Drill Bit Design Optimization with Unique Hydraulics Pushing Drilling Performance Boundaries and Establishing World Record on Rotary Steerable System BHA: A Mahakam Success Story

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Abstract. A major oil and gas company operating in Mahakam, East Kalimantan identified a new and unique drill bit technology with the objective to improve drilling performance. Along with other techniques such as application of enhanced drilling parameters and fast drill pipe connection, drill bit design optimization with unique hydraulics is set up to break drilling performance records. This paper focuses on the drill bit design optimization.

Careful analysis of the drilling challenges faced in Mahakam Area Tunu Field 8 ½" section allowed the operating company to identify and select appropriate drilling practices and drill bit features that would solve specific drilling problems. As part of a continuous improvement philosophy, these features and technologies were then incorporated into a new drill bit design that was rapidly prototyped to solve the specific drilling issues encountered in this application. This new feature focuses on enhancing the drill bit hydraulics, effectively transporting the cuttings up faster than standard hydraulics.

The systematic approach to problem solving and careful selection of available technologies resulted in a record breaking first run performance when the new concepts were tested on a rotary steerable BHA. Quantitatively, new 24-hour footage and Rate of Penetration (ROP) records were set for the 8 ½" section, and the run was also one of the longest in this application with the rig reporting impressive directional response and smooth drilling. The second test of the unique hydraulics drill bit drilled deeper and pushed harder resulting in the previously set records being beaten again. This second test was also a new 24-hour world record for that rotary steerable tool. The performance was an increase of 50% faster than the previous 24-hour benchmark.

This case study serves as an example that drill bit optimization and best practices can lead to breaking drilling performance records resulting in cost savings by reducing the drilling time.

Keyword: Drill Bit Design; Unique Hydraulics; World Record; Drilling Performance; Mahakam

1 Introduction

Tunu is a mature giant gas field in Mahakam which already entering production declining phase. Most of the wells are targeting marginal reserve from combination of grid system and seismic target reservoir. This causes increase of trajectory complexity. Simple J-shape which was a standard profile since industrialization drilling campaign introduced in early 2000's is shifted to Semi S or Full S-shape profile which has more challenges such as stick-slip while drilling and difficulty during tripping out BHA. These issues lead to the increase of well duration and followed by well cost. In other hand, well cost has to be squeezed to support well economic and allow continuous drilling operation.

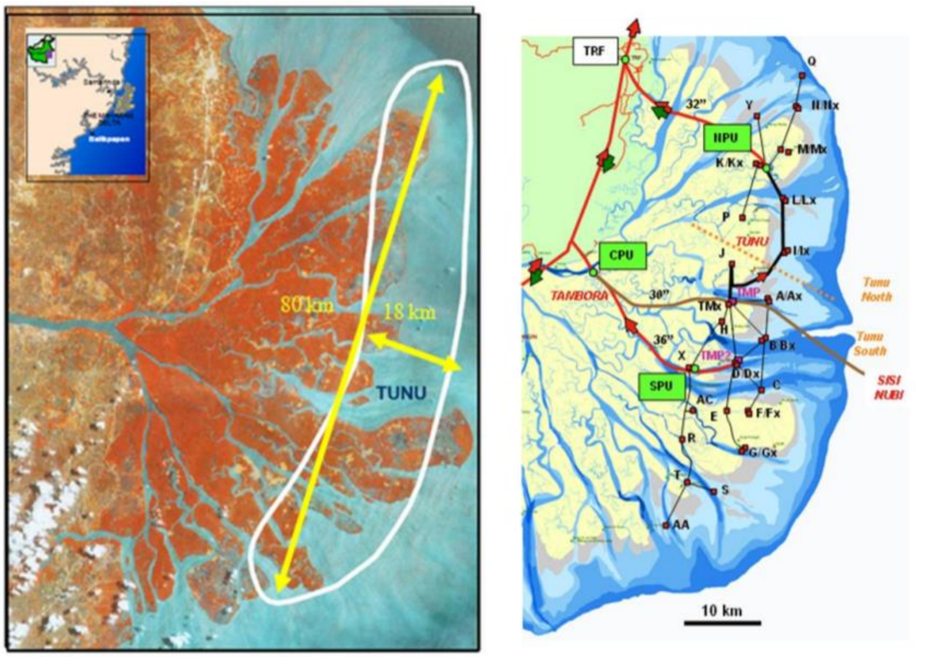

Figure. 1 – Tunu Gas Field in Swamp Area of Delta Mahakam (Purwanto et al, 2017)

Historically, the directional wells in Tunu Field was using Motor in surface section and RSS in the reservoir section. Both well sections were drilled by Polycrystalline Diamond Compact (PDC) Bit for more aggressive and high drilling efficiency. Drilling in reservoir section of the S-Shaped well with RSS experienced torsional stick-slip that cause the bit and BHA has premature damage, results slow ROP when the bit entering hard and interbedded formation. Unlike a steerable motor, drilling with a rotary steerable system poses a unique challenge. The OD gauge of the wellbore is close to the bit size causing increased contact between tubulars, especially between the stabilizers and the formation that often initiates torsional vibration or stick-slip. To rectify this issue, the BHA and bit design compatibility would be given serious consideration during the planning stage of the well (Jain et al.2007). Well trajectory is also optimized to reduce stick slip and increase drilling performance. One of the Key Performance Indicator (KPI) is the interval drilled per 24 hours. The benchmark is 1400 meters in 24 hours for Tunu.

2 Methodology

The typical main zone well in Tunu Field is drilled from 1200-1500 mTVD to 3300-4000 mTVD depending on the well location in the field. Usually the northern part of the field is shallower compared to the south. Formations are soft to medium in terms of compressive strength. 20" conductor pipe is driven down to 110 m, then followed by 12 ¼" surface section building at a 3 degree/30 meters dogleg severity (DLS), holding tangent to 9 5/8" casing point at 1200-1500 mTVD. The reservoir section is drilled with 8 ½" bit to 3300-4000 MTVD. Well trajectory is kept tangent whenever possible (Figure 1), however sometimes semi S or pure S type (Figure 2) down to vertical is inevitable. In such cases the drop rate is normally 1-1.5 degree/30 meters.

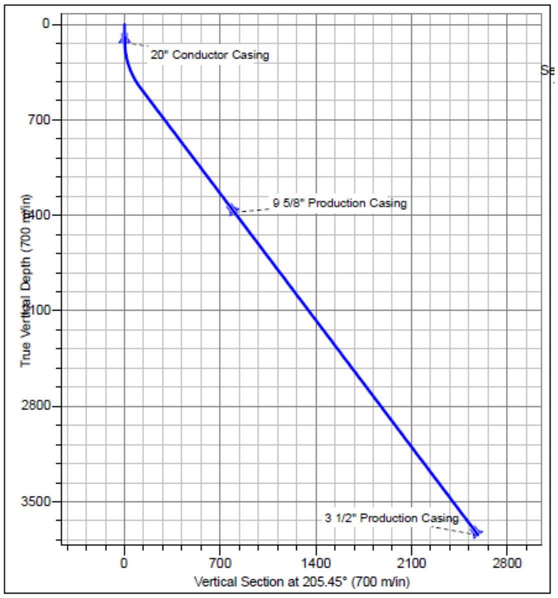

Figure 1. J Type Trajectory

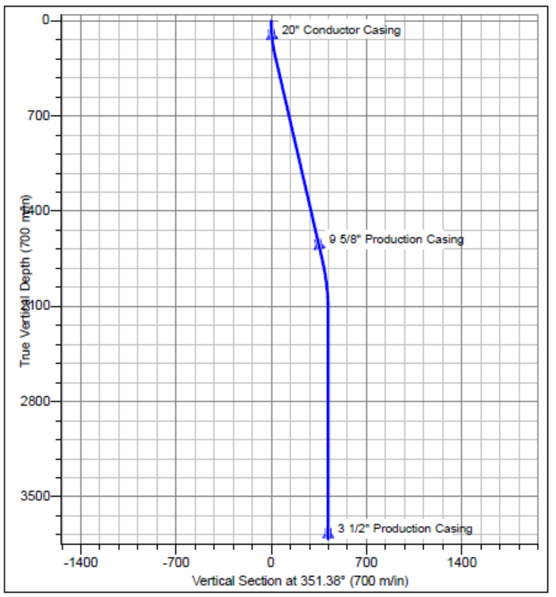

Figure 2. Full S Type Trajectory

The 8 ½" section is drilled using push the bit Rotary Steerable System from one the main directional drilling service providers (Figure 3). The RSS is fully rotational and able to steer the bit by pushing the pads into the formation. Command is given by downlinking, a method of communicating from surface to the tool by a series adjustments of the flow rate.

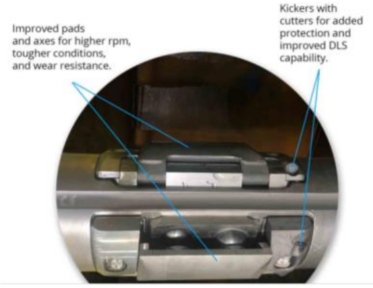

Figure 3. Pads of Push the Bit RSS

PDC drill bits has been utilized in Tunu Field since the early 2000s. The PDC bit design have evolved as the drilling becomes tougher. As discussed above, the main zone reservoir section in Tunu Field is drilled with 8 ½" drill bits. In recent years, the drill bits utilized for Tunu main zone were divided into two applications, fast version for shallower depths and durable version for deeper depths, both 6 blades and 16 mm cutter configuration. The drill bits were supplied by major drill bit companies. One of the major drill bit companies performed better than others, therefore were the preferred bit of choice for both the shallower (Figure 4) and deeper depth (Figure 5) drilling applications. From a quick glance, both drill bits are similar as they both have 6 blades, 16 mm cutters, secondary cutting structure and 6 nozzles. The obvious difference is the total cutter count, 60 and 63 pieces respectively for the fast and durable versions.

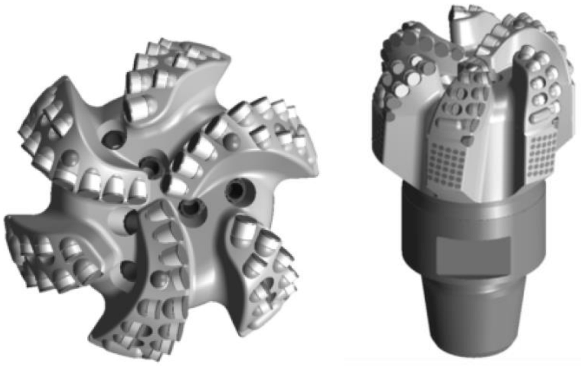

Figure 4. Fast 6 blades 16 mm Cutter Design for Shallower Main Zone Wells

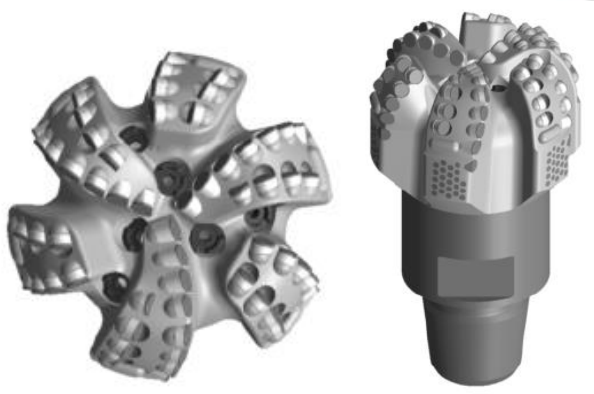

Figure 5. Durable 6 blades 16 mm Cutter Design for Deeper Main Zone Wells

The operating company launched a Maxi-Drill ROP optimization campaign in 2018 in order to increase drilling performance, particularly in the main zone drilling applications. Drill bits as the spearhead in a drilling BHA plays a major factor in the ROP optimization project. Other important factors include drill pipe fast connection and enhanced drilling parameters. The operating company also has personnel with in depth technical expertise on drill bits and performance drilling.

The technical study on drill bits and performance drilling intensified in order to achieve higher ROP and reduce drilling cost in Tunu Field. Drill bits were studied and compared side by side in a simple yet effective spreadsheet. Drill bit providers were asked to put all information pertaining to their drill bit designs into this spreadsheet. Besides the standard data such as blade count, cutter size, cutter count, and number of nozzles, the spread sheet includes in depth data such as cutter backrake angle, cutter chamfer, depth of cut limiter ROP engagement and open face volume to name a few. The data provided was kept confidential to the operator and not shared with any drill bit providers. The drill bit providers are given equal opportunities to deliver the most efficient and effective drill bit design.

3 Drill Bits New Technologies

The operating company gave every drill bit provider opportunities to trial their latest technology advancement in PDC drill bits. All design trials were based on 6 blades 16 mm configuration.

3.1 Self-Adjustable Depth of Cut Limiter Drill Bit

The new technology of Self-Adjustable Depth of Cut Limiter Drill Bit was introduced to solve the dynamic drilling dysfunction and mitigates stick slip. Jain et al. (2017) described the concept of self-adjusting depth of cut bit in SPE-184736-MS, the bit mitigates vibrations by resisting rapid changes in DOC that occurs during unfavorable dynamics events. When drilling smoothly, the bit results in gradually increasing DOC as it adapts to formations and operating parameters, resulting in faster and efficient drilling.

The adjustable DOCC element or the self-contained cartridges was placed on the cone area of the three main blades to center (Figure 6). The application of PDC bit with adjustable DOCC technology in Tunu Field was remarked as the first run in Asia Pacific region.

The mechanism provides the DOC control element with an ability to respond to the external loads through strategically designed retraction and extension strokes. The retraction stroke is rate-sensitive: the mechanism resists sudden inward motion and can absorb several thousand pounds of force over short durations of several seconds, but enables gradual retraction over a minute or more to adjust the ovoid exposure. When there is no external load on the ovoid, the mechanism activates the extension strokes, which is carried out rapidly within a fraction of a second (*Jain et al. 2017).*

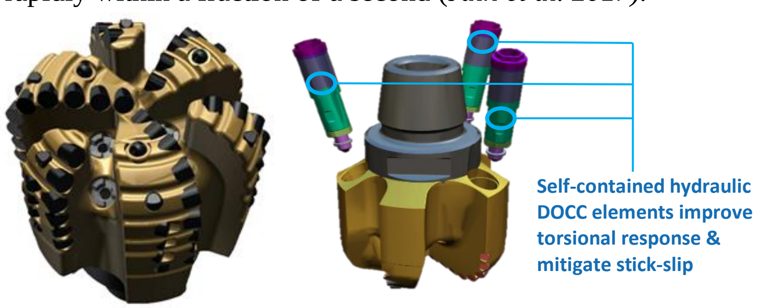

Figure 6 Self-Adjustable Depth of Cut Limiter Drill Bit

3.2 Shaped PDC Cutters

In the recent years, drill bit manufacturers released various shaped PDC cutters to increase toughness and assists in pre-fracturing the formation sheared. The idea of the shaped cutters is to crush and shear rocks at the same time. Various implementations across the world showed positive results hence the drill bit suppliers were given an opportunity to test these shaped cutters in Tunu Field.

Two major drill bit providers were selected to test their shaped PDC cutters in Tunu Field. The first provider brought in an axe shaped PDC cutter (Figure 7) that cuts rock in a combination of shearing and crushing method. Based on lab testing by the drill bit provider, this type of cutter is claimed to achieve 22% deeper penetration compared to standard PDC cutter. The thicker diamond table that is 70% more than the standard PDC also provides extra toughness when absorbing frontal impact.

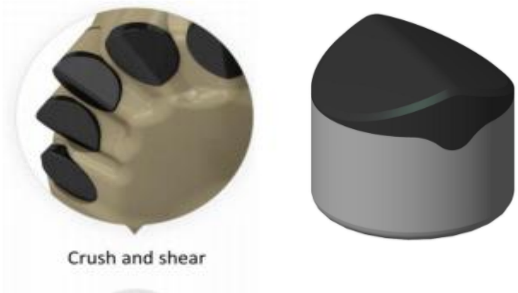

Figure 7. Axe Shaped PDC Cutter

The second drill bit provider offered their flagship 4D shaped PDC (Figure 8) cutter that creates a plough effect, which increases point loading in the shearing direction while reducing drag and creating smaller cuttings. The plough effect is claimed to:

- Increase point loading and stress concentration, while reducing the force needed to fail most formations and improve fracture propagation.
- Reduce drag by minimizing surface contact with the formation, while allowing cuttings to be efficiently moved away from the cutter face.
- Decrease cuttings size by creating a flow channel that allows drilling fluid to undermine adhesion between cuttings ribbons and the cutter. This action separates and breaks the cuttings into smaller pieces for more efficient removal from the cutter and bit face.

Figure 8. 4D Shaped PDC Cutter

3.3 Efficient Backup Cutter Layout

Secondary row cutting structure in PDC bit is commonly used to drill oil and gas wells as it acts as a backup or insurance if the primary cutting structure wears out before drilling to casing point. The secondary row cutting structure standard placement is directly behind the primary cutting structure and recessed or not on par with the primary cutting structure. The new concept of efficient backup cutter layout launched by one of the major drill bit providers places the secondary row cutters behind the primary cutters however at a certain angle (Figure 9). With the unique placement, the secondary row cutters act as a depth of cut controller for the primary cutters, making the drill bit more stable.

Figure 9. Efficient Backup Cutter Layout Cutting Structure

3.4 Webbed Blade and Curved Nozzles Hydraulics

Webbed blades and curved nozzles (Figure 10) are recent hydraulics optimization techniques deployed by one of the independent drill bit providers. The webbed blade function is to have focused fluid flow and reduced fluid recirculation. The curved nozzles are designed to improved cutter cleaning and cooling. It also enhances cutting evacuation as the nozzles can be directed to a specific path as required.

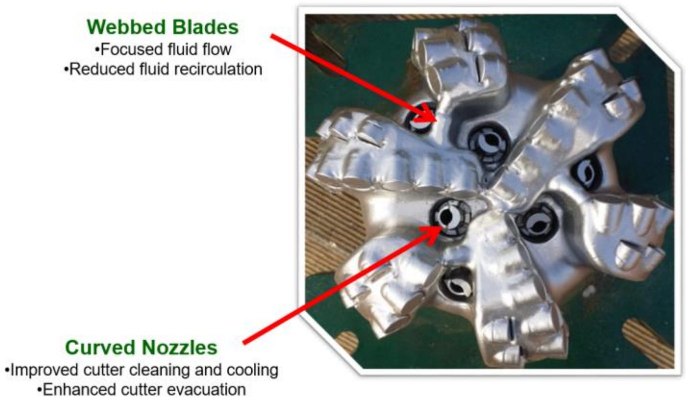

Figure 10. Webbed Blades and Curved Nozzles

Flow patterns show how both jets direct fluid flow (**Figure 11**). Schnuriger et al (2017) described that with standard nozzles, the fluid energy impacts the hole bottom nearer the center. Most of the cuttings are generated in the shoulder area. Energy is dissipated in the center of the bit and does not reach this area as effectively. Curved nozzles redirect the flow to place more energy into the area where more cuttings are generated.

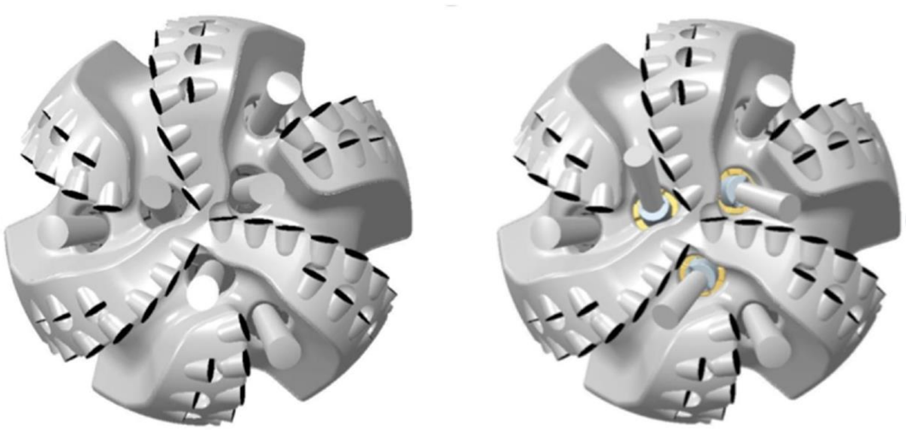

Figure 11. Flow Patterns for Curved (right) and Standard Nozzles (left)

Computational Fluid Dynamics (CFD) simulation confirms that flow velocity for curved nozzles are higher towards the outer area of the drill bit, where it is needed the most. CFD velocity field streamlines across the face of the bit to depict how nozzle changes affect fluid velocity (Figure 12). Measured in meters per second, velocity quickly dissipates at the center of the bit when standard nozzles are used. The extension and orientation of the curved nozzles moves the fluid energy towards the high cutting area with almost twice as much velocity.

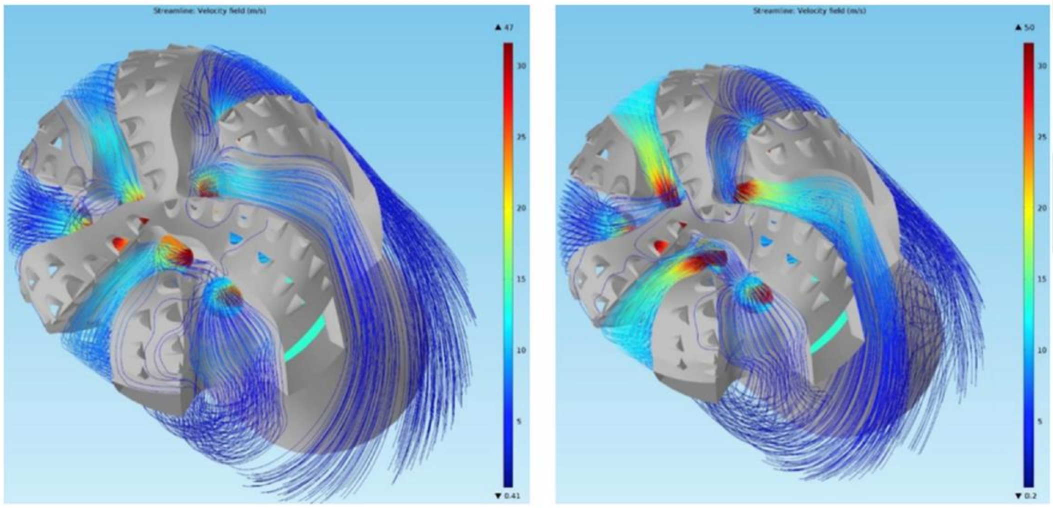

Figure 12. CFD Streamlines for Curved (right) and Standard Nozzles (left).

3.5 Unique Hydraulics Configuration

Optimum drilling performance is always the goal of every operating company. However sometimes many factors are hindering this objective. One of the factors limiting drilling performance is related to the poor cuttings evacuation on a drill bit during drilling formation. One of the lesser known independent drill bit providers, especially in the Asia Pacific region, has an innovative method on overcoming this performance limiter. The Mahakam based operating company identified this unique hydraulics configuration feature patented to the drill bit provider and combined with tailor made design for Tunu Field, gave the opportunity to the provider to trial run its first ever bit in Indonesia.

The unique hydraulics configuration features a split geometry in which the inner blade geometry is offset forward (Figure 13). The primary blades separate past the cone to free more area for the junk slot and prevent cuttings recirculation. This design creates specific large-volume flow channels that are capable of more readily carrying cuttings away from the face of the bit. Cuttings are therefore cleared from the cone up to seven times faster compared to conventional PDC designs, freeing up the bit's significant drilling potential.

The unique hydraulics design provides further improvement in cuttings evacuation through a significant increase in the maximum hydraulic dispersal rate, creating a 'double-barrel' hydraulics effect. The bit's nozzles are positioned to create dedicated fluid channels, ensuring that a high volume of fresh hydration reaches the cone and shoulder cutters, adding to bit performance and longevity. The high-velocity, tilted nozzles are built into the bit, in order to channel more drilling fluid onto the cutters themselves. In addition, this advanced bit design breakthrough provides for significantly improved bit face cleaning, adding to its overall enhanced performance. The bit's hydraulics are also designed to deliver additional benefits that expand the performance threshold. The increased hydraulic dispersal rate provides broader channels for the evacuation of cuttings, which prevents the cuttings from being recirculated, improving cutter performance and ROP. In addition, the bit's improved tool face control offers more effective directional drilling in curves, with good tool steerability.

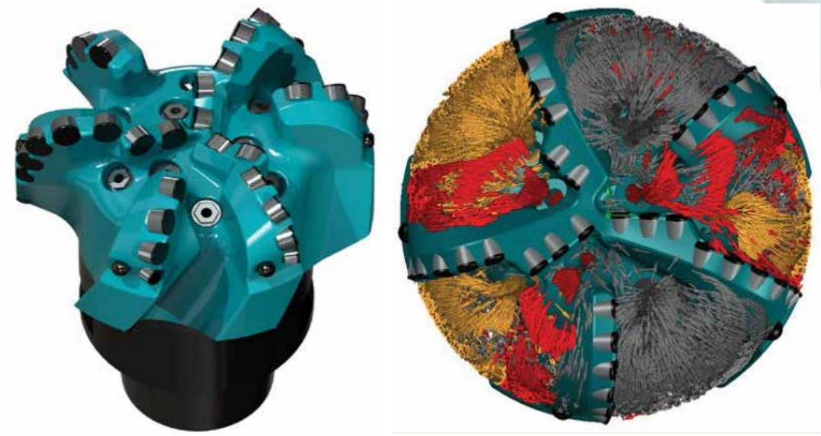

Figure 13. Unique Blade Geometry and Hydraulics Configuration

4 Results

As discussed, one of the key performance indicators (KPI) of the trials were the interval drilled in 24 hours. The initial performance benchmark and minimum objective is drilling 1400 meters in 24 hours. Drilling interval from shoe to TD is also a KPI. All drill bits were run with Push the Bit Rotary Steerable System from a major directional drilling services provider.

The 24 hours drilling performance for the latest drill bit technologies yielded various results (Table 1 and Figure 14). The first trial of Self-Adjusted DOCL bit did not surpass the 1400 meters in 24 hours objective, however the second trial came close to drilling a mile a day. The on bottom ROP yielded by the two runs in well 1 & 2 were 91.78 m/hr and 115.35 m/hr.

The Shaped Cutter from two different providers yielded very different results. The 4D Shaped Cutter successfully drilled 1910 meters in 24 hours in well 4, while the Axe Shaped Cutter was only able to achieve 1516 meters in 24 hours in well 3. However, to be noted that the 4D Shaped Cutter was a lighter set design of 6 blades 16 mm configuration compared to the Axe Shaped Cutter bit.

The Efficient Backup Cutter Layout bit design performed just above the benchmark and minimum objective. The bit drilled 1434 meters in 24 hours in well 5, yielding an on bottom ROP of 101.06 m/hr.

The Webbed Blade and Curved Nozzles bit only drilled 1282 meters in 24 hours, however the run was deemed partially inconclusive as there were some parts were controlled drill due to high ECD issues. Nevertheless, the bit performed with an on bottom ROP of 101.67 m/hr.

The Unique Hydraulics bit first trial yielded positive results, although it was the first run in Indonesia for the independent and lesser known drill bit provider. The bit drilled 1798 meters in 24 hours or 398 meters above the performance benchmark and minimum objective. The on bottom ROP yielded was 128.25 m/hr. The second run surpassed the benchmark and objective by more than 50%. The bit drilled 2109 meters in 24 hours, yielding an on bottom ROP of 147.48 m/hr. The 2132 meters in 24 hours interval drilled was a new world record on a Rotary Steerable System BHA. Previous record was listed at 2116 meters drilled in 24 hours through lateral, which is considerably easier due to the homogeneous formation.

Bit Co.	Bit Technology	Well	Depth In (mMD)	Depth In (mTVD)	Depth Out (mMD)	Depth Out (mTVD)	Interval (m)	OB Time (hrs)	OB ROP (m/hr)	Inc In (deg)	Inc Out (deg)
B	Self Adjusted DOCL	1	1554	1474	2849	2645	1295	14.11	91.78	23.56	23.01
B	Self Adjusted DOCL	2	1424	1371	3017	2896	1593	13.81	115.35	17.00	16.15
S	Shaped Cutter Axe	3	1740	1444	3256	2686	1516	14.67	103.34	40.02	20.29
N	Shaped Cutter 4D	4	1376	1323	3286	3158	1910	15.71	121.58	17.00	16.12
H	Efficient Backup Layout	5	1464	1423	2898	2849	1434	14.19	101.06	14.17	0.22
V	Webbed Blade & Curved Nozzles	6	1394	1212	2676	2220	1282	12.61	101.67	39.90	31.05
U	Unique Hydraulics	7	1402	1230	3200	2865	1798	14.02	128.25	32.90	17.17
U	Unique Hydraulics	8	1698	1424	3830	3125	2132	14.30	149.09	37.80	36.51

Table 1. Drilling Performance of Various Drill Bit Technologies in 24 hours Period

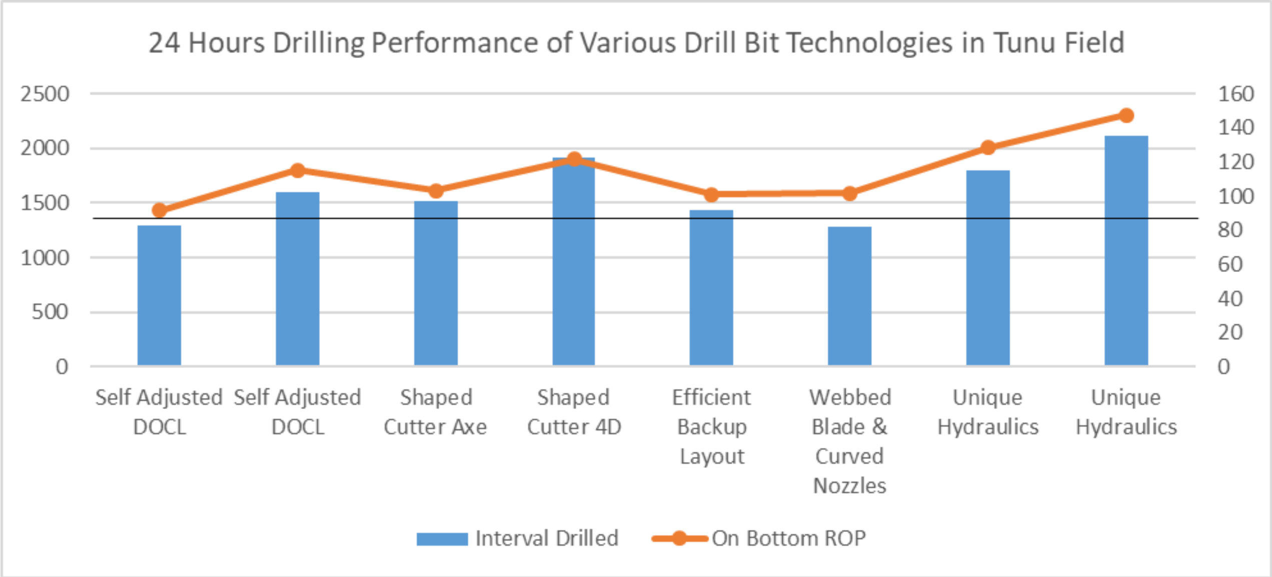

Figure 14. Drilling Performance of Various Drill Bit Technologies in 24 hours Period

All the drill bits trialed drilled to TD and drilled more than 2200 meters, proving their durability (Table 2). The Unique Hydraulics bit in its second trial drilled the longest interval, with 2906 meters and achieved the highest on bottom ROP at 91.99 m/hr, a new Tunu Field record.

Bit Technology	Well	Depth In (mMD)	Depth In (mTVD)	Depth Out (mMD)	Depth Out (mTVD)	Interval (m)	OB Time (hrs)	OB ROP (m/hr)	Inc In (deg)	Inc Out (deg)	Dull Condition
Self Adjusted DOCL	1	1554	1474	4215	3978	2661	49.40	53.87	23.56	11.08	1-4-BT-S-X-I-ER-TD
Self Adjusted DOCL	2	1424	1371	3713	3565	2289	26.76	85.54	17.00	17.50	1-2-WT-G-X-I-ER-TD
Shaped Cutter Axe	3	1740	1444	4616	3964	2876	74.22	38.75	40.02	19.80	1-2-WT-S-X-I-NO-TD
Shaped Cutter 4D	4	1376	1323	4074	3918	2698	62.71	43.02	17.00	15.50	1-7-RO-S-X-I-ER-TD
Efficient Backup Layout	5	1464	1423	3691	3641	2227	29.90	74.48	14.17	0.37	2-3-BT-A-X-I-CT-TD
Webbed Blade & Curved Nozzles	6	1394	1212	3835	3311	2441	34.04	71.71	39.90	17.30	1-3-BT-G-X-I-ER-TD
Unique Hydraulics	7	1402	1230	4013	3640	2611	28.48	91.68	32.90	17.50	1-1-CT-S-X-I-ER-TD
Unique Hydraulics	8	1689	1415	4595	3741	2906	31.59	91.99	37.80	36.48	1-6-BT-S-X-I-WT-TD

Table 2. Drilling Performance of Various Drill Bit Technologies to TD

With both trials delivering positive results, the Unique Hydraulics drill bit proved the concept of faster cutting evacuation as a game changer in Tunu Field drilling. This is due to the concentrated flow that focuses on each sector of the cutting structure and prevent cuttings recirculation. Drill bit hydraulics and cleaning plays a very important part in drilling performance, especially in soft to medium hard formations. The bit design can still be further optimized to deliver more performance by altering the cutter backrakes and adjusting or removing the depth of cut limiters.

The first trial of the Unique Hydraulics bit yielded a dull condition of 1-1-CT-S-X-I-ER-TD (Figure 15). The cutting structure was mostly in good condition. The bit body showed signs of erosion on the back of the blades and blade rubbing was found in the inner area due to the high ROP and depth of cut the bit delivered during drilling.

Figure 15. Dull Condition of Unique Hydraulics Bit First Trial

The second trial of the Unique Hydraulics bit yielded a dull condition of 1-6-BT-S-X-I-WT-TD (Figure 16). The severe dull condition was due to the bit drilling deeper compared to the first trial while being pushed with more drilling parameters.

Figure 16. Dull Condition of Unique Hydraulics Bit Second Trial

5 Conclusion

The high volume of drilling in Mahakam in general and Tunu Field to be more specific, coupled by the reduced reserves, requires optimum drilling performance in order to reduce the overall well cost. Various drill bits technologies by different drill bit providers were given the opportunity to be trialed. The technologies trialed were Self Adjusted Depth of Cut Limiter, Shaped PDC Cutters, Efficient Backup Cutter Layout, Webbed Blade & Curved Nozzles, and Unique Hydraulics drill bits.

The trials yielded various results, with the Unique Hydraulics drill bit coming out as the best performer. The bit drilled 2132 meters in 24 hours period, a new world record for RSS BHA. The concept of enhanced cuttings removal by dedicated flow cleaning the bit cutting structure proves to be effective in optimizing the drilling performance. Further design enhancements and trial of new technologies will be done as part of continuous improvement process in the Maxi-Drill project.

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