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Development of an automated drilling fluid selection tool using integral geometric parameters for effective drilling operations

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ABSTRACT

Modern-day climate and environmental factors are largely responsible for the different geometric characteristics exhibited by formation zones/petroleum reservoirs which makes them highly selective with respect to their adaptation to drilling fluids. However, recent advances in drilling technology, such as, the development of an appropriate drilling fluid automation system carried out in this study, have shown prospects for tremendous improvements in well performance with a subsequent reduction in well dormancy/shutdown. Based on the mud density calculations from the simulation and field measurements, it is evident that the novel drilling fluid selector system has a characteristic algorithm that is suitable for predicting the performance of drilling fluids within limits of accuracy as high as 95–99% for wellbore sizes/diameters and depth, in the range of 8–16" and 0–15,760 ft which is a good step towards attaining a fully automated drilling operation.

1. Introduction

The Exploration and Production (E&P) industry have continued to drill more and more technically complex wells owing to the need to boost production in consonance with the growing demand for hydrocarbon. Around the world, hydrocarbon exploration and well development projects have expanded progressively and these were occasioned by the recent advancements in oil economics, gas exploration as well as drilling technology. The improvements recorded in oil and gas exploration, have led to the drilling of extended-horizontal and ultra-deep water wells which are technically challenging and expensive. One of the challenges encountered is hole cleaning which is caused by the selection and use of an in appropriate drilling fluid or improper mud treatment (Adenubi et al., 2018; Dokhani et al., 2016). To ensure an efficient and relatively safe drilling operation, an appropriate mud design and selection are required. When one fails to appropriately evaluate the performance of a drilling fluid for a given well, there are high tendencies of cost overrun and hole instability which may subsequently result in loss of the well. To avoid fluid-related challenges, the selected drilling fluid design must be somewhat flexible, so as to accommodate several design parameters. At the design stage, it is vital to identify the technical challenges that the properties of the selected fluid may impact on the wellbore/hole-section. Literature has shown that the objective of successfully completing a well is not only to reach the desired depth, but to also ascertain the formation evaluation requirements and productivity potential of the reservoir (Pink et al., 2012). These challenges can be adequately managed with the help of a real-time drilling fluid selection tool that has the capacity to choose the target-fluid for a particular operation, ensure high well-performance and thus remedy wellbore problems (Okoro et al., 2015; Jain and Mahto, 2017). Real-time computer models are integral parts of drilling automation systems that have been developed and tested to provide oversight-monitoring and prediction over during drilling operation. Drilling automation is the control of the drilling process by computers which ultimately reduces human intervention. The most significant effort in drilling fluid automation has been on real-time drilling fluid monitoring. Although post-drilling analysis is necessary, information gathering and quick action/response in real-time are rather, of higher importance. When selecting a drilling fluid for a particular hole-section, it is expected that the selected fluid is cost effective without jeopardizing wellbore stability during drilling (Okoro et al., 2018a,b). Selection of an apt drilling fluid is a vital component in well completion operations, hence, a good drilling mud helps eliminate additional cost for the

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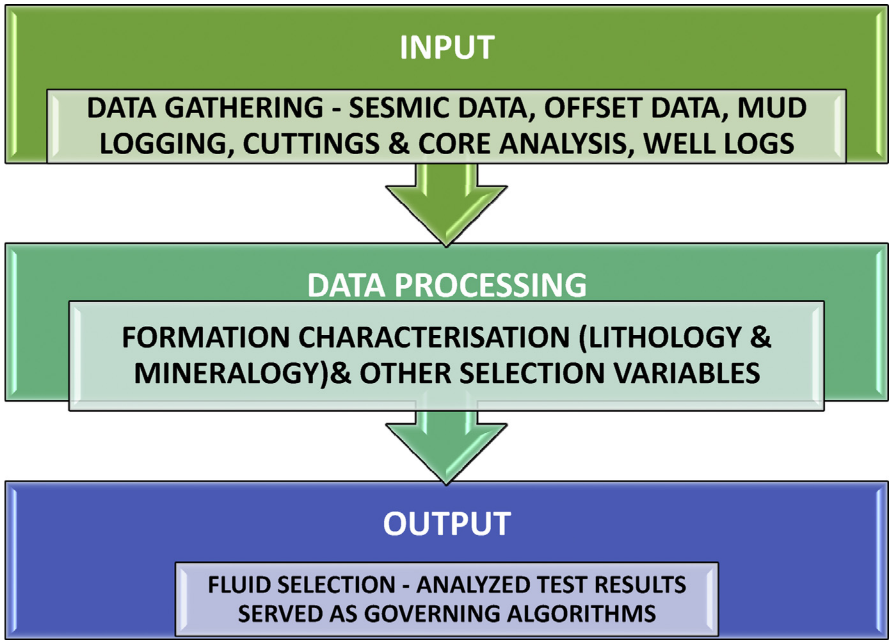

Fig. 1. Flow chart for the developed model.

Table 1
Algorithm for fluid selection for inhibitive and non-inhibitive fluid selection.

Fluids Selection Variables	Algorithm								
Fluid Types	1	2	3	4	5	6	7	8	9
Dispersed	NO	NO	YES/NO	YES	YES	YES	NO	NO	NO
Environmental Impact	3	2	2	2	2	3	3	3	3
Base Fluid	FW/SW	FW	FW/SW	FW/SW	FW/SW	DIESEL	DIESEL OIL	ALT OIL	ALT OIL
Temperature Tolerance	2	1	2	3	2	3	4	2	3
Density	Medium	Low	Medium	Medium	Medium	Medium	High	Medium	Medium
Chemical Cont Tolerance	2	2	3	2	2	3	3	3	3
Filtrate/Loss Circ	2	1	3	3	3	2	1	2	2
Solid Tolerance	2	1		1	1	3	3	3	3
Formation Inhibition	1	2	3	3	2	3	3	3	3
Salt Formation	YES	NO	NO	YES	NO	YES	YES		
Cutting Inhibition	3	1	3	3	2	3	3	3	3
Solid Removal	3	3	3	2	1	1	3	1	3
Lubricant Properties	2	2	2	2	2	3	3	3	3
Deviated Wells			YES		YES	YES	YES	YES	

*Density: Low = Below 9 ppg; Medium = 9–12; High = 13.2–16 ppg.
*To convert to Specific Gravity (S.G), divide the mud density in ppg by 8.33 (Okoro et al., 2018a).

operator. The ability of the operator to simulate down-hole conditions in order to optimize drilling fluid design is one of the key factors that reduce the non-productive time during drilling operations. It also allows real-time management of wellbore conditions through measurements while drilling. Successful drilling requires knowledge of the type and characteristics of the formation being drilled which will help determine the type of fluid to be used during drilling and well completion. However, the objective of this study is to develop a real-time computer model that integrates characteristics of the formation zone such as geological composition (lithology and mineralogy) in its algorithm which helps to ascertain the optimum fluid features from core data analysis using data generated from Measurements While Drilling (MWD) and Logging While Drilling (LWD) operations.

Table 2
Mud system-formation interaction prediction parameters.

Drilling Fluid Types	Formation Test	Mud Interaction Outcomes
Lignosulphate Base fluids	Bulk Hardness	Temperature Tolerance
PHPA Base fluid	Dispersion Testing	Density
Bentonite/KCL Polymer	Accretion Test	Chemical Content Tolerance
KCL base fluid	Linear Swelling	Filtrate Control
Gypsum base fluid	Immersion Testing	Solid Tolerance
Lime base fluid	Cappillary Suction Test	Formation Inhibition
Diesel invert emulsion fluid	X-Ray Diffraction	Salt Formatio
100% diesel invert emulsion	Cation Exchange Capacity	Cutting Inhibition
Invert emulsion, ester base		Solid Removal

2. Background

2.1. Automation in drilling operations

The drive for automation in drilling operations can be attributed to: data overload from real-time tools, well complexity, knowledge transfers from skilled personnel to nonprofessionals, and the potential economic benefits therein as compared to when the process is operated manually. The past fifteen years have witnessed a push in automation within the oilfield-drilling industry. The automation involves the drilling of well-bores using systems and subsystems controlled by computer programs to some degree. Endsley and Kaber (1999) noted that complementation of

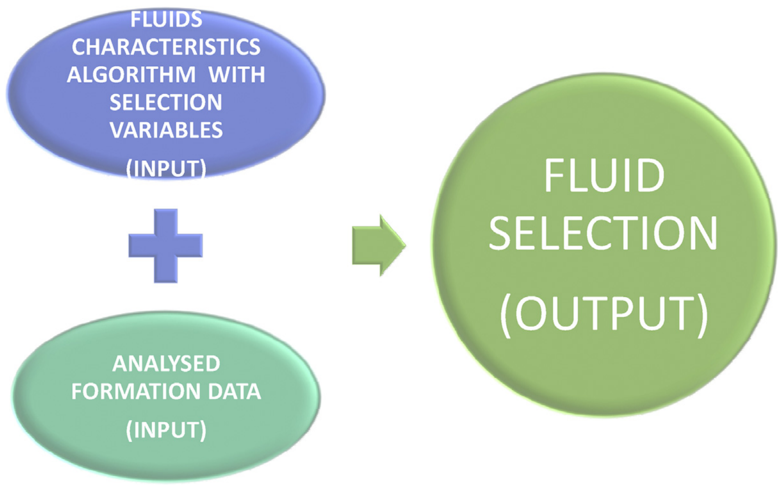

Fig. 2. Mud system selection model flow chart.

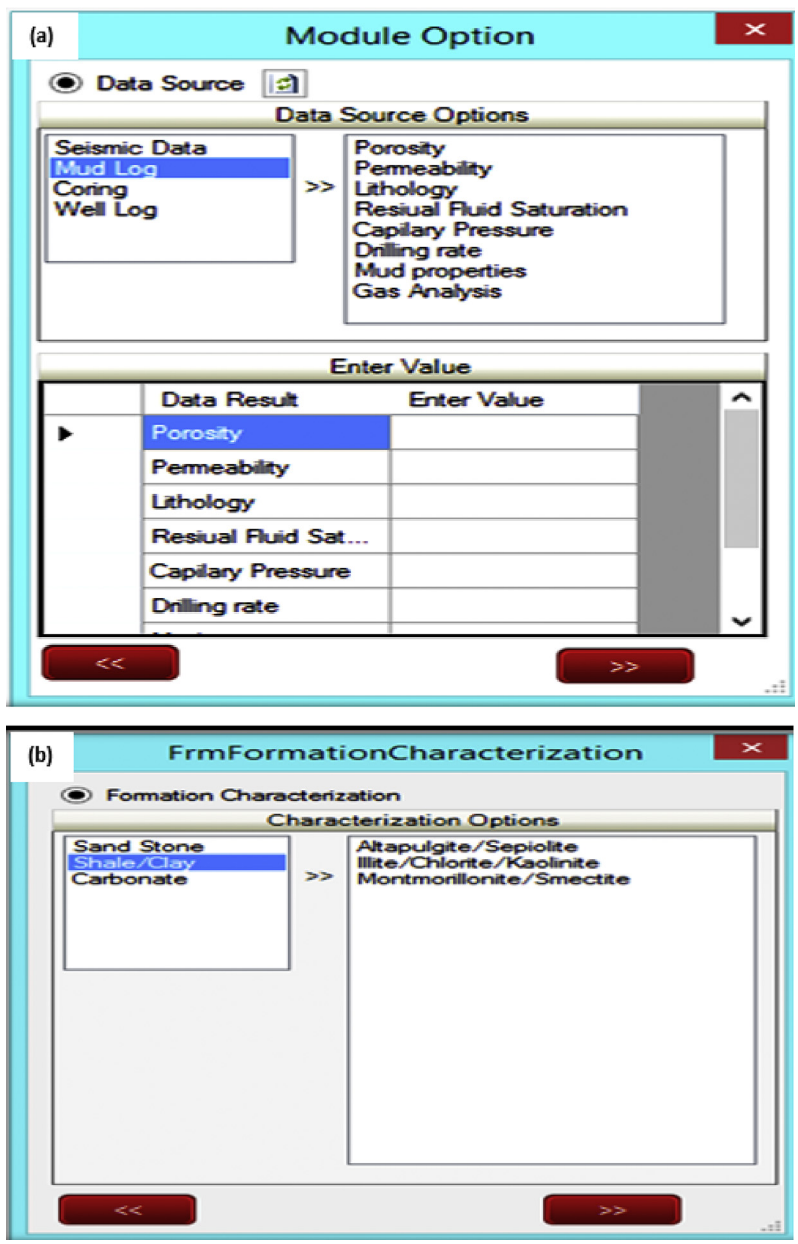

Fig. 3. (a) Formation-type hole-section, (b) Selected drilling mud systems template.

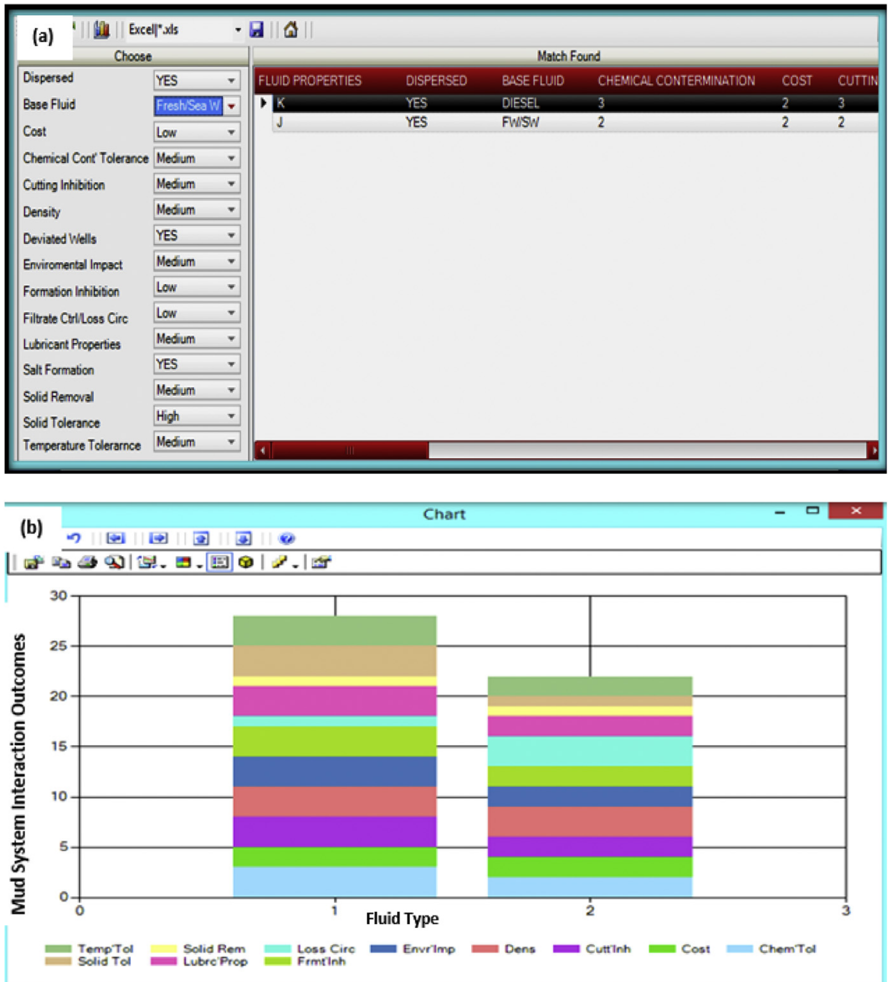

Fig. 4. (a) Selected Drilling Mud System, (b) Interaction of the Selected Mud systems with the Formation Chart.

automation with some sense of human judgment enhances performance. This is adjudged true in the area of drilling and well engineering because drilling automation comprises of a hierarchy of subsystems which is not entirely independent of human intervention.

The summary and progress of automated subsystems for rig-floor operations have been highlighted by Eustes (2007) and SØndervik (2013). El Dorry and Dufilho (2012) identified drilling automation as a step in the right direction because, it was observed that the automated program regulates the gravitational force (g-force) that vibrates the shaker basket constantly regardless of the load at any particular time which in turn optimizes the shale shaker performance.

Software models are now being developed to monitor and predict data in real time which make-up the automation spectrum while drilling oil/gas wells. These models monitor the drilling process, deliver advice to the drilling team and set points for the hardware or even take direct control of the hardware operations in some cases. When planning a well construction, post-drilling information and analyses still remain essential components; however, the information gathered holds greater value when used for validation.

2.2. *Automation of drilling fluid selection for different hole-sections*

The most significant effort on drilling fluids automation has been on real-time monitoring of the rheological properties of the fluid while drilling. Based on recent advances in drilling technology, the oil and gas industry has the mandate to develop robust, automated equipment to measure critical fluid properties and type, for drilling purposes as it relates to specific hole-sections. Geehan and Zamora (2010) discussed extensively, on the ultimate success of drilling fluid automation where they itemized the conditions for success as largely dependent on data optimization obtained from real-time monitoring of data management systems connected to interpretation-schemes and prediction analyzers that will convert the collected data into useful knowledge.

One of the major assumptions for automated wellbore drilling fluid selection systems is the availability of accurate, consistent and complete information. Because, the more the available data, the more accurate the generated results. Operators have indicated interest in developing automated drilling fluid selection tools with focus on their total integration in drilling automated systems. Part of the drilling fluid mixing process has

Table 3
Basic information for the well.

Well Name	Well-G
Well Type	Oil Producer
License	OML XXX
Operator	CLIENT
Partners	97.5 % CLIENT and 2.5 % CEI
Proposed Well Intent	Appraisal/Development
Planned Start Date	May 2017
Planned Duration	50 days
Rig Floor Elevation	17 m AMSL
Water Depth	310 m BMSL
TD	PH: 1,817.00 m MD/1,817.00 m TVD BRT Horz. Landing: 2,157.00 m MD/1,761.60 m TVD BRT Horizontal: 2,666.00 m MD/1,761.60 m TVD BRT

Table 4
The Drilling Fluid Program for each Hole-Section in Well A.

Interval	Mud Type	Properties	
16″ Hole section (0–5810)ft	Bentonite/KCl Polymer Mud system	From: 0–2000ft Mud Grad: 0.45–0.46psi/ft MFV: 80–100 Sec/qt PV: 10–15cp YP: 25–35lbs/sq ft MBT: +/- 20–25ppb PH: 9.0–9.5	2000–5510ft 0.46–0.48psi/ft 65–80 Sec/qt 20–30cp 22–25 lbs/Sq ft 10–12.5 ppb 9.0–9.5
12.25″ Hole (5810–11890) ft	Synvert Mud	Mud Grad: 0.52–0.55 psi/ft MFV: +/- 55–60 s/qt PV: 15–18 cp YP: 20–30 lbs/Sq ft HTHP/Loss: +/- 5 cc O/W: 70/30 Ex Lime: 1.5 Es: >400volts	
8.5″ Intermediate Hole (11890–15760)ft	Synvert Mud	Mud Grad: 0.52–0.55 psi/ft MFV: +/- 55–60 s/qt PV: 15–18 cp YP: 20–30 lbs/Sq ft HTHP/Loss: +/- 5 cc O/W: 70/30 Ex Lime: 1.5 Emulsion stability: >400volts	

been automated in some North Sea rigs. Examples of existing automated systems on North Sea rigs are drilling fluid/bulk transfer systems, and drilling fluid density regulation systems. Rig site engineers' benefit from the automation of the drilling process which helps to simultaneously oversee more than one well for remote operating engineers. Wellbore instability challenges contribute to non-productive time which subsequently results in high amounts of drilling costs (Eme et al., 2015; Vajargah and Oort, 2015). Wellbore formation has different pressure windows, and these pressure windows apply to different ranges of equivalent drilling fluid densities that should be used during drilling operations. The referred pressure window is determined by two boundaries which are the fracture pressure and formation pressure. Thus, each formation section requires a specific drilling fluid with distinct properties. A drilling fluid with density lower than the pore pressure capacity will result in an influx of formation fluid into the wellbore causing a kick. Also, a drilling fluid density higher than the fracture gradient will cause drilling-induced tensile fractures that will result in loss of drilling mud into the formation. Magalhães et al. (2016) have made known their advocacy for the E&P industry to fully automate their drilling operations.

From experience, drilling mud is said to be directly or indirectly related to virtually all drilling challenges; this does not completely

Table 5
The Drilling Fluid Program for each Hole-Section in Well B.

Interval	Mud Type
16″ Hole Section (0–1500) ft	Bentonite Spud Mud
(1500–6300) ft	KCL/Polymer Mud
12.25″ Hole Section (6300–9655) ft	Pseudo Oil Based Mud (POBM)
8.5″ Hole section (9655–10500) ft	Pseudo Oil Based Mud (POBM)

Table 6
Well-A formation characterization.

Interval	Formation Type
16″ Hole Section: (0–2000) ft	Sandstone
(2000–5510) ft	Shaly Sandstone
12.25″ Hole Section: (5510–11890) ft	Claystone, Shale, Sandstone
8.5″ Hole section: (11890–15760) ft	Shale, claystone, Sandstone

Table 7
Well-B formation characterization.

Interval	Formation Type
16″ Hole Section (0–1500) ft	Unconsolidated Sandstone
(1500–6300) ft	Sandstone
12.25″ Hole Section (6300–9655) ft	Claystone, Soft Shale, Consolidated Sandstone
8.5″ Hole section (9655–10500) ft	Hard Shale, claystone, Sandstone

suggest that drilling mud is responsible for these challenges, however, when it is properly selected and identified, it has the potential to alleviate problems arising from drilling operations. Thus, selection and proper application of the drilling mud systems are key factors for a successful drilling operation.

3. Methodology

Planning the drilling fluid begins with the acquisition of all relevant geological and appropriate offset well data. These include pressure gradient and pore fracture profiles, formation characteristics, instability intervals, and the presence of a soluble salt layer. Good information gathering is absolutely essential for good well engineering (Dosunmu and Okoro, 2012). Thus, this necessitates communication between people who are concerned with the different parts of the operation.

This study develops a real-time computer model that integrates the characteristics of a formation such as geological composition (lithology and mineralogy), pore pressure, permeability, porosity, reactivity and hydration in an algorithm which is capable of selecting and simulating the most suitable mud system required for a hole-section with consideration for cost, application and performance.

3.1. Data gathering

The data required to characterize the formation serves as part of input data for the tool. The input data include Seismic data, Offset well data, Mud logging data, Cuttings analysis, Coring, Well logging, and Formation characterization. These data sources were used to identify the lithology, mineralogy, porosity, permeability, formation fluid and pressure window of the formations.

3.2. Development of the mud selection tool

The drilling fluid system was developed based on the type of well to be drilled. The overkill mud system was designed for an exploratory well while an optimum mud system was designed for a developing well. A real-time fluid selection tool was developed through the integration of the

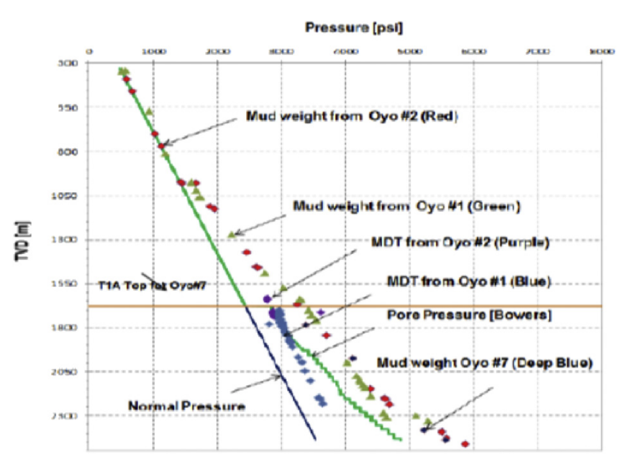

Fig. 5. Pore/Fracture Pressure Prognosis for the Offshore Well used as Case Study.

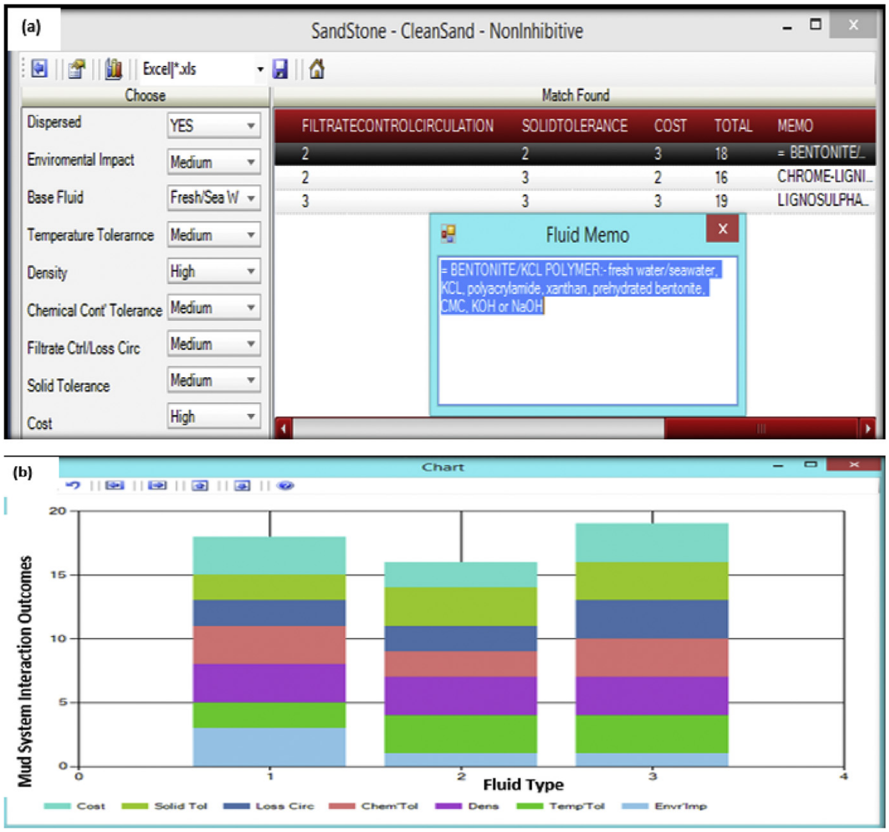

Fig. 6. (a) Well-A predicted Mud for 16″ Hole Section, (b) Selected Mud performance Analysis Chart for the 16″ Hole-Section.

formation data and geological composition in the drilling fluid characteristic-algorithm. The model development flow chart is presented in Fig. 1.

The applied drilling fluid-algorithms were developed through tests such as bulk hardness, dispersion, accretion, linear swelling and immersion, capillary suction, X-ray diffraction, and cation exchange capacity tests, in order to determine the ability of the fluids to successfully drill the characterized formation. The analyses of these test results served as the governing algorithms for the drilling fluid selection for each hole-section. Using the developed algorithms, a computer model was developed using Microsoft visual basic programming language. The data for the variables incorporated into the fluid selection algorithm were obtained from the literature (Okoro et al., 2018a,b; Okoro and Dosunmu, 2014). The fluid selection source code is contained in the supporting document.

There are many drilling fluid additives which are used to develop the key properties of the muds. The varieties of fluid additives reflect the complexities inherent in mud systems currently in use. Mud complexity often poses more difficulty and challenge when under the confines of unfavourable drilling conditions. Weighted materials are used to increase the density of water or oil-based drilling fluids. Most of these materials are insoluble and require Viscosifiers to get them suspended in a mud system. Mud weights higher than that of water whose average specific gravity is 8.3 ppg are required to control formation pressures. Table 1 shows the fluid selection model algorithms developed using the fluid test results; based on algorithms, a computer model was developed using Microsoft Visual Basic programming language for the accurate prediction of mud density for 3 different runs.

3.3. *Predicting mud system interaction with the formation*

The drilling fluid characteristic-algorithm, that predicts the interaction of the mud system and formation were developed to determine the ability of the fluids to successfully drill the particular hole-section under consideration. The following test data were considered and applied in developing the model; bulk hardness, dispersion and accretion testing, linear swelling, cation exchange capacity and data from X-Ray diffraction tests. The analyzed test results served as the input data for the model algorithms for the fluid selection model (Table 2) and the possible outcomes of the mud-formation interaction are presented in the multi-layer bar-chart. This helps the well-engineer to analyze and compare the performance of the selected mud system and its interaction with the wellbore formation.

The process of the mud system selection for a particular open hole-section is presented in Fig. 2.

4. Results and discussions

The computer tool for the drilling fluid selection has a user friendly interface and it is an interactive tool that allows for instant decision making. The selection sequence is as follows:

The Well Data allows the user to provide information about the well to be drilled.

The Well type – it is important to select the oil and gas well type for proper and effective drilling mud design/selection.

The Data Source – the data source template allows the input of the required variables for the characterization of the formation to be drilled.

The Formation Type – The type of formation expected to be drilled is selected from the interface shown in Fig. 3a.

Drilling Fluid Selection – the required variables and properties for the fluid were chosen as illustrated on the template shown in Fig. 3b, and these variables inform the tool on the appropriate high performance drilling fluid to select for successful drilling of the formation zone.

Analysis of the Selected Drilling Fluid – the chart in Fig. 4 analyses and

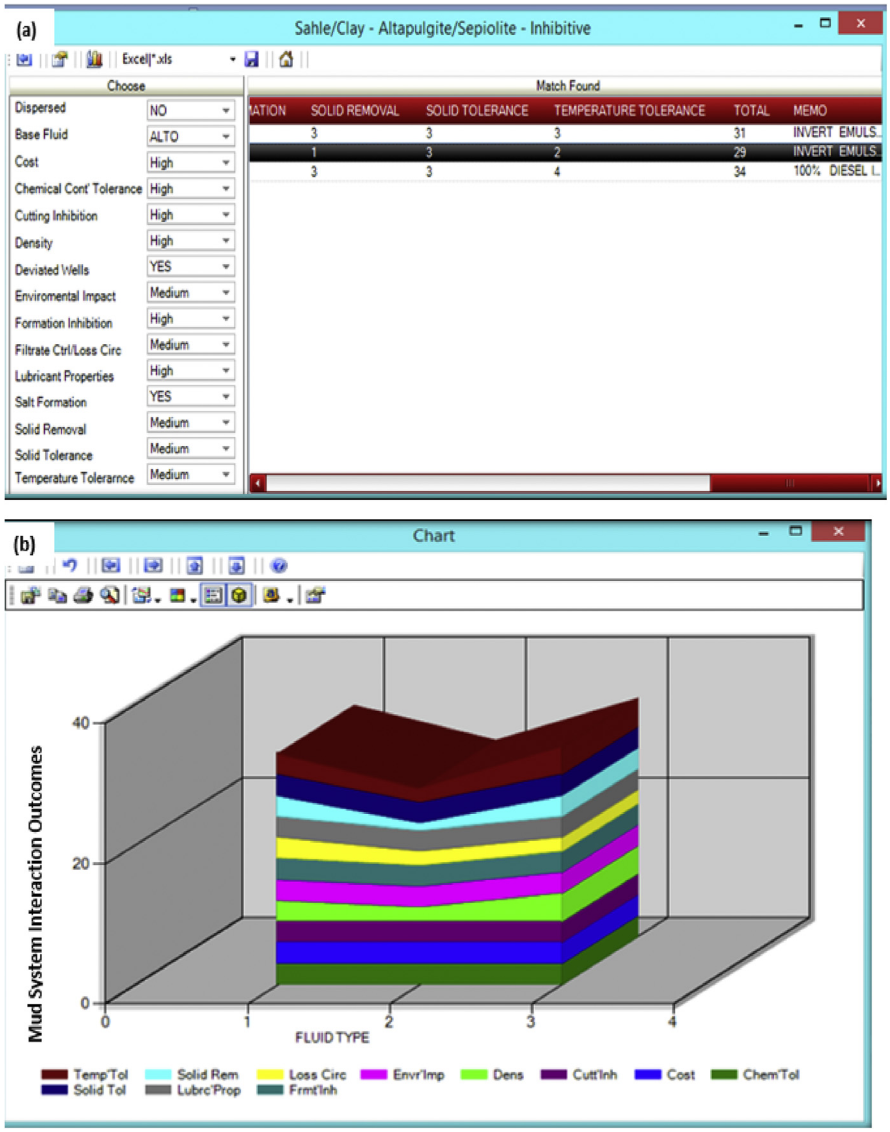

Fig. 7. (a) Well-A predicted Mud for 12.25″ and 8.5 Hole Section, (b) Selected Mud Systems Performance Analysis Chart for both Hole Sections.

predicts the performance of the selected drilling fluid when it interacts with the proposed formation to be drilled in the wellbore.

4.1. Model simulation and validation

The simulation and validation data were from a field located Offshore Niger Delta at an average water depth of about 290–335 m. the Well information and variables in Tables 3, 4, 5 and Fig. 5 were used for data simulation and validation.

4.2. The proposed automated drilling fluid selection tool

The automated mud selector was used to select drilling fluids for Wells A and B using data from formation characterization as contained in Table 6.

4.2.1. Well-A simulation and validation of the proposed tool

For the 16” Hole-Section, the tool selected three water based drilling fluids that are capable of drilling that particular formation without any wellbore instability (Fig. 6a). The mud systems include (i) Bentonite/KCl polymer, (ii) Chrome-lignin based fluid and (iii) Lignosulphate based fluid. Thus, the operator has the option of considering cost and environmental factors such as variations in temperature, pressure and air space around the wellbore since these mud systems are capable of getting the work done without challenges such as wellbore instabilities arising.

The drilling fluid performance analysis chart (Fig. 6b) generated by the proposed Tool, identified the Bentonite/KCl polymer mud as the most environmentally friendly mud among the selected drilling fluids. This implies that the Bentonite/KCl polymer mud is the preferred choice for this hole-section. For the 12.25″ and 8.5” hole-sections, the Tool also selected three high performance drilling fluid systems for both sections (Fig. 7a). They are (i) the Invert Emulsion Polyolefin based fluid, (ii) Invert Emulsion Ester based fluid and (iii) 100% Diesel Invert Emulsion fluid.

The drilling fluid selection tool performance chart (Fig. 7b) identified 100% Diesel Invert Emulsion mud as the best overall and it is followed by Invert Emulsion Polyolefin based fluid, however, it is not environmentally friendly when compared with the other two drilling fluids. Thus, the Invert Emulsion Polyolefin based fluid becomes the preferred mud system for the hole-sections.

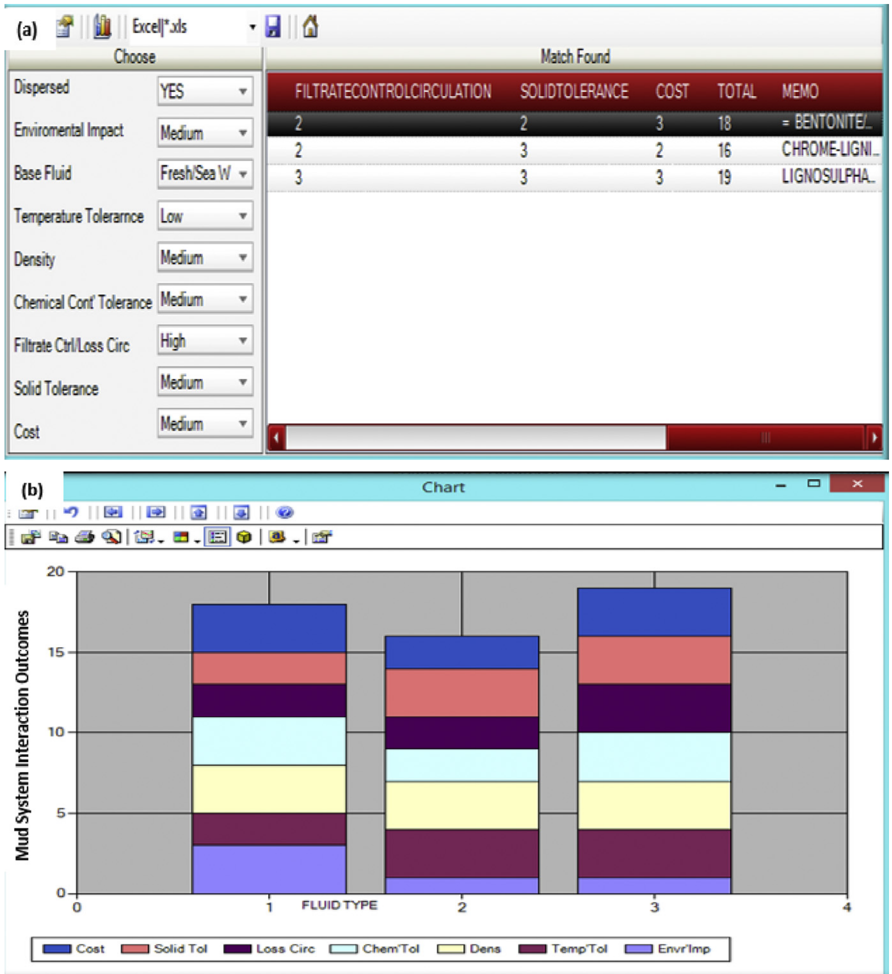

Fig. 8. (a) Well-B predicted Mud for 16″ Hole-Section (b) Selected Mud Performance Analysis Chart for Well-B 16″ Hole Section.

Table 8
Comparison of the Automated Tool predictions and Field Mud Systems used.

Well A and B Hole Sections	Automated Tool Selected Drilling Fluids	Predicted Mud Density	Manually Selected Drilling Fluids Used in Wells A & B	Field Measurement	Predicted Mud Density (ppg)		
					Run 1	Run 2	Run 3
16″	Bentonite/KCL Polymer Mud	High	Bentonite/KCL Polymer Mud	13.1	12.9	12.5	12.7
12.25″	Synvert Mud/Pseudo-oil base mud (Synthetic Mud)	Medium	Invert Emulsion, Polyolefine base Mud (Synthetic Mud)	11.7	11.2	11.6	11.3
8.5″	Synvert Mud/Pseudo-oil base mud (Synthetic Mud)	Medium	Invert Emulsion, Polyolefine base Mud (Synthetic Mud)	11.8	11.7	11.4	11.2

4.2.2. Well-B simulation and validation of the proposed tool

For the 16" Hole-Section, the tool selected (i) Bentonite/KCl polymer, (ii) Chrome-lignin based fluid and (iii) Lignosulphate based fluid as mud systems suitable for the hole-section (Fig. 8a). When their performances with the formation and environment were considered using the chart presented in Fig. 8b, Bentonite/KCl polymer mud was selected as the most suitable among the three mud systems.

For the Well-B 12.25″ and 8.5" Hole sections, it was observed that the Tool selected and chose the same mud system as selected for Well-A because both wells have similar formation type and characteristics (Table 7). Thus, Invert Emulsion Polyolefin based fluid was preferred due to environmental factors.

4.3. Mud system selected via automation and manually selected mud systems for the field

Taking a cue from Table 1 (Proposed Mud Selection Algorithm), Table 8 shows the comparison of the drilling fluids selected by the proposed Tool for three different runs and the actual drilling mud densities used in drilling the wells under consideration. From the estimated values, it is evident that the accuracies of the predicted mud densities lie within the region of 95–99%, that is, the simulation results were almost similar to the results obtained using the field mud systems for each hole section in the two wells. However, the selection process was different for each scheme. Fig. 9 shows the predicted mud density from the automated tool.

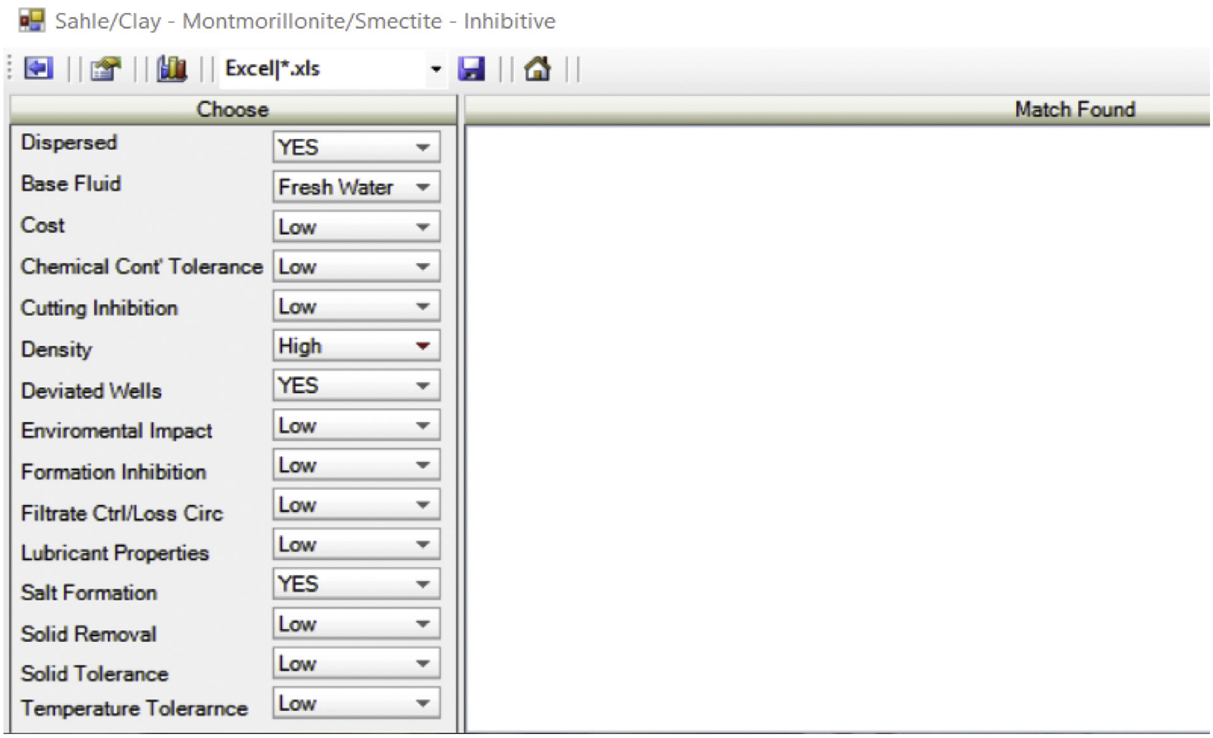

Fig. 9. Mud Density and outcome predictions by the Automated Mud Selection Tool.

5. Conclusion

A real-time computer fluid selection Tool has been developed for selecting high-performance drilling fluids with the ability to ensure minimal wellbore instability, thereby reducing non-productive time and overall well cost. This is a significant and novel approach for making Real-Time Drilling Fluid selection as well as well performance evaluation which will in turn, advance drilling automation to new frontiers and subsequently result in increased well productivity and quality towards improved personnel safety for effective risk management. From the findings of this research, the novel-automated drilling fluid selector gave significant levels of accuracies in the range of 95–99% for each mud type (Table 7) when compared with results obtained from field operations.

Declarations

Author contribution statement

Emeka Emmanuel Okoro: Performed the experiments; Wrote the paper.

Adedotun O. Alaba: Conceived and designed the experiments.

Samuel E. Sanni & AdewaleDosunmu: Analyzed and interpreted the data.

Evelyn B. Ekeinde: Contributed reagents, materials, analysis tools or data.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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References

Adenubi, A.S., Igwilo, K.C., Okoro, E.E., Mamudu, A.O., 2018. Data for analyzing drilling fluid ability to effectively achieve hole cleaning for high shear and low shear rates. Data in Brief 19, 1515–1521.

Dokhani, V., Ma, Y., Yu, M., 2016. Determination of equivalent circulating density of drilling fluids in deepwater drilling. J. Nat. Gas Sci. Eng. 34, 1096–1105.

Dosunmu, A., Okoro, E.E., 2012. Determination of moisture adsorption isotherm of shale from agbada formation using GAB model. Res. J. Eng. Sci. 1 (4), 27–33.

El Dorry, K., Dufilho, B., 2012. Automation improves Shakers performance. In: Paper SPE 151180 Presented at the IADC/SPE Drilling Conference and Exhibition. March, San Diego, California, USA, pp. 6–8.

Eme, C., Dosunmu, A., Anyanwu, C., Okoro, E.E., Ekeinde, E., 2015. Experimental model for the determination of Hydration potential of Niger-Delta shales for drilling mud design. In: SPE-178293-MS, Nigerian Annual Technical Conference and Exhibition.

Endsley, M.R., Kaber, D.B., 1999. Level of Automation effects on performance situation awareness and workload in a Dynamic control task. Ergonomics 42 (3), 462–492.

Eustes III, A.W., 2007. The evolution of automation drilling. In: Paper SPE 111125 Presented at the SPE Annual Technical Conference and Exhibition. Anaheim, California, pp. 11–14 November.

Geehan, T., Zamora, M., 2010. Automation of Well-construction fluids domain. In: Paper SPE 128903 Presented at IADC/SPE Drilling Conference and Exhibition. February, New Orleans, Louisiana, USA, pp. 2–4.

Jain, R., Mahto, V., 2017. Formulation of a water based drilling fluid system with synthesized graft copolymer for troublesome shale formations. J. Nat. Gas Sci. Eng. 38, 171–181.

Magalhães, S.C., Scheid, C.M., Calçada, L.A., Lutterbach, L.M.M., Rezende, R.S., Waldmann, A.T.A., 2016. Real time prediction of suspended solids in drilling fluids. J. Nat. Gas Sci. Eng. 30, 164–175.

Okoro, E.E., Dosunmu, A., 2014. Experimental Analysis of Shale for evaluating Shale drilling fluid interaction in Agbada formation. Br. J. Appl. Sci. Technol. 4 (35), 4878–4907.
Okoro, E.E., Dosunmu, A., Iyuke, S., 2018a. Data on Cost analysis of drilling mud displacement during drilling operation. Data in Brief 19, 535–541.
Okoro, E.E., Dosunmu, A., Oriji, B., Iyuke, S., 2015. Impact of reversible Invert emulsion drilling fluid rheology on productivity. In: SPE-178308-MS, Nigerian Annual Technical Conference and Exhibition.
Okoro, E.E., Igwilo, K.C., Mamudu, A.O., Ekeinde, E.B., Dosunmu, A., 2018b. Data on shale-water based drilling fluid interaction for drilling operation. Data in Brief 19, 1620–1626.
Pink, T., Bruce, A., Kverneland, H., 2012. Building an automated drilling system where surface machines are controlled by downhole and surface data to optimize the well construction process. In: Paper SPE 150973 Presented at the IADC/SPE Drilling Conference and Exhibition. March, San Diego, California, pp. 6–8.
SØndervik, K., 2013. Autonomous robotic drilling systems. In: Paper SPE 163466 Presented at the SPE/IADC Drilling Conference and Exhibition. March, Amsterdam, The Netherlands, pp. 5–7.
Vajargah, A.K., Oort, E.V., 2015. Determination of drilling rheology under downhole conditions by using real-time distributed pressure data. J. Nat. Gas Sci. Eng. 24, 400–411.