

COMPARISON OF FILTRATION LOSS REDUCTION IN HORIZONTAL DIRECTIONAL DRILLING MUD USING RICE STRAW WITH INDUSTRIAL ADDITIVES

* Bantita Terakulsatit¹ and Sakchai Glumglomjit²

^{1,2} School of Geotechnology, Institute of Engineering, Suranaree University of Technology,
Nakhon Ratchasima, Thailand 30000

*Corresponding Author, Received: 08 Aug. 2025, Revised: 05 Sep. 2025, Accepted: 06 Sep. 2025

ABSTRACT: Frac-out is a prevalent challenge in Horizontal Directional Drilling (HDD), arising when drilling fluid pressure exceeds the mechanical strength of surrounding geological strata. This induces fractures, allowing fluid to escape into subsurface formations or reach the surface, thereby compromising operational efficiency and threatening nearby ecosystems. Addressing this issue, the present study explores rice straw—a cellulose- and silica-rich agricultural byproduct—as a natural additive in HDD fluids. Its performance was compared with conventional industrial additives, including Carboxymethyl Cellulose (CMC) and Lost Circulation Materials (LCM), under controlled conditions at room temperature and pressures of 20, 50, and 100 psi. Key parameters examined included fluid viscosity, filtration loss, and mud cake formation. CMC, at 0.7% concentration, exhibited optimal rheological properties with the highest viscosity and lowest filtration loss across all pressures. Rice straw at 7% concentration showed promising results in enhancing mud cake thickness and minimizing fluid loss, particularly at low pressure, though its structural stability diminished at higher pressures. LCM maintained consistent mud cake formation but had limited impact on viscosity and fluid retention. Morphological analysis via SEM revealed that composite formulations containing mixed additives improved microstructural density and filtration uniformity. These findings highlight rice straw's viability as a cost-effective and eco-friendly alternative to synthetic additives, especially for use in moderate pressure drilling and environmentally sensitive conditions.

Keywords: Lignocellulose, Fluid Loss, Viscosity, Carboxymethyl Cellulose, Lost Circulation Materials, Rheology.

1. INTRODUCTION

Horizontal Directional Drilling (HDD) often encounters a critical operational challenge: the unintended migration of drilling fluids into subsurface formations or surface leakage, commonly referred to as “frac-out.” This occurs when the hydraulic pressure of the drilling fluid exceeds the strength of surrounding geological formations, causing fractures that allow fluid to escape [1]. Frac-out can disrupt operations, increase project costs, and pose environmental risks, as the fluid—typically containing bentonite and chemical additives—may contaminate soil, surface water, and groundwater.

Several factors influence frac-out, including geological conditions, drilling fluid properties, and operational parameters such as pumping pressure [2]. Effective mitigation requires integrated planning, real-time monitoring, and adaptive response strategies. A key approach involves optimizing the rheological and chemical properties of drilling fluids such as viscosity, density, and additive composition to better match formation characteristics. Additives like bentonite and synthetic polymers are commonly used to seal fractures and stabilize boreholes, improving efficiency and reducing fluid loss [3]. Industrial additives such as Lost Circulation

Materials (LCM) and Carboxymethyl Cellulose (CMC) are widely used to enhance viscosity and control fluid loss [4]. While effective, these additives raise environmental concerns due to energy-intensive production, long-term persistence in nature, and potential toxicity. This highlights the need for more sustainable, cost-effective alternatives.

Although CMC is widely used across industries, research on rice straw's application in drilling fluids remains limited. Prior studies have shown its potential in biodegradable films [5] and nanoparticle-based fluid loss control [6], but comprehensive evaluation in HDD contexts is lacking. One promising but underexplored alternative is rice straw, an agricultural byproduct often burned in open fields, contributing to air pollution and PM_{2.5} emissions. Repurposing rice straw as a drilling fluid additive offers dual benefits: reducing environmental impact and providing functional value. Rich in cellulose, hemicellulose, lignin, and silica [7], rice straw contains components like those in conventional additives like CMC and LCM. This study aims to fill that gap by assessing rice straw-derived additives in terms of viscosity and filtration behavior, comparing their performance with established industrial additives.

The paper outlines the methodology employed to prepare drilling fluid samples, analyze their chemical composition, and assess their viscosity, filtration properties, and mud cake behavior under varying pressures. Subsequently, results from FTIR, XRF, XRD, rheological testing, filtration loss experiments, and SEM-based morphological analysis are discussed in detail. The comparative performance of rice straw, CMC, and LCM is analyzed across various concentrations and pressure conditions. The paper concludes by summarizing key findings, emphasizing the potential of rice straw as a sustainable additive, and offering recommendations for future improvements and practical applications in HDD operations.

2. RESEARCH SIGNIFICANCE

This study introduces a novel application of rice straw, an abundant agricultural byproduct, as a sustainable additive for reducing filtration loss in Horizontal Directional Drilling (HDD) mud. Unlike previous research that relies heavily on synthetic materials such as CMC or LCM, this work uniquely compares rice straw's performance against industrial additives under controlled pressure conditions. The investigation highlights its microstructural behavior, mud-cake enhancement, and fluid-retention potential, revealing its suitability for moderate-pressure drilling. By integrating SEM-based morphological analysis, the study provides original insights into composite additive interactions, offering a cost-effective and eco-friendly alternative for HDD operations.

Table 1. Composition of the various drilling water based-mud samples.

Composition of mud	Appearances	Water based mud (g)	Base mud + 0.3 wt.% (g)**	Base mud + 0.7 wt.% (g)	Base mud + 7 wt.% (g)
Water		3000	-	-	-
Bentonite		150	-	-	-
Rice Straw		-	9.45	22.05	220.5
LCM		-	9.45	22.05	220.5
CMC		-	9.45	22.05	220.5

Note: ** 0.3% wt. of additive concentration was used for XRD and XRF analysis.

3. METHODOLOGY

2.1 Preparation of Drilling Fluid Samples

Bentonite is widely utilized across various industries for its exceptional water absorption and swelling capabilities. In horizontal directional drilling (HDD), it serves as a primary component of drilling mud, functioning as a lubricant and aiding in the removal of cuttings from boreholes, thereby facilitating pipe installation. To improve mud performance, additives such as carboxymethyl cellulose (CMC) and lost circulation material (LCM) are commonly used.

Rice straw employed in this study was sourced from post-harvest fields in Nakhon Ratchasima, Thailand. It was air-dried, ground, and sieved to obtain particles smaller than 63 microns (Sieve No. 230). The processed rice straw, along with CMC and LCM, was divided into two batches for chemical and physical property testing. These tests were conducted using water-based drilling mud at the Science and Technology Equipment Center, Suranaree University of Technology.

The base drilling mud was prepared by mixing 150 grams of bentonite per liter of water. For X-ray Fluorescence (XRF) and X-ray Diffraction (XRD) analyses, 0.3% of each additive was incorporated. Each formulation was blended for 30 minutes using a high-speed mixer, following API RP13B-1 standards [8]. Additives were gradually introduced into the agitated base fluid to prevent lump formation. For viscosity, filtration, and morphological evaluations, samples were prepared at 0.7% and 7% additive concentrations. All tests were performed in triplicate for consistency.

2.2 Chemical Property Analysis

Chemical composition of the samples was determined using an Energy-Dispersive XRF (ED-XRF, Horiba XGT-5200). Mineralogical analysis was conducted using XRD with a Bruker D2 Phaser. Fourier Transform Infrared Spectroscopy (FTIR) was employed to identify organic compounds, molecular structures, and functional groups present in rice straw, CMC, and LCM.

2.3 Viscosity and Filtration Properties Tests

Viscosity and filtration properties were evaluated in accordance with API RP13B-1 and the standards set by the Institution of Civil Engineers (ICE) [9]. Viscosity tests were performed on laboratory-scale drilling mud samples containing 0.7% and 7% weight/volume concentrations of rice straw, lost circulation material (LCM), and carboxymethyl cellulose (CMC). Measurements were taken at 27 °C using a motor-driven viscometer (Fann Model 35). Filtration characteristics and filter cake thickness were assessed using an API Fann Filter Press at 27 °C under pressures of 20, 50, and 100 psi, following the

API filtration test protocol with a duration of 30 minutes.

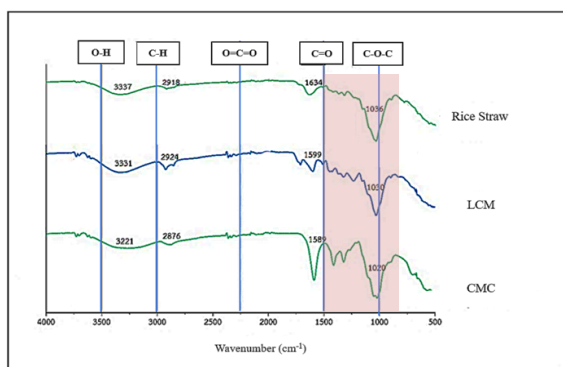
3.4 Morphology Analysis by Scanning Electron Microscope (SEM)

Drilling mud cake samples for SEM are dried at low temperatures to preserve structure, fragmented into small pieces, and mounted on carbon stubs using conductive adhesive. A thin coating of gold, platinum, or carbon is applied to prevent charging. This preparation enables high-resolution imaging of surface morphology and microstructure, essential for evaluating drilling fluid performance.

4. RESULTS AND DISCUSSION

3.1 Fourier Transform Infrared (FTIR) Analysis

Figure 1 illustrates the FTIR microscope analysis, confirming the presence of key functional groups in rice straw, CMC, and LCM. Rice straw is composed mainly of cellulose, hemicellulose, lignin, and silica. The FTIR spectra show that rice straw shares several functional groups with CMC and LCM, including O–H, C–H, and C–O (from cellulose and hemicellulose), C=O (from carboxymethyl groups), and C–O–C linkages (from sugar structures and ether bonds in CMC) [10], [11]. These overlapping functional groups suggest that rice straw has chemical compatibility with CMC and LCM. Its lignocellulosic matrix and silica content contribute to desirable rheological and filtration properties, making it a promising natural alternative to synthetic additives in drilling fluids. This supports the potential of rice straw as a sustainable and cost-effective substitute for industrial materials like CMC and LCM in drilling applications [10], [11].



Note: Refer to Lignocellulose Biofingerprint Region.

Fig. 1 Fourier Transform Infrared (FTIR) spectra of rice straw, LCM, and CMC.

3.2 Elemental and Mineralogical Composition Analysis

Table 2 summarizes the elemental composition of drilling mud samples with 0.3% additive by weight. Rice straw exhibited the highest silicon dioxide (SiO₂) content at 72.36%, attributed to phytoliths (silica-rich structures naturally occurring in plant tissues) [12]. The base mud also showed substantial SiO₂ levels (56.00%), typical of water-based drilling fluids. In contrast, CMC and LCM contained significantly lower SiO₂, contributing minimally to overall silica content. At low concentrations, these additives did not notably alter SiO₂ levels, indicating limited impact on the mud's elemental profile.

The mineralogical composition including montmorillonite, quartz, calcite, magnesite, and sodium, which provides insight into how each additive influences rheology, viscosity, filtration efficiency, and fluid stability. The presence of quartz correlates with the elevated SiO₂ levels observed in both rice straw and base mud.

3.3 Viscosity Analysis and Drilling Mud

Table 3 compares the viscosity properties of drilling mud formulations containing 0.7% by weight of CMC, LCM, and rice straw, as well as 7% by weight of LCM and rice straw. CMC at 0.7% yielded the highest values for plastic viscosity (PV), apparent viscosity (AV), and yield point (YP), indicating a strong thickening effect. Although CMC was not tested at 7%, its performance at low concentration highlights its effectiveness in enhancing fluid viscosity and gel strength—key factors for efficient cuttings suspension and hole cleaning during drilling operations [13].

LCM showed consistent PV and YP values at both concentrations, suggesting limited sensitivity to dosage changes. This behavior implies that LCM primarily serves as a mechanical plugging agent rather than a rheological modifier. Increasing its concentration beyond 0.7% does not significantly improve viscosity [13].

Rice straw demonstrated a moderate increase in viscosity at 7% compared to 0.7%, indicating a concentration-dependent effect. However, its thickening capability was less pronounced than CMC.

Operationally, higher viscosity improves cuttings transport, especially in deviated or horizontal wells. However, excessive viscosity can increase pump pressure, energy consumption, and risk of formation damage. While CMC is ideal for high-performance drilling, its use should be balanced with cost and operational constraints. Rice straw offers a cost-effective and eco-friendly alternative for moderate viscosity enhancement, particularly in budget-sensitive or environmentally regulated operations [14].

The viscosity data provides practical guidance for additive selection based on well conditions. For shallow, low-pressure wells, rice straw at 0.7%

maintains AV like base mud with slight PV and YP improvements, making it a sustainable choice. In medium-depth wells, rice straw at 7% enhances AV, PV, and YP, supporting better cuttings transport. For deep, high-pressure wells, CMC at 0.7% delivers superior viscosity performance, though adjustments to pump pressure may be needed. In loss circulation zones, LCM at both concentrations maintains stable viscosity, reinforcing its role in mechanical plugging for fractured or porous formations.

Overall, tailoring additive selection to specific drilling conditions ensures optimal wellbore stability, cuttings transport, and fluid circulation, while balancing performance, cost, and environmental impact.

3.4 Filtration Loss

Figure 2 illustrates the filtration loss behavior of various drilling mud formulations under pressures of 20, 50, and 100 psi. At 20 psi (Fig. 2A), the base mud showed the highest filtration loss, indicating poor fluid retention. In contrast, the formulation with 0.7% CMC exhibited the lowest loss, confirming its effectiveness even at low pressure. Both rice straw and LCM improved fluid retention compared to the base mud, with rice straw slightly outperforming LCM at certain intervals. These results are consistent with higher-pressure tests, though overall losses were lower due to reduced pressure.

Table 2. Elemental and mineralogical composition of drilling mud samples with each additive.

Elements (%)	Base Mud	LCM	CMC	Rice Straw	Based mud +0.3%CMC	Based mud +0.3%LCM	Based mud + 0.3%Rice Straw
Si ₂ O	56.00	34.92	15.81	72.36	55.98	56.85	56.06
Al ₂ O ₃	14.59	-	-	-	14.68	14.74	14.37
Na ₂ O	-	-	83.16	-	-	-	-
K ₂ O	-	22.91	-	18.37	-	-	-
CaO	2.04	28.48	-	7.24	2.05	1.90	1.97
MgO	4.40	-	-	-	3.83	4.87	5.43
MnO ₂	-	1.45	-	-	-	-	-
Fe ₂ O ₃	20.32	10.55	-	-	20.63	18.95	19.29
Cr ₂ O ₃	-	1.32	-	-	-	-	-
TiO ₂	2.00	-	-	-	2.07	2.02	2.01
Total (%)	99.35	99.63	98.97	97.97	99.24	99.33	99.13
Minerals (%)							
Montmorillonite	33.94	n/a			24.79	30.17	40.46
Quartz	20.36				29.72	17.29	44.18
Calcite	24.71				18.38	18.18	2.25
Magnesite	14.45				5.25	15.74	13.11
Sodium	6.53				21.86	18.63	-
Total (%)	100				100	100	100

Table 3. Viscosity analysis and drilling fluid performance.

Additives	Proportion	AV	PV	YP
	%	(cP)	(cP)	(lb/100 ft ²)
Base Mud	0	12.8	5.4	14.8
Base Mud+RS**	0.7	12.8	6.8	12.4
Base Mud+LCM	0.7	11.9	5.2	13.4
Base Mud+CMC	0.7	127.9	48.4	159
Base Mud+RS**	7	20.3	10.8	19
Base Mud+LCM	7	46.3	21.4	49.8

Note: **RS refers to Rice Straw

Table 4. Viscosity property versus operational recommendations.

Additives	Best for	Proportion	Notes
CMC	High-performance and suitable use in deep wells	0.7%	Strong viscosity boost
LCM	Lost circulation control	0.7–7%	No viscosity change
Rice Straw	Eco-friendly and low budget operations	7%	Moderate viscosity improvement

At 50 psi (Fig. 2B), filtration loss increased over time, with the base mud showing the highest loss. The 0.7% CMC formulation maintained superior performance, while rice straw and LCM also reduced fluid loss. Rice straw consistently outperformed LCM at several intervals, indicating its potential as an effective additive. These results suggest CMC is the most efficient, followed by rice straw and then LCM [15], [16]. At 100 psi (Fig. 2C), filtration loss rose across all formulations. The base mud remained the least effective, while 0.7% CMC continued to deliver the lowest values, confirming its stability under high pressure. Rice straw remained effective, outperforming LCM, which showed limited efficiency [16]. Overall, CMC demonstrated the best performance across all pressure levels. Rice straw offers a promising, cost-effective, and eco-friendly alternative. LCM, while beneficial, had a lesser impact. As pressure increases, filtration loss rises, making additive selection crucial for maintaining fluid performance and minimizing formation damage [15].

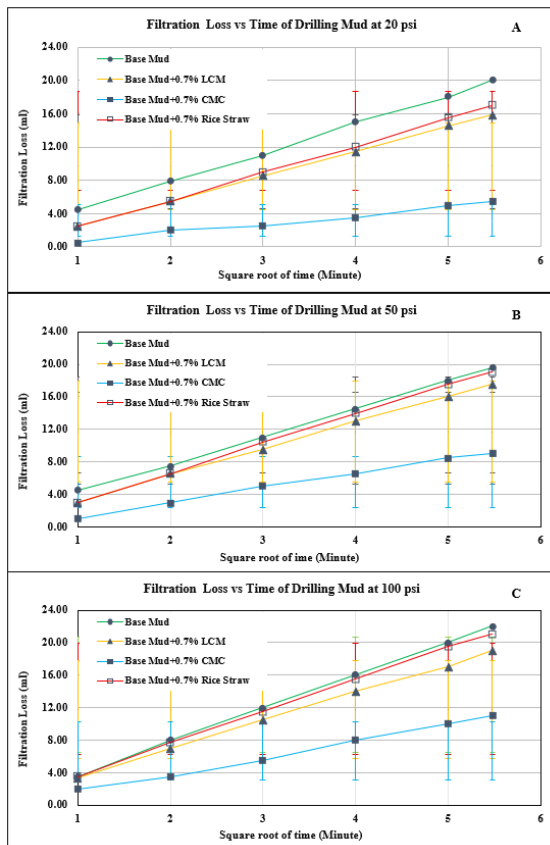


Fig. 2 Filtration loss (ml) versus square root of time (in minute) of base mud and base mud with 0.7% by weight CMC, LCM, and rice straw concentration at 20 psi (A), 50 psi (B), and 100 psi (C).

Figure 3 illustrates filtration loss behavior under the same pressure conditions, emphasizing the impact of additive concentration. At 20 psi (Fig. 3A), filtration loss increased over time for all mud types. The base mud showed the highest loss, while formulations with 7% rice straw and LCM significantly reduced fluid loss. Rice straw performed slightly better than LCM, suggesting greater effectiveness under low-pressure conditions [17, 18].

At 50 psi (Fig. 3B), filtration loss continued to increase over time. The base mud exhibited the highest fluid loss, confirming its limited retention capability. Both additives—7% LCM and 7% rice straw—improved fluid retention, with rice straw consistently outperforming LCM. These results reinforce rice straw's potential as a sustainable and effective drilling fluid additive [17,18].

At 100 psi (Fig. 3C), filtration loss was further amplified. The base mud maintained poor performance, while the formulation with 7% rice straw remained effective, outperforming LCM and significantly reducing fluid loss. This confirms rice straw's viability under elevated pressure conditions [17,19].

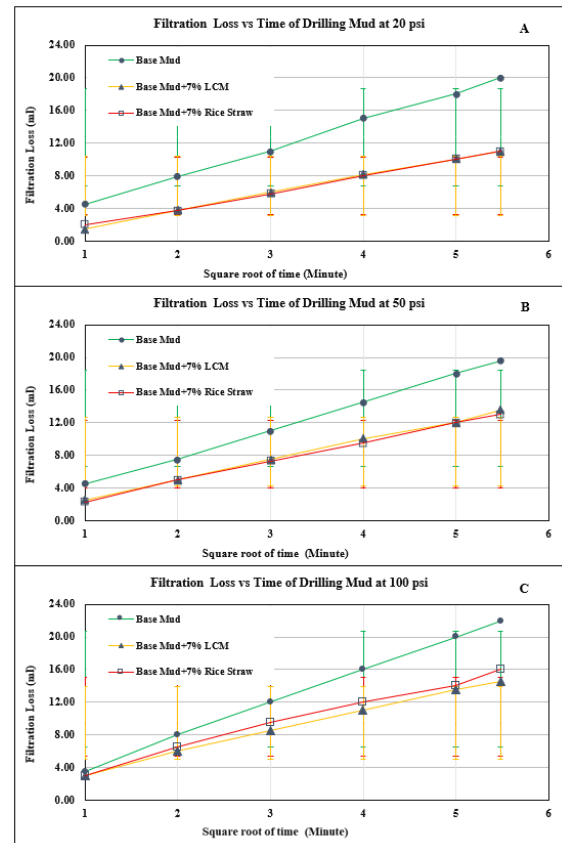


Fig. 3 Filtration loss (ml) versus square root of time (in minute) of base mud and base mud with 7% of LCM and rice straw additive concentration at 20 psi (A), 50 psi (B), and 100 psi (C).

A comparative analysis across three pressure levels (20, 50, and 100 psi) and two additive concentrations (0.7% and 7%) revealed that filtration loss increases with pressure. Among all tested additives, CMC at 0.7% consistently showed the lowest filtration loss, especially under high pressure, confirming its superior fluid retention capability.

Rice straw at 7% performed nearly as well as CMC and better than LCM, reinforcing its potential as a natural, cost-effective alternative. Increasing additive concentration from 0.7% to 7% improved performance for both rice straw and LCM, indicating a concentration-dependent effect.

However, rice straw's performance at 100 psi declined due to possible compaction or erosion, affecting sealing efficiency. Unlike CMC, which remains stable, rice straw's effectiveness appears pressure sensitive. Its natural composition, while environmentally friendly, may lack the mechanical resilience required for high-pressure drilling environments.

3.5 Mud Cake Thickness

Figure 4 illustrates the mud cake thickness of various drilling mud formulations under pressures of 20, 50, and 100 psi. The base mud shows a notable reduction in thickness at 100 psi, indicating compromised structural integrity under elevated pressure. This aligns with previous findings that high pressure can degrade mud cake quality, reduce sealing capacity, and potentially lead to wellbore instability [20].

In Figure 4A, the mud containing 0.7% rice straw exhibits the highest thickness at 20 psi (4.56 mm), but thickness decreases at higher pressures, confirming pressure-induced degradation. The addition of 0.7% LCM results in slightly lower thickness at 20 psi (4.24 mm) compared to base mud, suggesting an effect on initial structural buildup. Meanwhile, 0.7% of CMC maintains relatively stable thickness across pressures, performing well especially at 50 psi.

Overall, rice straw at 0.7% demonstrates the best performance in preserving mud cake thickness under pressure, while LCM and CMC also contribute to structural integrity, though to a lesser extent.

In a separate test series with 7% additive, base mud showed the greatest thickness reduction at 100 psi, confirming limited pressure resistance. Drilling based mud with 7% LCM maintained more consistent thickness—greater than base mud at 20 and 100 psi, but slightly lower at 50 psi indicating improved structural stability (Fig. 4B). This supports findings that optimized particle size and solid content enhance mud cake performance under pressure [21]. Mud with 7% rice straw had the highest initial thickness (6.5 mm at 20 psi), suggesting strong sealing, but declined sharply at higher pressures, indicating potential compressibility or reduced integrity.

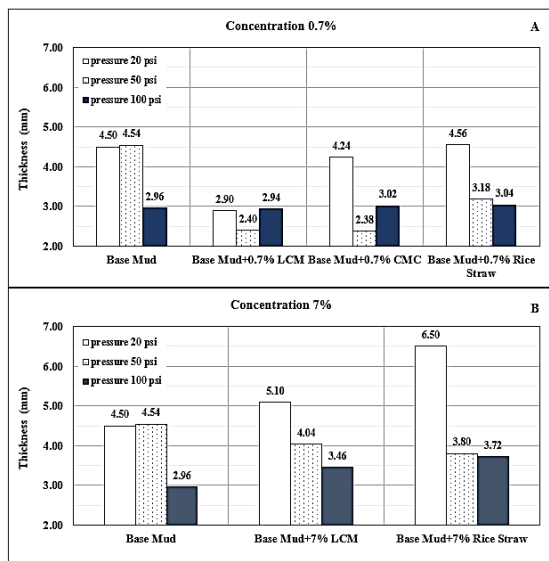


Fig. 4 Mud cake thickness (in millimeters) of drilling mud mixed with 0.7% (A) and 7% (B) concentration of rice straw, LCM, and CMC at 20 psi (white square), 50 psi (dotted square), and 100 psi (black square).

Mud cake thickness is crucial for wellbore stability, filtration control, and drilling efficiency. A thin, compact mud cake minimizes fluid invasion and preserves formation integrity, while excessive thickness can cause torque, drag, sticking, and cementing issues. Under high pressure, reduced thickness may indicate erosion or compaction, weakening sealing capacity. Additives like LCM, CMC, and rice straw enhance mud cake properties. Rice straw performed well at low pressure but requires further study under elevated conditions. LCM showed better structural integrity across pressures, making it suitable for fractured formations. Optimizing mud cake thickness and additive selection is key to drilling performance.

3.6 Texture, Morphology, and Microstructure

A microscopic analysis was performed to assess the texture, morphology, and microstructure of various drilling fluid additives. LCM exhibited a rough, fibrous texture with visible strands and an irregular surface. Its morphology consisted of elongated, loosely packed fibers forming an open, directionally aligned microstructure (Fig. 5A). When blended with base mud, LCM transformed into a smoother, more uniform texture with a compact morphology. The fiber separation was reduced, and the microstructure appeared denser and less aligned (Fig. 5B), indicating improved dispersion and particle bonding within the fluid matrix [12].

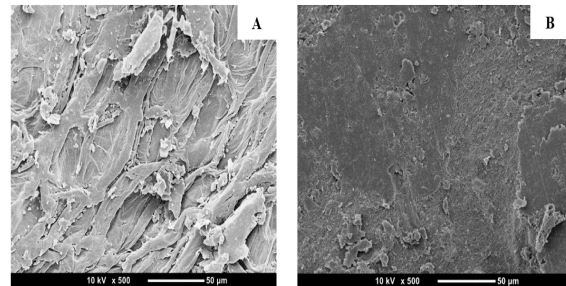


Fig. 5 Morphological characteristics of LCM (A) and LCM-mixed drilling mud (B) at 500× magnification.

CMC exhibited a porous, irregular texture with large voids and rough surfaces, indicating weak particle bonding. Its coarse morphology and loosely connected microstructure (Fig. 6A) suggest limited structural integrity. When mixed with base mud, CMC formed a finer, more compact texture with smaller, evenly distributed pores. The morphology became more homogeneous and tightly packed, while the microstructure (Fig. 6B) showed enhanced particle interconnection, improving fluid retention and stability [22].

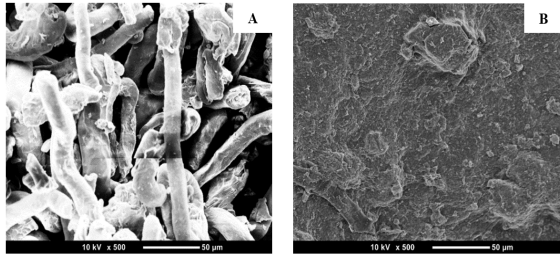


Fig. 6 Morphological characteristics of CMC (A) and CMC-mixed drilling mud (B) at 500× magnification.

Rice straw initially displayed a highly porous texture with open-cell morphology and a loose microstructure (Fig. 7A). After mixing with base mud, its texture became smoother and pore structure more refined. The microstructure (Fig. 7B) appeared denser and more interconnected, indicating improved mechanical stability and potential for effective filtration control [23].

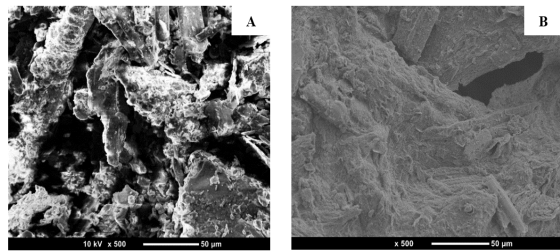


Fig. 7 Morphological characteristics of rice straw (A) and rice straw-mixed drilling mud (B) at 500× magnification.

Microscopic observations reveal that additive blending significantly enhances the structural characteristics of drilling fluids. Porosity and microstructure critically affect filtration behavior. LCM, with their fibrous, open structure, permits higher flow rates but are less effective at trapping fine particles. In contrast, mixed LCM exhibits a denser microstructure, enhancing particle retention and reducing permeability—ideal for fine filtration [12]. Rice straw's neutral impact on flow rate suggests it may be best suited for stable formations or when maintaining consistent fluid movement is critical, while CMC and LCM are better for loss-prone zones. Texture and structural comparisons are based on SEM images, as summarized in Table 5.

In summary, all this investigation represents that rice straw offers a sustainable, cost-effective alternative to conventional drilling additives, showing strong performance in reducing filtration loss and enhancing viscosity—especially at higher concentrations. Its effectiveness under low to moderate pressure conditions makes it suitable for eco-sensitive and budget-conscious HDD projects. However, limitations include reduced structural

stability under high pressure, variability in raw material quality, and potential challenges in storage and processing. Field-scale application requires further trials to optimize concentration, handling, and performance across diverse geological settings.

Table 5. Summary of comparison of texture, morphology, and microstructure for each material pair based on the SEM.

Characters	LCM to Base Mud Mixed LCM (Fig. 6A & B)	CMC to Base Mud Mixed CMC (Fig. 7A & B)	Rice Straw to Base Mud Mixed Rice Straw (Fig. 8A & B)
Texture Change	Rough → Smooth	Porous → Fine	Very Porous → Smoother
Morphology Change	Fibrous → Compact	Coarse → Homogeneous	Open-cell → Refined
Microstructure Change	Open → Dense	Loose → Interconnected	Loose → Denser
Flow Rate	Low	Low	No change
Particle Retention	High	Very High	High
Filtration Consistency	High	Very High	High

4. CONCLUSIONS

This research highlights the potential of rice straw as a sustainable and effective additive for enhancing drilling fluid performance in HDD. Comparative analysis with conventional additives such as CMC and LCM revealed that rice straw significantly improves viscosity, filtration control, and mud cake thickness, particularly at higher concentrations. At 0.7%, CMC consistently delivered the highest viscosity and lowest filtration loss across all pressure conditions, confirming its superior rheological and sealing properties. Rice straw at 7% showed comparable performance, outperforming LCM and approaching the effectiveness of CMC under both low and high-pressure conditions, attributed to its high silica content and lignocellulosic structure.

While LCM contributed to mechanical plugging and mud cake thickness, its impact on viscosity and fluid retention was limited. Morphological analysis indicated that mixed formulations of rice straw, CMC, and LCM enhanced microstructural density and particle interconnection, improving filtration consistency and mechanical stability.

For future work, it should explore chemical or thermal modification techniques aimed at enhancing the compressive strength and structural resilience of rice straw. Blending rice straw with more robust materials or optimizing particle size distribution may also improve its performance under high-pressure conditions.

5. ACKNOWLEDGEMENTS

This research was financially supported by (i) Suranaree University of Technology (SUT), (ii)

Thailand Science Research and Innovation (TSRI), and (iii) the National Science, Research and Innovation Fund (NSRF) under grant number NRIIS 195671. The author gratefully acknowledges the support and contributions of the staff and the advisory student involved in the preparation and testing of the drilling mud samples.

6. REFERENCES

- [1] Daneshy, A., and King, G., Horizontal well frac-driven interactions: types, consequences, and damage mitigation. *J Pet Technol.*, 391 (71), 2019, pp. 45–47.
- [2] Chen, B., Barboza, B.R., Sun, Y., Bai, J., Thomas, H.R., Dutko, M., Cottrell, M., and Li, C. A., Review of Hydraulic Fracturing Simulation. *Arch Computed Methods Eng*, 29, 2022, pp. 1–58. <https://doi.org/10.1007/s11831-021-09653-z>.
- [3] King, G.H., Rainbolt, M.F., and Swanson, C., Frac hit induced production losses: Evaluating root causes, damage location, possible prevention methods and success of remedial treatments, SPE Annual Technical Conference and Exhibition, San Antonio, Texas, USA, October 2017.
- [4] Global Drilling Fluid & Chemical Ltd. CMC and LCMS, 2025. [cited 2025, July 21]. Available from: <https://www.oil-drilling-fluids.com/cmc-lv>.
- [5] Banthao, C., Kumpolsan, P., Baimark, Y., Wongkasemjit, S., and Pakkethati, K., Improvement the properties of Poly(L-Lactide) films with cellulose fiber from rice straw waste in agricultural products. *International Journal of GEOMATE*, 18(70), 2020, pp. 43–48.
- [6] Noah, A.Z., Control fracture in sand formation using smart drilling fluid throughout experimental approach. *International Journal of GEOMATE*, 11(27), 2021, pp. 2704–2711
- [7] Masrullita, M., Nurlaila, R., Zulmiardi, Z., Safriwardy, F., Auliani, A., and Meriatna, M., Synthesis carboxyl methyl cellulose (CMC) from rice straw (*Oryza Sativa L.*) waste. *International Journal of Engineering, Science and Information Technology*, 2(1), 2021, pp. 24–29.
- [8] American Petroleum Institute (API), API Recommended Practice 13B-1: Field testing water-based drilling fluids (5th ed., Includes Errata 1–3), API Publishing Services, 2019.
- [9] ICE (Institution of Civil Engineers), ICE Specification for Piling and Embedded Retaining Walls. Thomas Telford, London, UK, 1996.
- [10] Pushpa, S.R., Sukumaran, R.K. & Savithri, S., Rapid quantification of lignocellulose composition in rice straw varieties using artificial neural networks and FTIR spectroscopic data, *Biomass Conv. Bioref.*, 2023. <https://doi.org/10.1007/s13399-023-05032-9>.
- [11] Hamzah, H.T., Veluru S.V., Surya D.V., Ramesh, P., Rao, C.S., Palla, S., Abdullah, T.A., Synergistic effects and product yields in microwave-assisted in-situ co-pyrolysis of rice straw and paraffin wax, *Process Safety and Environmental Protection*, Vol. 182, 2024, pp. 45-55.
- [12] Nguyen, K., Mehrabian, A., Santra, A., Phan, D., and Bathija, A., Lost circulation material size selection for naturally fractured rocks, the International Petroleum Technology Conference, Dhahran, Saudi Arabia, February 2024.
- [13] Mohamed, A., Salehi, S., and Ahmed., R., Experimental investigation of a smart LCM using a high-temperature flow loop for geothermal drilling, United States: Unpublished Work, 2021. <https://doi.org/10.1016/j.geothermics.2021.102066>.
- [14] Borah, R., Puzari, S., and Mech, B., Comparative analysis of bio-additives and conventional additives in non-damaging drilling fluid using Landmark Software for interpretation, 2025. https://doi.org/10.1007/978-981-96-3667-9_9.
- [15] Gokul, K., Prabhu, T. R., and Rajasekaran, T., Processing and evaluation of mechanical. properties of sugarcane fiber reinforced natural composites, *Trans. Indian Inst. Met.*, 70, 2017, pp. 2537–46.
- [16] Aleqabi, Z., Alrazzaq, A., and Wayo, D., Laboratory study investigating the impact of different LCMs additives on drilling mud rheology and filtration, *Iraqi Journal of Chemical and Petroleum Engineering*, 25, 2024, pp. 115-122.
- [17] Sufri, M.A.S.B., Study on Rice Husk as Lost Circulation Material, Project of Petroleum Engineering, Universiti Teknologi PETRONAS, Malaysia, 2012.
- [18] Agwu, O.E., and Akpabio, J.U., *Journal of Petroleum Science and Engineering*, Vol. 163, 2018, pp. 185–198.
- [19] Nasiri, A., Shahrabi, M.A., and Moraveji, M.K., Application of new eco-friendly LCMs for combating the lost circulation in heavy-weight and oil-based mud. *RSC Adv.*, 8 (9685), 2018.
- [20] Li, X., Zhang, Y., and Chen, H., Hydro-mechanical modeling of mud cake behavior under pressure, *Journal of Petroleum Science and Engineering*, Vol. 215, 104567, 2024.
- [21] You, F., Zheng, Y., Wu, Y., Guo, Y., Xu, Z., and Leng, L., Influence of corn starch acid hydrolysate on reservoir damage: The key role of molecular structure. *International Journal of Biological Macromolecules*, Vol. 308, Part 1. 2025.
- [22] da Luz, R.C.S., Fagundes, F.P. and Balaban, R.D.C., Water-based drilling fluids: the contribution of Xanthan gum and carboxymethylcellulose on filtration control, *Chem. Pap.*, 71, 2017, pp. 2365–2373. <https://doi.org/10.1007/s11696-017-0231-7>.
- [23] Saasen, A., Omland, T. H., Ekrene, S., Brévière, J., Villard, E., Kaageson-Loe, N., Tehrani, A., Cameron, J., Freeman, M., Growcock, F., Patrick, A., Stock, T., Jørgensen, T., Reinholt, F., Amundsen, H. E. F., Steele, A., and Meeten, G., Automatic Measurement of Drilling Fluid and Drill-Cuttings Properties, *SPE Drill & Compl.* 24, 2009, pp. 611–625.