Evaluation of environment friendly micro-ionized litchi leaves powder (LLP) as a fluid loss control agent in water-based drilling fluid

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Abstract

This work investigates the efficacy of a biodegradable natural product, litchi leaves powder (LLP) as a filtration loss control agent in the water-based drilling fluid formulations. In order to evaluate the potential of litchi leaves powder (LLP), a strict protocol of experimentations according to API (American Petroleum Institute) standard has been followed. The experimental outcome showed that before hot rolling and after hot rolling of mud samples at 100 °C it was observed that 3–5% Concentration of LLP significantly increased the rheological parameters such as PV, YP and gelation of drilling fluid as compared to reference mud. Also, LLP reformed the filtration loss control characterization, suggesting a better biodegradable fluid loss reducing agent. After hot rolling at 100 °C for 18 h, the water-based drilling fluid with LLP as an additive showed a marked reduction in filtration control property as compared to reference Mud (RM). Experimental results concluded that 5% concentration of LLP significantly reduced the filtration loss of drilling fluid by 70.6% as compared to reference mud under the influence of 100 psi pressure. However, the conventional fluid loss additive CMC (LVG) reduced the filtration loss by maximum 67.5% as compared to reference mud. Therefore, LLP can be used as an alternative to CMC (LVG) in water-based drilling fluid with a maximum subsurface temperature of 100 °C.

Keywords Environment friendly additive · Drilling fluid · Litchi leaves powder (LLP) · CMC · Filtration loss

Abbreviations

API	American Petroleum Institute
AV	Apparent Viscosity
PV	Plastic Viscosity
YP	Yield Point
LLP	Litchi Leaves Powder
RM	Reference Mud
CMC (LVG)	Carboxymethyl Cellulose (Low Viscous Grade)
°C	Degree Celsius
psi	Pounds square inch
LTLP	Low Temperature-Low Pressure
lb/bbl	Pounds per barrel

lb/gal	Pounds per gallon
AHR	After Hot rolling
BHR	Before Hot rolling
FTIR	Fourier transform infrared

Introduction

A drilling fluid is designed in order to cater various functions during drilling and its high efficiency is rated high, if the various chemical additives and polymers are mixed to the base fluid to fulfil the required parameters of the drilling fluid, such as density, shale stabilization, filtration loss control, alkalinity, lubricity, etc. (Gray et al. 1980; Okorie et al. 2009). As per environmental aspect, oil-based drilling fluids are more toxic than water-based drilling fluids. So keeping in view these facts and the environmental compatibility, it has initiated an interest among users to use water-based drilling fluid as compared to the oil-based drilling fluid (Amanullah 2007). Corncob and sugar cane additives have been used as viscosifying agent. The results of this study showed that when the concentration of sugarcane and corncob were increased from 6 to 10 parts per billion (ppb), there was an

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advancement in PV, but YP and gel strength were reduced (Iranwan et al. 2009). 20 parts per billion (ppb) concentrations of rice husks reduced the filtration loss in water-based mud by 65%. But it was observed that a higher concentration of rice husk gave unwanted effect on the plastic viscosity (Okon et al. 2014). Banana peel provided alkalinity to the drilling fluid system (Iheagwara et al. 2015). Similarly, the banana peel ash (BPA) was used as a substitute for NaOH in water-based mud. The experimental results showed that banana peels ash (BPA) has a tendency to increase the pH of drilling mud and thereby mitigated the corrosion problem. On comparing BPA with NaOH, it was observed that there was better improvement in pH ranging from 12 and 14% in the case of banana peels (Adebowale and Raji 2015).

Other natural additives such as extracted cellulose from corn cob (Nmegbu and Bekee 2014), extracted cashew and mango leaves (Omotioma et al. 2014), and extracted potato starch from potato tubers (Nyeche et al. 2015), etc. have been used as filtration loss control and rheological properties modifiers in water-based drilling fluids. Potato peels powder (PPP) is an environmental friendly additive to be used as thinner, pH reducer, and fluid loss controlling agent (Al-Hameedi and Husam 2019). However, another study showed the use of mandarin peels powder (MPP) as a filtration loss control additive to substitute the conventional chemicals used in water-based drilling fluid (Al-Hameedi and Alkinani 2019). In our previous study, Stem peels powder of *Grewia optiva* fibre (particle size 250 μm) has been used as cost effective and environment friendly non-invasive fluid additive in water-based fluid to prevent the invasion of external fluid into the reservoir section (Prakash et al. 2020).

In this study, litchi leaves powder (LLP) has been investigated as an environment friendly filtration loss control additive in the water-based drilling fluid. *Litchi chinensis* is an evergreen tree which belongs to the *spindaceae* family. Litchi trees are mainly found in China, India, Thailand, Vietnam, Australia, Israel and the South-Eastern United States. Extensive laboratory works have been conducted where LLP was tested at different concentrations w.r.t. reference mud. The experimental outcomes suggested that this natural

product, i.e. LLP is an environmental friendly, cost effective, drilling fluid additive. The performance of the drilling fluid was found to be at par excellence with litchi leaves powder (LLP) when it was compared with a conventional fluid loss additive CMC (Carboxymethyl Cellulose).

Basis of choice of litchi leaves for the study

Biomolecules content Litchi leaves have greater content of carbohydrate, i.e. 72.547%. Beside this, it also contained 31.041% crude fibre, 12.751% crude protein, 2.022% crude fat and 2.04% of total nitrogen (Shukla et al. 2014).

Cost analysis The cost of conventional fluid loss control additives, e.g. CMC (LVG) and Polyanionic cellulose are 4.96 USD per Kg and 6.0 USD/Kg, respectively (Okoro et al. 2018). However, LLP is a natural waste and easily available from the natural resources in a huge quantity. Therefore, LLP is more cost effective than CMC (LVG) and PAC (LVG).

Materials and methods

Preparation of micro-ionized litchi leaves powder (LLP)

The sample [as shown in Fig. 1a] was cleaned manually to get rid of unwanted foreign materials. Then, it was dried in an oven at 70–75 °C for about ~4–6 h. After drying, it was then again cleaned manually and chopped into small pieces [as shown in Fig. 1b]. Finally, the sample was ground into very fine particles with the help of good quality Grinder Machine [shown in Fig. 1d].

Sieve analysis test was conducted to determine the particle size of litchi leaves powder (LLP). The fine LLP was sieved through 125 μm (μm) (120 US Mesh sieve) to obtain micro-sized fine particle [shown in Fig. 1c]. The reason for using 125 μm particle size as because smaller the size of

Fig. 1 a Collected raw Litchi leaves, b Small Pieces of Litchi Leaves, c The Litchi Leaves Powder (125 μm), d Grinder

additive gives better filtration loss control ability of the drilling mud (Ghazali et al. 2014; Perlmutter 2005).

Experimental procedures

pH

5% (w/v) sample was taken in deionized/distilled water and stirred on magnetic stirrer for 10 min, then determined the pH of the solution at 24 ± 2 °C by using a calibrated pH meter. The result is shown in Table 1.

Moisture content

10 g of dried sample was taken in a pre-weighed bottle with lid. Removed the lid and placed both the lid and bottle separately in an air oven at 105 ± 2 °C temperature. Keeping for 5 h in air oven, when the sample was dried completely, placed the lid on the bottle inside the oven and then cooled in desiccator before weighing. Removed and replaced the lid quickly to equalize the pressure inside the desiccator. Repeated the process till constant weight was obtained (Chichung et al. 2003; Ayurveda formulary of India 2000). The result is shown in Table 1.

Calculation:

Table 1 Properties of Litchi Leaves powder (LLP)

S. No	Properties	Observation/values
1	Physical state	Powder
2	Colour	Yellow-Greenish
3	pH of 5% sample in Distilled water at 24 ± 2 °C	6.5
4	Moisture content at 105 ± 2 °C, per cent by mass	6

Table 2 The results of adding various concentrations of LLP on the properties of Reference Mud, Before Hot Rolling (BHR)

S.N	Properties	Values					
		Reference Mud (RM)	1% LLP	2% LLP	3% LLP	4% LLP	5% LLP
1	Mud weight (ppg)	8.6	8.6	8.55	8.5	8.4	8.35
2	pH	10.5	10.4	10.4	10.2	10.1	10.0
3	PV (cp)	7.0	10	12	14	18	20
4	YP (Ib/100ft ²)	12	13	15	18	20	25
5	Gel 0 (Ib/100ft ²)	8	10	12	14	16	18
6	Gel 10 (Ib/100ft ²)	16	17	19	22	24	26
7	Mud temperature (°F)	75	75	75	75	75	75
8	7.5 min filtrate (cc)	13	8.0	6.2	4.7	4.3	3.4
9	30 min filtrate (cc)	27	15	12.3	9.5	8.6	6.8
10	Filter cake thickness (mm)	3	2.8	2.4	1.8	1.6	1.4
11	Mud cake temperature (°F)	77	77	77	77	77	77

$$\text{Moisture content \% (w/w)} = \frac{(W2 - W1)}{W1} \times 100$$

where W1 = Weight of bottle with lid + Sample, W2 = Weight of bottle with lid + Dried Sample.

Mud sample preparation

A freshwater bentonite-based drilling fluid was prepared as per API (American Petroleum Institute) standards. The standard procedure involves the addition of 25 gms of bentonite powder and 0.7 gm of caustic soda (NaOH) in 350 ml of fresh water. The mixture was kept for maturation for 24 h. Since freshwater bentonite-based drilling fluid is a colloidal system and the maximum hydration & yield of bentonite is pH based, caustic soda, as an important ingredient added for maintaining proper alkalinity, pH to be maintained at maximum 10.5.

The drilling fluid prepared with bentonite and caustic Soda (NaOH), here it was referred as Reference Mud. The rheological and fluid loss property of the reference mud was measured, and the results are tabulated in Table 2.

The mud samples were grouped into two sets, nomenclature as Set-1 & Set-2. In Set-1, 1%, 2%, 3%, 4% & 5% of 125 µm sized litchi leaves powder (LLP) were added to reference mud, respectively, and mixed thoroughly for 10 min in order to get a homogeneous mixture of bentonite mud with litchi leaves powder. Consequently, the rheological properties of each sample including low temperature-low pressure (LTLTP) filtration test were carried out on each set of samples and the results acquired are presented in Table 2.

Set-2, an another set of samples 0.6%, 0.8%, 1.0%, 1.2% and 1.4% of CMC (LVG) was added to reference mud, respectively, and mixed by stirring the mixture for 10 min to obtain a homogeneous mixture. The, the rheological properties, fluid loss volume and mud cake thickness of the

Set-2 were similarly measured and the data are presented in Table 3.

After evaluating the above sets of samples at low pressure-low temperature, the reference mud and Set-1 and Set-2 mud samples were now put in ageing cells and hot rolled at 100 °C for 18 h. Hot rolling of mud samples is necessary because during the drilling the bottom hole temperature of well is increased with increasing the well depth. Therefore, temperature distribution under circulation and shut in conditions is necessary to maintain the viscosity, fluid loss, pH shale inhibition, etc. properties of the drilling fluid and prevent the invasion of annulus fluid fluxed into formation during loss circulation problem in oil and gas geothermal wells (Fomin et al. 2003).

The rheological properties and low temperature-low pressure filtration test of all these hot rolled samples were then carried out and the results are presented in Tables 4 and 5, respectively.

Filtration test (low pressure, low temperature test)

API specified filter press is used to determine the filtration properties of the drilling fluid. A Whatman 50 filter paper was placed in the API cell and then it was filled by the mud. Then, 100 psi pressure was applied to the API cell at room temperature. Then, the volume of filtrate was measured after 7.5 and 30 min (American Petroleum institute 2003).

Filter cake characteristic measurements

The qualitative measurements of the filter cake like thickness, thinness, firm, rubbery, sticky, smooth, etc. were determined as per API Standard. The cake characterizations such as slickness and texture were determined subjectively by physical examination, whereas the thickness of cake was measured quantitatively by using a scale and reported in

Table 3 The results of adding various concentration of CMC (LVG) on the properties of Reference Mud, Before Hot Rolling (BHR)

S. no	Properties	Values					
		Reference Mud (RM)	0.6% CMC	0.8% CMC	1.0% CMC	1.2% CMC	1.4% CMC
1	Mud weight (ppg)	8.6	8.6	8.62	8.63	8.64	8.64
2	pH	10.5	10.2	10.1	10	9.9	9.8
3	PV (cp)	7.0	16	20	24	28	32
4	YP (lb/100ft ²)	12	17	39	41	43	46
5	Gel 0 (lb/100ft ²)	8	18	22	26	32	34
6	Gel 10 (lb/100ft ²)	16	26	30	38	42	48
7	Mud temperature (°F)	75	75	75	75	75	75
8	7.5 min filtrate (cc)	13	3.5	3.0	2.7	2.6	2.5
9	30 min filtrate (cc)	27	11	10.2	9.3	8.1	7.6
10	Filter cake thickness (mm)	3	2.4	2.2	2.1	1.8	1.6
11	Mud cake temperature (°F)	77	77	77	77	77	77

Table 4 The results of adding various concentration of LLP on the properties of Reference Mud, After Hot Rolling (AHR) at 100 °C for 18 h

S. no	Properties	Values					
		Reference Mud (RM)	1% LLP	2% LLP	3% LLP	4% LLP	5% LLP
1	Mud weight (ppg)	8.6	8.6	8.62	8.64	8.65	8.68
2	pH	10	9.8	9.7	9.6	9.4	9.2
3	PV (cp)	06	07	10	12	14	16
4	YP (lb/100ft ²)	07	08	09	14	15	18
5	Gel 0 (lb/100ft ²)	06	08	13	16	18	19
6	Gel 10 (lb/100ft ²)	12	14	18	20	22	25
7	Mud temperature (°F)	75	75	75	75	75	75
8	7.5 min filtrate (cc)	16	8.6	7.6	6.6	5.6	4.7
9	30 min filtrate (cc)	32	17	15.3	13.2	11.2	9.4
10	Filter cake thickness (mm)	3.5	3.1	2.8	2.5	2.2	1.8
11	Mud cake temperature (°F)	77	77	77	77	77	77

Table 5 The results of adding various concentration of CMC (LVG) on the properties of Reference Mud, After Hot Rolling (AHR) at 100 °C for 18 h

S. no	Properties	Values					
		Reference Mud (RM)	0.6% CMC	0.8% CMC	1% CMC	1.2% CMC	1.4% CMC
1	Mud weight (ppg)	8.6	8.63	8.64	8.66	8.68	8.68
2	pH	10	9.9	9.8	9.6	9.3	9.0
3	PV (cp)	06	16	16	24	26	41
4	YP (lb/100ft ²)	07	20	28	35	38	42
5	Gel 0 (lb/100ft ²)	06	14	18	20	24	28
6	Gel 10 (lb/100ft ²)	12	24	28	32	38	42
7	Mud temperature (°F)	75	77	77	77	77	77
8	7.5 min filtrate (cc)	16	7.0	6.3	6.0	5.7	5.3
9	30 min filtrate (cc)	32	14	12.7	12.0	11.5	10.4
10	Filter cake thickness (mm)	3.5	2.9	2.7	2.5	2.3	2.1
11	Mud cake temperature (°F)	77	77	77	77	77	77

millimetres. (Okorie et al. 2019; Amanullah and Tan 2001) (Fig. 2).

Permeability of the filter cake

The permeability of the filter cake is calculated from the relationship between the measured filtrate loss volume and time (shown in Eq. 1) (Elkatatny et al. 2012; Engelhardt 1954).

$$K = (Q_t \times l_t \times \mu) \times \frac{1}{2P \times F \times t} \quad (1)$$

where K = The permeability of the filter cake (k), Q_t = volume of the filtrate in cm³ after time t , l_t = Filter cake thickness in cm, μ = viscosity of the filtrate in centipoise, P = The filtration pressure in Atmosphere, F = Effective filter surface in cm², t = time in seconds.

Results and discussions

FTIR analysis of LLP

Fourier transform infrared spectroscopy with 500–4000 cm^{−1} range was used to analyse the characterization of the LLP. Figure 3 shows the FTIR spectrum of raw LLP. The band at 3420 cm^{−1} assigned to the O–H and N–H stretching group through hydrogen bonding, indicating the presence of the hydroxyl and amino functional groups. The absorption band at 2925 cm^{−1} and 2853 cm^{−1} is attributed to the Aliphatic C–H stretching vibration, showing the alkyl group (–CH₂–). The peak at 1733 cm^{−1} assigned to C=O stretching vibration, showing the presence of a carbonyl group (ketone or aldehyde). The band at 1624 cm^{−1} is assigned to the, N–H bending vibration, indicating the presence of amino (–NH₂) group. The absorption band at 1515 cm^{−1}

Fig. 2 a API LTLF filter press used for the experiment, b filter cake thickness (3.5 mm) of Base Mud after hot rolling, c filter cake thickness (1.8 mm) of 5% LLP Mud after hot rolling

Fig. 3 FTIR Spectrum of LLP

Fig. 4 Schematic diagram of electrosorption experimental device (Xie et al. 2018)

corresponds to N–H bend (secondary amine). The peak at 1457 cm^{-1} corresponds to C–H bending vibration while the peak at 1375 cm^{-1} correspond to C=O symmetrical stretching vibration, indicating the presence of carboxylic group. The absorption peaks from 1318 to 1058 cm^{-1} correspond to C–O stretching, C–N stretching and C–C bending vibration. The absorption peaks from 891 to 518 cm^{-1} represent to C–X stretching vibration ($X = \text{Cl, Br, I}$), showing the presence of halide group.

Electrosorption experiment

Electrosorption device is used for conducting electrosorption experiment. This device consists of three parts: a power supplier controller, electrolytic cell and a plug in electrosorption plate, as shown in Fig. 4.

Approx. 2L quantity of drilling fluid (containing 5% LLP in fresh water) was put in the electrolytic cell and

inserted electrosorption plates into the corresponding slot. The area of the immersed plate in the drilling fluid is 92.4 cm^2 (12 cm (length) $\times$ 7.7 cm (width)). When target voltage of experiment is achieved, started the adsorption time of sample. After the completion of experimental time, the adsorbed solid particles of sample at electrosorption plates were scraped into a beaker and put it in an oven for drying. When sample was dried completely, the amount of solid particles adsorbed during the whole experiment was calculated by the difference in the initial and final weight of the sample (Xie et al. 2018). Experimental outcomes represented in Fig. 5a illustrated that with increasing the electrosorption voltage from 10 to 36 V, increase the adsorbed mass of solid particle from 1 to 2.4 gm, respectively, on the surface of electrosorption plates. Similarly, experimental results shown in Fig. 5b revealed that the mass of solid particles adsorbed is directly proportional to the adsorption time. The mass of solid particles adsorbed were increases from 1 to 6.5 gm with increasing the adsorption time from 3 to 30 min, respectively.

Mud samples analysis

The data generated by experimental evaluation of this eco-friendly additive (litchi leaves powder) reflects the property of fluid loss control. Apart from fluid loss reduction, its effect on mud weight (MW), plastic viscosity (PV), yield point (YP), gel strength and other physical as well as chemical properties were also studied. An account of the experimental results discussing comprehensively each property at different level of concentration of LLP was also carried out against the reference mud sample.

Fig. 5 **a** Effect of electrosorption voltage on the adsorbed solid particle mass. **b** Effect of electrosorption time on the adsorbed solid particle mass

Fig. 6 Effect of different dosages of LLP on mud weight of drilling fluid samples

Fig. 7 Effect of LLP on pH

Effect of LLP on the specific gravity of drilling fluid

The experimental data represented in Tables 2 and 4 reveal that even after the sample was hot rolled at 100 °C, this green additive had no impact on specific gravity of drilling fluid. The specific gravity of samples invariably showed very negligible changes in the physical properties of mud at any concentration ranging from 1 to 5% with respect to reference mud sample. This indicated that LLP is a light natural product with low specific gravity. As evident from the data, Fig. 6 shows that the addition of 1%, 2%, 3%, 4% and 5% concentrations of the LLP to reference mud resulted in the increasing trend of specific gravity varying from 0.23 to 0.58%. At low range of temperature, before hot rolling, it was observed that the specific gravity of mud decreased with increasing the concentration of LLP due to foaming phenomenon. The foaming is a physical surface phenomena which is removed by adding suitable defoaming agents.

Effect of LLP on the pH of drilling fluid

All aqueous-based drilling fluid systems are colloidal in nature and stable in alkaline environment. The befitting range of alkalinity encompassing various types of inhibitive drilling fluids is stable in the alkaline range from pH 9 to 10.5. The alkalinity of the system also inhibits the corrosion characteristic of drilling fluid on the drilling equipment's. pH less than 7 represent the acidic medium and pH more than 7 represent the basic medium, whereas neutral solution represent the pH equal to 7 (MI-Drilling fluids 2000).

Experimental data set showed that after hot rolling of the drilling fluid sample for 18 h at 100 °C, It was found that pH of mud has been reduced by 2–8% with varied concentration of LLP from 1 to 5%, respectively (as shown in Fig. 7). However, pH of mud has been reduced by 1–10% with varied concentration of CMC(LVG) from 0.6 to 1.4%, respectively, as compared to reference mud.

Fig. 8 Effect of LLP on the Rheological Properties of Drilling Fluid before hot rolling (BHR)

Fig. 9 Effect of LLP on the Rheological Properties after hot rolling at 100 °C (AHR)

Effect of LLP on the rheological properties of drilling fluids

Plastic viscosity (PV)

Plastic viscosity of the drilling mud should be less as possible. PV indicates solid–solid and solid to liquid interaction. An enhancement of PV reduced the YP and decreased the hole cleaning capacity of drilling mud (Baker 2006). The experimental data represented in Figs. 8 and 9 show that 1–2% concentration of LLP had little effect on plastic viscosity w.r.t reference mud. However, 3–5% concentration of LLP significantly increased the PV as compared to reference sample, due to frictional forces that may have increased due to the addition of LLP additive. Hence, to control the enhancement of PV, optimization is required. This optimization of LLP addition is based on section, size, depth of the formation drilled and also on the lithology of formation. It was also observed that the enhancement of PV with the various concentrations of LLP was very less as compared to that of CMC (LVG) which makes LLP a better additive than CMC because low PV indicates that

the formulated drilling fluid has a good capability for smooth drilling operations without any complications.

Yield point (YP)

The experimental results represented in Figs. 8 and 9 show that after the addition of this natural product YP of drilling fluid was increased as compared to YP of reference mud. Although there was little effect on the YP with increasing concentration of LLP from 1 to 2%, but as concentration increased from 3 to 5% there was an exponential enhancement in YP by twice to thrice as compared to reference mud. The YP of reference mud after hot rolling was 7 cP. However, the YP of 3%, 4% and 5% LLP mud were increased to 14cP, 15cP and 18cP, respectively. This enhancement in YP indicates that LLP increased the magnitude of attractive forces among the particles of drilling fluid, which would be supported in the lifting of drill cuttings from the bottom hole to the surface.

Gel strength

Gelation/Gel strength of any drilling fluid is a thixotropic property that helps the system to hold suspended drill cutting during the static condition. Gel strength is mainly expressed in gel 0 and gel 10. The gelation measure at 10 s is called gel 0 while the gelation measure at 10 min is called Gel 10. Figures 8 and 9 indicate that the gel strength of drilling mud was increased with increasing the concentration of the LLP as compared to the gel strength of reference mud. After hot rolling of mud samples (shown in Fig. 9), the Gel 0 and Gel 10 value of reference mud were 8 and 16, respectively. However, the gel 0 value of 1%, 2%, 3%, 4% and 5% LLP-based mud were 10, 12, 14, 16 and 18, respectively. Similarly, the Gel 10 value of 1%, 2%, 3%, 4% and 5% LLP-based mud were 17, 19, 22, 24, 26, respectively. The experimental results of Gel 0 and Gel 10 are showing fragile gelation not a progressive gelation. As per Ramsey (2019), Baker (2006) fragile gelation is very essential for optimum drilling operation means the difference between the Gel 0 and Gel 10 values should be less, because this gelation ensure that no excess share stress is required to break the gel again into the fluid when drilling operation would be resumed. Hence, due to good gelation property of LLP, it will help to hold the drill cuttings during the static condition. FTIR test shows the presence of hydroxyl (–OH) group, indicating the reason of moderate effect of LLP on the viscosity and gelation of drilling fluid.

Effect of litchi leaves powder (LLP) on the filtration properties of drilling fluid system

The experiment is carried out at ambient room temperature and at 100 psi pressure through the Whatman filter paper

that acts as a semi-permeable membrane. The samples of drilling fluid were hot rolled at 100 °C for 18 h and then the filtration loss was measured.

The filtration loss of different mud samples was measured at two conditions: before hot rolling (BHR) and after hot rolling (AHR). Figure 10 shows that before hot rolling, the filtration loss volume of reference mud was 27 ml while after hot rolling at 100 °C for 18 h the filtration loss volume of same mud was increased to 32 ml. This observed result is due to decrease of edge to edge and edge to face attractive forces among the bentonite particles with temperature. Thus, to control filtration loss in drilling fluid, the external fluid loss agents such as LLP were used to introduce the cross-linking in the bentonite particles. The result as presented in Table 4 revealed that after hot rolling of mud samples at 100 °C for 18 h, there was a reduction of about 70.6% (i.e. from 32 to 9.4 ml) in filtration loss volume at 5% concentration of LLP mud sample. This filtration loss reduction indicates that LLP introduced the cross-linked among the bentonite particles by strengthening the edge to edge and edge to face force of attraction between the particles. However, a comparison result of LLP and the standard polymers CMC (LVG) fluid loss volume are presented in Tables 4 and 5, respectively. Figure 11 shows that after hot rolling of mud samples at 100 °C, the filtration loss of 1.4% CMC was reduced by 67.5% (from 32 to 10.4 ml). These results indicate that 5% LLP and bentonite particles formed an effective seal as compared to CMC (LVG) during the filtration loss. Therefore, the fluid loss control ability of 5% LLP is more favourable than 1.4% CMC.

Effect of LLP on the filter cake of Drilling Fluid

Filter cake thickness

Experimental results showed that after hot rolling at 100 °C, LLP significantly reduced the filter cake thickness as compared to base mud and the CMC (LVG) mud system. 4% and

Fig. 10 Effect of LLP on the Filtration loss

Fig. 11 Effect of CMC (LVG) on Filtration loss before and after hot rolling at 100 °C

5% LLP have reduced the filter cake thickness by 37.14% and 48.5%, respectively (shown in Fig. 12), whereas 1.2% and 1.4% CMC (LVG) reduced the filter cake thickness by 34.28% and 40%, respectively, as compared to base mud (shown in Fig. 13). Hence, it has been inferred that 5% concentration of LLP significantly reduced the filter cake thickness, which is comparable to the optimized concentration 1.4% of CMC (LVG).

The FTIR spectrum of LLP shows various functional group like –OH, –COOH and –NH₂ group. These functional group have a great tendency to form inter and intramolecular cross-link among the particles (Ermis et al.2018). The chemical cross-linking in the drilling fluid made filters cake impermeable, strengthful and thin, as a results the filtration loss was reduced significantly by the addition of LLP additive.

Slickness and strength of the filter cake

From the physical examination of filter paper (shown in Fig. 2c), it was seen that the filter cake formed by the 5% LLP was smooth, strengthening and slippery. These

Fig. 12 Effect of LLP on the filter Cake Thickness (mm)

Fig. 13 Effect of CMC (LVG) on the Filter Cake Thickness (mm)

Fig. 15 Effect of CMC (LVG) on the Filter Cake Permeability

Fig. 14 Effect of LLP on the filter Cake Thickness permeability

characterizations of filter cake would help in the prevention of differential pipe sticking.

Mud cake permeability

The filter cake is formed on the permeable medium when the liquid part of the drilling fluid migrated through the medium under the influences of the pressure during drilling. The experimental data represented in Fig. 14 shows that after hot rolling of mud samples at 100 °C, the permeability of the filter cake was reduced with increasing the concentration of LLP. The permeability of the filter cake formed by 4% and 5% LLP was 2.5×10^{-5} D and 1.9×10^{-5} D, respectively. While the permeability of 1.4% CMC was 2.5×10^{-5} D (shown in Fig. 15) These data proved that the filter cake formed by 4–5% LLP mud have a greater plugging tendency to prevent the flow of filtrate from the filter cake as compared to 1.4% CMC. However, due to the higher permeability of the filter cake made by reference mud, i.e. 12.9×10^{-5} D, indicates the greater filtration loss in reference mud (Table 6).

Table 6 Cake permeability for water-based mud formulated after hot rolling of mud samples at 100 °C

Concentration	Filter cake permeability (D)	Concentration	Filter cake permeability (D)
RM	12.9×10^{-5}	RM	12.9×10^{-5}
1% LLP	6.08×10^{-5}	0.6% CMC (LVG)	4.6×10^{-5}
2% LLP	4.9×10^{-5}	0.8% CMC (LVG)	3.9×10^{-5}
3% LLP	3.8×10^{-5}	1% CMC (LVG)	3.5×10^{-5}
4% LLP	2.8×10^{-5}	1.2% CMC (LVG)	3.05×10^{-5}
5% LLP	1.9×10^{-5}	1.4% CMC (LVG)	2.5×10^{-5}

Conclusion

The detailed experimental studies carried out on litchi leaves powder have ultimately qualified it as one of the best fluid loss green additive, a natural waste of litchi plant (*Litchi chinensis*), easily biodegradable. The study can be concluded by following few observations:

- LLP is a biodegradable, non-pollutant, cost effective, multifunctional, bio-enhancer and environmentally friendly additive.
- The thermal stability of the LLP as drilling fluid additives has been proven to withstand a range of temperature up to 100 °C. This temperature resistant property make it more effective additive in the water-based drilling fluid.
- FTIR spectrum confirmed the different functional group such as hydroxyl (–OH) group, carbonyl group (aldehyde or ketone), carboxylic acid (–COOH), amine group and halide group in the LLP.
- The samples of the LLP blended drilling fluid, hot rolled at 100 °C, had negligible effect on the mud weight. There was no increase in the total solid content and hence specific gravity of resultant drilling fluid was almost constant. The foaming issue associated with the

addition of this product was taken care of, by adding suitable de-foamers.

- The addition of LLP had little effect on plastic viscosity at 1–2% concentration. However, at higher concentration, above 2%, plastic viscosity was found to be increased, although this enhancement was very less as compared to CMC Polymer, which make it better additive than CMC.
- Addition of the LLP had little effect on the yield point of drilling fluid at lower concentration (1–2%), but at higher concentration (3–5%) it increased YP as compared to reference mud.
- LLP significantly reduced the filter cake thickness of drilling fluid. After hot rolling at 10 °C, 4% and 5% LLP reduced filter cake thickness by 37.14% and 48.57%, respectively, as compared to reference mud.
- LLP was found to be an effective water loss reducer and a befitting natural product that prevents hydration of very active clay and shale formation. It is a commercially viable alternative to other costly polymer like CMC, used for fluid loss reduction in the system. Results showed that after hot rolling at 100 °C for 18 h, 4–5% Litchi LLP reduced filtration loss by maximum 70.6%. Its effect was compatible with 1.4% of CMC (LVG).

Hence, it has been concluded that the LLP is stable up to 100 °C like an existing fluid loss additive CMC (LVG). Therefore, 5% concentration of LLP can be used as a filtration loss control additive as an alternative to the optimized concentration of CMC (LVG) in water-based drilling fluid.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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