) and maximizing the rate of penetration (ROP). Factors affecting the MSE value are weight on bit (WOB), torque, rate of penetration (ROP), and revolutions per minute (RPM) of drilling bits. A relationship between WOB and ROP is shown in Fig. 7.

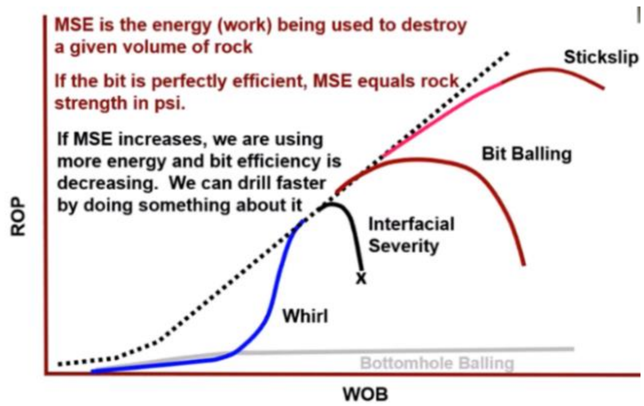

Fig. 7. A relationship between WOB and ROP [25]

The volume of the drilled hole is calculated by multiplying the area drilled by the depth drilled (Δh). Meanwhile, the required work energy can be calculated by multiplying the force by the distance. In drilling operations, two forces are acting on the drilling bit, namely weight on bit (WOB) and torque (rotary force). The MSE value can be calculated using equation 2 [26].

$$MSE = \frac{WOB}{Area} + \frac{120\pi \times RPM \times Torque}{Area \times ROP} \quad (2)$$

Where:

MSE	= Mechanical Specific Energy (psi)
WOB	= Weight on Bit (lb)
RPM	= Rotations Per Minute
Torque	= Rotational torque (in-lb)
Area	= Cross-sectional area of bit (in^2)
ROP	= Rate of Penetration (in/hour)
P	= Penetration per Revolution (in/rev)

Based on equation (2), the bit weight is the main factor that influences the amount of energy for destroying the rock formations.

2.5. Scoring

A drilling bit with better performance has higher ROP, higher dull grading, lower CPF, and lower MSE values. Hence, a score in the range of 1-3 was given to the drilling bit based on the performance. For each parameter, the better the performance of the drilling bit, the higher the score was given to the drilling bit. Then, the average score for each drilling bit was calculated using equation (3).

$$\text{Average score} = \frac{(\text{ROP score} + \text{dull grading score} + \text{CPF score} + \text{MSE score})}{4} \quad (3)$$

3. Results and Discussion

3.1. Analysis of rate of penetration (ROP), evaluation of dull grading, analysis of cost per foot (CPF), and analysis of mechanical-specific energy (MSE) values

In accordance with the final drilling report, in the geothermal wells at the company of XYZ especially in the 12 ¼" hole, a casing with a diameter of 10 ¾" was installed where previous drilling had been carried out using a 12 ¼" hole. In this study, the performance analysis of each drilling bit will be carried out using four parameters, namely analysis of the rate of penetration (ROP), evaluation of dull grading, analysis of cost per foot (CPF), and analysis of mechanical-specific energy (MSE) values required for each drilling bit to produce the same ROP value of 15 m/hour for drilling the quartz formations.

3.1.1. Analysis of Rate of Penetration (ROP)

The drilling efficiency can be evaluated through the ROP value [27]. Reduction in both drilling time and cost can be obtained by increasing the ROP [28]. As explained in the research methodology, the normal ROP values are in the range of 11 – 13 m/hour [8].

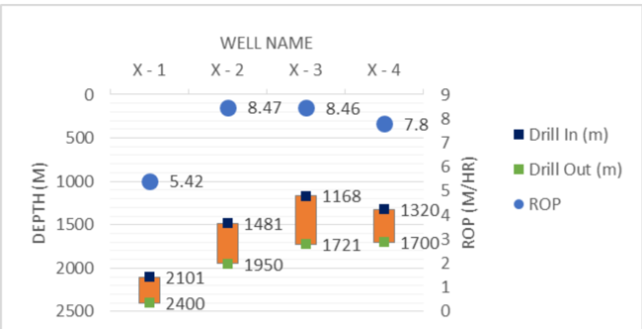

Fig. 8. Rate of Penetration of TCI drilling bit

Figure 8 shows the ROP values generated by the TCI drilling bit. The TCI drilling bit used in the four wells (X-1, X-2, X-3, and X-4) had ROP values in the range of 5 – 8 m/hour and an average ROP value of 7.5 m/hour. These results indicated that the ROP value of the TCI drilling bit for the 12 ¼" hole was low.

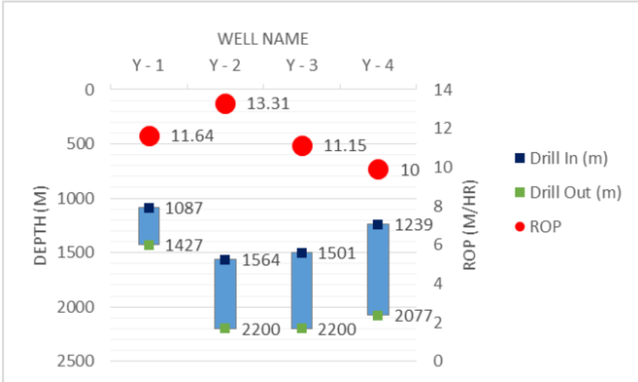

Fig. 9. Rate of Penetration of PDC drilling bit

Figure 9 shows the ROP values generated by the PDC drilling bit. The PDC drilling bit used in the four wells (Y-1, Y-2, Y-3, and Y-4) had ROP values in the range of 9 – 13 m/hour and an average ROP value of 11.5 m/hour. These results indicated that the ROP value of the PDC drilling bit for the 12 ¼" hole was normal.

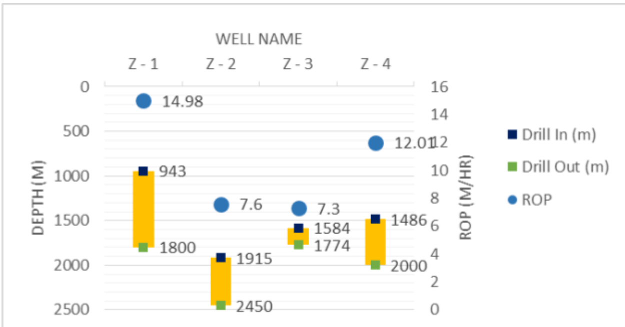

Fig. 10. Rate of Penetration of Kymera hybrid drilling bit

Figure 10 shows the ROP values generated by the Kymera hybrid drilling bit. The Kymera drilling bit used in the four wells had ROP values in the range of 7 – 15 m/hour and an average ROP value of 10.5 m/hour. These results indicated that the ROP value of the Kymera drilling bit for the 12 ¼" hole was normal enough.

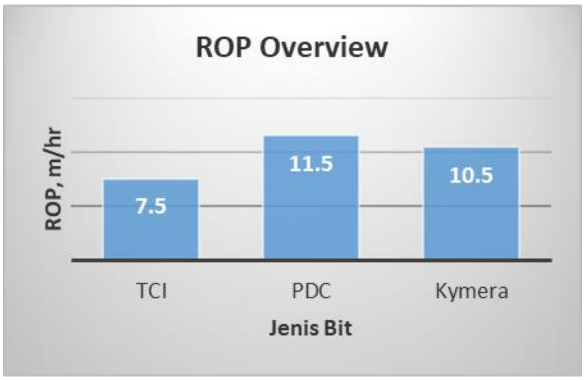

Fig. 11. ROP Overview

Figure 11 shows the results of the average ROP values produced by the three types of drilling bits for 12 ¼” holes in twelve wells in the fields of the company of XYZ. The highest ROP value resulted from the PDC drilling bit, which was 11.5 m/hour. Meanwhile, the lowest ROP value resulted from the TCI drilling bit, which was 7.5 m/hour.

3.1.2. Evaluation Dull Grading

The dull grading evaluation of the three types of drilling bits was conducted to determine the durability of each type of drilling bit for 12 ¼” holes. The durability of the drilling bit is greatly influenced by the depth intervals and the characteristics of the rock formation.

Table 1. Dull Grading of TCI drilling bit

Well Name	TCI Dull Grading	TCI durability (metres)
X – 1	2-6-WT-A-E-I-CT-TD	299
X – 2	2-3-WT-A-E-7/16-BT-TD	469
X – 3	2-6-WT-A-F#3-I-BT-BHA	553
X – 4	2-2-WT-A-E-I-CT-TD	380

Table 1 shows the dull grading of the TCI drilling bit in the four wells. Dull grading in Table 1 explains that TCI had broken teeth that were quite severe in the outer cutting structure in Wells X – 1 and X – 3 which were indicated by a value of 6 out of 8. In Well X – 2, TCI experienced under gauge up to 7/16. The under gauge value that occurred on the drilling bit had the potential to cause pipe sticking because the diameter of the drilling bit was smaller than the diameter of the stabilizer during drilling operations. In Well X – 3, TCI failed in sealing at cone number 3. Sealing damage on the drilling bit can cause a drastic decrease in ROP value because the cone was damaged in its seal so it cannot rotate properly. The damage experienced by the TCI in these four wells was caused by the characteristics of the rock formation which was too abrasive.

Table 2. Dull Grading of PDC drilling bit

Well Name	PDC Dull Grading	PDC durability (metres)
Y – 1	2-2-WT-A-X-3/16-LT-CP	340
Y – 2	1-2-WT-S-X-I-NO-TD	636
Y – 3	1-2-WT-S/G-X-1/16-CT-TD	699
Y – 4	1-2-WT-S-X-I-CT-TD	838

Table 2 shows the dull grading of the PDC drilling bit in the four wells. The dull grading data in Table 2 shows that the PDC was damaged in Wells Y-1 and Y-3. PDC experienced an under gauge of 1/16 in Well Y – 3 where PDC had drilled to a depth of 669 metres. PDC experienced an under gauge of 3/16 in Well Y – 1 where PDC had drilled to a depth of 340 metres. The under gauge on the PDC was caused by the abrasive characteristics of the rock formation.

Table 3. Dull Grading of Kymera drilling bit

Well Name	Kymera Dull Grading	Kymera durability (metres)
Z – 1	TCI: 1-1-WT-A-E-I-NO-TD PDC: 1-1-WT-A-X-I-NO-TD	857
Z – 2	TCI: 1-1-WT-A-E-1-NO-TD PDC: 1-1-WT-A-X-1-NO-TD	535
Z – 3	TCI: 1-1-WT-A-E-I-BT-TD PDC: 0-0-NO-A-X-I-NO-TD	191
Z – 4	TCI: 1-1-WT-A-E-I-BT-HR PDC: 1-1-WT-S-X-I-CT-HR	514

From the dull grading data produced by Kymera for the four wells (Table 3), no serious damage was observed. This was due to the design of the drilling bit which was very suitable for the rock formation of the four wells. Even at a considerable depth, namely up to 857 metres, this drilling bit type was still in good condition as indicated by the Well Z – 1. In other words, Kymera had a better dull grade compared to TCI and PDC.

3.1.3. Analysis of Cost Per Foot (CPF)

In the cost per foot (CPF) analysis of each drilling bit, some data has been obtained from the related company (the company of XYZ). The CPF analysis [29] requires a standardization of the obtained data such as rig operational cost per day and bit hours of each drilling bit. The available data include:

- The rig operational cost per day of USD 80,000
- The bit cost for TCI of USD 17,000
- The bit cost for PDC of USD 60,000
- The bit cost for Kymera of USD 65,000
- The ROP used in this analysis was the average ROP
- Bit hours was the accumulation of tripping time and drilling time

Table 4. CPF of TCI

TCI							
Well Name	**Footage (m)**	**Footage (ft)**	**Bit Hours**	**ROP (m/hour)**	**Rig Cost (USD)**	**Bit Cost (USD)**	**CPF (USD/ft)**
X – 1	299	981	55.2	5.42	184,000	17,000	205
X – 2	469	1,539	55.4	8.47	184,667	17,000	131
X – 3	553	1,814	65.4	8.46	218,000	17,000	130
X – 4	380	1,247	48.7	7.8	162,333	17,000	144
AVERAGE							**152**

Table 4 shows the CPF values of the TCI drilling bit used in the four wells. The depth drilled by the TCI bit in each well was different, ranging from 299 to 553 metres. The usage time of TCI in the four wells also varied, ranging from 48.7 to 65.4 hours. Therefore, the use of the TCI drilling bit for the four wells resulted in different CPF values. The highest CPF value was generated at Well X – 1, which was 205 USD/ft. Meanwhile, the lowest CPF value was generated at Well X – 3, which was 130 USD/ft. The average CPF value produced by the TCI drilling bit was 152 USD/ft.

Table 5. CPF of PDC

PDC							
Well Name	**Footage (m)**	**Footage (ft)**	**Bit Hours**	**ROP (m/hour)**	**Rig Cost (USD)**	**Bit Cost (USD)**	**CPF (USD/ft)**
Y – 1	340	1,115	29.2	11.64	97,333	60,000	141
Y – 2	636	2,087	47.8	13.31	159,333	60,000	105
Y – 3	699	2,293	62.7	11.15	209,000	60,000	117
Y – 4	838	2,749	84.1	10	280,333	60,000	124
AVERAGE							**122**

Table 5 shows the CPF values of the PDC drilling bit used in the four wells. The depth drilled by the PDC bit in each well was different, where the lowest depth was 340 metres, while the highest depth was 838 metres. The usage time of PDC in the four wells ranged from 29.2 to 84.1 hours. Therefore, the use of the PDC drilling bit for the four wells resulted in different CPF values. The highest CPF value (141 USD/ft) was obtained at Well Y-1, while the lowest CPF value (105 USD/ft) was obtained at Well Y-2. The average CPF value produced by the PDC bit was 122 USD/ft which was lower than the average CPF value produced by the TCI bit.

Table 6. CPF of Kymera

Kymera							
Well Name	**Footage (m)**	**Footage (ft)**	**Bit Hours**	**ROP (m/hour)**	**Rig Cost (USD)**	**Bit Cost (USD)**	**CPF (USD/ft)**
Z – 1	857	2,812	57.2	14.98	190,667	65,000	91
Z – 2	535	1,755	70.4	7.6	234,667	65,000	171
Z – 3	191	627	26.1	7.3	87,000	65,000	243
Z – 4	514	1,686	42.8	12.01	142,667	65,000	123
AVERAGE							**157**

Table 6 shows the CPF values generated by the Kymera drilling bit in the four wells. Kymera bit is a drilling bit with the highest price, which is USD 65,000. The depth drilled by Kymera bit in each well was different. The highest depth value that can be drilled by Kymera was 857 metres at Well Z – 1, while the lowest depth value was 191 metres at Well Z – 4. The usage time of the Kymera bit in each well was also different, which was around 26.1 – 70.4 hours. Hence, the CPF value generated by the Kymera bit in each well was different. The average CPF value of Kymera bit was 157 USD/ft. The average CPF value of the Kymera bit was higher than the average CPF values of TCI and PDC bits.

3.1.4. Analysis of Mechanical Specific Energy (MSE)

The MSE can be used to investigate the drilling efficiency [30]. Hence, MSE can be considered to improve drilling efficiency [31]. In the analysis of MSE produced by the three types of drilling bits, the drilling process was carried out in the same formation (quartzite) in 3 different wells with the same ROP of 15 m/hour.

Table 7. Analysis of MSE

Drilling Bit	*Diameter (inch)*	*WOB (klbs)*	*RPM*	*Torque (ft-lb)*	*ROP (m/hour)*	*MSE (kpsi)*
TCI	12.25	45	217	12.59	15	560
PDC	12.25	15	196	13.14	15	295
Kymera	12.25	17	221	15.2	15	363

Table 7 shows the MSE values generated by the three types of drilling bits. The highest MSE value was produced by the TCI drilling bit, which was 560 kpsi. Meanwhile, the lowest MSE value was produced by the PDC drilling bit with a value of 295 kpsi. In producing an ROP of 15 m/hour, the PDC drilling bit was the most effective of all drilling bit types. This was because the MSE value generated by the PDC was the smallest. With the lowest possible MSE value, the value of the input energy (from axial and rotary forces) was very small.

Based on the weight on bit (WOB) of the three types of drilling bits, TCI had the highest WOB value, which was 45 klbs. Meanwhile, the WOB values of PDC and Kymera were not much different. The WOB value of PDC was 15 klbs and the WOB value of Kymera was 17 klbs.

3.2. Selection of the Most Suitable Type of Drilling Bit

Selection of the most suitable drilling bit for a 12 1//4" hole was conducted by analysing the values of the rate of penetration (ROP), dull grading, cost per foot (CPF) and mechanical specific energy (MSE) of the three drilling bits (TCI, PDC, and Kymera bits).

Based on the analysis of the rate of penetration (ROP) (Figure 11) for the three types of drilling bits on 12 existing wells with 4 wells for each type of drilling bit, the PDC drilling bit resulted in the highest ROP value of 11.5 m/hour, followed by Kymera with ROP value of 10.5 m/hour and TCI with the slowest ROP value of 7.5 m/hour. Thus, for the ROP parameter, the PDC, Kymera, and TCI bits were given a score of 3, 2, and 1, respectively. A previous study [12] reported the same findings as this study, where the ROP of the Kymera bit (7.9 m/hour) was higher than that of the TIC bit (4.9 m/hour). Furthermore, a previous study [25] developed a dynamic model for predicting the ROP in the drilling process. In simulation, the ROP value was set in the range of 1.5 – 3.2 cm/min (or 0.9 – 1.92 m/hour) [27]. Furthermore, the ROP values for the 12¼" hole in the Well-1 with the formation of Khisha and Mudawrah were 10.17-14.63 ft/hour (or 3.1-4.46 m/hour) [32]. The ROP values reported in the previous studies [27, 32] were lower than those reported in this study. Hence, the difference in the ROP values might be caused by many factors, one of them is formation strength [33].

From the results of the dull grading analysis (Tables 1-3), the Kymera drilling bit had the longest durability of 857 metres, followed by the PDC drilling bit with a durability of 838 metres and the TCI drilling bit with a durability of 553 metres. Thus, for the dull grading parameter, the Kymera, PDC, and TCI bits were given a score of 3, 2, and 1, respectively.

Based on the cost per foot (CPF) analysis of the 12 wells, PDC had the cheapest CPF value, namely 122 USD/ft, followed by TCI with a CPF value of 152 USD/ft. Meanwhile, the most expensive CPF of 157 USD/ft resulted from the use of the Kymera drilling bit. Thus, for the CPF parameter, the PDC, TCI, and Kymera bits were given a score of 3, 2, and 1, respectively. A previous study reported different results from this study [12]. The previous study [12] stated that the Kymera bit resulted in a lower CPF than the conventional TCI bit. The difference in findings between the previous study and this study might be caused by the difference in rock formation properties.

Based on the mechanical specific energy (MSE) analysis, it can be concluded that in producing an ROP of 15 m/hour, the three types of drilling bits required different MSE values. The most effective type of drilling bit was the PDC with the smallest MSE value of 295 kpsi, followed by the Kymera bit with an MSE value of 363 kpsi and the TCI bit with an MSE value of 560 kpsi. Thus, for the MSE parameter, the PDC, Kymera, and TCI bits were given a score of 3, 2, and 1, respectively. This study found that the Kymera bit had a higher MSE than the PDC. However, a previous study [34] reported that the use of hybrid PDC can decrease by 749 % MSE compared to the conventional PDC. The difference in findings between the previous study and this study might be caused by the difference in rock formation properties.

The summary of the values of all parameters for the three drilling bits is shown in Table 8. Meanwhile, the summary of the scores for the three drilling bits is presented in Table 9. Based on the calculation, the average score for TCI, PDC, and Kymera drilling bits was 1.25, 2.75, and 2, respectively. Therefore, the drilling process in the 12 ¼" hole at the company of XYZ was better to use the PDC drilling bit because the PDC drilling bit has a higher average score than the two others.

Table 8. Bit Selection Rating

Hierarchy	ROP (m/hour)		DULL GRADING (Durability) (metres)		CPF (USD/ft)		MSE (kpsi)	
1	PDC	11.5	Kymera	857	PDC	122	PDC	295
2	Kymera	10.5	PDC	838	TCI	152	Kymera	363
3	TCI	7.5	TCI	553	Kymera	157	TCI	560

Table 9. Scoring the drilling bits

Parameters	Score of drilling bits		
	TCI	PDC	Kymera
ROP (m/hour)	1	3	2
Dull grading (metres)	1	2	3
CPF (USD/ft)	2	3	1
MSE (kpsi)	1	3	2
Total Score	**5**	**11**	**8**
Average Score	**1.25**	**2.75**	**2**

4. Conclusions

Based on the result and discussion, some conclusions have been written below:

1. From the ROP analysis, the PDC drilling bit had a higher ROP value than the TCI and Kymera drilling bits, which was 11.5 m/ hour.
2. From the evaluation of dull grading, the Kymera drilling bit had the highest durability, which was 857 metres.
3. From the cost per foot (CPF) analysis, the PDC drilling bit had the lowest CPF value, which was 122 USD/ft.
4. From the mechanical specific energy (MSE) analysis, in producing an ROP of 15 m/hour, the three types of drilling bits required different MSE values. The most effective type of drilling bit was the PDC which had the smallest MSE value, namely 295 kpsi.
5. Comprehensively, for the drilling process on the 12 ¼" holes at the company of XYZ, the most suitable drilling bit type was the PDC drilling bit because it had the highest average score.

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