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Comparison of Mud Motor and the Rotary Steerable System (RSS) As Two Main Directional Drilling Methods

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Abstract

As the global demand for oil and gas continues to rise, the safe, efficient, and cost-effective drilling of directional and horizontal wells demands advanced technology. Achieving these objectives relies on strategic drilling methods, employing techniques such as Rotary Steerable Systems (RSS) and Positive Displacement Mud Motors. Complex well trajectories face drilling operations with lots of challenges, particularly in deep and highly deviated wells. Issues such as high dogleg severity, low Rate of Penetration (ROP), and tool sticking can lead to substantial financial losses for operators. In extreme cases, inadequately drilled directional wells may even lead to abandoning the well. Advancements in both mud motors and rotary steerable systems (RSS) have significantly enhanced directional drilling capabilities over the past decade. While mud motors remain a reliable and cost-effective solution for many projects, the increasing complexity of modern reservoirs and the need for precise well placement has led to widespread use of RSS technologies. This review article compares the mud motor and the rotary steerable system (RSS) as two main directional drilling methods in different aspects. The results show that the application of RSS in comparison with conventional mud motors not only gives technical advantages but also has an economic advantage.

1. Introduction

Directional drilling is the practice of drilling non-vertical wells to reach subsurface targets that are not directly beneath the drilling location. It involves controlling the trajectory of the wellbore to follow a predefined path, allowing access to reservoirs that are otherwise inaccessible with vertical drilling [1].

The applications of directional drilling are shown in Figure 1.

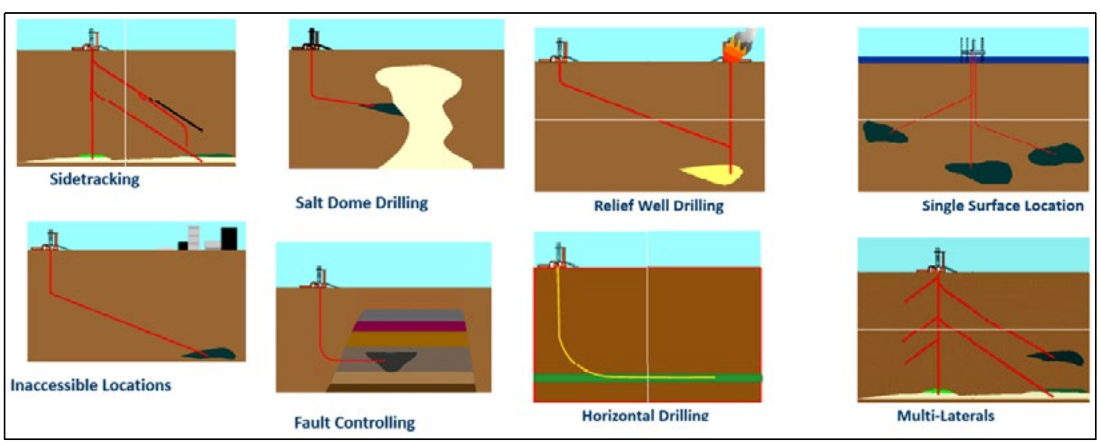

Figure 1: Directional Drilling Applications

1.1 Principles of Directional Drilling

Most directional wells begin as vertical wellbores. At a designated depth, known as the kickoff point (KOP), the directional driller deflects the well path by increasing well inclination to begin the build section. Surveys taken during the drilling process indicate the direction of the bit and the tool face, or orientation of the measurement sensors in the well. The directional driller constantly monitors these measurements and adjusts the trajectory of the wellbore as needed to intercept the next target along the well path.

1.2 Directional BHA

Initially, directional drilling involved a simple rotary bottomhole assembly (BHA) and the manipulation of parameters such as weight on bit (WOB), rotary speed and BHA geometry to achieve a desired trajectory. Changes in BHA stiffness, stabilizer placement and gauge, rotary speed, WOB, hole diameter, hole angle and formation characteristics all affect the directional capability and drilling efficiency of a BHA.

By varying stabilizer placement in the drill string, directional drillers can alter side forces acting on the bit and the BHA, causing it to increase, maintain or decrease inclination, commonly referred to as building, holding or dropping angle, respectively.

- To **build** angle, the directional driller uses a BHA with a full-gauge near-bit stabilizer, another stabilizer between 15 to 27 m [50 to 90 ft] above the first and a third stabilizer about 9 m [30 ft] above the second. This BHA acts as a fulcrum, exerting a positive side force at the bit.
- Building Bottom Hole Assembly In Directional Drilling are shown in Figure 2.

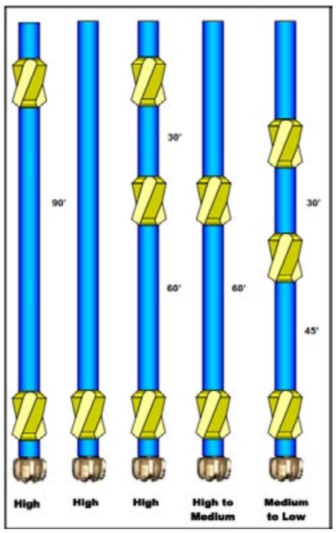

Figure 2: Building Bottom Hole Assembly In Directional Drilling

- To **hold** angle, the directional driller uses a BHA with 3 to 5 stabilizers, placed about 9 m apart. This packed BHA is designed to exert no net side force.

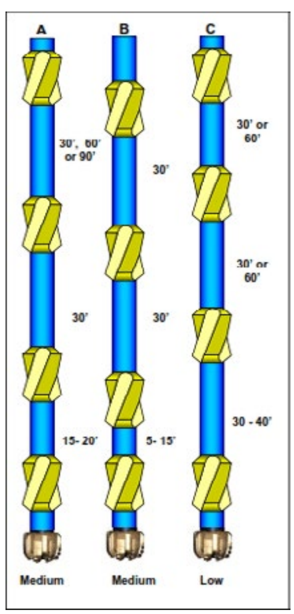

Figure 3: Directional Holding BHA

- To **drop** angle, the directional driller uses a BHA with the first stabilizer 9 to 27 m behind the bit. This BHA acts as a pendulum, exerting a negative side force at the bit.

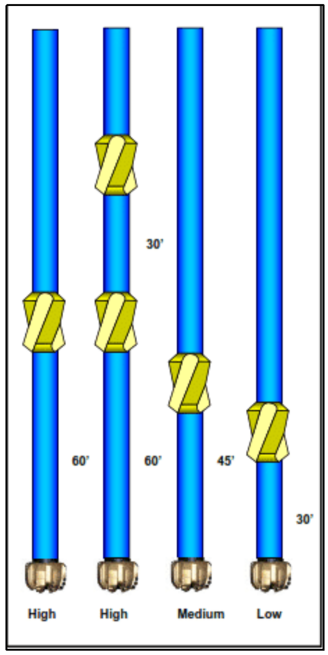

Figure 4: Pendulum Assembly or Dropping BHA

1.3 Jetting Assembly

A jetting assembly provides directional capability while drilling through loose or unconsolidated formations. Jetting bits are roller cone bits with either a large extended nozzle in place of one of the cones, or with one large nozzle and two small nozzles. The large nozzle provides the "high side" reference, and the well path is deflected by alternately sliding or rotating the drill string. Another way is to plug two nozzles and circulate mud just by one nozzle.

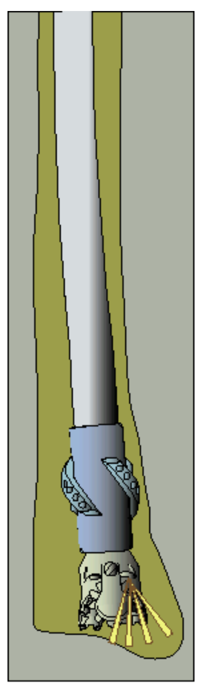

Figure 5: Jetting (One large bit nozzle) Used in Soft Formations

1.4 Whip Stock

A whipstock is a wedge-shaped steel tool deployed downhole to mechanically alter the well path. The whipstock is oriented to deflect the bit from the original borehole at a slight angle and in the direction of the desired azimuth for the sidetrack. It can be used in cased or open holes.

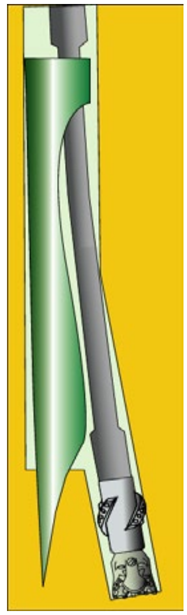

Figure 6: Open Hole Whip-stocking. Used in medium to hard formations

Whipstock and directional BHA are not so practical, because trip out and trip in is required in the operation of these tools. Nowadays, conventional steerable motor and RSS are more common in directional drilling operations.

1.5 Mud Motors

Mud motors, also known as positive displacement motors (PDMs), are a widely used technology for directional drilling. They function by converting the hydraulic power of the drilling fluid (mud) into mechanical energy that drives the bit without rotating the entire drill string. A key advantage of mud motors is their simplicity and reliability, making them particularly useful in cost-sensitive projects or when downhole conditions are challenging.

1.6 Mud Motors Operational Mechanism

A mud motor consists of a rotor and stator arrangement. The rotor turns as drilling fluid is pumped through the motor, causing the drill bit to rotate. The conventional steerable motor is a mud motor equipped with bent housing (Figure 7). This bent housing allows for the deflection of the wellbore. The bent housing of conventional steerable motor is the important factor that affects build rate in deviating the well trajectory. It is designed with a certain angle from the centerline of the motor called bent angle. This angle led to side force on the drill bit. The bent angle in PDM can be adjusted as needed [2]. By varying the bend angle of the motor assembly, operators can adjust the direction of drilling. Mud motors are typically used for medium-to-hard formations and are suited for wells that require high build rates.

Different parts of mud motors are shown in Figure 7.

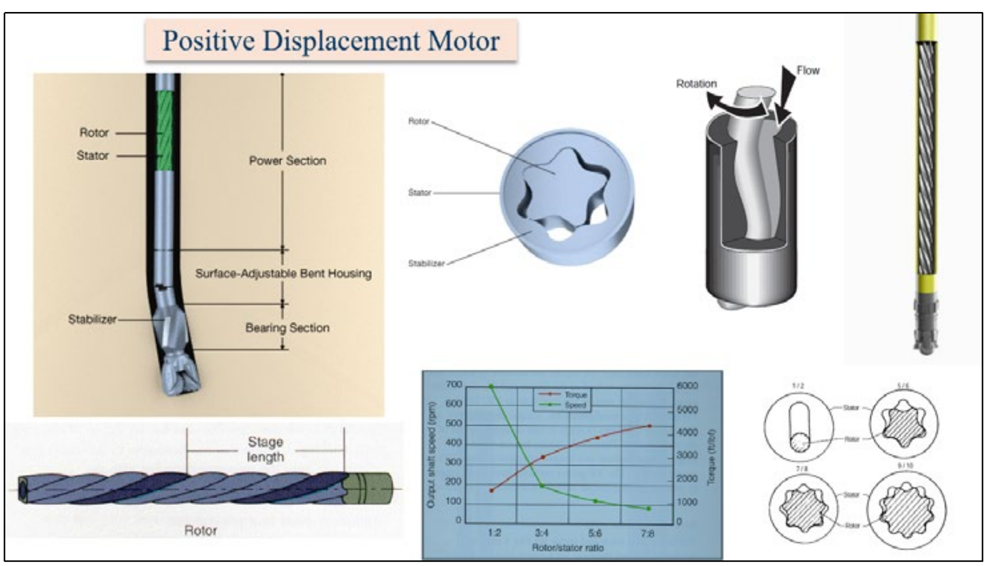

Figure 7: Different Parts of Mud Motors

There are two steering modes in drilling using the conventional steerable motor, rotating and sliding. The rotating mode is drilling with drill string rotation. The rotating mode is used for drilling vertical or tangent section, where inclination changes is not expected. In sliding mode, drill string rotation is prohibited and rotary motion only occurs in the drilling bit. The sliding mode is used in deflecting the wellbore. Deflection in the wellbore is due to bent housing in steerable mud motor. The Directional Driller has to make calculation according to the length of slide and the length of rotating to get the desired build rate.

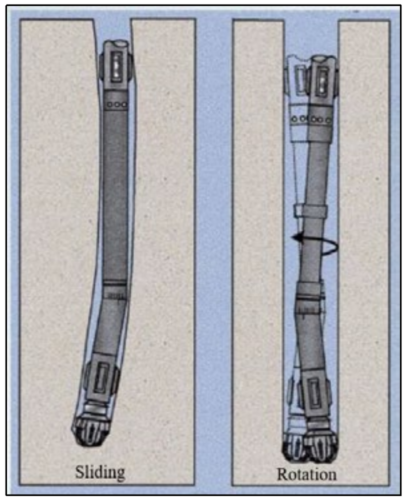

Figure 8: Rotating and Sliding Steering Modes

1.7 Advancements

Significant improvements have been made in the efficiency and durability of mud motors. For example, advancements in elastomer technology for stators have resulted in increased motor life and performance in high-temperature and high-pressure conditions (HPHT). Recent field studies have shown that newly designed stators have improved performance of mud motors and their life by 30% [3]. Moreover, advancements in telemetry and real-time downhole data collection have improved steering accuracy with mud motors. Modern systems can now integrate sensor packages that provide immediate feedback on drilling conditions, enabling more precise control of well trajectory [4].

2. Limitations

Despite their advantages, mud motors have limitations. They tend to be less efficient at high angles of deviation and struggle in formations that cause rapid wear on the motor's internal components. Additionally, controlling the exact trajectory with mud motors can be more challenging than with more advanced systems, particularly over long distances [5]. Some of mud motor disadvantages are:

- Micro Dogleg/Crooked well profile
- Toolface adjustment at Sliding
- String Hanging while sliding
- String Sticking resulting from no rotation in sliding mode
- Poor Hole Condition and Cutting Bed creation

2.1 Rotary Steerable System (RSS)

A modern alternative to mud motor is the technology of rotary steerable systems (RSS), created in the late 1990s. Since then, this technology keeps developing and has transformed the directional drilling industry. The most important feature and, accordingly, the main advantage of RSS is that this technology provides a directional drilling process along with continuous rotation of the entire drill string, thereby improving cleaning conditions and the quality of the borehole, preventing sticking and spiral twisting of pipes, ensuring the transfer of the necessary load on bit to optimize the speed of penetration, save time and cost. In addition, RSS reduces twisting and axial loads, as well as stick & slip phenomena, compared to directional drilling using mud motors. The use of rotary steerable systems provides the possibility of drilling longer intervals with a uniform diameter, which facilitates the running of the casing string. World leaders in the production of RSS are companies: Baker Hughes, Schlumberger, Halliburton, and Weatherford.

The advantages of RSS technology are:

- Continuous drill string rotation
- No reduction in ROP while sliding
- Better hole cleaning
- Steerable without sliding (100% rotation).
- Long Reach & Designer Trajectories possible
- Fewer wiper trips
- Optimized drilling parameters
- Higher overall ROP
- Decrease time of drilling the well
- Improving the quality of the wellbore with minimal micro-curvature
- Produced smoother boreholes

The disadvantages include:

- The need of top drive
- The need to use powerful and reliable pumps
- the use of expensive bits, specially designed and manufactured for such systems.
- daily cost is higher than mud motor

The conventional steerable motor is often chosen as an alternative to using RSS just because the daily cost is lower than RSS. RSS is not a brand-new technology. This technology was introduced in the ’90s. Since then, this technology keeps developing and has transformed the directional drilling industry. From the experiences, drilling using RSS produced smoother boreholes and better hole cleaning than using the conventional steerable motor [6]. RSS also gives another benefit such as making drilling with a more sophisticated target or 3D trajectory possible [7]. Although RSS offers a lot of benefit than the conventional steerable motor, this technology is often avoided in directional drilling projects where directional drilling accuracy is not the main issue. RSS is considered as the high-profile technology due to its pricey daily cost. Rotary steerable systems according to the method of controlling the displacement of the bit relative to the axis of the well can be divided into two main types of push-the-bit and point-the-bit.

- **Push-the-bit systems** use pads that extend from the body of the tool to push against the borehole wall, altering the bit's trajectory. The principle of operation of the RSS type "Push the bit" This type of system consists of a drilling process control unit and a measurement while drilling (MWD) tele system module. The base unit includes navigation sensors, a distributing valve and guide vanes. The control unit for the drilling process includes a downhole computer and a turbine generator or lithium batteries. During drilling, the downhole computer checks the design data loaded into it with the values coming from the MWD module. If there is a need to change the drilling path, the downhole computer, using navigation sensors, transmits information to the distributing valve, which directs the hydrodynamic energy of the drilling fluid to the guide blades that extend from the body. As a result, the entire assembly is repelled from the well wall in a given direction.

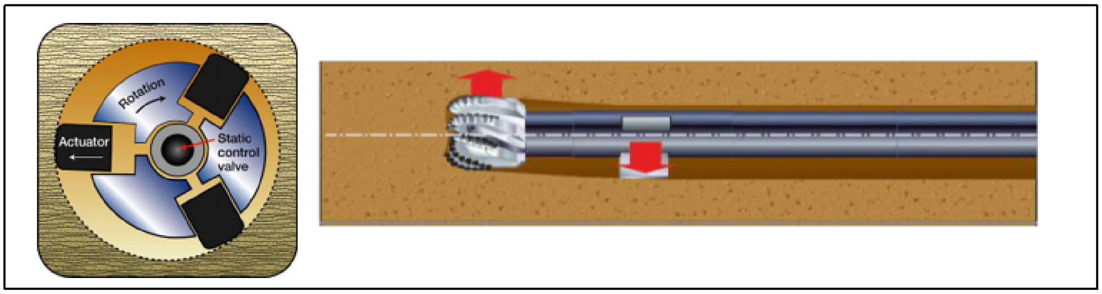

Figure 9: Push-the-Bit RSS

- **Push-the-bit RSS** tools have shown excellent results in complex formations, such as in deepwater drilling, where maintaining borehole integrity is essential [8].

- **Point-the-bit systems** use a rotating sub to adjust the angle of the bit relative to the borehole. This allows for continuous control of the bit's orientation and provides superior well placement accuracy. Bit positioning is achieved by shifting the drive shaft relative to the layout, or by changing its curvature, which causes a change in angle. The principle of operation of the RSS type "Point the bit" This type of system is a hardware-equipped, over-bit stabilizer consisting of three main components, including a rotating mandrel (drive shaft), an eccentric inner sleeve, and a weighted non-rotating outer case. The tool works by controlling the direction of the eccentric inner sleeve, which biases the mandrel and, accordingly, the bit in a given direction. [9].

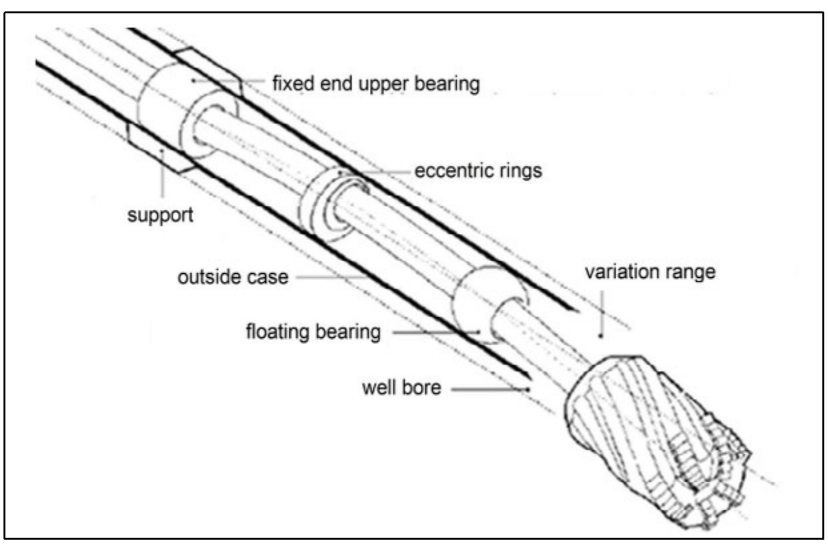

Figure 10: RSS Point-the-Bit [9]

2.2 Comparison Between Mud Motors and RSS

When comparing mud motors and RSS, several factors must be considered, including cost, control, and application. Drilling using RSS produced smoother boreholes and better hole cleaning than using the conventional steerable motor [6]. RSS also gives another benefit such as making drilling with a more sophisticated target or 3D trajectory possible [7]. Although RSS offers a lot of benefit than the conventional steerable motor, this technology is often avoided in directional drilling projects where directional drilling accuracy is not the main issue. RSS is considered as the high-profile technology due to its pricey daily cost. When high accuracy in drilling operation is not the main issue, the conventional mud motor can be used as a reliable tool in directional drilling operations. The conventional mud motor is often chosen as an alternative to using RSS just because the daily cost is lower than RSS [10].

2.3 Rate of Penetration

Mud motor uses sliding mode in building or dropping wellbore angle and due to not rotating the string results to:

- Reduce hole cleaning
- Increase friction between drill string and wellbore.
- These friction forces reduce the weight transfer to the bit.
- Reduction of bit rotation speed.
- Reduce rate of penetration due to low weight transfer to the bit

RSS enables drill string rotation while deviating the wellbore. ROP of RSS was not much different from the conventional steerable motor in tangent section. But in build/drop section ROP of RSS was higher 4 times than ROP of the conventional mud motor. This huge difference was caused by sliding action in the conventional steerable system, which is a time-consuming operation [10].

2.3.1 Daily Cost

The daily cost of using RSS system is almost 5 times higher than a conventional steering mud motor and making mud motor the preferred choice for budget-conscious projects or wells with moderate directional control needs.

2.3.2 Drilling Time

According to previous drilled well in 12 ¼ hole section, RSS drills 4 times faster than the conventional steerable motor.

2.3.3 Total Drilling Cost

Total cost per day includes the cost of the drilling rig and drilling services in terms of standby and operational charge, and their personnel cost. Since RSS can finish the well about 4 times faster than the conventional mud motor, the final total drilling cost will be about 2 times cheaper on RSS in comparison with a mud motor.

2.3.4 Borehole Quality

Good borehole quality can lower down the risk of Lost in Hole. good quality borehole will have an impact in running casing process and reduce the overall drilling rig cost. Figure 11 shows borehole quality comparison (using caliper log) between RSS and conventional steerable motor from wells in the Gulf Coast Area. This figure depicts that RSS produces smoother borehole than conventional steerable motor [10].

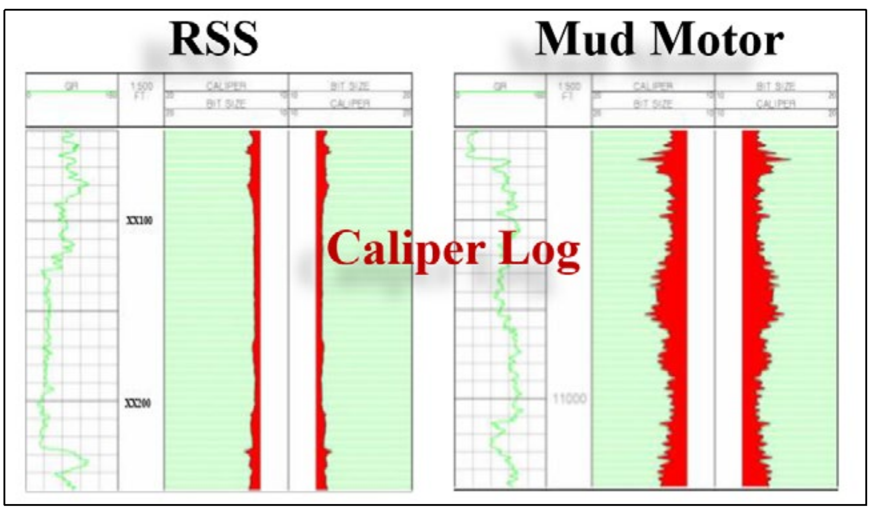

Figure 11: Borehole Quality Comparison Between RSS and Conventional Steerable Motor

2.3.5 Lost In Hole

Comparison of LIH incidents between RSS and conventional mud motor show that rotary steerable system LIH rate was only 15% of the conventional systems [10].

2.3.6 Steering Control

RSS tools offer superior control over wellbore trajectory, particularly in complex or high-angle wells where precise steering is essential.

2.3.7 Drilling Speed

RSS tools generally allow faster drilling rates due to their ability to rotate the drill string while steering, whereas mud motors require intermittent stops to adjust trajectory [11]. RSS gives smoother borehole and less tortuosity than the conventional steerable motor. These conditions provide indirect benefit such as reducing the time for casing installation and improving the quality of logging data. In conclusion, the application of RSS not only gives technical advantages but also has an economic advantage.

2.3.8 Comparison Between Point-the-Bit and Push-the-Bit RSS

As mentioned above, RSS has better performance in comparison with mud motor. On the other hand, there are two types of RSS. In the following push-the-bit and point-the-bit RSS will be compared.

2.3.9 Tool Complexity and Cost

- **Point-the-Bit RSS** has complex internal steering mechanisms that require actuators to tilt the bit directly. Point-the-Bit RSS has more moving parts and sensors, more frequent inspections and potential downtime for maintenance, leading to higher long-term costs.

- **Push-the-Bit RSS** has fewer internal components. lower purchase or rental cost compared to point-the-bit systems. According to fewer moving parts and a simpler steering mechanism (relying on side force or pads), has less maintenance costs.

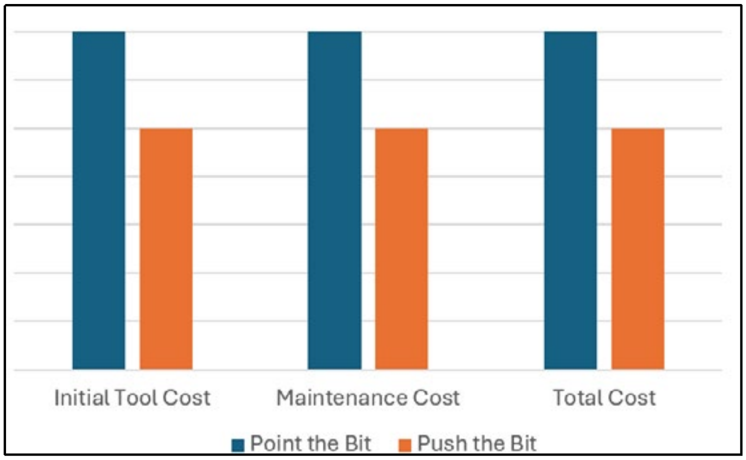

Figure 12: Push-the-Bit and Point-the-Bit RSS Cost Comparison

2.3.10 Operational Efficiency and Rig Time

- **Point-the-Bit RSS has higher precision:** better wellbore precision and control, reduce the need for corrections or sidetracking. The smoother wellbore delivered, lower drag and torque, faster and more efficient drilling. In the long term, this can reduce operational time and associated rig costs.
- **Push-the-Bit RSS has lower precision:** Rougher wellbore increased torque and drag. This can slow down the drilling process and increase time spent on wellbore conditioning, potentially raising the overall cost of the operation.

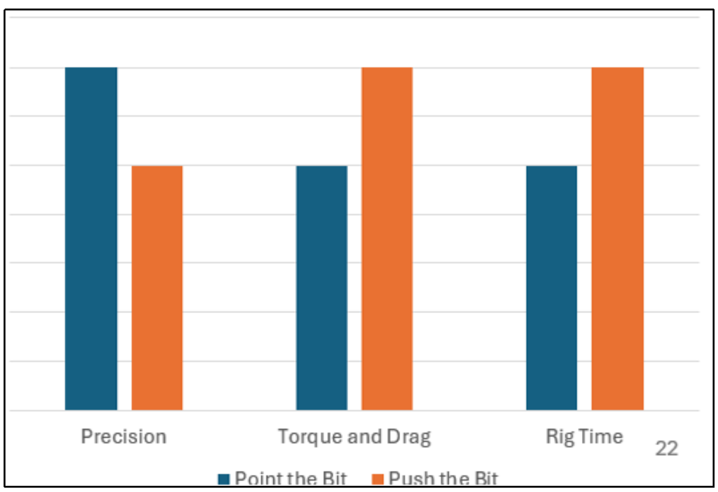

Figure 13: Push-the-Bit and Point-the-Bit RSS operational Efficiency and Rig Time

2.3.11 Bit Wear and Replacement

- **Point-the-Bit (Lower bit wear):** Drilling the well with precise directional control leads to less lateral force, reducing drilling bit wear. This extends the life of the bit, lowering replacement costs and minimizing trips out of the hole.
- **Push-the-Bit (Higher bit wear):** The lateral force applied in push-the-bit systems can increase wear on the bit, particularly in hard formations. This can lead to more frequent bit replacements, increasing operational costs through bit purchases and non-productive time (NPT) for trips out of the hole.

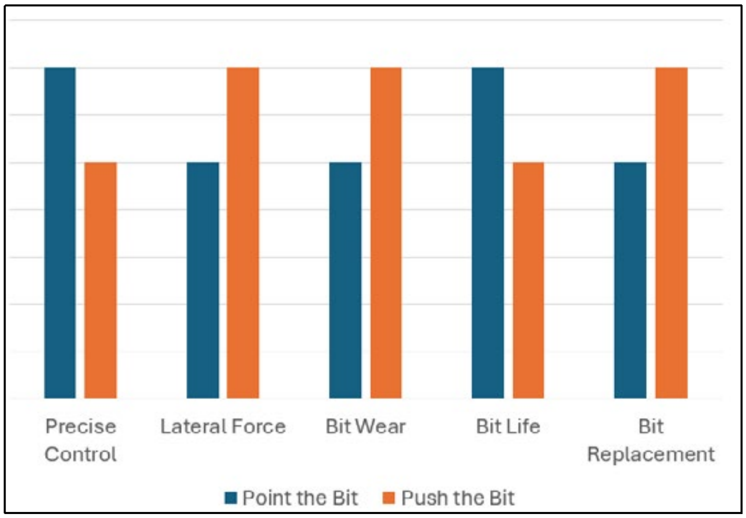

Figure 14: RSS Comparison in Bit Wear and Replacement

2.3.12 Wellbore Quality and Post-Drilling Costs

- **Point-the-Bit (Smoother wellbore):** The high-quality, smooth wellbore delivered by point-the-bit systems reduces the risk of hole problems (e.g., stuck pipe, excessive torque, difficulty running casing). This lowers post-drilling costs such as completion and casing running operations.
- **Push-the-Bit (Rougher wellbore):** The rougher wellbore from push-the-bit systems can increase the risk of hole instability, making it more challenging to run casing or completions. This can increase the overall costs of post-drilling operations due to potential wellbore issues.

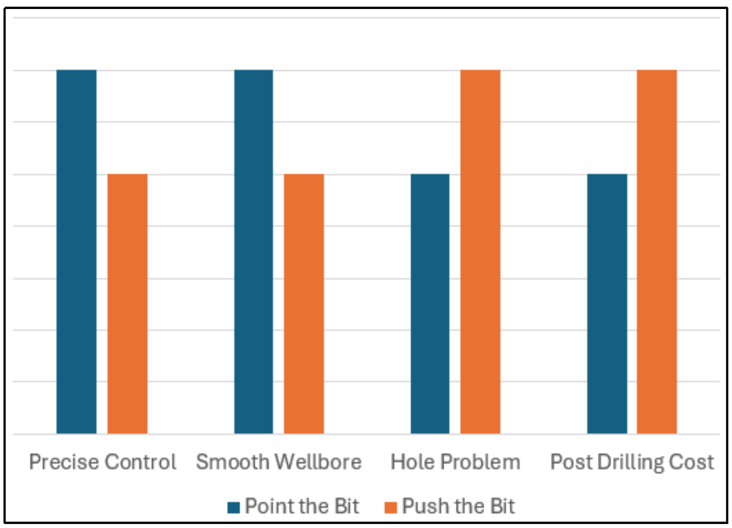

Figure 15: RSS Comparison in Wellbore Quality and Post-Drilling Costs

2.3.13 Formation Considerations

Point-the-Bit (Versatile in various formations): Effective in a wide range of formations, better cost efficiency in formations where precision and smoother wellbores are critical.

Push-the-Bit (Optimal in soft formations): More cost-effective in soft to medium formations. In harder formations, bit wear and slower progress increase drilling costs.

2.3.14 Overall Operational Cost

- **Point-the-Bit** RSS has higher upfront cost but according to lower bit wear, fewer wellbore issues, and smoother operations in complex formations has long-term savings.
- **Push-the-Bit** RSS has lower upfront costs and may be more cost-effective in **soft formations** or wells where higher build rates are needed. However, in more challenging environments, the increased bit wear and potential wellbore issues could raise operational costs.

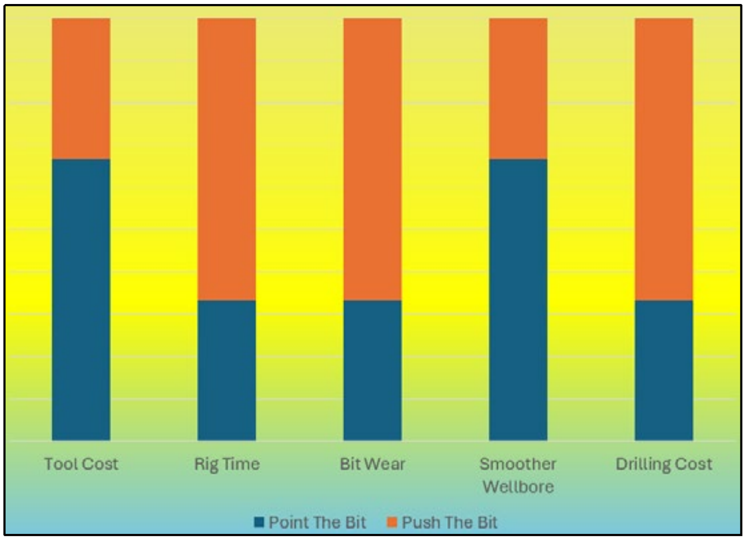

Figure 16: Push-The-Bit and Point-The-Bit Total Comparison

3. Conclusion

Advancements in both mud motors and rotary steerable systems have significantly enhanced directional drilling capabilities over the past decade. While mud motors remain a reliable and cost-effective solution for many projects, the increasing complexity of modern reservoirs and the need for precise well placement has led to widespread use of RSS technologies. RSS tools generally allow faster drilling rates due to their ability to rotate the drill string while build or drop inclination. RSS gives smoother borehole and less tortuosity than the conventional steerable motor. These conditions provide indirect benefit such as reducing the time for casing installation and improving the quality of logging data. Application of RSS not only gives technical advantages but also has an economic advantage. Point-the-Bit RSS in comparison with Push-the-Bit has higher upfront cost, but according to lower bit wear, fewer wellbore issues, and smoother operations in complex formations will help to reduce, cost of the well.

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