

Original Research Article

OPTIMIZATION STUDY ON THE RHEOLOGICAL CHARACTERISTICS OF WATER BASED DRILLING FLUID USING *ARACHISHYPOGAEA* SHELLS CELLULOSE

Abstract

The key process parameters for the rheological characteristics of water-based drilling fluid (WBDF), Using *Arachishypogaea* shells cellulose (AHSC) were optimized using the two-level-two factor full factorial design of Response Surface Methodology (RSM). This research reveals the key outcomes of investigations, carried out on the formulation of a sustainable drilling fluid system, where AHSC is used as a fluid loss additive and a rheological modifier having no toxicity and high biodegradability. The characterization and pretreatment of the AHSC were carried out. Meanwhile, the result of the proximate analysis revealed that the AHSC had 70.40% cellulose, which is a good additive for drilling mud formulation that displays related functions as some of the foreign viscosity and fluid loss polymers like polyanionic cellulose used in producing drilling muds. It was established that, additive concentration and filtration time had significant effects on WBDF formulation while the optimum results were obtained as: 6g, 15 minutes and 11.58ml for additive concentration, filtration time and filtration loss, respectively. This investigation indicates that the proposed fluid loss additive and rheological modifier can minimize environmental hazards and have proved to be a cost-effective eco-friendly alternative in this challenging phase of the hydrocarbon exploration industry.

Keywords: Water based drilling mud; *Arachishypogaea* shells; Biodegradable; drilling fluid rheology; Optimization

1. INTRODUCTION

The process of designing drilling fluids is crucial and increasingly interesting in the drilling operation [1]. Drilling fluids' primary purposes include transporting cuttings from the wellbore to the surface, supplying the proper amount of mud weight to manage formation pressure, lubricating and cooling drill bits and casing, and supporting the weight of the drill bit and drill pipe [2,3]. Therefore, drilling fluid or mud is an essential component of any drilling process. It is the central component of drilling operations, and it must be created and regulated to fulfil its functions in the well. Water-based drilling fluid, oil-based drilling fluid, and synthetic-based drilling fluid are the three main types of drilling mud that are frequently used in drilling techniques. But the choice of drilling fluid depends on what the drilling formation is doing [4]. Water-based muds (WBM) are used for more drilling fluid applications since oil-based muds have substantially worse environmental effects [5].

Due to its low cost and relative environmental friendliness compared to oil-based drilling fluid, water-based drilling fluid is undoubtedly the most often used drilling mud in oil and gas exploration [6]. Any drilling fluid's performance is influenced by its rheological characteristics, including apparent viscosity, plastic viscosity, yield point, and gel strength [7]. To endure down-hole conditions, the drilling fluid's rheological properties must remain constant over time. If the rheological qualities significantly decrease, the mud additives are not stable under the down-hole circumstances [8]. Drilling fluids and their additives are essential to drilling operations and project costing; as a result, it is necessary to produce environmentally friendly drilling fluid additives that are both affordable and fit the requirements for smooth operation in geologically challenging scenarios [5].

Over the past few decades, research and development policies around the world have become increasingly focused on effective environmental management and efficient use of the resources at hand. As a result, there is significant interest in enhancing the rheological properties of water-based drilling fluid in order to satisfy the market's current need for environmentally safe, economically viable drilling fluid. This is due to the fact that drilling muds with less of an impact on the environment are highly wanted over traditional diesel-based mud systems, especially in light of the impending harsh environmental rules, according to Saket et al., [9]. Utilizing agricultural waste lignocellulose resources to create water-based drilling fluid is crucial for achieving this.

The current research demonstrates the process of formation and data analysis of a sustainable drilling fluid system, where biodegradable *Arachishypogaeashells* (groundnut husks) is used as a fluid loss additive and rheological modifier because; it is environmentally friendly and does not contend with food supply. The cellulose processed from groundnut husk is tested as an alternative for the current practice of using polyanionic cellulose in the drilling fluid formulation [5]. The drilling mud production process is enhanced by different operating parameters. Therefore, it is essential to determine the optimum values of these process parameters using RSM, for drilling mud production development and industrial application. However, there haven't been many investigations on drilling muds that have used *Arachishypogaea* shells or water-based formation. According to Atul et al., [5], the groundnut shell-based fluid loss additive and rheological modifier can reduce environmental risks and has shown to be a practical and affordable green choice in this difficult stage of the petroleum exploration sector. Researchers have reported a number of further works, as in refs [10,11], among others. None of the works in the aforementioned articles reported using the RSM tool to optimize the process variables. Igwilo et al., [12] claim that the use of software for data analysis as well as, the optimization of process parameters for optimal results are the current trends in research.

Box and Wilson developed the Response Surface Methodology (RSM), an optimization approach to make it easier to progress production processes in various industries, particularly the chemical industry [13]. The main benefit is its ability to reduce the numerical strength of experiments, which is required to access the effects of many parameters as well as their interactions on the result. The improvement of industrial process characteristics accelerates industrial development, which eventually leads to profit [12]. RSM consequently focused on enhancing chemical processes to produce better results, such as higher yield and purity at lower costs. The RSM system was made possible by the use of incremental experimentation, which included variables such as pressure, reaction duration, pH, temperature, and reactant ratio [14].

According to the researches that have been done so far, RSM has not been used to optimize drilling mud which, is water-based and contains cellulose from *Arachishypogaea* shells. Therefore, it is essential to fill this knowledge gap. As a result, the current study presents major findings from investigations into the development of a sustainable drilling fluid system, where *Arachishypogaea* shells are employed as a fluid loss additive and a rheological

modifier with zero toxicity and high biodegradability. The study also aims to optimize the process variables that influence the formulation.

2. Materials and Method

2.1. Preparation of raw material

The groundnut was bought in Rivers State, Nigeria's Oil Mill Market. The raw groundnut seeds were taken out, and the extraction was done with the shells. The shells were pre-treated by dipping them into a 10:1 solution to shell ratio of 0.5N sodium hydroxide solution for an overnight period at room temperature. After that, the solution was heated for 30 minutes to 80°C. The pre-treated sample was fully drained and then washed twice in warm water and once in cold. Any remaining alkali was subsequently neutralized in a weak acetic acid solution, dried in the oven, and then mixed into a fine powder.

2.2 Characterization of the pre-treated sample

2.2.1 Determination of hemicellulose and cellulose

The pre-treated sample was characterized to determine the compositions of the groundnut shell using the method employed by Narendra and Yiqi [15]. The pretreated sample was introduced into a flat bottom round flask. 500ml of 18% NaOH solution was introduced into it and stirred at room temperature for 30 minutes. During stirring, the flask was covered using aluminium foil. Then, the solution was filtered using a vacuum pump. It was washed with 500ml of 20% acetic acid in hot water. The solution was later washed with hot distilled water to neutralize it and then filtered. The filtrate was tested with a pH meter to confirm the neutrality of the residue. The residue was oven dried at 80°C for 1 hour. The percentage hemicellulose and cellulose were calculated using equations (1 and 2) respectively.

$$\% \text{ hemicellulose} = \frac{\text{initial weight} - \text{final weight}}{\text{initial weight}} \times 100 \quad (1)$$

$$\% \text{ cellulose} = \frac{\text{final weight of the sample}}{\text{initial weight}} \times 100 \quad (2)$$

2.2.2 Determination of lipid

The pre-treated sample was weighed into a 1000ml flat bottom flask. 100ml of n-hexane was introduced into the sample and shake vigorously until the sample was completely submerged. The mixture was covered using masking foil tape. It was then allowed to stand for 48 hours

for complete lipid extraction. The n-hexane which has the oil dissolved in it was gradually decanted from the sample and sample allowed to dry at ambient temperature.

$$\% \text{ lipid} = \frac{\text{Initial weight of the sample} - \text{final weight of the sample}}{\text{initial weight of the sample}} \times 100 \quad (3)$$

2.2.3 Determination of lignin

The residue of the sample was introduced into a three neck round bottom flask fitted with reflux condenser to determine the lignin content. 500ml of 7.5% weight by volume (w/v) aqueous hydrogen peroxide solution was introduced into the solution and was refluxed at 90°C for 2 hours. The solution was allowed to cool and filtered using a vacuum pump. It was then washed with hot water to neutralize the residue and it was allowed to dry at ambient temperature. The lignin content was determined using equation (4).

$$\% \text{ lignin} = \frac{\text{initial weight of the residue} - \text{final weight of the residue}}{\text{initial weight of the residue}} \times 100 \quad (4)$$

2.3 Formulation of the drilling mud sample

The production methods of the drilling mud and the determination of the rheological and allied properties of the mud were carried out based on the API drilling mud production standards [16, 4, 17]. The mixing method used by Joel et al., [4] was adopted. The various quantities of the raw materials were measured using the graduated cylinder and electronic weighing balance. The raw materials were then poured, one after the other, with an interval of 5 minutes into the steel cup of the single spindle mixer. The application of the raw materials was carried out in a descending order. The mud samples were formulated in the absence and presence of various concentrations of the groundnut shell cellulose. As each material is being put into the mixer, the mixer is powered to cause the spindle to rotate and mix the contents inside the steel cup being held at a fixed position. As the materials have been completely applied into the mixer steel cup, it was allowed for 30 minutes, under stirring condition, for a total uniformity of the materials to give finely formulated water and oil based drilling mud. This procedure was carried out with varying concentration of groundnut shell cellulose.

2.4 Testing of the muds

The densities of the muds were determined by the use of drilling fluid balance and also the pH meter was used to measure the pH of the formulated muds. The measurement of rheological properties of the formulated drilling mud was carried out using Viscometer.

Rheological readings, America Petroleum Institute Testing, 600 RPM, 300 RPM, were noted. Furthermore, 10 seconds, 10 minutes and 30 minutes gel strength data were also noted down. Plastic viscosity, yield point and apparent viscosity of the drilling muds were calculated using Equations (5), (6) and (7) respectively [18]:

$$\text{Plastic Viscosity (PV), cP} = 600 \text{ RPM reading} - 300 \text{ RPM reading} \quad (5)$$

$$\text{Yield Point (YP), lb/100 ft}^2 = 300 \text{ RPM reading} - \text{Plastic Viscosity (PV)} \quad (6)$$

$$\text{Apparent Viscosity (AV), cP} = 600 \text{ RPM reading} / 2 \quad (7)$$

2.5 Optimization of fluid loss control in water base drilling fluid

Central composite design (CCD) of response surface methodology (RSM) Design Expert software (version 10) trial version was used in this study to design the experiment and to optimize the fluid loss control conditions. The experimental design employed in this work is a two-level-two factor full factorial design, including 13 experiments. Concentration of the GNC additive (g) and filtration time (minutes) were selected as independent factors for the optimization study. The response chosen is filtration loss, Y (ml) obtained from filtration process of water base drilling fluid. Five replications of center points were used in order to predict a good estimation of errors and experiment was performed in a randomized order. The actual and coded levels of each factor are shown in Table 1. The coded values were designated by -1 (minimum), 0 (center), $+1$ (maximum), $-\alpha$ and $+\alpha$. Alpha is defined as a distance from the center point which can be either inside or outside the range. It is noteworthy to point out that the software uses the concept of the coded values for the investigation of the significant terms, thus equation in coded values was used to study the effect of the variables on the responses. The empirical equation is represented as shown below:

$$Y = \beta_0 + \sum_{i=1}^2 \beta_i X_i + \sum_{i=1}^2 \beta_{ii} X_i^2 + \sum_{i=1}^2 \sum_{j=i+1}^2 \beta_{ij} X_i X_j \quad (8)$$

Selection of levels for each factor was based on the experiments performed to study the effects of process variables on the fluid loss test.

Table 1: Studied range of each factor in actual and coded form fluid loss control in water base drilling fluids using groundnut shell cellulose as additive.

Factor	Units	Low level	High level	- α	+ α	0 level
Conc. of GNC additive (A)	(g)	2(-1)	6(+1)	0(-2)	8(+2)	4
Filtration time (B)	Minutes	15(-1)	25(+1)	10(-2)	30(+2)	20

3. Results and discussion

3.1. Composition of the groundnut shell

The results of proximate analysis of the sample in terms of chemical compositions (hemicellulose, cellulose, lignin and other extracts) are presented in Table 2. It was discovered that groundnut starch sample is rich in carbohydrate having cellulose content of 70.40% which is close to that of the PAC of 78.5%. This shows that it is a good additive for drilling mud formulation which displays related functions as some of the foreign viscosity and fluid loss polymers like polyanionic cellulose used in producing drilling muds [19]. However, the cellulose content (78.5%) obtained in this study is higher than the values (63.5%) reported in previous studies [20]. Pretreatment can make a difference in the compositions of samples.

The variations could also be a result of the sample's origin [21], as the sample for this investigation came from River State in Nigeria. Different cultivation sites may result in variations in the lignocellulose content of the same types due to variations in soil temperature [22], altitude [23], light intensity [24], and soil moisture content [25, 26]. Additionally, previous research has shown that the amount of cellulose and hemicellulose in biomass is significantly impacted by drought stress [26–29].

Table 2: Composition of the groundnut shell

S/N	Composition	Percentage by weight (%w/w)
1	Lipid	2.30
2	Lignin	0.70
3	Hemicellulose	25.60
4	Cellulose	70.40

3.2 Result of Properties of formulated mud samples

Table 3 presents the properties of water based mud samples (A, B, C, D and E) prepared. The mud pH, mud density and the specific gravity are shown for the five samples.

Table 3: Properties of formulated mud samples

Sample	Water based mud		
	pH	Mud density (ppg)	Specific gravity
A (0g GNC)	10.5	8.7	0.84
B (2g GNC)	11.5	8.47	1.14
C (4g GNC)	12	8.42	1.14
D (6g GNC)	11	7.79	1.10
E (8g GNC)	14.6	8.06	1.20

GNC = Groundnut Cellulose.

It could be observed from the table that the pH, mud density and specific gravity of the mud prepared from groundnut husk cellulose is higher than that of the standard mud and this could be due to presence of the groundnut cellulose. From the pH value, the formulated muds are in alkaline state [16, 17]. Similar results of this finding have also being reported by Onuh et al., [30] for fluid loss properties of mud formulated with concentrations of coconut shell and/or corncobs.

3.4. Optimization of fluid loss control in water base drilling fluid

A sum of 13 experimental runs was gotten from two-level-two factor full factorial design matrix, with two experimental process factors (Concentration of additive and Filtration time). The design plan was used to optimize the volume of fluid loss using groundnut cellulose additive in water base mud. The filtration loss depends on the results if there is significant variation for combination of process parameters. The empirical relationship between filtration loss and the two variables in coded values obtained by using the statistical package Design-Expert 10 version for determining the levels of factors which gives optimum filtration loss was given by the equation below. Quadratic regression equations that fitted the data are shown in equations (9):

$$Y_{WBM} = 11.66 + 0.29A + 0.24B - 0.18AB - 0.33A^2 + 0.03B^2 \quad (9)$$

Where Y_{WBM} is the response variable (volume of fluid loss) and A-B are the coded values of the independent variables. The above equation represents the quantitative effect of the factors (A and B) upon the response (Y). Coefficients with one factor represent the effect of that particular factor while the coefficients with more than one factor represent the interaction between those factors. Positive sign in front of the terms indicates synergistic effect while negative sign indicates antagonistic effect of the factor. The adequacy of the above proposed model was tested using the Design Expert sequential model sum of squares and the model test statistics. From the sequential test, F- values for linear, quadratic and polynomial models are 4.23; 80.43 and 22.56 respectively. It can be seen that the model F-values of the quadratic model is large compared to the values for the other models for the equation. And from the statistics test, the regression coefficient ($R^2 = 0.9829$) is high, and the adjusted R^2 (0.9707) is in close agreement with the predicted R^2 (0.8802) value. The coefficient of variance (CV) is the ratio of the standard error of the estimate to the mean value of the observed response and is considered reproducible once it is not greater than 10%. In this work, the CV obtained is 0.96%. The "Adeq Precision" value measures the signal-to-noise ratio. A ratio greater than 4 is desirable. From this experiment, a ratio of 34.043 was observed, which indicate an adequate signal. This model can be used to navigate the design space. This test is shown in Table 4.

Table 4: Significance of regression coefficients of filtration loss using the design-expert version 10 for WBM.

Source	Degree of freedom	Sum of square	of Mean Square	F-value	P-value (Prob >F)
Model	5	4.76	0.95	80.43	< 0.0001
A	1	1.02	1.02	86.21	< 0.0001
B	1	0.70	0.70	59.19	0.0001
AB	1	0.12	0.12	10.35	0.0147
A ²	1	2.53	2.53	213.77	<0.0001
B ²	1	0.021	0.021	1.76	0.2267
Residual	7	0.083	0.018		
Lack of Fit	3	0.055	0.00688	2.68	0.1822
Cor.					
Total	12	4.84			

Std. Dev. = 0.11; Mean = 11.38; C.V.% = 0.96; PRESS = 0.58; $R^2 = 0.9829$; Adj. $R^2 = 0.9707$; Pred. $R^2 = 0.8802$; Adeq. Precision = 34.043

The ANOVA results for the model terms are given in Table 4. Analysis of variance (ANOVA) was applied for estimating the significance of the model at 5% significance level and shown in Tables 4. A model is considered significant if the p-value (significance probability value) is less than 0.05. From the p-values presented in Table 4, it can be stated that the linear terms A, B and interaction term AB, with the quadratic terms A^2 are significant model terms. Based on this, the insignificant terms of the model were removed and the model reduced to equation 10:

$$Y_{WBM} = 11.66 + 0.29A + 0.24B - 0.18AB - 0.33A^2 \quad (10)$$

The experimental data were also analyzed to check the correlation between the experimental and predicted filtration loss and the normal probability and residual plot, and actual and predicted plot are shown in Figures 1 and 2 respectively. It can be observed from the figures that the data points on the plot were reasonably distributed near to the straight line, indicating a good relationship between the experimental and predicted values of the response, and that the underlying assumptions of the above analysis were appropriate. The result also suggests that the selected quadratic model was adequate in predicting the response variables for the experimental data.

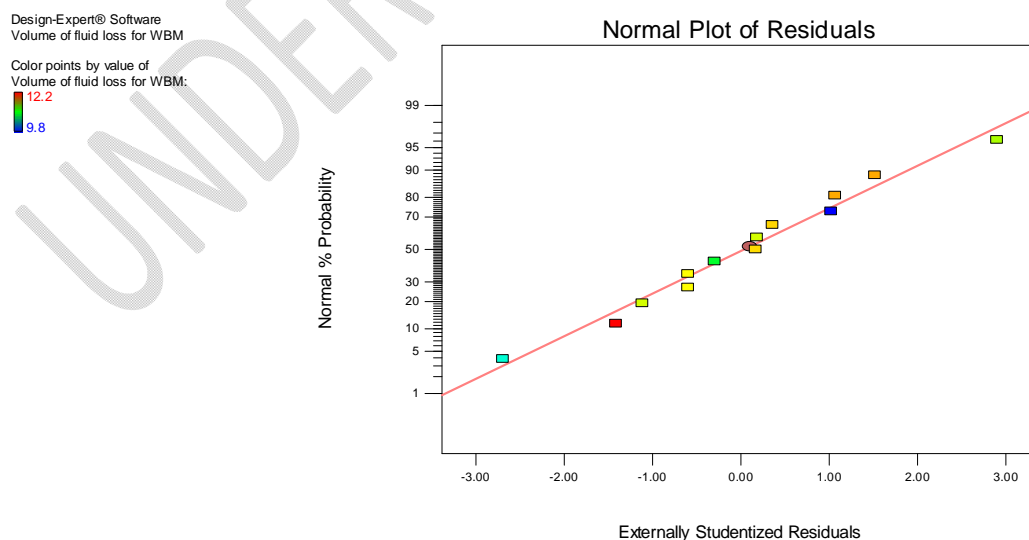


Figure 1: Plot of normal probability versus residuals for filtration loss with WBM

Design-Expert® Software
Volume of fluid loss for WBM

Color points by value of
Volume of fluid loss for WBM:

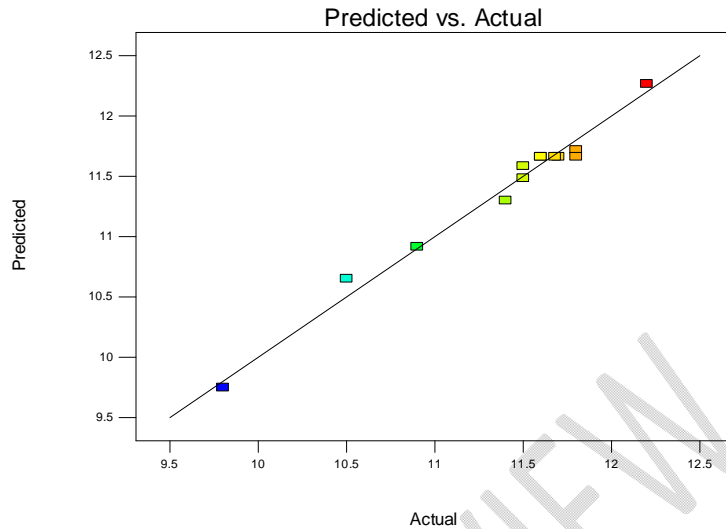


Figure 2: Plot of predicted values versus the actual experimental values for filtration loss with WBM

3.4.1 Three Dimensional Surface Plot and Contour Plot for filtration loss

The 3D response surface plot and contour plot were generated to estimate the effect of the combination of the independent variables on the filtration loss. This plot is shown in Figure 3. Figure 3 shows the interaction effect of concentration of additive (groundnut cellulose) and filtration time on filtration loss in WBM. It is observed that the filtration loss increased as both filtration time and concentration of additive increased. This shows progressive decrease in filtration rate of mud with increasing time of filtration and additive concentration. The decreasing in filtration rate was resulted from continuous mudcake deposition and compaction until formation of a constant thickness and stable mudcake had been formed completely.

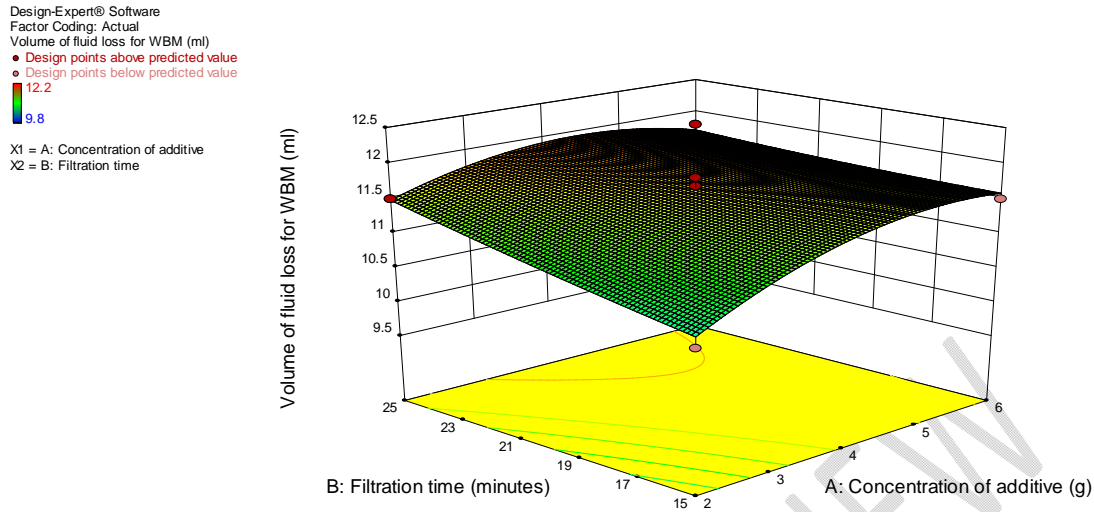


Figure 3: Response surface 3D plot indicating interaction effects of factors concentration of additive and filtration time.

3.4.2 Validation of the optimum parameters of the mud

Optimization is concerned with selecting the best among the entire set by efficient quantitative methods. The goal of optimization however, is to find the values of the variables in the process to yield the best value of the performance criterion [12].

The filtration loss was therefore, optimized with the design expert to minimize the volume of fluid loss. Maximum filtration loss of 11.58ml was obtained at optimum conditions of concentration of additive (GNC), 6g and filtration time of 15minutes. The filtration loss control under the obtained optimum operating conditions was carried out in order to evaluate the precision of the quadratic model; the experimental value and predicted values are shown in Table 5. Comparing the experimental and predicted results, it can be seen that the error between the experimental and predicted are less than 1%, therefore it can be concluded that the generated model has sufficient accuracy to predict the filtration loss control for WBM.

Table 5: Results of the model validation for WBM (experiment to validate the optimum filtration loss)

Mud type	Additive concentration (g)	Filtration time (Minutes)	Experimented filtration loss (ml)	Predicted filtration loss(ml)	% Error
	A	B			
WBM	6	15	11.5	11.58	0.7

4.1 Conclusion

The quadratic model of two-level-two factor full factorial design was an adequate model, for the water based drilling mud formulation using *Arachishypogaea* shells cellulose. It was found that Additive concentration and Filtration time had significant effects on WBM formulation while the optimum results were obtained as: 6g, 15 minutes and 11.58ml for additive concentration, filtration time and filtration loss, respectively. It can be concluded that, the *Arachishypogaea* shells can be successfully used (when the optimum conditions are observed) as a cost-effective biodegradable alternative to industrial-grade PAC-LVG, which acts to reduce the API Filtration losses.

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