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Optimization of Alternative CMC Sources from Rice Husk, Sawdust, and Caustic Soda, and The Effect of pH Increase on Filtration Loss and Rheology of Drilling Mud

Lisa Samura[1], Cahaya Rosyidan[1], Mustamina Maulani[1], Andry Prima[1], Maman Djumantara[1], Dina Asmaul Chusniyah[1,2], Aqlyna Fattahanisa[1], Bayu Satiyawira[1], Mentari Gracia Soekardy[1], and Brilliani[1]

[1]Petroleum Engineering Department, Universitas Trisakti
Kyai Tapa Street no.1, Jakarta, Indonesia.

[2]Institute of Geology and Geophysics, Chinese Academy of Science, University of Chinese Academy of Science
No. 19, Beitucheng Western Road, Chaoyang District, Beijing, 100029, PR China.

Corresponding author: Lisa Samura (lisa.samura@trisakti.ac.id)

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ABSTRACT - Drilling mud plays a vital role in maintaining wellbore stability, carrying cuttings, and controlling formation pressure during drilling operations. Typically, Carboxy Methyl Cellulose (CMC) is used to enhance mud viscosity and reduce filtration loss, but its synthetic nature makes it relatively expensive. This study investigates rice husk and sawdust as natural, cost-effective alternatives to CMC. Various compositions were evaluated using the Box-Behnken design in Response Surface Methodology (RSM) to optimize the mud formulation. Results indicate that a combination of 6 g rice husk and 6 g sawdust provides the best performance in improving rheological properties such as yield point and gel strength, while significantly reducing filtration loss. Gradual addition of caustic soda (NaOH) effectively increases mud pH to the ideal range (9–11), enhancing chemical stability. RSM successfully modeled the statistical relationship among variables and facilitated identification of the optimal formulation.

Keywords: rice husk, sawdust, carboxy methyl cellulose, mud rheology, response surface methodology

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INTRODUCTION

Drilling mud is a critical component in drilling operations, functioning as a lubricant and coolant for the drill bit and drill pipe, while also playing a vital role in maintaining well control by utilizing its hydrostatic pressure to prevent the influx of formation fluids as revealed in a study by Salihu in 2025 (Salihu et al., 2025). It also forms a mud cake along the borehole wall to minimize fluid loss into surrounding formations. There are two main types of drilling mud: water-based and oil-based. However, during drilling through highly permeable zones, large fractures, or low-pressure formations, a problem known as loss circulation can occur where drilling fluid escapes into the formation, leading to a loss of pressure balance (Rubiandini, 2009). This can result in serious operational issues such as non-productive time, increased costs, blockage of productive zones, and even loss of well control. To mitigate this, additives like carboxymethyl cellulose (CMC) are often used to enhance viscosity and water retention through their hydrophilic and gel-forming properties, but CMC is relatively expensive (Abshar, 2022), prompting the need for more economical alternatives (Course, 1995; Ferdy Muhammad Zakhrifady, 2018, 2018; Inteq, 1995; Kementrian Pendidikan Dan Kebudayaan Republik Indonesia 2019; Pamungkas, 2004; *Zakhrifady Hidrolika Pemboran dan Pengangkatan Cutting*, n.d.)

Agricultural and industrial wastes such as rice husk and sawdust, which are abundantly available in Indonesia, offer promising alternatives (KRT Nur Suhascaryo et al., 2021). These materials are rich in cellulose as to previously researched by Ysbaa (Ysbaa et al., 2024), a natural polymer capable of forming viscous gels that can effectively seal formation pores, reduce filtration loss, and stabilize the mud lower concentrations, demonstrating its system (Aggrey et al., 2019; Agwu & Akpabio 2018; Jaf et al., 2023; Sharif, 2018). A study found that rice husk reduced filtration loss by up to 64.89%, outperforming CMC and PAC at effectiveness in forming efficient filter cakes along the wellbore wall (Handayani 2025; Tindaon et al., 2011). Additionally, caustic soda (NaOH) is commonly used to adjust pH, improve clay dispersion, and enhance mud rheology (Al-Ghanimi & Al-Zubaidi 2020; Amer et al., 2022; Satiyawira, 2018; Shoaib et al., 2022). Maintaining a high pH is essential, as low pH or acidic conditions can cause corrosion in the drill string and reduce its operational lifespan .(Hamid 2016, 2018; Nurmajid Abdurrojaq et al., 2021).

This research investigates the combined effects of rice husk, sawdust, and caustic soda as additives in water-based drilling mud, focusing on their influence on rheological properties and filtration loss(Abdurrojaq et al., 2022; Ariyon et al., 2025), that is in line with the previous research by Shuvo, Sultan and Ferdous in 2024 (Shuvo et al., 2024).

The study aims to determine the optimal formulation that ensures effective performance while remaining cost-efficient and environmentally friendly. To achieve this, the response surface methodology (RSM) with a Box-Behnken design is applied using design expert software, allowing for systematic optimization of additive concentrations and compositions to improve the overall quality and stability of the drilling mud (Alhajabdalla et al., 2021; Asmungi et al., 2023; Aziz & Aziz, 2018; Dbik et al., 2022; Raghupathy & Amirthagadeswaran 2014)

METHODOLOGY

This research applies an experimental laboratory approach integrated with statistical analysis using RSM. The drilling mud formulation is optimized through a Box–Behnken design to determine the ideal combination of rice husk (Figure 1), sawdust (Figure 2), and caustic soda (NaOH).

The study focuses on assessing how variations in these natural additives influence the rheological behavior and filtration performance of water-based drilling mud (WBM).

The primary materials used in this study include 22.5 g of bentonite as the base ingredient, 350 mL of fresh water, rice husk, sawdust, and NaOH. Rice husk and sawdust are selected due to their high cellulose content, which allows them to function as natural polymers capable of enhancing viscosity, minimizing filtrate invasion, and forming effective filter cakes. Caustic soda is added to maintain the mud pH within the recommended range of 9–11, ensuring chemical stability and preventing corrosion of drilling components. Prior to use, all solid materials are dried and sieved to obtain uniform particle sizes and ensure consistency in the experimental procedures.

The additive composition is determined using a Box–Behnken design, with three variables rice husk, sawdust, and NaOH each varied at three levels. A total of 17 experimental runs is conducted to evaluate the effects of these variables on key mud parameters, including apparent viscosity, plastic viscosity, yield point, gel strength, pH, and filtration loss. The experimental matrix for drilling mud composition is presented in the corresponding table.

The analysis begins with the preparation of drilling mud by mixing bentonite with water, followed by the addition of rice husk, sawdust, and NaOH according to the Box–Behnken design. Once the mud is prepared, viscosity testing is carried out to measure flow resistance. Yield Point (YP) testing evaluates the mud's ability to resist movement of suspended solids, while gel strength testing assesses the mud's capacity to maintain suspension after static periods. Apparent viscosity is calculated based on flow parameters. Filtration loss tests are performed using an API filter press to

Figure 1. Rice husk (Kordi et al., 2024)

Figure 2. Rice husk (Priya et al., 2025)

Table 1. Design of drilling mud sdditive composition

Std	Run	Rice husk (gram)	Sawdust (gram)	Caustic soda (NaOH) (gram)
5	1	2	6	1
13	2	6	6	1.5
6	3	10	6	1
15	4	6	6	1.5
12	5	6	10	2
14	6	6	6	1.5
4	7	10	10	1.5
10	8	6	10	1
9	9	6	2	1
2	10	10	2	1.5
3	11	2	10	1.5
8	12	10	6	2
1	13	2	2	1.5
16	14	6	6	1.5
17	15	6	6	1.5
11	16	6	2	2
7	17	2	6	2

measure filtrate volume and mud cake thickness, and pH testing is conducted to ensure the chemical balance of the mud.

The study combines experimental laboratory testing with analytical evaluation of results. All data, including rheology parameters (AV, PV, YP, gel strength), filtration loss, and mud cake thickness, are analyzed statistically using Design Expert software. Design Expert is a specialized statistical and optimization tool widely used for designing experiments, evaluating factor interactions, and developing predictive models in engineering and scientific research. The software provides comprehensive capabilities for constructing response surface models, generating ANOVA tables, assessing model significance, and visualizing factor–response relationships through diagnostic plots, contour plots, and response surface maps. In this study, Design Expert facilitates the implementation of the Box–Behnken Design (BBD), allowing systematic evaluation of the combined effects of rice husk, sawdust, and caustic soda on the drilling mud properties. The software automatically generates statistical indicators such as R^2, Adjusted R^2, Predicted R^2, and Adequate Precision, which are used to assess model quality and reliability. The optimization of additive concentrations is achieved through RSM, and the model's predictions are validated by comparing them with experimental results from selected runs, ensuring that the optimized formulation remains statistically robust and experimentally reproducible.

RESULT AND DISCUSSION

Based on the results of the experiment conducted using the API Filter Press, several important findings were obtained regarding the treatment of mud mixtures of Sawdust and Rice Husk. One of the observed results was the average height of the mud cake produced. For the sawdust mixture, the average height of the mud cake formed was around 0.6 cm, while for the rice husk mixture, the average height of the mud cake produced was slightly lower, around 0.5 cm. This difference indicates a variation in the physical properties of the mud caused by the composition of the materials used, with sawdust tending to produce a thicker mud cake compared to rice husk.

Furthermore, the observation of the pH values of the filtrate water produced also showed a significant difference between the two mixtures. In the rice husk mud mixture, the pH of the filtrate water ranged from 7 to 8, which is considered neutral to slightly alkaline. This indicates that the

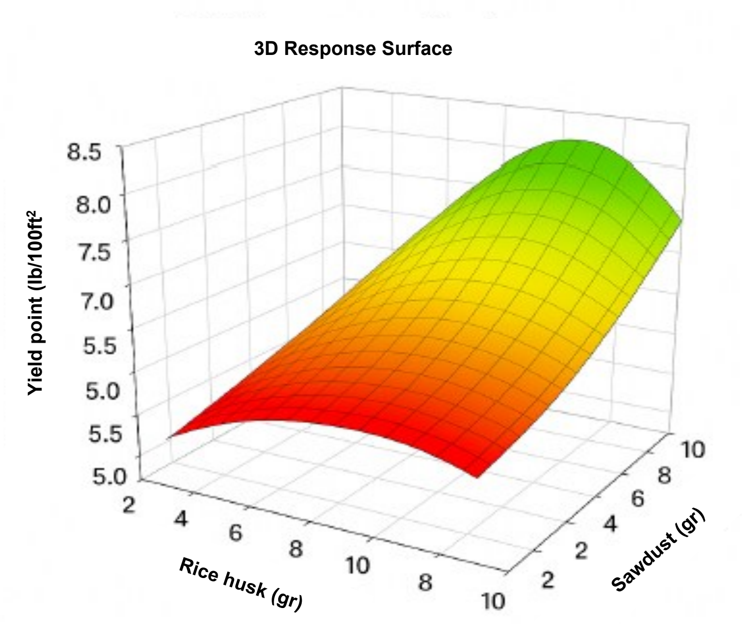

Figure 3. Response surface yield point against rice husk and sawdust

ANOVA for Linear model

Response | Linear ·ot

Source	Sum of Squares	df	Mean Square	F Value	P Value	
Model	1532.45	1	1350.69	11.90	0.0901	significant
Linear	1532.35	1	1328.16	11.90	0.0001	
A:Solutant	739.26	2	38.35			
B:Time	2190.83	1	350.53	5.21	0.1447	significant
Residual	59.35	2	24.77			
Lack of Fit	505.00	22				
Pure Error	1537.33	29				

Factor coding is (-1,0,+1) Partial

The Model F-value of 112.00 implies the model is significant. There is only a 0.01% chance that a "Model F-value" this large could occur due to noise.

Values of Prob > F less than 0.05000 indicate model terms are significant. In this case A and B are significant model terms. Values greater than 0.1000 indicate the terms are not significant, relative to the pure error. Ut Fit. F-value this large could occur due to noise. A non-significant lack of fit is good – it means the model fit, this model is shown in coded factors.

Fit Statistics

R²	0.9788	Adjusted R²	6.953	-0.0001
Adjusted R²	0.9675	Predicted R²	0.9351	863
PRESS	0.2750	34.2387	64.2387	1,000
Adeq Precision	34.2387	34.2388	2.2321	1,000
P Value	+0.0001	0.301	0.0001	1,000

Fit Statistics

	R²	Adjusted R²	Predicted R²
R²	0.9788	0.9675	0.9351
Adjusted R²	0.9675	0.9957	0.2750
PRESS	0.9351	2.2720	34.2387
Adeq Precision	34.2387		< 0.0001

The Predicted R² of 0.9331 is in reasonable agreement with the Adjusted R² of 0.9615. Adequate Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 34.239 indicates an adequate signal. This model can be used to navigate the design space.

Coefficients | Coded Equation | Actual Equation

Coefficients in Terms of Coded Factors

Factor	Coefficient	Standard Error	95% CI Low	VIF
Intercept	27.7500	0.380	46.921	1.000
A:Solutant	14.5000	0.680	2.070	1,000
B:Time	-3.6500	0.680	2.721	1.000

The final equation expressing the expected change n response per change in cach in the for noded vritie. The MRE parisnen uplytion factori.s.0.9. of 1.000 indicating ho municadimeerity. The equation is shown in coded factors. D""– F21 = 1-/ = 0.0001.

Figure 4. Analysis of variance (ANOVA) output

filtration process with rice husk produces filtrate water closer to a neutral condition, which may be safer for further applications. On the other hand, in the sawdust mud mixture, the pH of the filtrate water was higher, ranging from 9 to 10, indicating a more alkaline nature. This condition may suggest an increase in the base content in the filtrate water derived from Sawdust, which could affect the characteristics or stability of the water. Additionally, observations of the filtrate water showed that the filtrate produced from the Sawdust mixture was more turbid and thicker compared to the filtrate produced from the rice husk mixture. This may be attributed to the nature of the sawdust particles, which are more difficult to filter or contain more dissolved substances that cannot be fully separated by the tool. In contrast, rice husk produces a clearer filtrate, indicating that its particles are easier to separate or filter during the process (Figure 3).

This study investigates the impact of alternative materials, specifically rice husk and Figure 4 describes the Analysis of variance (ANOVA) output and model statistics for the linear viscosity model generated using Design Expert. The ANOVA table shows that the overall model is statistically significant ($p < 0.05$), indicating that the selected factors meaningfully affect the viscosity response. Among the individual factors, rice husk (Factor A) exhibits a significant linear effect, whereas sawdust (Factor B) and caustic soda (Factor C) show non-significant contributions within the tested range. The Fit Statistics panel demonstrates strong model adequacy, with an Adjusted R^2 and Predicted R^2 that are in reasonable agreement, confirming that the model reliably predicts experimental trends. The coefficients table further highlights the magnitude and direction of each factor's influence, showing that rice husk contributes positively to viscosity, consistent with the one-factor plot results. Overall, this figure summarizes the statistical validation supporting the linear model and confirms the robustness of the experimental design, reinforcing that rice husk is the primary determinant affecting viscosity in the formulated drilling mud system.

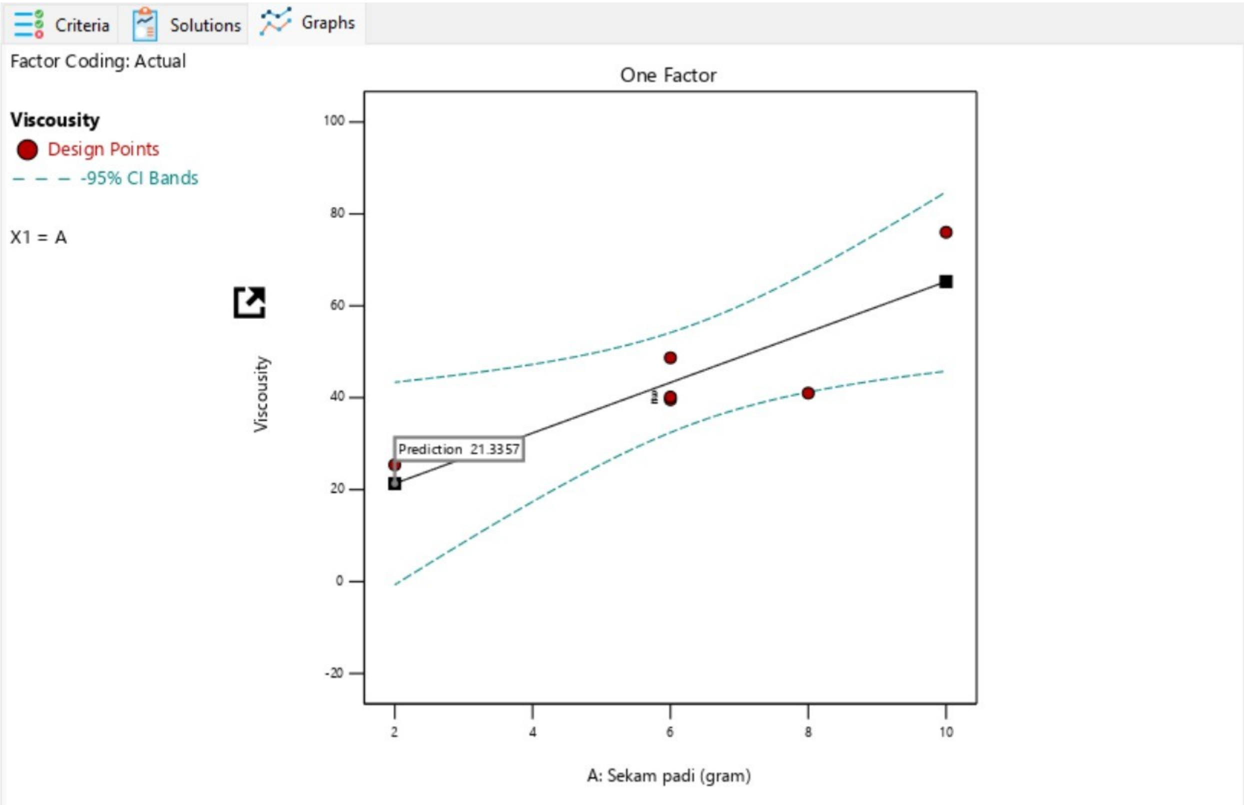

Figure 5. One factor plot – viscosity vs rice husk

Figure 5 explains One-factor plot showing the effect of rice husk (Factor A) on the viscosity of the drilling mud as generated by the Design Expert model. The plot indicates a generally linear increase in viscosity with higher rice husk concentrations, as reflected by the fitted prediction line. The red points represent the actual experimental data, while the blue dashed curves denote the 95% confidence bands of the model prediction. The proximity of the data points to the model line illustrates the adequacy of the model across the tested factor range. These results confirm that rice husk exerts a significant linear influence on viscosity, consistent with the ANOVA findings. Moreover, the upward trend suggests that the cellulose-rich structure of rice husk effectively enhances the internal friction and particle-to-particle interactions within the mud system, resulting in a measurable increase in flow resistance.

The narrow spacing between the confidence bands also indicates that the model provides a reliable prediction with relatively low variability, reinforcing the robustness of the statistical relationship between rice husk concentration and viscosity. This behavior further supports the hypothesis that rice husk acts as a natural rheology modifier capable of improving the consistency of water-based drilling fluids without the need for synthetic polymers.

Next, figure 6 depicts the one-factor plot for viscosity versus sawdust, confirming the positive correlation between sawdust content and the mud's viscosity profile.

This thickening behavior can be advantageous in scenarios requiring enhanced carrying capacity for cuttings, but it also needs careful optimization to avoid excessive water loss and reduced yield point. A clear increase in viscosity was observed as the sawdust concentration increased, which is consistent with the prediction that the coarse particle structure of sawdust enhances internal friction and strengthens the mud network. For plastic viscosity, a non-linear behavior was evident: it increased to a peak at moderate concentrations of sawdust, followed by a decline, and then increased again at higher levels. This suggests that the effect of sawdust on plastic

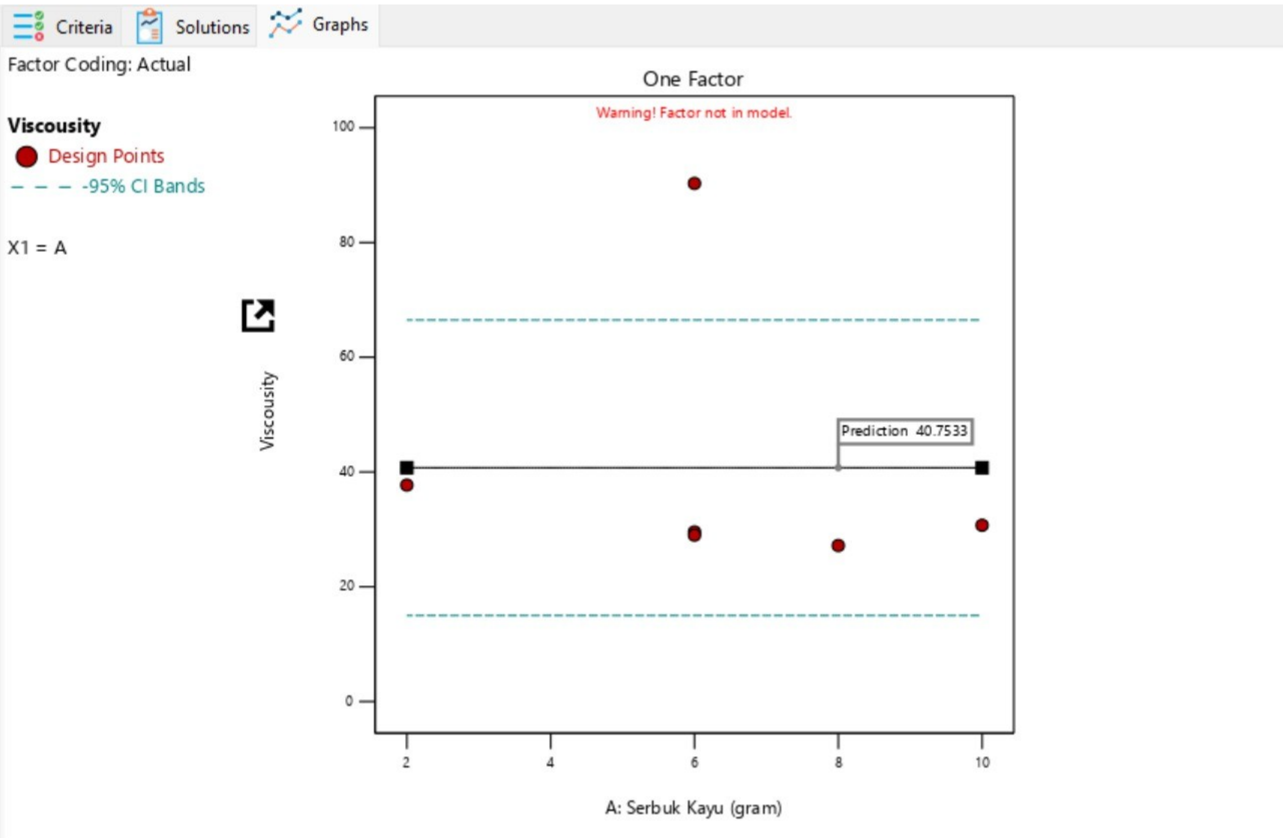

Figure 6. One factor plot – viscosity vs sawdust

viscosity is complex, likely due to particle-particle interactions and the way sawdust particles distribute within the mixture.

The yield point showed a noticeable decrease with increasing sawdust, indicating that excessive sawdust may reduce the mud's structural stiffness and make it more prone to deformation under stress. Gel strength measurements, particularly within the first 10 seconds, revealed a reduction with sawdust addition, suggesting that sawdust hinders the formation of a robust gel structure in the short term. However, water retention improved slightly, as sawdust helped bind water within the mixture and slowed down evaporation, although at higher concentrations it could also lead to increased water loss due to void formation in the mud structure.

Figure 7 illustrates the relationship between caustic soda (NaOH) dosage and the resulting pH value of the drilling mud. The graph shows a consistent and progressive increase in pH as the NaOH concentration increases from 0 to 2 grams, demonstrating the strong alkaline behavior of caustic soda within the mud system. This upward trend indicates that even small increments of NaOH are effective in shifting the mud chemistry toward an alkaline state, which is essential for achieving the recommended operational pH range of 9–11. Maintaining this alkaline condition improves the dispersion of bentonite clay particles, enhances rheological stability, and helps prevent the flocculation or aggregation of solids within the fluid.

Furthermore, the observed trend suggests predictable and controllable pH adjustment, enabling mud engineers to regulate chemical conditions with precision during formulation and field applications. A higher pH also contributes to corrosion inhibition on drilling equipment by reducing the solubility of corrosive ions in the fluid. The smooth curvature of the plotted line reflects the absence of abrupt chemical reactions or buffering effects, indicating that NaOH interacts uniformly with the mud matrix. Overall, this figure demonstrates the critical role of caustic soda as a pH modifier and highlights its importance in maintaining the chemical stability and operational performance of water-based drilling muds.

Figure 8 intepreets a series of graphs illustrating the effects of rice husk and sawdust additions on the rheological properties of the drilling mud, which align with the statistical trends identified through the RSM optimization and ANOVA significance analysis. The Yield Point graph shows that rice husk produces a steady and progressive increase in YP values, indicating a consistent strengthening of the internal mud structure. This behavior corresponds with the ANOVA results, which identify rice husk as a statistically significant linear factor in the model. In contrast,

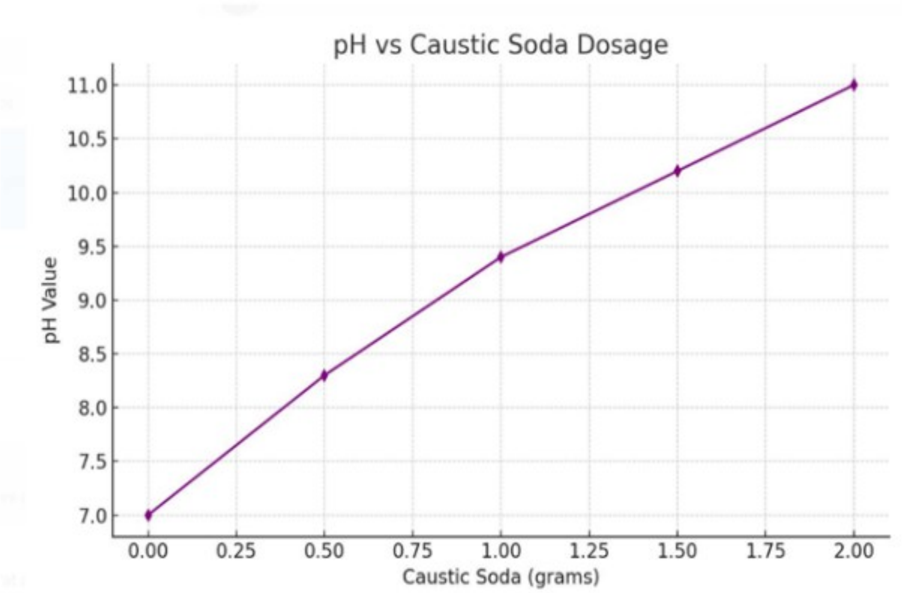

Figure 7. The effect of caustic soda on pH value

sawdust exhibits a highly fluctuating response with a sharp peak at lower concentrations followed by a decline, reflecting the non-linear behavior captured in the RSM model and suggesting strong interaction effects with other variables in the system.

The Plastic Viscosity graph also demonstrates that rice husk contributes to a more predictable and gradual increase in viscosity, consistent with the positive linear contribution predicted by the model. Sawdust, however, displays pronounced variations rising sharply at certain concentrations and dropping at others mirroring its lower statistical significance and stronger non-linear effects in the ANOVA output. For Gel Strength at 10 minutes, rice husk again shows a stable upward trend, supporting the model's indication that rice husk improves the long-term structural stability of the mud under static conditions. Sawdust, on the other hand, shows an initial strengthening effect but subsequently decreases at mid-range concentrations before rising again, reflecting instability in gel formation and a weak linear contribution within the RSM framework. A similar pattern is observed in the Gel Strength at 10 seconds graph: sawdust produces an early spike at low concentrations but loses consistency at higher levels, whereas rice husk maintains a more linear and predictable increase aligned with the high model fit (R^2) between experimental and predicted values.

Overall, the graphs in Figure 8 reinforce the statistical findings that rice husk is the most stable and influential factor across the rheological parameters. Thus, the sawdust exhibits complex, non-linear behavior with variable effects. These outcomes suggest that any optimized drilling fluid formulation should account for the strong linear contribution of rice husk and the sensitivity of sawdust's response to concentration changes in order to achieve a balanced and operationally reliable rheological profile.

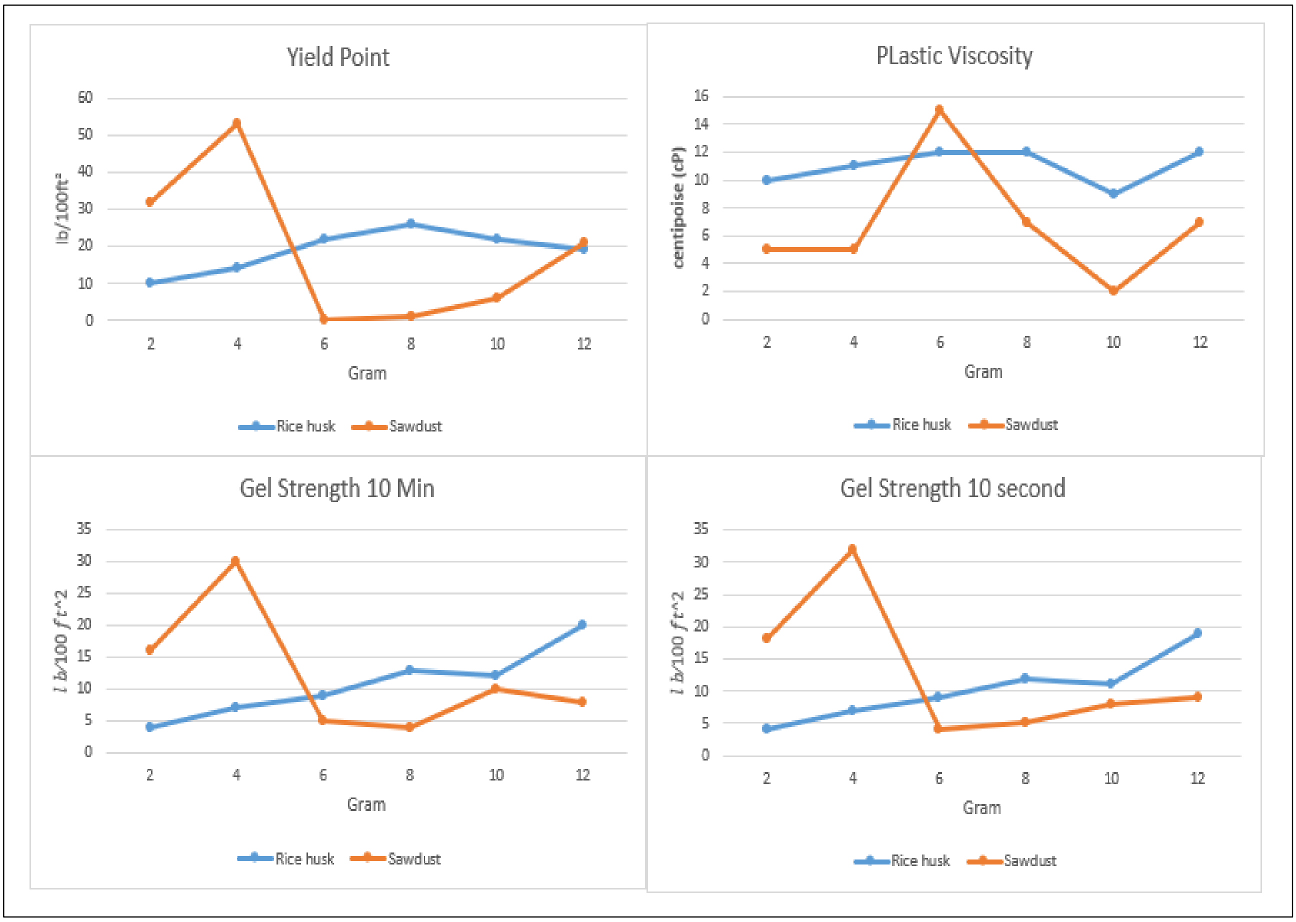

Figure 8. The effect of rice husk and sawdust addition on rheological properties of drilling Mud

CONCLUSION

The findings of this study demonstrate that rice husk and sawdust are viable raw materials for producing cellulose-based additives with rheological properties suitable for drilling mud formulation. Both materials enhance key parameters such as yield point, gel strength, and filtration loss. Their utilization not only provides a sustainable alternative to synthetic polymers like carboxy methyl cellulose (CMC) but also aligns with the principles of waste valorization by converting agricultural and industrial residues into high-value drilling fluid additives.

The results from the optimization process show that the most effective composition for mud stability is achieved with the combination of 6 grams of rice husk and 6 grams of sawdust. This composition yields the highest performance in terms of yield point, reaching 8.1 lb/100 ft², while maintaining favorable gel strength and filtration loss characteristics. This optimal ratio demonstrates the synergistic effect of combining fine-particle rice husk with fibrous sawdust to achieve balanced rheological behavior.

The gradual addition of caustic soda (NaOH) was found to be an effective pH control mechanism, increasing the mud's pH to an optimal value of 10.2. Maintaining this alkaline condition contributes to improved chemical stability of the mud, enhances clay particle dispersion, and reduces filtration loss, all of which are essential for sustaining the operational efficiency and integrity of drilling fluids under varying field conditions.

The use of Response Surface Methodology (RSM) proved to be a reliable approach for modelling the statistical relationships among the variables and identifying the optimal formulation of drilling mud additives. RSM facilitated a deeper understanding of how each additive affects mud performance, enabling the development of a cost-effective, environmentally friendly, and technically robust drilling fluid formulation. These findings provide a valuable foundation for future applications of natural additive-based mud systems in the oil and gas industry.

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GLOSSARY OF TERMS

Symbol	Definition	Unit
RSM	Response Surface Methodology	
NaOH	Natrium Hidroksida	
CMC	Carboxy Methyl Cellulose	
YP	Yield Point	(lb/100 ft)
PV	Plastic Viscosity	(CP)

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