International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(Research Article)

Optimization of drilling design at different well depths with respect to specific energy

Maha IE * and Ndubuisi EC

Department of Petroleum and Gas, Faculty of Engineering, University of Port Harcourt, Rivers State, Nigeria.

International Journal of Science and Research Archive, 2024, 11(02), 976–983

Publication history: Received on 12 February 2024; revised on 29 March 2024; accepted on 01 April 2024

Article DOI: https://doi.org/10.30574/ijsra.2024.11.2.0496

Abstract

Drilling operations cost millions of Dollars and its success depend largely on some key parameters. Some of these parameters include wait on bit (WOB), rate of penetration (ROP), revolution per minute (RPM) and specific energy, also known as specific mechanic energy. In the design of the drilling program, keen interest must be paid to their variation, else, drilling problems which will lead to non-productive time will ensue. Therefore, this study focused on the optimization of bit design through selection of the bit with lowest specific energy possible to reduce drilling cost and improve efficiency via the consideration of critical parameters such as WOB, ROP drilling cost per foot and specific energy (Mechanical specific energy).

In this study, data were collected from 5 wells – ASSA North 004, ASSA North 005, ASSA North 006, Gbetiokun 7 and Benisede, all in Niger Delta. Specific energy was computed using mechanic energy and specific energy relations while the cost optimization was done using drilling cost relation. These data were carefully analyzed and the results of specific energy for the five wells selected wells were obtained. The values of the specific energy at desired depths were used to track the performance of drill bits at that depth. The bit used for ASSA North 005 was found to be most suitable as it maintained lowest specific energy for different depths.

The study therefore gave an insight into the importance of specific energy of the drill bit while carry out bit selection for an efficient and cost-effective drilling operation. The bit used for the drilling of ASSA North well was selected because it has the minimum specific energy.

Keywords: Specific energy; Data; Mechanic energy; Cost Optimization; Parameter; Efficiency; WOB; ROP

1. Introduction

Specific energy is a drilling concept that has to do with mechanical energy required by a bit to drill out a unit volume of rock. It is also called mechanical specific energy. Mechanical Specific Energy (MSE) and Rate of Penetration (ROP) are two key factors for evaluating the efficiency of a drilling process. MSE is defined as the energy required in removing a unit volume of rock [1]. ROP generally refers to the depth of cut per unit time and it is proportional to the depth of cut per revolution which is equivalent to the depth of cut for a single cutter [2]. In rock cutting, modes of failure would transit from ductile to brittle as the depth of cutting increases [2] [3] and this study is focused on ductile failure mode of shallow cutting which is encountered in most of the cutting and drilling operations. Most laboratory experiments have been focused on evaluating MSE and ROP separately, to maximize ROP or to minimize MSE through investigating the influence of rock properties and operation conditions [4]. Recent work shows that it is more effective to strategize the drilling operation by combining these parameters. For example, the real-time surveillance of MSE is effective to optimize ROP [5]. Also, extensive experiment results show that the MSE generally decreases with ROP [5] [6] [3] [7], indicating the possibility to maximize ROP and minimize MSE simultaneously.

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* Corresponding author: Maha I. E

Based on field experience, the bit's mechanical rotary energy is significantly more effective in breaking rock than its hydraulic energy. ROP might be significantly increased if the hydraulic energy of the mud flow is transformed into mechanical rotational power. Positive Displacement Motors, PDM is now frequently used in hard formation drilling to increase ROP in the field. When using PDM for rotating drilling, the Motor Bit shaft rotates first, followed by the entire string, which is produced by the power section of PDM converting the hydraulic energy of the mud flow into mechanical rotary power [8]. Additionally, while drilling in sliding mode, bit rotation is only produced by the PDM as drilling fluid is forced through the drill string. There are currently few efficient MSE models to accurately mimic the actual downhole drilling for rotating drilling with PDM because it has proven challenging to directly monitor PDM rotary speed and torque in downhole settings.

MSE, as previously mentioned, is the energy needed to break up a unit volume of rock. The ratio of energy to rock volume will not change much when a bit is performing at its best. The formation's CCS is correlated with the smallest MSE that is attained. Operationally, this connection is utilized by monitoring if the MSE (min) is approximately equal to the formation's confined compressive strength (CCS) and modifying drilling parameters like WOB or RPM to maximize ROP. The bit is considered to be at optimal efficiency if the MSE (min) increases with WOB and stays almost equal to the CCS of the formation. The bit has failed if the MSE (min) suddenly rises and is much more than the formation's confined compressive strength (CCS). Bit balling, bottom Hole Assembly, BHA (Stabilizers) balling. Drilling performance may decline overall and tools will be damaged if the causes of aforementioned problem are not treated at the time they occur.

The word "balling" is referred to material accumulation on the bit and/or other Bottom Hole Assembly that prevents part of the WOB from being transferred to the cutting structure settings to enhance ROP, like WOB or RPM. They are typically found in soft shaly formations, and lowering WOB and raising flow rates can relieve them. Bit balling and BHA balling are rare when using a PDM to drill in hard rock, although vibrations are a typical occurrence. Three modes are present in downhole vibrations: bit bounce (axial), stick-slip (torsional), and whirl (lateral). They increase weights downhole, leading to various bit and tool failures that raise the expense of tool replacement and maintenance in addition to the number of trips needed. Actually, by modifying WOB or RPM on the surface, these vibrations in rotating drilling with PDM could be efficiently minimized.

Assuming that the bottom hole has been well cleaned, an optimization technique for drilling parameters can be suggested for rotating drilling with PDM. This will maximize ROP, enable operators to drill for longer periods of time, and save needless excursions. The drilling parameters optimization approach for rotating drilling with PDM [8] is flow charted in Figure 8 and is based on real-time MSE monitoring to determine the bit's founder point [9]. Drilling efficiency stays at its highest level when MSE (min) = CCS. In this area, the bit just requires extra energy; it is not limited by a special inefficiency. If we raise WOB alone given an RPM, the ROP will grow significantly and finally approach the founder point.

2. Methodology

2.1. Determination of the Best Bit for Each formation Using Well History

A drilling operation's effectiveness can be evaluated using two key metrics: mechanical specific energy (MSE) and rate of penetration (ROP). The MSE is the amount of energy required to remove one unit volume of rock [14]. ROP typically refers to the depth of cut per unit of time. It is proportionate to the depth of cut per revolution and correlates to the depth of cut for a single cutter [10]. The bulk of cutting and drilling activities use shallow cutting, which is the subject of this study's ductile failure mode. As cutting depth grows in rock cutting, failure modes would change from brittle to ductile [10, 2]. The evaluation of MSE and ROP has accounted for the majority of lab testing.

2.2. Data Gathering from Selected Wells in Niger Delta

2.2.1. Assa North Field

The Assa North field, also known as Ohaji South, is situated in the northeastern region of SPDC-operated OML-21 and crosses over into neighboring, non-SPDC-operated OML 53. The distance from Port Harcourt is 70 kilometers to the northwest. ASSA-001 made the discovery of the field in 1961, and since then, five further wells (ASSN-001, ASSN-002, AGGA-002, OHAS-001, and OHAS–002) have been drilled into the structure. The field is made up of a series of stacked reservoirs with shoreface and channel deposits in them. Nine of these reservoirs—found in the D02, H, and E sands—are hydrocarbon-bearing. H1000X and H4000X are the primary reservoirs, containing more than 80% of the hydrocarbon volume in the field. Six development wells will be drilled in the first phase, two in the H4000X reservoir and four in the H1000X reservoir. One of the two crestal wells intended to develop the H4000X reservoir is the H4D1 well. Anticipated ultimate recovery from the H4D1 (ASSN 003) well is estimated to be 152 Bscf of gas and 29 MMstb of condensate, with an estimated well potential of 70 MMscf/d. Drilling has already taken place on ASSN 004, 005, and 006, and ASSN 006 is currently being completed for production (SPDC End of Well Reports).The Assa North and Ohaji Southfields are expected to contain reserves of 4.3 trillion cubic feet (Tcf) of gas in addition to 215 million barrels (MMbbls) of condensate (NS Energy, 2023),

2.2.2. Benisede Field

Nigeria's Bayelsa state is home to the Benisede Upstream Field. Nigerian Agip Oil Co Ltd (5%), NNPC Ltd (55%), The Shell Petroleum Development Co of Nigeria Ltd (30%), and Total E&P Nigeria Ltd (10%) are the owners of the upstream field. The Shell Petroleum Development Co of Nigeria Ltd. is in charge of running it. Operations for the project began in 1976 (NNPC Archives, 2015). Name, resource type, asset status, stage, owner and equity stakes, operator, product specifications (gravity, CO_2, sulfur), location, and key operational data (production, start and end years, reserves, and capital and operating costs) are among the fundamental details included in the Benisede Upstream Field profile. Along with pertinent news, agreements, and contract information, we also offer proprietary estimates of production, capital and operational expenses, and other important economic indicators.

This report is available on demand and will be sent upon request. After the purchase, the report will be sent out within two to three business days, excluding weekends and holidays. Depending on the usefulness and availability of data, some elements of the report may be changed or eliminated (Global Data, 2023).

2.2.3. Gbetiokun Field

OML 40 is situated southeast of Gbetiokun Field. Gbetiokun-1 found the field in 1987; SPDC drilled it; and four wells—Gbetiokun-2 (SPDC), Bime-1, and Bime-2 (Chevron)—drilled in 1990–91, further evaluated the field. With the re-completion of the Gbetiokun -1 well by Elcrest/NPDC JV, the Gbetiokun field produced its first oil in July 2019. Between 2019 and 2021, seven more wells (Gbetiokun-3 to 8) were drilled in the field, bringing the asset's output from zero to an all-time high of 17,000 bopd in December 2021. By the end of 2021, cumulative production is expected to be 6.36 MMbbls. The 22,000 barrels per day early production facility processes crude into a storage vessel. It is then evacuated by shuttle barge to the Benin River Valve station, where it is pumped into the export pipeline to the LACT Unit in Otumara, and from there to the FOT.

2.3. Estimation of Specific Energy

For the appropriate bits, the specific energy approach provides a straightforward method. Its definition is the amount of energy required to extract a single unit volume from the drilled rock. Any homogeneous unit can be used. By relying on the force lost at the bit in a minute, the equation of specific energy can be obtained [11].

$$E=W*2 \quad \ldots\ldots\ldots\ldots\ldots..1$$

Where:
E: The mechanical energy, lb.-inch.
W: Weight on bit, lb.
N: Revolution per minute, RPM.
R: Radius of bit, inch.

The equation of raised rock volume in one minute is:

$$V = \pi r^2 * PR \ldots\ldots\ldots\ldots\ldots\ldots..2$$

Where: PR: rate of penetration ft. /hr.

By dividing equation 1 and equation 2 to get the equation of specific energy

$$SE = E/V \ldots\ldots\ldots\ldots\ldots\ldots..3$$

$$SE = W* \pi r^2 * N\pi r^2 * PR \quad \ldots\ldots\ldots\ldots\ldots..4$$

Where:
SE: Specific Energy, (lb-inch/inch^3)

The equation of SE in lb-inch/inch^3 units is:

$$SE=10\ WN/R*ROP \ldots\ldots\ldots\ldots 5$$

By using the diameter of bit D in equation 5 instead of R where R=D/2, the equation 5 Will be:

$$SE=20\ WN/D*ROP \ldots\ldots\ldots\ldots\ldots 6$$

3. Results

3.1. The Relationship between the Specific Energy and Performance of Drilling Bit at Different Depth

The relationship between the performance of different bits at different depths were shown in figures 1 – 6.

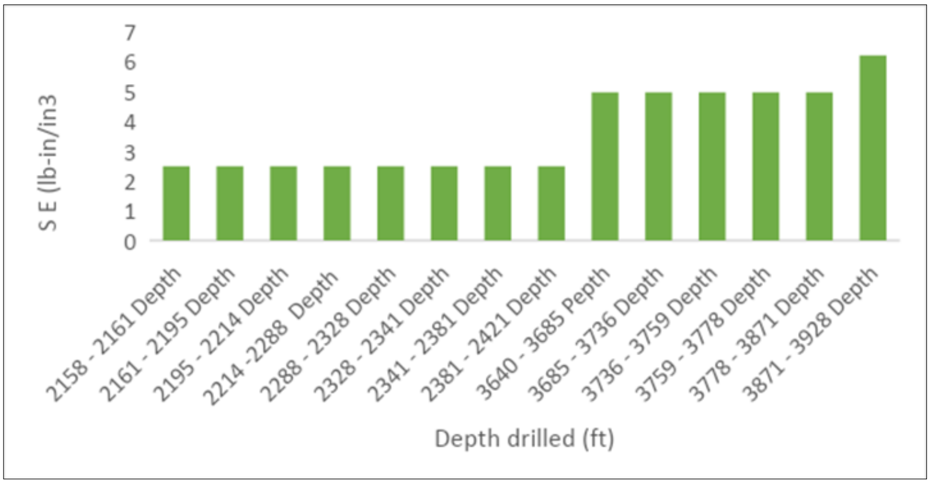

Figure 1 Variation of SE with depth drilled using bit size, 16in at the location, ASSA North 004

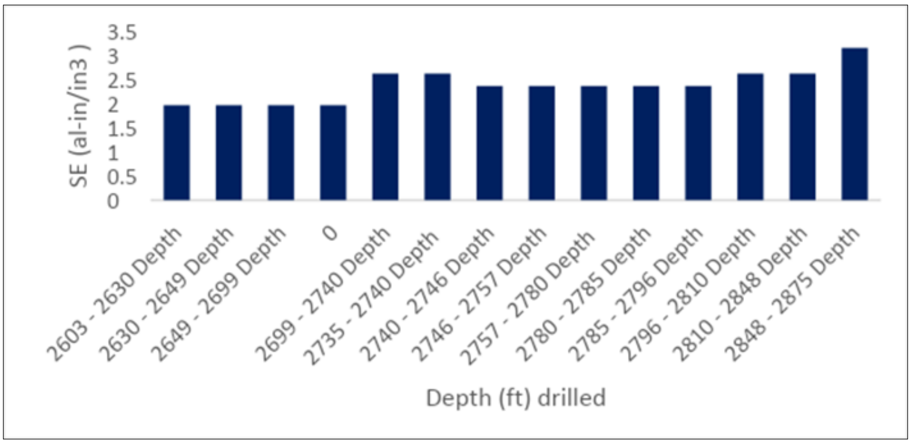

Figure 2 Change in SE with respect to depth using drilling bit size, 22in for Well ASSA North 005

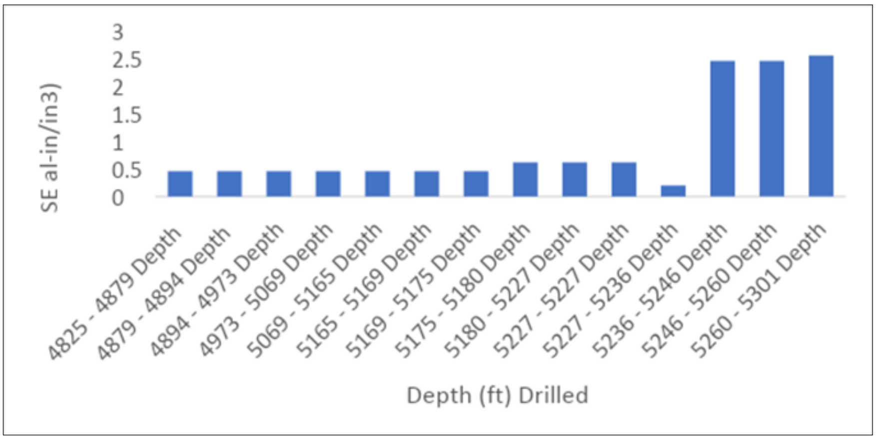

Figure 3 Change in SE with respect to depth using drilling bit size, 16in for Well ASSA North 005

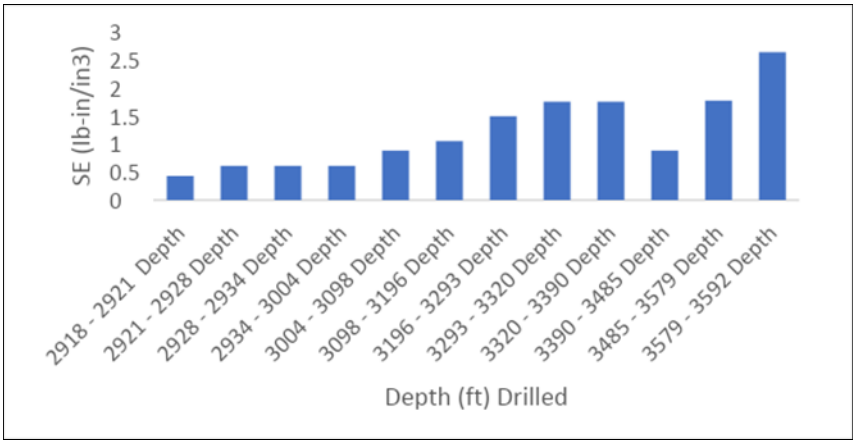

Figure 4 Change in SE with respect to depth using drilling bit size, 16in for ASSA North 006 Well

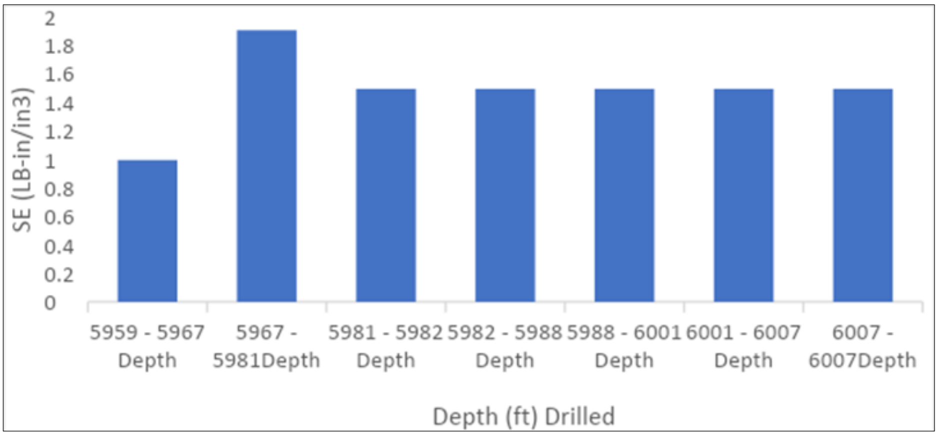

Figure 5 Change in SE with respect to depth using drilling bit size, 16in for Benisede Well

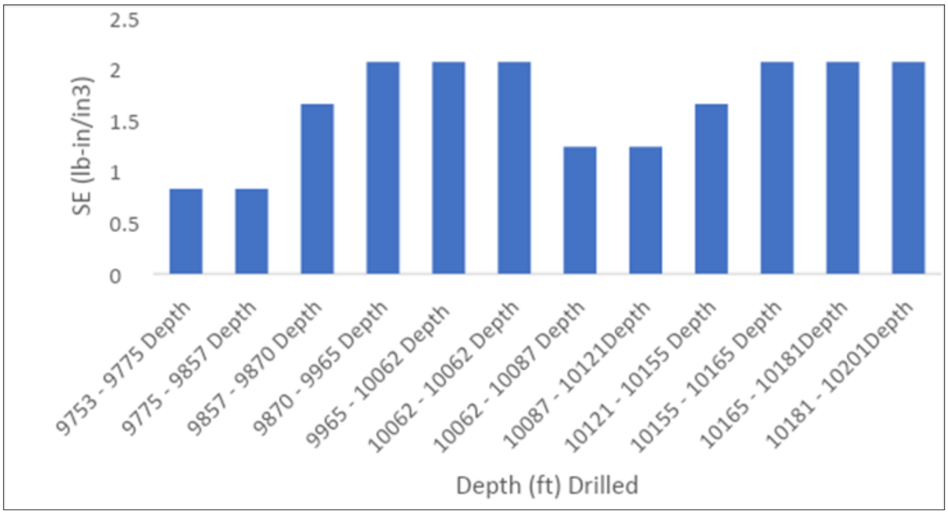

Figure 6 Change in SE with respect to depth using drilling bit size, 16in for Gbetiokun 4 well

4. Discussion

4.1. Performance of the Drill Bit at Different Depths Using SE

Data were obtained from different well histories in Niger Delta. The results showed the changes in the performance of drill bits of different sizes at different depths. In well ASSA 004 (Figure 1), the drilled bit with the size 16in was used to drill different zones, it was shown that the specific energies kept changing alongside the ROP at different depths. The specific energy was low and constant between the depths of 2158 – 2161 and 2381 – 2421 while it increased significantly at the depth intervals of 3640 – 3685 to 3871 - 3928. It indicated that the bit performed optimally at the former depth range and poorly at the latter. This followed the finding by Harmer (2013) that the lower values of SE at different depths the higher the performance of the bit. Therefore, the bit deign was suitable for drilling at the depth interval of 2158- 2421ft while drilling the next hole section needed a change of drill bit that could withstand harder formation. Figure 2 showed the performance of another bit size (22in) used to another well, Assa 005 North. The results indicated that the drill bit used between the depths 2603 – 2630ft and 2649 – 2699ft was effective as it drilled at the lowest possible specific energy level while the depth intervals2699 – 2740ft and 2848 – 2875ft while between 2699 – 2740ft and 2848 – 2875ft has high specific energy values showing that the bit was unsuitable and needed a change. In contrast with the performance of the drill bit size of 22in used for Assa North 005, another bit size of 16in was used to drill to another well in the same field, the result showed that between the depth intervals of 4825 – 4879ft and 5227 – 5236ft, the bit was optimized as the specific energies of the drill bit were at the barest minimum (Figure 4). Well parameters from well Assa North 006 were to determine the specific energy of the drill bit at different well depth and it was obtained that it has very low energies at the depth intervals of 2918 – 2921ft and 3004 – 3098ft (Figure 6) showing optimized bit selection because efficient drilling operation is obtained at low specific energy. However, there was a sudden drop in the specific at some point in the drilled depth interval of 3390 – 3485ft. This seemly improved behaviour of the drill bit could be a result of encountering a soft formation zone. The specific energy could also be seen a function of the hardness of the zone. If the formation rock is very hard, it could lead to increased SE. increased SE in turn is an indication of poor performance of a drill bit. For Gbetiokun 4, the bit performed well at the depth intervals of 9753 – 9775 ft and 9775 – 9857ft and depth interval of 10062 – 10087 to 10087 – 101210ft which was indicated by the reduced specific energy (Figure 6).

The work done by Yaneng [12], clearly showed the relationship between the specific energy and depth. It was found that the specific energy decreased as the depths of drilling increased. Cutting is inefficient because the little chamfer has a significant impact on MSE at small depths (less than 0.4 mm). Since the MSE levels off at a value that is roughly equivalent to the unconfined compressive strength, its effect decreases at high depths (such as 1 mm). The rate at which wear progresses is not insignificant for the latter. Its MSE likewise often declines with depth before leveling out; because of its high confined compressive strength, high contact stress, and growing wear flat length, it differs significantly from that of cutting soft rock at ambient pressure conditions [12]. In this study it was observed that the as the depth increased, the specific energy slightly increased (Figures 1 – 6), confirming the conclusions of the work done by Yaneng [12], higher SE is an indication that there is poor hole cleaning and resultant bit balling Miguel [13]. The challenge robs off on the efficiency of the drilling operations. The higher the SE, the higher the cost of drilling operations. So, drilling operations must be done in such a way that the SE is greatly reduced. The ROP is increased when the SE is minimal as observed from the study. Wears and tears of the drilling bit could lead to increase SE because more energy will be needed to drill deeper into the form as a result of low ROP.

4.2. Ball Up (BU) and Frictional Losses of the Drill Bit

When using water-based mud (WBM) to drill soft, sticky formations, BU occurs. Cuts that are swollen and sticky may stick to the bit and block the waterways, garbage slots, individual blades, or even the bit itself. A significant reduction in penetration rate is caused by severe balling, which clogs the cutting structure of a bit. More standpipe pressure (SPP) and increased rotating torque are the outcomes. Furthermore, there is a decrease in the quantity of cuttings that are carried to the surface from the bit and annulus [14].

The ROP changes are usually premised on the balling of the drill bit at some depths. In the course of the drilling operation, as a result of this challenge, the rate of penetration is reduced meanwhile high specific energy has been applied. The balling results in loss of energy from the drill bit as frictional loss, causing few feet to be drilled.

This work shades more lights on the effect of drilling different depths on the specific energy. The specific energy (SE) must be monitored closely to ensure that it does not exceed the minimum possible value as the main objective of well design drilling program is to drill at lowest possible SE and high ROP to achieve drilling optimization. The Directional Drillers, DD can only control the SE using weight on bit (WOB), ROP. RPM and torque [15].

5. Conclusions

- The result showed that bits RSS1, RSS2 and RSS3 had minimum specific energy which translated to optimized drill bit design.
- The result showed that drill bit performance depends on RPM and WOB.
- There was an inverse relationship the specific energy (SE) and ROP whereas ROP depends on RPM and WOB.
- The drilling had an effect on the specific energy; the drilling specific energy increased slight as the drilling depth increased, impacting negatively on the ROP, and in general the over-all efficiency of the drilling operation.

Compliance with ethical standards

Acknowledgement

We acknowledge the support of the University of Port Harcourt in the course of this study.

Disclosure of conflict of interest

The authors declare no conflicts of interest.

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