Malaysian Journal of Chemistry, 2026, Vol. 28(1), 170-182
(Special Issue: *3rd International Conference on Industry-Academia Initiatives in Biotechnology & Chemistry, iCIABC2025*)

Optimization of Saponin Extraction from Coconut Husk using Design of Experiments (DOE) for Enhanced Water-Based Mud (WBM) Performance

Norida Binti Ridzuan* and Chiew Kah Heng
Faculty of Chemical and Process Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Lebuh Persiaran Tun Khalil Yaakob, Gambang 26300 Kuantan, Pahang, Malaysia
*Corresponding author (e-mail: norida@umpsa.edu.my)

This study explores coconut husk an abundant agricultural waste in Malaysia as a sustainable source of saponins for enhancing water-based mud (WBM) performance. Saponins were extracted using Soxhlet extraction and optimized through Design of Experiments (DOE) considering extraction time, sample mass and ethanol concentration. Gading coconut husk produced the highest saponin yield as confirmed by foam tests. ANOVA results showed that sample mass and ethanol concentration significantly affected extraction efficiency ($p < 0.05$) while extraction time had minimal impact. Fourier Transform Infrared Spectroscopy (FTIR) and Gas Chromatography-Mass Spectrometry (GC-MS) confirmed the presence of saponin functional groups and 5-dihydroxy-6 methyl 4 H-Pyran-4-One (DDMP) glycosides. When incorporated into WBM, both extracted and commercial saponins improved rheological and lubricity properties. Although commercial saponins yielded higher viscosity and gel strength, the coconut husk-derived saponins provided better fluid loss control and formed thinner mud cakes indicating strong compatibility with WBM systems. These findings highlight coconut husk as a promising eco-friendly surfactant source, offering an effective alternative to synthetic additives. This work supports the valorization of agricultural waste and promotes greener drilling fluid technologies. Future studies should refine purification methods and investigate synergistic combinations with nanoparticles or polymers to further enhance WBM performance.

Keywords: Water-based muds, coconut husk, saponins; surfactant, extraction

Received: June 2025; Accepted: November 2025

Drilling mud is renowned for lubricating drill bits and transporting drill cuttings to the surface during hydrocarbon extraction in the oil and gas industry. It serves a multifaceted purpose beyond mere lubrication. When drilling a deep hole, challenges such as rise in temperature and atmospheric pressure, difficulty in maintaining the straightness of the drill hole, heat generated in equipment causing breakdown are common [1]. To make deep hole drilling efficient and safe, drilling mud has been introduced to improve the sustainability of the drilling method. Drilling muds can be separated into oil-based muds (OBM) and water-based mud (WBM). Both drilling muds have their own properties in terms of rheology and physical and chemical properties [2].

Many challenges are encountered when drilling a well in the oil and gas industry. Over the past decades, the average depth of drilled wells has increased significantly from approximately 3,635 ft in 1949 to about 5,964 ft in 2008 mirroring the depletion of shallow reservoirs and the shift toward deeper formations [3]. Technological advancements have certainly enabled this progress. However, as the depth of the well increases, friction between the drill bit and formation rock becomes a significant issue during hydrocarbon extraction. The high temperature generated from drilling activity and interaction with formation rock can lead to heat-induced stress on the drill pipe. This increases the risk of mechanical failure, particularly due to torque accumulation during deep drilling [4, 5]. Such conditions necessitate the use of advanced drilling fluids with robust thermal and rheological stability to ensure safe and effective operations.

Another critical concern in drilling is wellbore instability, where the wellbore wall fails to maintain its structural integrity, leading to collapse, caving, and sand production. Wellbore instability can result in operational delays, increased maintenance costs, and even blowouts. Drilling fluids play a crucial role in maintaining wellbore stability by exerting hydrostatic pressure and preventing formation fluid influx. WBMs are often preferred due to their ability to fixate clay in shale formations, thereby enhancing wellbore stability [6]. However, conventional chemical inhibitors used in WBMs may pose environmental and health risks. In response, the incorporation of biodegradable additives such as plant-derived surfactants or natural polymers has emerged as a promising alternative, offering comparable fluid

†Paper presented at the 3rd International Conference on Industry-Academia Initiatives in Biotechnology & Chemistry

loss control to potassium-based inhibitors while improving environmental sustainability [7].

In Malaysia, agricultural waste poses a pressing challenge due to inadequate management practices, leading to environmental degradation and resource wastage. With the country's thriving agricultural sector, including palm oil production, coconut husk, and other agricultural activities, the accumulation of waste such as palm oil biomass and fruit peels has become a significant concern. For instance, coconut husk waste from smallholders in areas like Bagan Datuk has been identified as a serious environmental and economic issue, with studies calling for sustainable management solutions such as composting and product upcycling [8]. Similarly, palm oil by-products such as empty fruit bunches (EFBs), palm kernel shells (PKS), and effluent are increasingly being converted into value-added materials like compost, biochar, and biogas [9]. Insufficient waste management not only contributes to pollution and soil degradation but also hinders the potential for resource recovery and value creation. Addressing these issues is crucial to promote sustainable development and mitigate environmental impacts in Malaysia's agricultural landscape.

With all the concern faces by the WBM, thus this research project aims to extract saponin from discarded coconut husk waste and explore its potential in enhancing WBM performance. The primary objectives are to optimize the saponin extraction process by examining various operational conditions, maximize the yield of saponin using the Design of Experiments (DOE) method, and thoroughly evaluate the resulting WBM's performance and stability through comprehensive mud testing. To achieve these goals, the study will begin by screening four types of coconut husks Matag, Hijau, Pandan, and Gading to identify the most suitable source of saponin.

EXPERIMENTAL

Chemicals and Materials

Table 1 lists the materials used in this study. Various coconut husk samples commonly found in Malaysia specifically the Hijau, Pandan, Matag, and Gading varieties were utilized. These husks were collected from local restaurants and fruit stall vendors. The samples were then subjected to phytochemical screening to identify the variety with the highest saponin content. Saponins were extracted from the selected coconut husks using the Soxhlet extraction method with 99% denatured ethanol as the solvent. A subsequent re-extraction was performed using n-butanol with a filter funnel to further purify the saponins. Following the extraction process, a WBM rheology test was conducted. Prior to testing, the WBM was formulated using bentonite, barite and potassium formate (formic acid potassium salt) as the base materials.

Sample Preparations

The husks were thoroughly washed with running water to remove any dirt and debris, then air-dried for 24 hrs. Once dried, they were cut into small pieces and ground into a fine powder using a heavy-duty grinder, achieving an 80-mesh particle size. The resulting powder was stored in sealed plastic bags and refrigerated at 4°C to preserve the saponin content.

Screening of Phytochemical Compound (Saponin Identity Test)

A 50 g sample of coconut husk was mixed with 250 mL of distilled water and boiled for 10 min at 70°C. The resulting mixture was filtered and 2 mL of the filtrate was transferred into a test tube. The solution was then shaken for 2 min and the foam level was observed after 5 min. This procedure was repeated for each husk variety, and the sample that produced the highest foam level was selected for subsequent saponin extraction.

Table 1. List of Materials

Materials	Function
Hijau Coconut Husk	Raw samples used for phytochemical screening
Pandan Coconut Husk	
Matag Coconut Husk	
Gading Coconut Husk	
99% Denatured Ethanol	Extraction of saponins using soxhlet method
n-Butanol	Re extraction process of saponins using filter funner.
Bentonite Powder	Formation of WBM
Barite	Formation of WBM

Table 2. The values for lower (−) and higher (+) levels of the factors investigated in factorial design.

Variables	Values	
	Low	Higher
Time of Extraction (hrs)	2	6
Mass of Sample (g)	10	30
Concentration of Denatured Ethanol (wt%)	70	90

Extraction of Saponin and Sample Purifications

Coconut husk powder was first defatted to remove non-polar components. A fixed amount of sample was placed into a Soxhlet thimble and extracted with 300 mL of n-hexane for 6 hrs in a fume chamber. Following defatting, saponin extraction was performed using the Soxhlet method based on the experimental design generated by Design Expert software (version 7.1.6). The key variables included extraction time, temperature, and ethanol concentration. For each run, 400 mL of 99% denatured ethanol was used, and the process was carried out at 90°C using a heating mantle. Upon completion, the ethanol was removed from the extract using an IKA RV8 rotary evaporator at 50°C and 100 RPM, leaving behind a concentrated saponin solution.

To purify the extract, n-butanol was added to the solution in a 3:1 ratio. The mixture was shaken three times and allowed to settle for 10 min to form two distinct layers. The lower layer containing impurities was removed, while the upper saponin-rich layer was retained. The butanol in the retained layer was removed using the rotary evaporator set at 55°C and 100 rpm until a dark, concentrated crude saponin sample was obtained. Finally, the crude saponin was dried in a Memmert hot air oven at 45°C until completely dry. The final product was stored for subsequent analysis.

Design of Experiment (DOE)

The Soxhlet extraction was performed according to the experimental run recommended by DOE, version 7.1.6. Table 2 outlines the variables involved in the experiment. Three key variables were considered: extraction time, temperature, and ethanol concentration.

Characterizations for the Extracted Saponins

Fourier Transform Infrared Spectroscopy (FTIR) Analysis

FTIR analysis was conducted using a Nicolet iS20 FTIR Spectrometer equipped with OMNIC Spectra software and a diamond crystal plate, capable of analyzing particles from 5 mm to 500 µm at a resolution of 0.25 cm^{-1}. A 5 g sample was placed on the cleaned crystal plate, scanned 32 times, and the transmittance spectrum was recorded to identify functional groups [12].

Gas Chromatography-Mass Spectrometry (GC-MS) Analysis

GC-MS was performed using an Agilent 7890A/ 5975C system with a DB-1ms column. A 1 g saponin sample was diluted in 1% methanol and injected (1 µL) into the system. The GC oven was programmed from 100°C to 300°C, with helium as the carrier gas at 1.5 mL/min. The sample was analyzed in full scan mode, and compounds were identified by comparing mass spectra to the NIST 2011 library

Preparation of Water-Based Mud (WBM)

WBM was prepared following API standards using high-shear mixing. A total volume of 400 mL was formulated by first adding 25.0 g of bentonite powder to water and mixing for 10 min. Then, 23.5 g of barite was added and mixed for another 5 min. Commercial or extracted saponin (0.15 g, 0.25 g and 0.35 g) was gradually introduced in three portions every 5 min during the final mixing stage. The total mixing time was 20 min. Mud density was monitored and adjusted as needed to minimize free water and ensure proper rheological performance [1].

WBM Performance Testing

Rheology Analysis

The mud sample is well mixed and free of air bubbles. Pour the sample into the viscometer cup. Then, take readings at the following speeds: 3 rpm, 6 rpm, 100 rpm, 200 rpm, 300 rpm, and 600 rpm. PV is calculated by subtracting the 300 rpm reading from the 600 rpm reading while the AV is determined by dividing the 600 rpm reading by 2. For YP, the value of PV is subtracted from the 300 rpm reading and lastly the measurement of Gel Strength determined by recording the 3 rpm reading at the start and after 10 min.

Muds Weight Test

The calibration of the mud weight is conducted by using a Fann model 140 mud balance. Before the start of experiment, the mud cup is checked and cleaned. Once the cleaning is done, the mud cup will be fill with WBM until it reaches the maximum lines. After the mud cup is fill, the lid is used to close the cup. It is then observed that the WBM will overflown the top lid of the mud cup. This indicates that the volume of the WBM is enough to conduct the experiment. If not, do fill the mud cup with WBM. After that, placed the whole balance arm on the top of fulcrum to balance the level glass. Observed the level glass until it reaches equilibrium. Once the level glass reach equilibrium, the data of the WBM weight is recorded.

Lubricity Test

A Qingdao Chuangmeng EP-B lubricity tester was used, where the WBM was placed in a sample cup and subjected to a controlled torque of 150 N.m for 5 min. The resulting lubricity factor, representing the friction, was then recorded. After each test, the lubricity tester was stopped, the applied torque was released, and the sample cup was removed and cleaned. The entire process, including a 5 min calibration period, was repeated for subsequent tests.

Filter Pressed Muds Test

The filter press test was conducted using a differential pressure of 80 psi (551 kPa) at room temperature (26°C) for 30 min. Hardened filter paper served as the filtration medium. The amount of fluid loss was measured to evaluate the filtration rate of the WBM. After the test, the mud cake formed on the filter paper was examined, and its thickness was measured. Both fluid loss and mud cake data were used to assess the WBM's effectiveness in controlling fluid invasion.

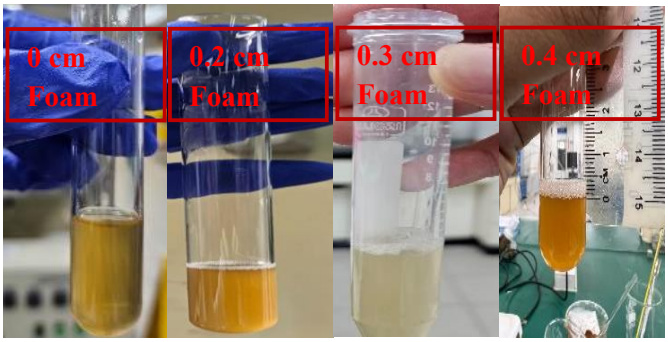


Figure 1. Phytochemical Test Foam results of (a) Hijau, (b) Pandan, (c) Matag, and (d) Gading.

Table 3. Results of saponin yield gain from DOE

Std	Run	Factor A: Time of Extractions, (hr)	Factor B: Mass of Sample, (g)	Factor C: Concentration of Denatured Ethanol, (g)	Response 1: Yield of Saponins, (g)
6	1	6.00	10.00	90.00	0.55
3	2	2.00	30.00	70.00	0.94
2	3	6.00	10.00	70.00	0.49
1	4	2.00	10.00	70.00	0.04
8	5	6.00	30.00	90.00	1.95
7	6	2.00	30.00	90.00	2.03
4	7	6.00	30.00	70.00	0.68
5	8	2.00	10.00	90.00	0.17

RESULTS AND DISCUSSION

Phytochemical Test on Saponin Identity

Table 3 presents the foam height results from the phytochemical screening used to identify saponin content in different coconut husk powders. Foam formation indicates the presence of saponins due to their natural surfactant properties. Among the four samples tested, Gading coconut husk powder recorded the highest foam height at 0.4 cm, suggesting it contains the highest concentration of saponins. Matag and Pandan husks showed moderate foam heights of 0.3 cm and 0.2 cm, respectively, indicating a lower but notable presence of saponins. In contrast, Hijau coconut husk powder produced no foam (0.0 cm), suggesting little to no saponin content. These results, supported visually by Figure 1 (a)–(b), highlight Gading husk as the most suitable candidate for further saponin extraction. The differences in foam height may be attributed to the natural variation in coconut types, growing conditions, or maturity. This simple foam test serves as an effective preliminary method to screen saponin-rich samples, consistent with established phytochemical methods where stable foam indicates saponin presence [10].

Saponin Yield from the Extraction

Table 3 shows the results of 8 experiments generated from the software of DesignExpert V7. The highest yield (2.03 g) was achieved with 30 g of powder, 6 hrs extraction time, and 90% ethanol, while the lowest yield (0.04 g) resulted from 10 g of powder, 2 hrs extraction time, and 70% ethanol.

Analysis of Variance (ANOVA)

The experimental data were validated through Analysis of Variance (ANOVA), as presented in Table 4. The statistical analysis confirmed that the model is significant ($p = 0.0059$), indicating that the selected variables have a meaningful influence on the saponin extraction yield. Among the individual factors, sample mass ($p = 0.002$) and ethanol concentration ($p = 0.0057$) contributed significantly to the yield. In contrast, extraction time ($p = 0.1265$) showed no significant effect, suggesting it plays a lesser role in the extraction process. The sum of squares further supports this, with sample mass and ethanol concentration showing values of 2.37 and 0.81, respectively, compared to only 0.03 for extraction time. Additionally, the interaction effects between time and sample mass (AB, $p = 0.0262$), and between sample mass and ethanol concentration (BC, $p = 0.0078$) were also significant. These findings emphasize that optimizing sample mass and ethanol concentration is crucial for improving saponin extraction efficiency. The model equations derived from these findings, provide a predictive tool for optimizing saponin extraction is shown as below:

$$\text{Yield of Saponin} = 0.85125 + 0.17688\,(\text{A}) - 0.13337\,(\text{B}) - 0.022375\,(\text{C}) - 7.3125 \times 10^{-3}\,(\text{AB}) + 2.7125 \times 10^{-3}(\text{BC})$$

Table 4. Analysis of Variance (ANOVA).

Source	Sum of Squares	df	Mean Square	F Value	p-value	
Model	3.97	5	0.79	170.2	0.0059	Significant
A - Time of Extraction	0.03	1	0.03	6.44	0.1265	
B - Mass of Sample	2.37	1	2.37	507.31	0.002	
C - Concentration of Ethanol	0.81	1	0.81	174.33	0.0057	
AB	0.17	1	0.17	36.7	0.0262	
BC	0.59	1	0.59	126.24	0.0078	
Residual	9.33E-03	2	4.66E-03	---	---	---
Cor Total	3.98	7	---	---	---	---

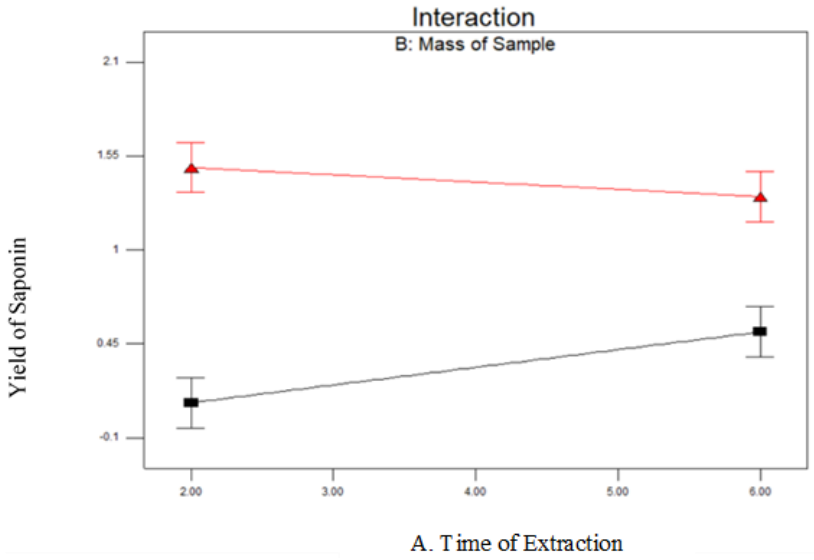


Figure 2. Interactions graph between factors on saponin yield with mass of sample and time of extraction.

Main Effect Analysis on the Amount of Saponin Yield

The interaction plot in Figure 2 indicates that saponin yield increases with longer extraction time at low sample mass, likely due to improved solvent penetration and mass transfer efficiency. However, at high sample mass, the yield slightly decreases over time, possibly due to solvent saturation or limited diffusion, which reduces extraction efficiency. This suggests that while longer extraction time benefits lower sample amounts, it may not enhance yield at higher masses. The crossing lines confirm a significant interaction between extraction time and sample mass, emphasizing the need to optimize both parameters simultaneously for efficient and effective saponin extraction [7, 11].

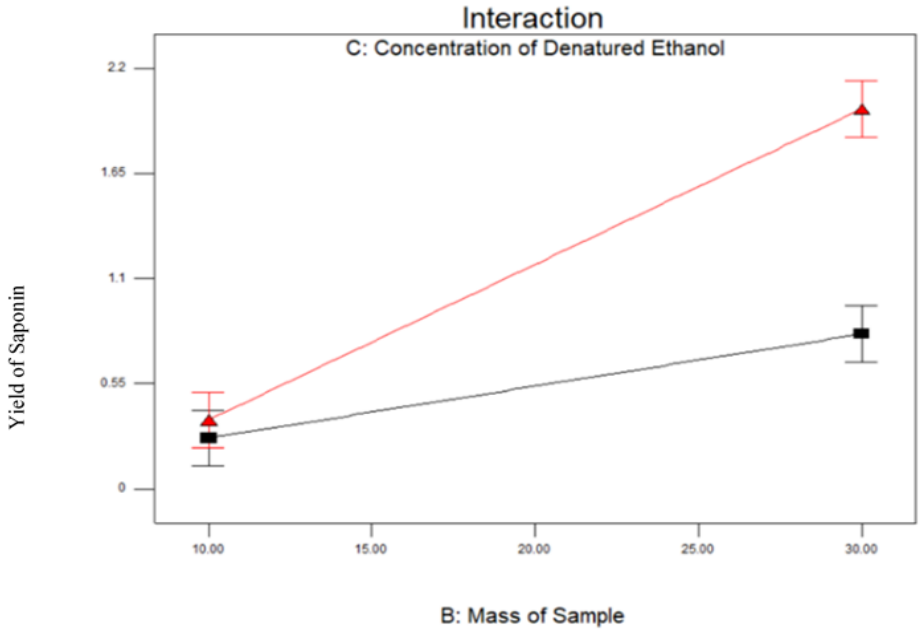


Figure 3. Interactions graph between factors on saponin yield with mass of sample and concentration of denatured ethanol.

The interaction plot in Figure 3 shows the combined effect of sample mass and ethanol concentration on saponin yield. As both sample mass and ethanol concentration increase, saponin yield rises significantly—more so with higher ethanol concentration (red line). This trend indicates that 99% denatured ethanol is more effective in extracting saponins, especially at higher sample masses. The likely reason is that ethanol enhances cell wall permeability and solubilizes saponins more efficiently, leading to greater compound release. The sharp increase at higher mass with 99% ethanol suggests a synergistic effect, where increased solvent strength matches the higher saponin content, optimizing extraction efficiency

Model Validation

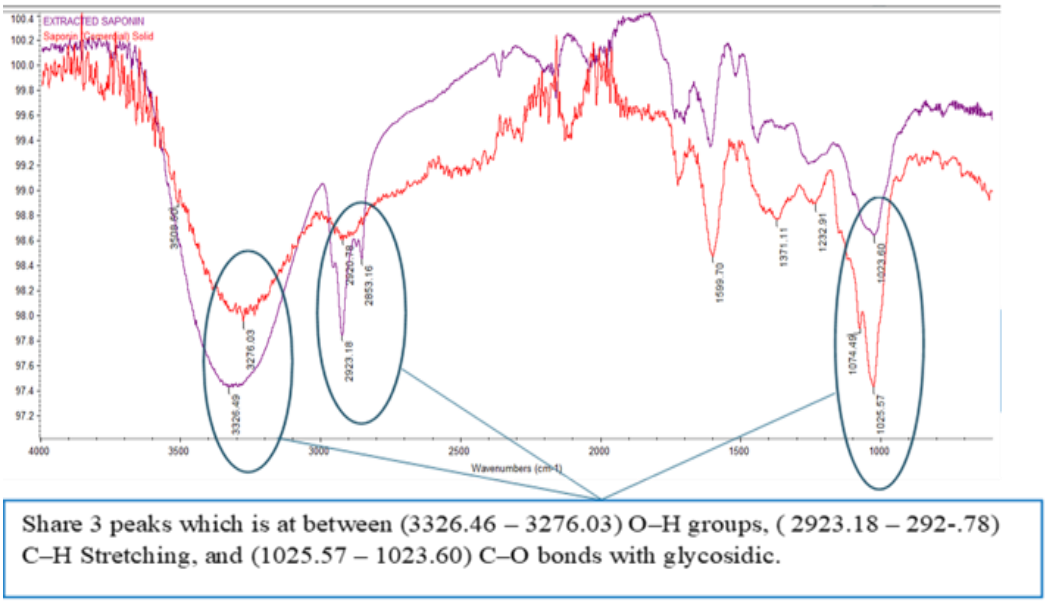
The equation model was validated by comparing the predicted saponin yield with the actual yield obtained from extraction, as shown in Table 5. The validation yielded an accuracy of 122%, confirming the model's reliability for predicting saponin production.

FTIR Analysis on the Extracted Saponin

The results in Figure 4 show the FTIR analysis of extracted saponin (purple line). To further confirm the existence of the saponin, the commercial saponin (red line) is also taken for analysis for cross-references. The results show that both commercial saponin and extracted saponin share a similar graph [12]. Both graphs from research findings share a similar peak graph at 1000 cm $^{-1}$, 2900 – 2400 cm $^{-1}$, and 3600 - 3000 cm $^{-1}$. The results of the FTIR are interpreted as shown in Table 3.5. The commercial and extracted saponins both detected the organic compound of O – H Group, C – H Group, and C – O Glycosides. These results are in tally with the findings from [12] where the same organic compound is also detected in the component. Thus, this has concluded that the extracted compound can be related to saponin. For further confirmation, a GCMS analysis is conducted to determine any related chain and direct linkage to prove the existence of saponins.

Table 5. Validation of Equation Model.

Factors			Yield Predicted,	Yield Obtain,	Accuracy,
A	B	C	g	g	%
2	15	70	0.27	0.22	122



Purple line: extracted saponin Red line: commercial saponin

Figure 4. FTIR absorption spectral data of extracted saponin and commercial saponin.

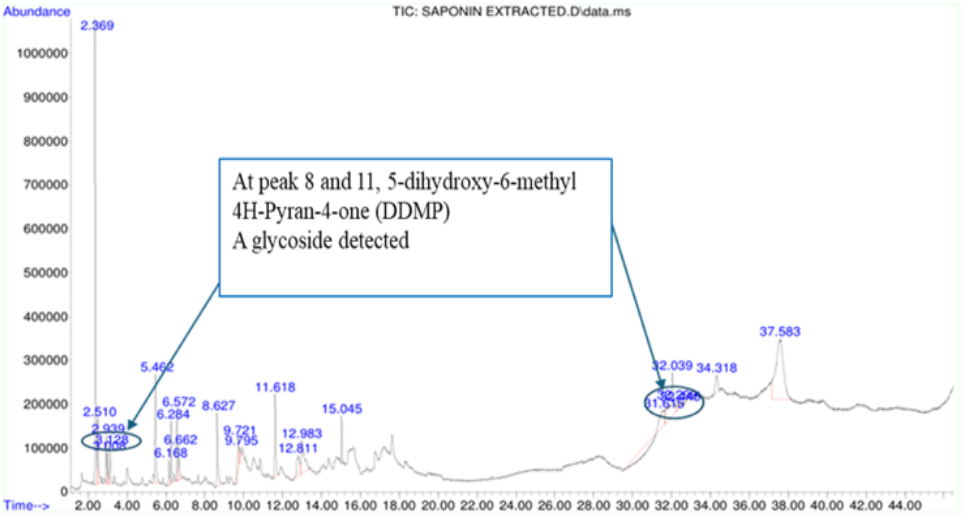


Figure 5. GCMS Analysis for Extracted Saponin.

GCMS Analysis on the Extracted Saponin

The analysis of the extracted saponin has detected 5-dihydroxy-6 methyl 4 H-Pyran-4-One (DDMP) at the retention times of 3 and 32 as shown in Figure 5.

DDMP is identified as one of the major groups of saponins [13]. With the presence of DDMP (2,3-dihydro-3,5-dihydroxy-6-methyl-4H-pyran-4-one) glycosides, this has further clarified the identification of C-O glycosidic linkages through FTIR and the confirmation of DDMP via GCMS provided conclusive evidence that the compound extracted from coconut husk powder is indeed a saponin.

Analysis on the WBM Performance

Effect of Saponin on the WBM on the Rheology

The viscosity behavior of both extracted and commercial saponin was investigated at two shear rates: 300 rpm and 600 rpm as shown in Table 6. At 300 rpm, the base fluid (0 g saponin) exhibited a viscosity of 8.8 cP for both saponin types. With increasing saponin concentration, extracted saponin showed a moderate rise in viscosity from 10.8 to 14.8 cP, while commercial saponin displayed a more significant increase, peaking at 19 cP at 0.35 g. Similarly, at 600 rpm, extracted saponin ranged from 14 to 22.7 cP, whereas commercial saponin increased more steeply from 14 to 28.7 cP. The sharper viscosity increase with commercial saponin indicates higher efficiency in altering fluid rheology, likely due to higher purity or more active surface properties. The results also demonstrate shear-thinning behavior viscosity decreases with increasing shear rate which is beneficial for drilling applications as it allows for easier pumping at high shear rates while maintaining sufficient viscosity at low shear for effective cuttings transport. The relatively lower viscosity of extracted saponin suggests its molecular structure or purity level may limit its performance compared to commercial alternatives. Overall, both saponin types are viable rheology modifiers, but commercial saponin offers superior thickening properties under varying shear conditions.

Table 6. WBM viscosity at 300 rpm and 600 rpm.

Viscosity, cP at 300 rpm				
Type of saponin/Amount of saponin, g	0	0.15	0.25	0.35
Extracted Saponin	8.8	10.8	13.8	14.8
Commercial Saponin	8.8	14.5	15	19
Viscosity, cP at 600 rpm				
Extracted Saponin	14	16.7	21	22.7
Commercial Saponin	14	22	22.7	28.7

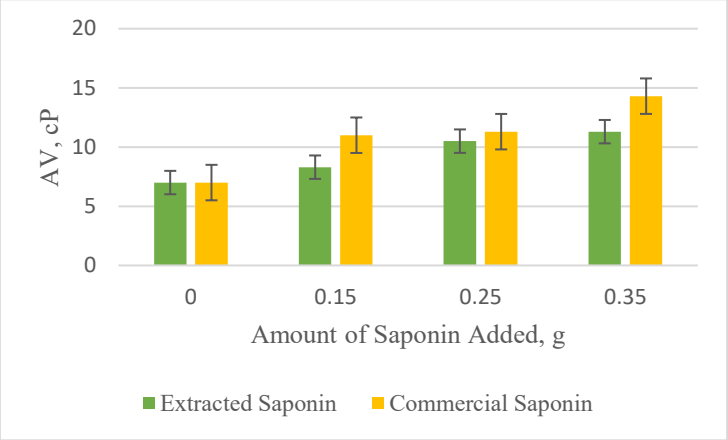


Figure 6. AV vs Amount of Saponin Added.

Effect of Saponin on the WBM on the AV

The importance of AV in rheology testing of WBM is for the measurement of fluid resistance flow at a specific shear rate and temperature. It is used to determine the thickness and consistency of the fluid. Based on Figure 6, both commercial and extracted saponins increased the AV of WBM, with commercial saponin exhibiting a more substantial effect. Commercial saponin increased AV by 7.3 cP, while extracted saponin increased it by 4.3 cP. This aligns with previous research indicating that surfactants increase AV by promoting clay particle flocculation, leading to thicker mud. The higher AV, particularly with commercial saponin, is advantageous for cuttings transport and borehole stability [14].

Effect of Saponin on the WBM on the PV

Figure 7 shows both commercial and extracted saponins increased the plastic viscosity (PV) of WBM with increasing saponin concentration, though commercial saponin had a more pronounced effect. Commercial saponin increased PV by 4.5 cP, while extracted saponin increased it by 2.7 cP, a difference of 1.8 cP. This aligns with previous research suggesting that saponins, due to their hydrophilic and hydrophobic properties, modify water retention in WBM, thereby increasing PV [15].

Effect of Saponin on the WBM on the Gel Strength

Based on the Figure 8, both types of saponins were found to strengthen the mud by increasing its gel strength. However, the commercially produced saponin was more effective at strengthening the mud than the extracted saponin. It showed a larger increase in gel strength in both the initial and ten-minute measurements. This result is consistent with previous research that shows surfactants, substances like saponins, change how particles interact in a mixture, causing them to clump together, which leads to a stronger gel [6].

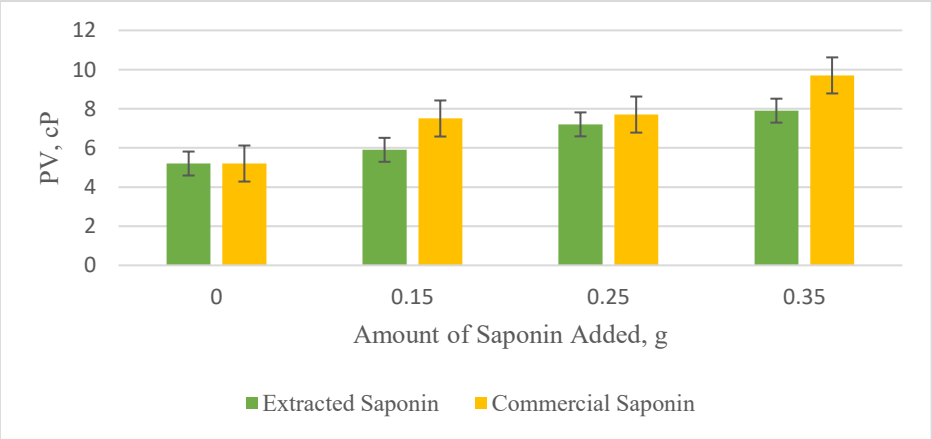


Figure 7. PV vs amount of saponin added.

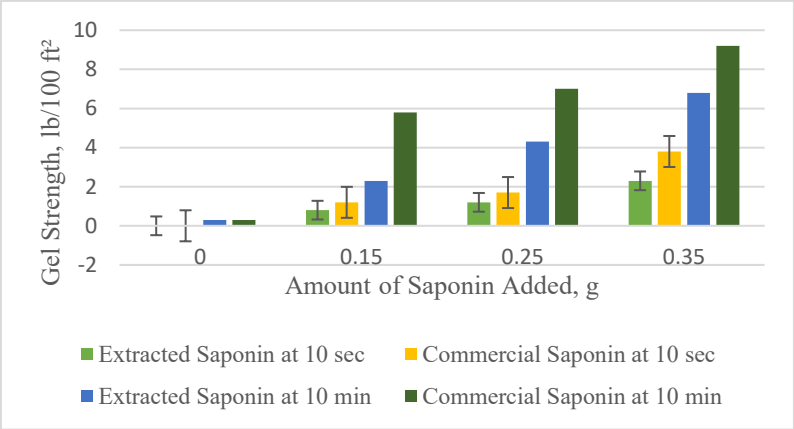


Figure 8. Gel strength vs amount of saponin added.

Effect of Saponin on the WBM on the Mud Weight

The mud weight is crucial in maintaining the wellbore stability by ensure that the pressure of the wellbore is stability. Table 7 shows a slight increasing trend in both commercial and extracted saponin. The data suggest that the addition of saponin has minimal impact on the weight of WBM, as only a small change is observed at 0.35 g of both commercial and extracted saponin, reaching 9.15 PPG. This indicates that saponin, whether commercial or extracted, does not significantly alter the density of WBM within the tested concentration range [16]

Effect of Saponin on the Water Based Mud on the Lubricity

Lubricity is a key characteristic of WBM that plays a vital role in drilling operations as it helps the muds to have ability to reduce friction between the drill string and the wellbore, minimizing torque and drag. As shown in Table 8, the addition of both commercial and extracted saponin reduces this friction, making the mud more slippery. The commercial saponin works slightly better than the extracted one. As more saponin is added, the friction decreases a bit more [11] which emphasize that saponins improve WBM stability but may slightly increase frictional resistance.

Table 7. Mud weight.

Mud Weight, PPG				
Type of saponin/Amount of saponin	0	0.15	0.25	0.35
Extracted Saponin	9.1	9.1	9.15	9.15
Commercial Saponin	9.1	9.1	9.1	9.15

Table 8. Lubricity factor.

Lubricity Factor				
Type of saponin/Amount of saponin, g	0	0.15	0.25	0.35
Extracted Saponin	61.5	53.8	51.1	48.3
Commercial Saponin	61.5	56.3	54.7	53.2

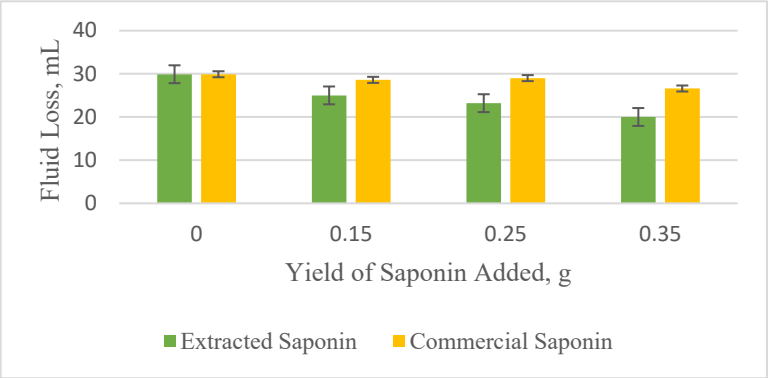


Figure 9. Fluid loss vs amount of saponin.

Effect of Saponin on the WBM on the Fluid Loss

The analysis of filter press mud is associated with the fluid loss behaviour of WBM. Figure 9 present the fluid loss data, demonstrating the impact of different additives on the fluid loss performance of WBMs. Without the addition of additives, the fluid loss reached the highest value of 29.9 mL. This result indicates poor filtrate control and ineffective rheological properties of WBM. However, by adding commercial saponin into WBM, the performance of WBM has moderately reduces the fluid loss ranging from 25 mL to 26.6 mL, demonstrating improved but limited fluid retention capacity. The result improved when the extracted saponin is mix into WBM as the addictive performs slightly better, with fluid loss values ranging from 23.2 mL to 26.1 mL, likely due to better compatibility with the WBM structure.

Effect of Saponin on the WBM on the Mudcake Thickness

For the mud cakes formation by the WBM has been summarized in Figure 10. The drilling mud without any additives created the thickest mud cake proving it weak fluid filtration properties. Adding commercial saponin reduced the thickness of the mud cake, indicating some improvement. Extracted saponin also reduced the mud cake thickness, performing similarly. This demonstrates that saponins, acting as surfactants, help stabilize the drilling fluid and reduce fluid loss. Combining saponins with nanoparticles can further enhance these effects as supported by previous research [17-18].

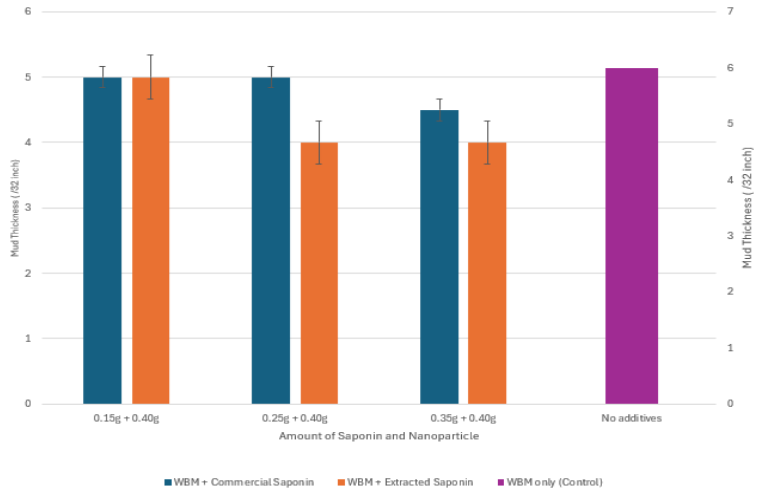


Figure 10. Mud cake thickness vs amount of saponin.

CONCLUSION

This study successfully demonstrated the feasibility of extracting saponins from coconut husk waste and utilizing them as a sustainable additive in water-based drilling muds. The DOE approach revealed that sample mass and ethanol concentration significantly influence saponin yield, with the optimal conditions yielding 2.03 g of saponin. Characterization using FTIR and GC-MS confirmed the identity and purity of the extracted compound. When incorporated into WBM formulations, the extracted saponin enhanced key mud properties such as viscosity, gel strength, and fluid loss control. Compared to commercial saponins, the extracted variant offered comparable lubricity and superior performance in reducing fluid loss and mud cake thickness, suggesting better structural compatibility with the mud matrix. While commercial saponin demonstrated higher viscosity improvements, the environmentally friendly and cost-effective nature of extracted saponins from agricultural waste makes them a viable alternative for drilling operations. This work supports the valorization of biomass waste and contributes to more sustainable drilling practices. Further refinement of extraction and purification methods could improve saponin activity and broaden its application across various wellbore conditions.

ACKNOWLEDGEMENTS

This study was supported by the Ministry of Higher Education (FRGS/1/2018/TK02/UMP/03/1, Grant No: RDU1901060) and Fundamental Research Grant from Universiti Malaysia Pahang Al-Sultan Abdullah (RDU230034). We also thank to Petronas Penapisan Kerteh, Malaysia for providing the crude oil samples for the research project.

REFERENCES

1. Omary, P. M., Ricky, E. X., Kasimu, N. A., Madirisha, M. M., Kilulya, K. F. & Lugwisha, E. H. J. (2023) Potential of Kaolin Clay on Formulation of Water Based Drilling Mud Reinforced with Biopolymer, Surfactant, and Limestone. *Tanzania Journal of Science*, **49**.

2. Mahmoud, A. A. A., Gajbhiye, R. & Elkatatny, S. (2023) Application of organoclays in oil-based drilling fluids: A review. *ACS Omega*, **8**, 29847–29858.

3. Rasool, M. H., Ahmad, M., Jawaad, A. & Siddiqui, N. A. (2024) Drilling fluid chemistry – Tracing the arc from past to present. *In Exploring the World of Drilling (IntechOpen)*.

4. Zhuang, G., Zhang, Z. & Chen, H. (2018) Influence of the interaction between surfactants and sepiolite on the rheological properties and thermal stability of organo-sepiolite in oil-based drilling fluids. *Microporous and Mesoporous Materials*, **272**, 143–154.

5. Min, C. & Zhang, S. (2018) Minimizing the HTHP filtration loss of oil-based drilling fluid with novel filtration control additives. *Journal of Petroleum Science and Engineering*, **167**, 155–162.

6. Lal, M. (1999) Shale stability: Drilling fluid interaction and shale strength. Society of Petroleum Engineers - SPE Asia Pacific Oil and Gas Conference and Exhibition 1999. *APOGCE 1999*.

7. Ali, I., Ahmad, M. & Ganat, T. (2022) Biopolymeric formulations for filtrate control applications in water-based drilling muds: A review. *In Journal of Petroleum Science and Engineering*, **210**.

8. Abd Wahid, M. Z. A., Zainal Abidin, M. N., Mohd Mokmin, A. I. & Sayuti, M. S. (2025) Preliminary insights into sustainable management of coconut waste from smallholders in Bagan Datuk, Malaysia. *Bioresources and Environment*, **3**, 57–68.

9. Samah, M. A. A. & Halim, A. H. A. (2024) Sustainable waste management in palm oil industry: Advancing composting practices for environmental and economic benefits. *Journal of Management World*, 807–811.

10. Rai, S., Kafle, A. & Devkota, H. P. (2023) Characterization of saponins from the leaves and stem bark of Jatropha curcas L. for surface-active properties. *Heliyon*, **9**, e15807.

11. Abu-Jdayil, B. & Ghannam, M. (2021) Effect of Surfactants on the Performance of Water-Based Drilling Fluids.

12. Almutairi, M. S. & Ali, M. (2015) Direct detection of saponins in crude extracts of soapnuts by FTIR. *Natural Product Research*, **29**.

13. Dawidowicz, A. L., Rado, E., Wianowska, D., Mardarowicz, M. & Gawdzik, J. (2008) Application of PLE for the determination of essential oil components from *Thymus vulgaris L. Talanta*, **76**.

14. Hadavimoghaddam, F., Rozhenko, A., Mohammadi, M. R., Mostajeran Gortani, M., Pourafshary, P. & Hemmati-Sarapardeh, A. (2023) Modeling crude oil pyrolysis process using advanced white-box and black-box machine learning techniques. *Scientific Reports*, **13**.

15. Heng, L., Vincken, J. P., Hoppe, K., van Koningsveld, G. A., Decroos, K., Gruppen, H., van Boekel, M. A. J. S. & Voragen, A. G. J. (2006) Stability of pea DDMP saponin and the mechanism of its decomposition. *Food Chemistry*, **99**.

16. Shadizadeh, S. R., Moslemizadeh, A. & Dezaki, A. S. (2015) A novel nonionic surfactant for inhibiting shale hydration. *Applied Clay Science*, **118**.

17. Santos, D. T., Cavalcanti, R. N., Rostagno, M. A., Queiroga, C. L., Eberlin, M. N. & Meireles, M. A. A. (2013) Extraction of polyphenols and anthocyanins from the Jambul (Syzygium cumini) fruit peels. *Food and Public Health*, **3**, 12–20.

18. Ridzuan, N., Ravinchandran, P. & Agi, A. (2025) Effect of saponin, gemini surfactant, and nanoparticle toward the water-based mud (WBM) drilling fluid properties. In *Key Engineering Materials*, **1030**, 59–72.