Optimization of a bio-based drilling fluid from waste Dacryodes Edulis (local pear) for oil exploration

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ARTICLE INFO

Article history
Received June 20, 2023
Revised 08 August, 2023
Accepted 04 September, 2023
Available online 07 September, 2023

Keywords
Bio-based
Drilling fluid
Local pear
Oil exploration
Optimization

ABSTRACT

This study focused on the development and optimization of a bio-based drilling fluid from local pear seed for oil exploration, which can help lessen the environmental impact of oil spills. Local pear seed being a biodegradable material was collected, prepared, its oil extracted, modified and optimized to obtain an eco-friendly and cost-effective drilling fluid. The selected materials used for this study was Local pear oil. The drilling fluid was characterized for proximate parameters and ultimate parameters. The prepared drilling fluid was optimized using response surface methodology (RSM) provided by Design-Expert software 13.0. Central composite design (CCD) was applied to study the variables affecting rheology of drilling fluid. The process factors which include pH (A), viscosity (B), mud density (c), temperature (D), rheology (E) interacted to produce the response (drilling fluid yield) for the studied sample. The optimized drilling fluid yield and the optimum values were obtained through iterations of one hundred (100) solutions and the best yield was selected at iteration number seven (95th solution), at a pH of 1, Viscosity of 119.783cP, mud density of 10.473kg/L, Temperature of 100°C, and Rheology of 76.809s-1, and the optimized drilling fluid yield value was 91.144%. The acidity and the alkalinity of the drilling fluid were measured by the concentration of the 9.5 ion in the fluid. Therefore, the biomaterial studied has demonstrated its optimal effectiveness and potential application as an additive for the development of drilling fluid for oil exploration.

1. Introduction

The growth in human population and economic activities such as oil exploration has caused an increase in the demand for energy [1]. Drilling is a very important activity when it comes to developing oil fields for oil exploration. Drilling fluids are the fundamental demand in the majority of drilling operations [2]. Drilling fluids (mud) are complicated compositions of interrelated components whose quality changes dramatically as pressure and temperature, solid content, time, pace of penetration, and drilling formation zone changes [3], [4]. It is critical to comprehend variations of drilling fluid parameters to overcome any drilling issues that may arise. Many investigations have been carried out to completely comprehend the changes in drilling fluid characteristics that occur downhole [5]. Drilling mud speeds up the drilling process by delivering bits to the exterior, effectively cleaning the wellbore [5], [6]. Diagnostic mud tests are performed on the drilling fluid throughout operations to manage the mud density, filtration, viscosity, solid content, rheology/flow characteristics, pH, and other parameters in order to maintain predetermined values and minimize drilling difficulties [7].

There exist several drilling muds, such as; synthetic-based [8], [9] water-based [10], [11] and oil-based [12]–[14]. The synthetic-based muds are more frequently used because they are more eco-friendly and faster to biodegrade than oil-based and water-based drilling fluid [9], [15]. Currently there is a shift to new biodegradable drilling fluid obtained from biomaterials which is cost effective, efficient, locally available, and more eco-friendly. Several studies have been carried out on the use of various biomaterials as bio-based drilling fluids. Such studies include Corn Starch [16], Sweet Potato Starch [17], Cashew and mango extract [18], burnt head of the palm sponge powder (BPHSP) and plantain peels derived powder (PPP) [19], Sweet Almond Oil [20], Cassava [21], and Mango Seed Oil [22]. However, from these studies, no research has been carried out on the use of local pear seed for the development of a bio-based drilling fluid for oil exploration. Furthermore, since drilling mud (fluid) is connected directly or indirectly to most drilling difficulties, there is also no particular drilling fluid that could solve all drilling difficulties [2], [23], [24]. Yet still, it is used to overcome most drilling problems. This study is focused on optimizing the drilling fluid (mud) developed from locally sourced material that is naturally degradable, eco-friendly, efficient and economically viable namely; local pear seed.

2. Method

2.1. Materials and tools

Materials used for the study include; local pear oil, n-hexane, diesel oil, bentonite, barite (CaCO3), Pac-R, filter paper. Experimental equipment considered were; industrial blender, Soxhlet extractor, weighing balance, measuring cylinder, hydrometer, Hamilton beach mixer, mud balance, FAN V-G viscometer, API filter press, conical flasks, separating funnel, beakers, reagent bottle, filter paper pH, meter, thermometer. A summary of materials and apparatus used is presented in Table 1.

Table 1. Materials and consumables considered

Materials	Sample Volume	Apparatus
n-hexane	300ml	Soxhlet extractor
local pear oil	300ml	Weighing balance
Diesel oil	300ml	Measuring cylinder
Bentonite	300ml	Hydrometer
Barite (CaCO3)	40g	Hamilton beach mixer
Pac- R	120g	Mud balance
Filter paper	18g	FAN V-G Viscometer
		API Filter press
		Conical Flasks
		Separating Funnel
		Beakers
		Reagent Bottle Filter paper pH meter
		Thermometer

2.2. Sample collection, preparation, and modification

50 kilograms of local pears were collected from local farmers. The seed was extracted from the parent stock locally. Fig. 1 shows the part of the pear that was studied.

Fig. 1. Local pear fruit

These seeds were removed from the ripe local pear fruits, which were sliced into little pieces and sundried. The seeds were further grinded with a local grinding machine to a powder form. Soxhlet extractor was used to extract the oil from the seeds after it was grounded. The grounded seeds were thoroughly rinsed with n-hexane before being filtered with the filter papers. To remove any remaining oil, the collected oil was filtered to make sure there were no impurities left.

Furthermore, 400g of the prepared sample were introduced into a flat bottom quick-fit flask. The flask was fixed to a reflux condenser and was placed in a water bath of 90oC. It was washed until neutral pH was obtained [25].

2.3. Experimental design for optimization

To study the optimal capabilities for development of the bio-based drilling fluid using extracted oil from local pear seed, the central composite design was applied. The fractional factorial design was applied to obtain optimal yield fluid conditions and interaction of process factors [26]. Experimentally, the process factors also called independent variables (such as; pH (A), viscosity (B), mud density (c), temperature (D), rheology (E)) interacted to produce the response also called the dependent variable (drilling fluid yield) for the studied sample.

Regression models were developed using Analysis of Variance (ANOVA) to predict the drilling fluid yield. The model equations for the drilling efficiency are second order polynomial regression equations containing linear and quadratic coefficients of the factors. The significance of the coefficients was assessed through the adjusted sum of squares, adjusted mean of squares, standard Fisher's F-test, and student T-test, all computed from design expert (version 13.0). Also, the significance of the regression coefficients was identified using P-values from the student T-test. For the T-test, the factors that most significantly had an effect on the drilling fluid % were identified. The response surface 3D plots of drilling fluid % and the variant process factors (A to E) were plotted and analyzed.

RSM was further employed to identify the optimum operating conditions (the levels at which the variant process factors would yield optimum performance). This was achieved with the aid of the design expert optimizer tool. A two-level five factor fractional factorial design method of optimization was adopted in this study. Model predictions for the best yield performance were verified with experimental measurements.

2.3.1. Fractional factorial design for optimization

The design was made using design expert (version 13) and consists of dependent variables which are the study process parameters A, B, C, D and E. During the design, the actual and coded concept was employed as shown in Table 2. A total of 32 experimental design runs were obtained using a two-level, five factor fractional factorial method. Each variant factor (A to E) was set at three different levels (low, high, and 0-levels) with $\alpha=\pm 2$, as coded values were designated by -2 (minimum), −1 (mid-minimum), 0 (centre), +1 (mid-maximum) and +2 (maximum). To get a reasonable estimation of errors, five design points per parameter (example, pH: 2, 4, 6, 8 and 10) was chosen. After the design, the following is achieved; effect of the variables on the response (drilling fluid yield %) using coefficient equation, determination of significant interaction, interaction plots, normal probability scatter plot and normal plot of standardized effect. These responses were carried out at optimum operating conditions predicted by RSM. The predicted optimum values were compared with actual experimental measurements. Furthermore, the coefficient of determination (R2), and adjusted R2 were used to appraise the correlation between the optimum values of the predicted and actual experiments for crude oil removal %.

Table 2. Experimental design Matrix for studied sample

Std	*Run*	Factor 1 *A:PH (A)*	Factor 2 *B: Viscosity (B)*	Factor 3 *C: Mud Density (C)*	Factor 4 *D: Temperature (D)*	Factor 5 *E: Rheology (E)*	Response 1 *Drilling Fluid Yield*
9	1	1	15	7.5	100	30	23.56
29	2	3	15	10.5	100	120	25.33
21	3	3	30	10.5	20	60	20.45
2	4	3	30	2.5	40	60	16.33
19	5	3	30	2.5	40	90	19.36
20	6	3	30	2.5	20	90	33.45
24	7	5	75	10.5	20	90	34.45
7	8	1	75	10.5	20	90	36.47
6	9	5	15	5	20	90	23.56
17	10	1	15	5	20	90	49.33
13	11	1	15	5	60	30	12.67
18	12	4	45	7.5	60	120	15.67
14	13	4	45	5	80	30	8.6
28	14	4	45	2.5	100	120	22.45
27	15	4	75	2.5	100	120	19.56
15	16	4	75	10.5	100	30	34.67
32	17	4	75	7.5	80	120	23.47
1	18	1	15	7.5	20	30	5.46
3	19	1	45	7.5	20	60	25.67
16	20	5	45	7.7	100	60	14.56
5	21	1	45	10.5	20	60	67.34
25	22	1	30	2.5	80	60	40.56
26	23	2	30	2.5	100	120	50.67
12	24	2	30	2.5	100	30	66.46
4	25	2	30	5	20	30	58.69
30	26	2	15	5	100	120	44.46
31	27	5	75	5	100	120	34.47
10	28	5	75	2.5	80	120	19.45
23	29	5	75	10.5	80	120	44.56
8	30	5	75	10.5	80	120	44.56
22	31	5	75	10.5	80	120	44.56
11	32	5	75	10.5	80	120	44.56

3. Results and Discussion

Table 3 determines the significant terms among the independent variables studied using the local pear seed oil for drilling fluid.

Table 3. ANOVA for drilling fluid yield

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	3352.81	15	223.52	123.4	0.7109	significant
A-PH (A)	9.43	1	9.43	0.0315	0.8613	
B-Viscosity (B)	249.82	1	249.82	0.8355	0.3743	
C-Mud Density (C)	0.2720	1	0.2720	0.0009	0.9763	
D-Temperature (D)	92.51	1	92.51	0.3094	0.5857	
E-Rheology (E)	12.74	1	12.74	0.0426	0.8391	
AB	113.14	1	113.14	0.3784	0.5471	
AC	269.41	1	269.41	0.9010	0.3566	
AD	4.58	1	4.58	0.0153	0.9030	
AE	5.91	1	5.91	0.0198	0.8900	
BC	74.82	1	74.82	0.2502	0.6237	
BD	12.02	1	12.02	0.0402	0.8436	
BE	1351.09	1	1351.09	4.52	0.0494	
CD	1024.12	1	1024.12	3.43	0.0828	
CE	46.20	1	46.20	0.1545	0.6994	
DE	86.76	1	86.76	0.2902	0.5975	
Residual	4784.01	16	299.00			
Lack of Fit	0.2503	5	0.0501	0.1502	0.9724	Nosignificant
Cor	8136.82	31				

[a.] Factor coding is **Coded**.
Sum of squares is **Type III – Partial**

The Model F-value of 123.4 implies that the model is significant. P-values greater than 0.0500 indicate model terms are significant. In this case A, B, C, D, E, AC, AD, AE, BD, BE, CD, CE, DE, B^2, C^2, D^2 are significant model terms. Also, the Lack of Fit F-value of 0.15 implies the Lack of Fit is not significant relative to the pure error. Non-significant lack of fit is good and shows that the model is fit.

3.1. Fit statistics using local pear oil for drilling fluid

From the fit statistics in Table 4, the predicted R^2 of 0.9984 is in reasonable agreement with the adjusted R^2 of 0.9961, the difference being less than 0.2. The Adequacy precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 50.23 indicates an adequate signal. Hence this model can be used to navigate the design space.

Table 4. Fit statistics Table

Fit statistics parameter			
Std. Dev.	0.561	R^2	0.9721
Mean	32.04	Adjusted R^2	0.9961
C.V %	0.8520	Predicted R^2	0.9984
		Adeq. Precision	50.23

3.2. Pear seed oil drilling fluid properties

The physicochemical properties of the pear seed oil such as density, viscosity, and flashpoint were obtained to be 0.90kg/m3, 51.75cP, and 230°C respectively. Also, a mud density of 9.98ppg was measured, having a 0.44 error when compared with the calculated density of 10.42ppg. However, the different rheological properties such as plastic viscosity, apparent viscosity, yield point, gel strength at 10 secs, and gel strength at 10 mins of the newly formulated bio-based drilling fluid were 130cP, 340cP, 420 Ib/100ft2, and Ib/100ft2 respectively. Furthermore, mud filtrate, and mud thickness of the formulated drilling fluid obtained from the pear seed oil were 121ml, and 7.4mm respectively.

Result of the toxicity test of the drilling mud and base oil for acute fish toxicity and biodegradability showed a 17-day survival using the newly formulated drilling fluids in comparison to 6-day survival using diesel. Also, 9.5 pH value of the formulated bio-based drilling fluid was obtained.

3.3. Actual and predicted values of the drilling fluid

The predicted values versus the actual values shows the yield plot for the drilling fluid developed from local pear seed oil. The plot was used to check if the points will follow a straight line to ascertain the normal distribution of the residuals. Fig. 2 indicates that the points were closely distributed to the straight line which confirms a good relationship between the actual (experimental) values and the predicted values of the response.

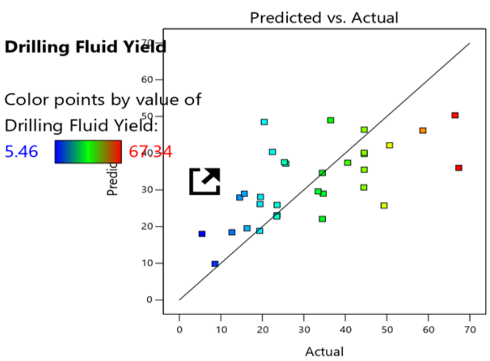

Fig. 2. Actual vs. Predicted plot of drilling fluid yield

The plots also demonstrated that the selected model was adequate in predicting the response variables in the experimental values. However, the table of result of the drilling fluid yield (%) using local pear seed is depicted in Table 5.

Table 5. Report from drilling fluid yield (%) using local pear seed

Run Order	Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residuals	Externally Studentized Residuals	Cook's Distance	Influence on Fitted Value DFFITS	Standard Order
1	23.56	23.11	0.4481	0.500	0.037	0.035	0.000	0.035	9
2	25.33	37.53	-12.20	0.500	-0.998	-0.998	0.062	-0.998	29
3	20.45	48.49	-28.04	0.500	-2.293	-2.710	0.329	-2.710[(1)]	21
4	16.33	19.53	-3.20	0.500	-0.262	-0.254	0.004	-0.254	2
5	19.36	18.84	0.5200	0.500	0.043	0.041	0.000	0.041	19
6	33.45	29.59	3.86	0.500	0.316	0.306	0.006	0.306	20
7	34.45	34.63	-0.1825	0.500	-0.015	-0.014	0.000	-0.014	24
8	36.47	48.97	-12.50	0.500	-1.022	-1.024	0.065	-1.024	7
9	23.56	25.88	-2.32	0.500	-0.190	-0.184	0.002	-0.184	6
10	49.33	25.72	23.61	0.500	1.931	2.134	0.233	2.134[(1)]	17
11	12.67	18.44	-5.77	0.500	-0.472	-0.460	0.014	-0.460	13
12	15.67	28.96	-13.29	0.500	-1.087	-1.093	0.074	-1.093	18
13	8.60	9.86	-1.26	0.500	-0.103	-0.100	0.001	-0.100	14
14	22.45	40.33	-17.88	0.500	-1.462	-1.521	0.134	-1.521	28
15	19.56	28.06	-8.50	0.500	-0.696	-0.684	0.030	-0.684	27
16	34.67	28.98	5.69	0.500	0.465	0.454	0.014	0.454	15
17	23.47	22.74	0.7281	0.500	0.060	0.058	0.000	0.058	32
18	5.46	18.02	-12.56	0.500	-1.027	-1.029	0.066	-1.029	1
19	25.67	37.13	-11.46	0.500	-0.937	-0.933	0.055	-0.933	3
20	14.56	27.92	-13.36	0.500	-1.093	-1.100	0.075	-1.100	16
21	67.34	35.98	31.36	0.500	2.565	3.236	0.411	3.236[(1)]	5
22	40.56	37.40	3.16	0.500	0.258	0.251	0.004	0.251	25
23	50.67	42.14	8.53	0.500	0.697	0.686	0.030	0.686	26
24	66.46	50.31	16.15	0.500	1.320	1.354	0.109	1.354	12
25	58.69	46.16	12.53	0.500	1.025	1.026	0.066	1.026	4
26	44.46	30.67	13.79	0.500	1.128	1.138	0.079	1.138	30
27	34.47	22.08	12.39	0.500	1.013	1.014	0.064	1.014	31
28	19.45	26.14	-6.69	0.500	-0.547	-0.535	0.019	-0.535	10
29	44.56	35.49	9.07	0.500	0.742	0.731	0.034	0.731	23
30	44.56	46.40	-1.84	0.500	-0.150	-0.146	0.001	-0.146	8
31	44.56	40.11	4.45	0.500	0.364	0.354	0.008	0.354	22
32	44.56	39.77	4.79	0.500	0.392	0.381	0.010	0.381	11

b. (1) Exceeds limits

3.4. Effect of drilling fluid properties on the bio-based drilling fluid yield

3.4.1. Effect of pH and Viscosity

Fig. 3 depicts the interaction effect between viscosity and pH on drilling fluid yield. This indicates that the yield increases with increase in viscosity and pH which is as a result of a positive significant effect of viscosity at 45, and pH of 3 respectively.

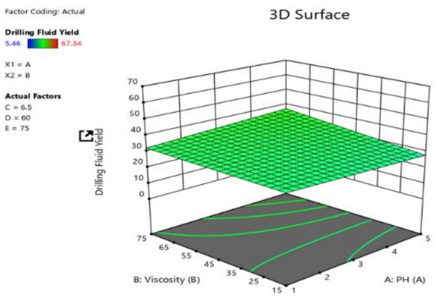

Fig. 3. 3D plot for interaction between drilling fluid pH (A) and drilling fluid viscosity (B) using local pear seed oil

3.4.2. Effect of pH and Mud density

Fig. 4 depicts the interaction effect between pH and mud density on drilling fluid yield. This indicates that the yield increases with increase in viscosity and pH which is as a result of a positive significant effect of density at 6.5 and pH of 3 respectively.

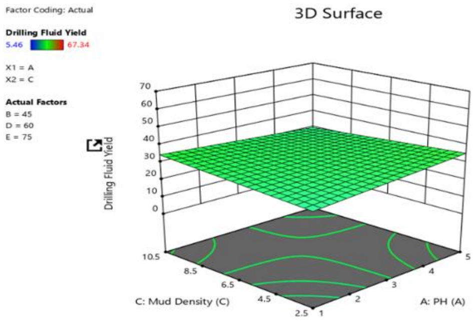

Fig. 4. 3D plot for interaction between drilling fluid pH (A) and drilling fluid mud density (C) using local pear seed oil

3.4.3. Effect of pH and Temperature

Fig. 5 depicts the interaction effect between pH and mud density on drilling fluid yield. This indicates that the yield increases with increase in viscosity and pH which is as a result of a positive significant effect of temperature of 60oC and pH of 3 respectively.

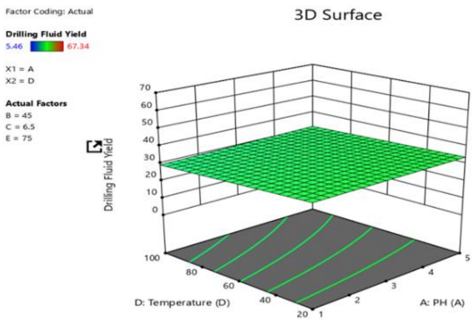

Fig. 5.3D plot for interaction between drilling fluid pH (A) and drilling fluid mud density (D) using local pear seed oil

3.4.4. Effect of pH and Rheology

Fig. 6 depicts the interaction effect between rheology and pH on drilling fluid yield. This indicates that the yield increases with increase in rheology and pH which is as a result of a positive significant effect of the rheology at 75 and a pH of 3 respectively.

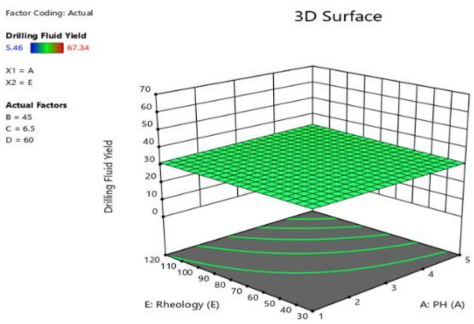

Fig. 6.3D plot for interaction between drilling fluid pH (A) and drilling fluid rheology (E) using local pear seed oil

3.4.5. Effect of Viscosity and Mud density

Fig. 7 depicts the interaction effect between mud density and viscosity on drilling fluid yield. This indicate that the yield increases with increase in mud density and viscosity which is as a result of a positive significant effect of the mud density at 6.5 and viscosity of 45 respectively.

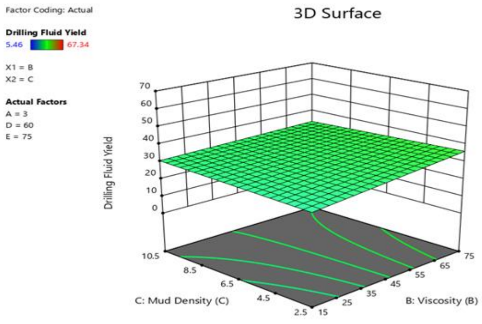

Fig. 7.3D plot for interaction between drilling fluid Viscosity (B) and drilling fluid Mud Density (C) using local pear seed oil

3.4.6. Effect of Viscosity and Temperature

Fig. 8 depicts the interaction effect between mud viscosity and temperature on drilling fluid yield. This indicates that the yield increases with increase in viscosity and temperature which is as a result of a positive significant effect of the viscosity at 45 and temperature of 60oC respectively.

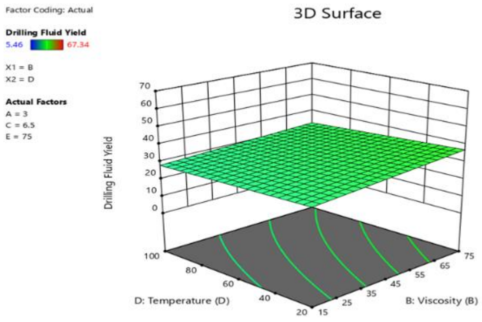

Fig. 8. 3D plot for interaction between drilling fluid viscosity (B) and drilling fluid Temperature (D) using local pear seed oil

3.4.7. Effect of Viscosity and Rheology

Fig. 9 depicts the interaction effect between mud viscosity and rheology on drilling fluid yield with normal contour and 3D plots respectively. This indicates that the yield increases with increase in viscosity and rheology which is as a result of a positive significant effect of the viscosity at 45 and rheology of 75 respectively.

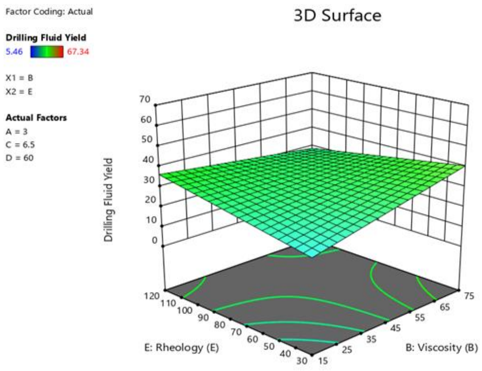

Fig. 9. 3D plot for interaction between drilling fluid viscosity (B) and drilling fluid Rheology (E) using local pear seed oil

3.4.8. Effect of Mud density and Temperature

Fig. 10 depicts the interaction effect between mud viscosity and rheology on drilling fluid yield with normal contour and 3D plots respectively. This indicates that the yield increases with increase in mud density and temperature which is as a result of a positive significant effect of the mud density at 6.5 and temperature of 60oC respectively.

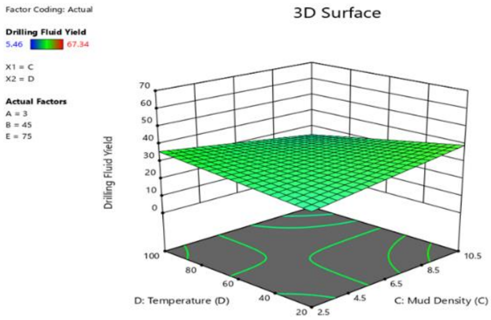

Fig. 10. 3D plot for interaction between drilling mud density (C) and drilling fluid temperature (D) using local pear seed oil

3.4.9. Effect of Mud density and Rheology

Fig. 11 depicts the interaction effect between mud density and rheology on drilling fluid yield with normal contour and 3D plots respectively. This indicate that the yield increases with increase in mud density and rheology which is as a result of a positive significant effect of the mud density at 6.5 and rheology of 75 respectively.

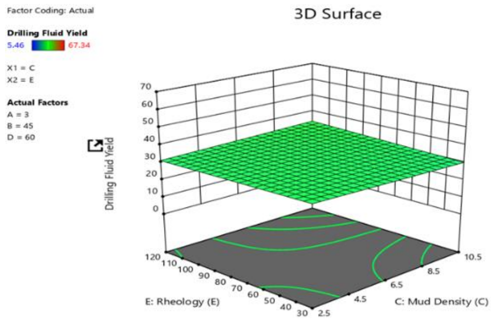

Fig. 11. 3D plot for interaction between drilling mud density (C) and drilling fluid rheology (E) using local pear seed oil

3.4.10. Effect of Temperature and Rheology

Fig. 12 depicts the interaction effect between mud temperature and rheology on drilling fluid yield with normal contour and 3D plots respectively. This indicate that the yield increases with increase in mud temperature and rheology which is as a result of a positive significant effect of the temperature of 60oC and rheology of 75 respectively.

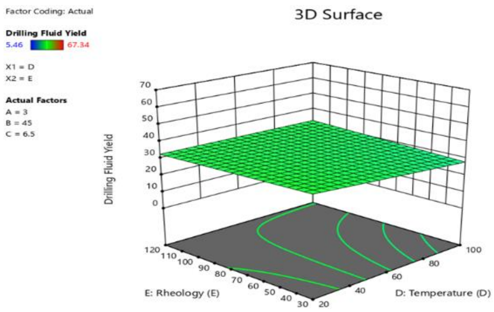

Fig. 12. 3D plot for interaction between drilling temperature (D) and drilling fluid rheology (E) using local pear seed oil

3.5. Optimization of drilling fluid yield

The optimized results as seen in Fig. 13(a) and Fig. 13(b) presents the optimum, desirability, standard error, and the optimized drilling fluid yield values from the input of the various parameters. The optimized drilling fluid yield and the optimum values were obtained through iterations of one hundred (100) solutions. The best yield was selected at iteration number seven (95), with a pH of 1, Viscosity of 119.783, mud density of 10.473, Temperature of 100, Rheology of 76.809, and optimized drilling fluid yield value of 91.144.

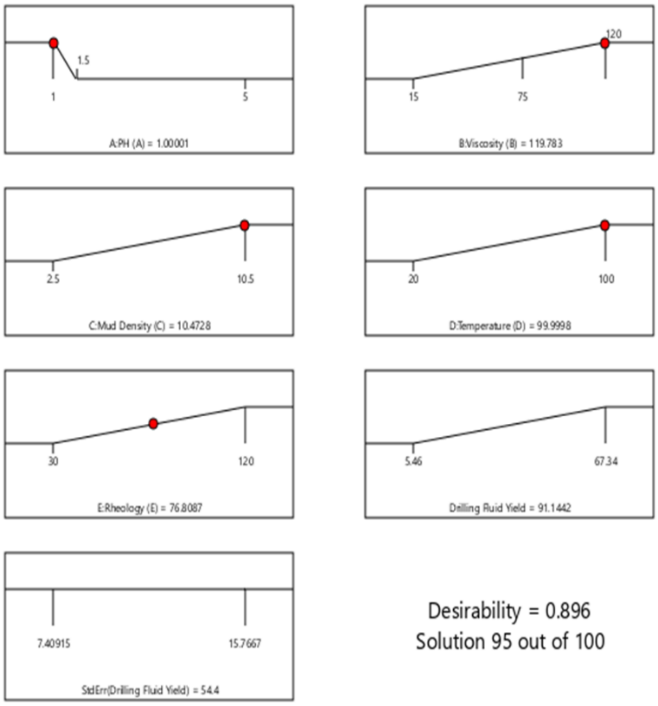

Fig. 13. (a) Optimization Ramp Graph

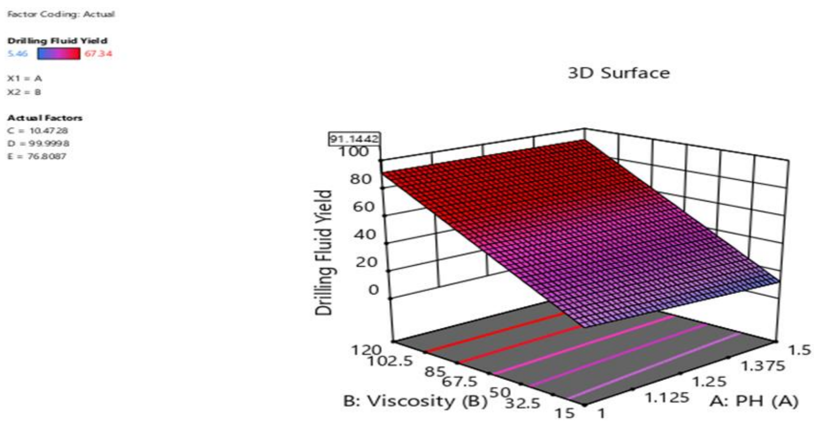

Fig. 14. (b) Optimized 3D graph

4. Conclusion

The optimized results show the optimum, desirability, standard error and the optimized drilling fluid yield values from the input of the various parameters. The optimized drilling fluid yield and the optimum values were obtained through iterations of one hundred (100) solutions and the best yield was selected at iteration number seven (95), at pH of 1, Viscosity of 119.783, mud density of 10.473, Temperature of 100, and Rheology of 76.809. The optimized drilling fluid yield value was 91.144. The Anova Table was applied to determine significant terms among the independent variables studied using the local pear seed oil for drilling fluid. The Model F-value of 123.4 indicated that the model is significant. P-values greater than 0.0500 also indicated that model terms are significant. In this case A, B, C, D, E, AC, AD, AE, BD, BE, CD, CE, DE, B^2, C^2, D^2 were significant model terms. Based on the study, the sample (local peer) exhibited a good drilling fluid for oil exploration. Hence, it is recommended that this optimized drilling fluid can be used as a substitute for other conventional based drilling fluid due to its eco-friendliness, biodegradability, cost effectiveness, and availability.

Acknowledgment

Special thanks to the clean fuels, energy, and environmental research lab in the Department of Mechanical Engineering, University of Cross River State, Nigeria.

Declarations

Author contribution. All authors contributed equally to the main contributor to this paper. All authors read and approved the final paper.
Funding statement. None of the authors have received any funding or grants from any institution or funding body for the research.
Conflict of interest. The authors declare no conflict of interest.
Additional information. No additional information is available for this paper.

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