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ORIGINAL PAPER

Development of high-performance water-based drilling fluid using biodegradable eco-friendly additive (Peanut Shells)

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Abstract
Drilling operation is considered an extremely high-cost business within the petroleum industry. The cost of drilling fluid represents 15–30% of drilling operations. Measurements of all drilling mud properties were conducted in aged and fresh conditions. Furthermore, high pressure and temperature (HTHP) API filtration experiments were executed, as well. The findings were used as a reference comparative point for three concentrations of peanut shell powder (PSP) to comprehend the influence of various concentrations of PSP on the characteristics of spud mud. The findings of this experimental research revealed that the cheap and biodegradable PSP can be exploited as a new multi-role additive to develop filtration and viscosity under surface and sub-surface conditions. Moreover, the study findings demonstrated the suitability of PSP to replace or at minimum substitute traditional and non-degradable chemicals used in the petroleum industry (e.g., lignosulfonate, chrome-lignosulfonate, resinex, etc.). In addition to the benefit of using PSP as a multifunctional additive, it is cheap, easy to prepare, locally available and attainable in large quantities, and friendly to the environment. In summary, PSP has a possibility to be applied in the oilfield as it withstood 79 °C (175 °F) temperature and 30 h of aged time. The application of PSP in the drilling process can mitigate the detrimental impacts of the non-biodegradable conventional chemical materials on personal health safety and the environment in addition to decreasing the overall cost.

Keywords Waste materials · Drilling mud · Peanut shells · Filtration characteristics

Introduction

After a consumer has used a product, there are often portions that are not consumed or utilized. This residual waste, or waste materials, begins to accumulate at collection sites and begin to pose health and environmental hazards. The source of waste products is diverse, including but not limited to households, industrial complexes, and commercial sites. The diversity of the sources creating the waste create different concerns depending on what is being disposed of, such as unsafe wastewater, toxic, radioactive, and food waste. The origins of several types of waste are described as the following (John Hopkins University 2006, p. 2):

- The portions of food that are disposed of to the environment such as fruit and vegetable peels, peanut shells, and sunflower shells.
- Household garbage varies and can be classified as either safe or unsafe items. Examples of household waste are batteries, cans, papers, household cleaners, etc.
- Any waste, such as chemical additives, pesticides, and solvent-based paints that cause a danger to personnel or the environment, is considered to be hazardous waste.
- Construction waste is the leftover or discarded materials produced by building sites. The most common construction waste is bricks, wood, concrete, etc.
- Wastewater is water contaminated with any waste. Industries and households can create wastewater
- Nuclear wastes are created from radioactive materials.

Waste materials are of increasing concern in modern society, as they cause many undesired impacts on safety

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and the environment. To reduce the impacts of wastes, it is crucial to develop methods of reusing waste products rather than discarding them in landfills. The petroleum industry could assist in providing a means for using waste materials by replacing traditional materials used with waste products that would otherwise end up in collection sites. For example, food wastes can be utilized as drilling mud additives for drilling operations (Al-Hameedi et al. 2019a, pp. 1–3). Other waste additives also demonstrate their ability to be exploited by the petroleum industry. Palm tree leaves and grass powder can be applied as environmentally friendly drilling mud additives (Al-Hameedi et al. 2019b, pp. 4–9; Al-Hameedi et al. 2019c, pp. 5–9; Al-Hameedi et al. 2019d, pp. 3–5). Moreover, other food wastes such as potato peels have proven the applicability to be used as drilling fluid additives (Al-Hameedi et al. 2019e, pp. 5–10).

Other researchers have also studied the potential use of wastes in different applications in the petroleum industry. Banana peels were tested to be employed in mud applications (Al-Hameedi et al., 2020a, pp. 1–6). Wastes generated from palm trees were used in drilling fluids; the results showed a reduction in properties associated with lost circulation and improved the seepage loss type (Ramasamy and Amanullah 2018, pp. 4–9). The application of plant waste additives extends beyond drilling into production and completion as well. Carpenter (2015, pp. 3–7) examined biodegradable materials' ability to plug perforations in a horizontal well in order to perform refracturing operations. Biodegradable additives were also used in the completion of fluid applications (Babey et al. 2015, pp. 3–8).

Patidar et al. (2020. pp. 8–15) conducted a lab study to explore the ability to invest the groundnut husk as an eco-friendly additive to modify the characteristics of the mud; however, the authors did not subject the mud blends of groundnut husk to the aged conditions (sub-surface environments), and only the fresh conditions applied to examine the efficiency of groundnut husk. On the other hand, this current research work overcomes this shortcoming and it introduced both the fresh and aged conditions, as well as both low temperature and pressure (LTLP) and high temperature and pressure (HTHP) filtration experiments to guarantee the effectiveness of peanut shells powder (PSP) at downhole conditions and the lab findings revealed that PSP was not affected by the aged conditions and it performed effectively.

Lab tests were implemented to locate the influences of introducing PSP to the base fluid. The evaluation tests include mud weight, rheology, pH, and fluid loss properties for both surface and sub-surface conditions. Hence, this work tests the applicability of a new eco-friendly additive−peanut shells powder (PSP) as new material to modify the physical properties of the drilling mud such as viscosity, filtration characteristics, and alkalinity. Subsequently, establishing an understanding of how the abundance of waste materials can contribute to achieving the objective of reducing the impacts of the petroleum industry, while also utilizing food and plant waste. The research was executed in the labs of the Missouri University of Science and Technology through the year 2020.

Peanut shells background

Drilling wells in the petroleum industry require the circulation of drilling mud streams which serves several purposes including lubrication of the drill bit, supporting of the borehole wall, plastering of the wall to prevent filtration of fluids out of the borehole, and transporting the cuttings to the surface. In general, drilling muds can result in undesirable chemical impacts on the reservoirs being drilled leading to adverse chemical reactions in the borehole. The negative chemical impacts on the borehole can be significantly minimized, and the drill pipe friction can also be reduced by adding selective PSP to drilling fluids (Forrest and Place II 1992, pp. 1–2).

The peanut is a plant that falls under the legumes family, which is similar to other plants, like beans, lentils, peas, and chickpeas. Peanuts are grown in Asia, Africa, North and South America, and Australia. The origin of the peanut is South America. The first international peanut plants were brought from South America and presented to Europe by Columbus (Patidar et al. 2020, pp. 1–4). Currently, peanuts are grown globally on different continents. Asia has the highest worldwide peanuts production rate of approximately 65.3%. The second highest is Africa with the peanuts production rate of 26.2%, followed by the Americas and Oceania with production rates of 8.4% and 0.1%, respectively (Patidar et al. 2020, pp. 1–4).

The 2016 statistical yearbook presented by the food and agriculture organization (FAO) shows that peanuts production reached an amount of 43.98 million tons which was produced over 27.66 million hectares (Perea et al. 2018, pp. 1–3). As far as the top five global countries which produce the highest peanuts, China with a total peanuts production of 33.31 million tons is considered the largest among all countries. The second-largest producer is India which produces 6.86 million tons, followed by other countries; Nigeria produces 3.03 million tons, the United States produces 2.58 million tons, and finally, Sudan produces 1.83 million tons.

Peanuts are used mainly for consumption by humans and by animals. Peanuts are used for a variety of purposes, but peanuts are extensively used as confectionery products, or as snacks. The peanuts confectionery products include sweets, cereals, biscuits, bread, and salads. In the United States, the largest product of peanuts is peanut butter. Peanuts are known to have an elevated fat percentage. Thus, they are being utilized to produce oils, creams, flours, inks, lipsticks, etc. Besides, peanuts have been successfully used to produce biofuel products, such as biodiesel (Patidar et al. 2020, pp. 1–4).

Peanut shell waste is generated by the peanuts industry. Peanut shell residue eliminated from the industry represents 25 to 30% of the total weight of the peanuts processed either for producing oil or for direct consumption as nuts. It is estimated that the annual world production of wasted shells from the peanut industry is about 11,000,000 tons. Therefore, a large amount of shell waste is readily available to be used as alternatives for generating energy, or for other potential applications or purposes (Patidar et al. 2020, pp. 1–4).

As far as utilizing peanut shells in drilling fluid, the hulls or shells from peanut plants, including the fibrous layer, can be ground up to a fine powder-like material that can be packed, and transported easily to the well site. The quantity of shell powder to be added to drilling fluids can range from one pound to forty pounds per barrel. Although the chemical reaction of shell-based additive in drilling fluid is not yet known, increasing efficiency in the drilling rate and decreasing adverse chemical reactions are anticipated. Using the peanut shell-based additives in drilling fluids may have potential benefits over conventional additives, including biodegradability and non-toxic, preventing seepage loss and stuck pipe, sealing off depleted sands and microfractures, reducing wall cake permeability, reducing bit balling, drag, and torque, and minimizing shale problems (Forrest and Place II 1992, pp. 1–2).

Materials and methods

Peanut shells powder (PSP)

First, the raw material of the peanut shells (PS) was compiled in-house as shown in Fig. 1. In order to dry peanut shells, they were put in an oven under 100 ºC (212ºF) for an hour. Next, peanut shells were left in a dry place for 2–3 days in the laboratory. Then, peanut shells were placed in the oven again for 45 min under the same previous temperature to ensure a complete drying process. To grind peanut shells into a fine powder, a food processer was utilized. To find the particle size of peanut shells, a sieve analysis was conducted. The size of the PSP particles was determined to be 53–297 µm. Figure 2 shows PS powder, while Fig. 3 exhibits the food processer used to grind PS. Figure 4 summarizes the procedure of gathering and preparing the PSP.

Fig. 1 The raw waste of peanut shells (PS)

Fig. 2 The peanut shells powder (PSP)

Methods

Fresh conditions (F.C)

To comprehend the impacts of multiple concentrations of PSP on drilling mud characteristics, reference mud (RM) was prepared, and it is composed of 0.2 g of NaOH, 700 cm^3 of water, and 42 g of bentonite. Next, measurements of all RM properties were conducted and compared with the measurements after adding three concentrations of PSP to RM. The rheological characteristics such as plastic viscosity (PV), yield point (YP), gel strengths (initial and final) were measured utilizing Model 800 Viscometer. Marsh funnel viscosity was measured using marsh funnel viscometer, while fluid density was measured utilizing mud balance (unpressurized). Mud filtration experiments were conducted at low pressure and temperature (LTLP) at 100 psi and 75 ºF using the LTLP API filtration press.

Fig. 3 The food processor

Moreover, mud filtration was measured at high pressure and temperature (HTHP) at 500 psi and 250 ºF using the HTHP API filtration press. The mud cake thickness was measured using manual and digital vernier calipers. Furthermore, the pH meter was used to measure pH.

0.75% (5.25 gm), 1.5% (10.5gm), and 2.5% (17.5 gm) concentrations of PSP were utilized and added independently to RM. To ensure no bacteria issues with PSP, the fluid samples including three different concentrations of PSP were placed in the laboratory under ambient conditions for 24 h. No bacteria issues were encountered with PSP. Then, the same measurements that were performed on RM have exactly been conducted to three separate concentrations of PSP to comprehend the impacts of PSP additives on RM. Figure 5 shows the apparatus utilized in this work.

Aged conditions (A.C)

The aging condition is a procedure where the drilling mud sample is permitted to fully develop its filtration and rheological characteristics (Fann Instrument Company 2005, pp. 16–22). The temperature has a significant effect on the chemical additives used to control fluid properties. Ambient laboratory conditions do not mimic the actual wellbore conditions. When conducting a pilot test, the chemical additives must be monitored constantly under aged conditions. As a result of elevated temperatures, mud properties may be changed and lead to critical problems (Basra oil Company 2016). Therefore, to test the possibility of utilizing PSP at underground conditions, PSP samples aged using an aging cell. Aging cells and a roller oven were utilized to mimic underground conditions (shown in Fig. 6). The samples were placed in an oven under dynamic roller conditions for 30 h at 79 °C (175 °F). Then, the samples were placed in the lab to test bacterial issues, and no bacterial issues were observed. The same previous experiments were executed for the aged samples. Then, the results of both aged and fresh conditions were compared.

Results and discussion

Table 1 highlights how the findings altered after presenting 0.75%, 1.5%, and 2.5% of PSP material for lab conditions. On the other hand, Table 2 shows the results of the aged conditions. Overall, under fresh and aged conditions, PSP additives have shown a great potential to decrease the rheological properties. Thus, it can be employed as a thinner in the mud system for water-based type. Also, the PSP can be used as a filtration control agent since it reduced filtration. Moreover, the findings show that PSP can be utilized as a pH reducer. The following sub-sections will discuss the results of PSP in detail.

Fig. 4 Preparation of peanut shells powder (PSP)

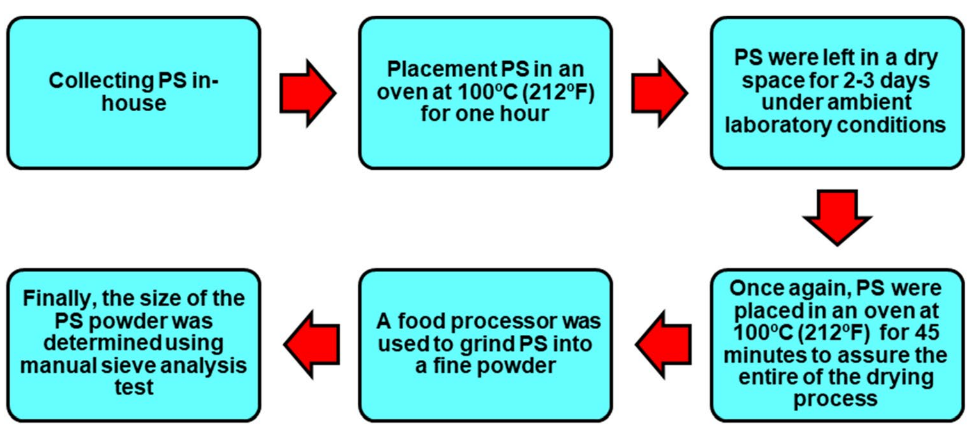

Fig. 5 The apparatus utilized in this work

(a) (b)

Fig. 6 **a** Roller oven, **b** Aging cell

Table 1 Summary of fresh conditions lab data (15 °C (60 °F))

Property	RM	0.75% PSP	1.5% PSP	2.5% PSP
Mud weight, (lb/gal)	8.6	8.6	8.6	8.6
Marsh funnel viscosity, (Sec.)	38	33	31	31
PV, (cp)	7	7	6	6
YP, (lb/100ft^2)	10	5	4	3
Initial gel strength, (lb/100ft^2)	11	7	6	4
Final gel strength, (lb/100ft^2)	18	11	10	8
pH	10.4	9.4	8.5	8.2
7.5 min filtrate, (cc) (LTLP)	6.25	4.5	4.25	4.25
30 min filtrate, (cc) (LTLP)	13	9.5	9	8.75
Filter cake thickness, (mm) (LTLP)	3.1	2	1.9	1.9
7.5 min filtrate, (cc) (HTHP)	19	14.5	14.25	14
30 min filtrate, (cc) (HTHP)	36	28	27.5	27
Filter cake thickness, (mm) (HTHP)	5.2	4	3.9	3.8
% by Vol. solids	1	1	1	1

Table 2 Summary of aged conditions lab data (79 °C (175 °F) & 30 h of aged time))

Property	0.75% PSP	1.5% PSP	2.5% PSP
Mud weight, (lb/gal)	8.6	8.6	8.6
Marsh funnel viscosity, (Sec.)	32	31	31
PV, (cp)	6	6	6
YP, (lb/100ft^2)	5	4	4
Initial gel strength, (lb/100ft^2)	7	4	4
Final gel strength, (lb/100ft^2)	12	9	9
pH	8.6	8.4	8.1
7.5 min filtrate, (cc) (LTLP)	3.5	3.25	3.5
30 min filtrate, (cc) (LTLP)	8	7.75	8
Filter cake thickness, (mm) (LTLP)	1.6	1.4	1.4
7.5 min filtrate, (cc) (HTHP)	15	14.5	14.5
30 min filtrate, (cc) (HTHP)	28.5	27.75	27.75
Filter cake thickness, (mm) (HTHP)	3.7	3.5	3.4
% by Vol. solids	1	1	1

Can the PSP be employed as a thinner additive?

This sub-section starts by discussing the change in the bounds of the bentonite material and the response in terms of its properties such as desperation, suspension, and flocculation. The first part of this finding discussion will be related to fresh conditions. The effects of blending 0.75% (5.25 gm), 1.5% (10.5 gm), and 2.5% (17.5 gm) concentrations of PSP on the rheological characteristics and marsh funnel viscosity were determined compared with the RM properties. The results revealed that PSP had no effect on PV at 0.75% additive, and it had a negligible impact on PV at 1.5% and 2.5% as compared to RM. Nevertheless, PSP additives significantly decreased YP, whereas 0.75% of PSP concentration reduced YP by 50%, while 1.5 and 2.5% of PSP additives were more efficient and minimized YP by 60% and 70%, respectively. Similarly, the three mixtures of PSP robustly minimized the specifications of gel strengths by comparing them to RM. In the same context, marsh funnel viscosity was reduced by 14% at 0.75% concentration and by 19% at 1.5% and 2.5% after adding PSP mixtures. Figures 7 and 8 exhibit the impact of all PSP blends on the rheological properties and viscosity of the marsh funnel as compared to RM for lab conditions, respectively.

On the other hand, sub-surface terms of 30 h and at 79 °C (175 °F) had a slight favorable influence on the viscosity of marsh funnel and rheology and for all additives of PSP when compared to the same additives of PSP at lab conditions. The results elucidate that the concentration variation did not influence YP, PV, and marsh funnel viscosity, while the effectiveness of the blends variation was minor for gel strengths. Hence, it can be deduced that PSP efficiently behaved under the simulated wellbore conditions, and it can be invested as a thinner agent. Figures 9 and 10 show the impact of three PSP mixtures on rheological properties and marsh funnel viscosity at sub-surface terms when comparing them to the three PSP additives at lab terms, respectively.

In consequence, all blends of PSP reduced the rheological characteristics and marsh funnel viscosity at the surface and downhole terms. Besides, the findings disclosed that PSP was not impacted by the aged terms. On the contrary, downhole conditions slightly enhanced the desperation and suspension of the base fluid when comparing to lab conditions. Moreover, outcomes exhibited higher concentrations of PSP in the base fluid resulted in more reduction in the rheological properties. Hence, 0.5–1% concentrations of PSP material are recommended to be invested as a viscosity reducer during penetrating rocks to provide better performance. Accordingly, the findings of the lab exhibited the

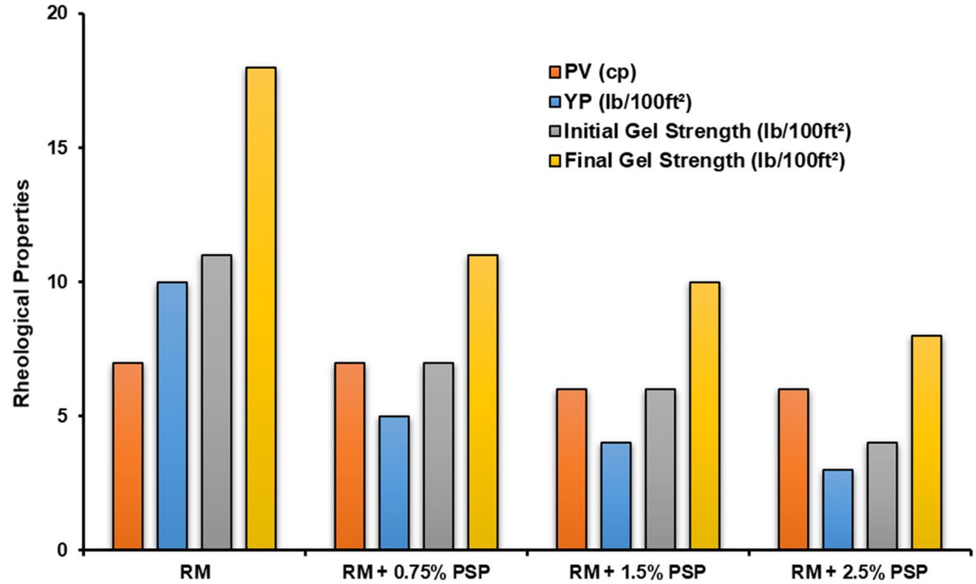

Fig. 7 Influences of PSP on rheological properties at fresh conditions (15 °C (60 °F))

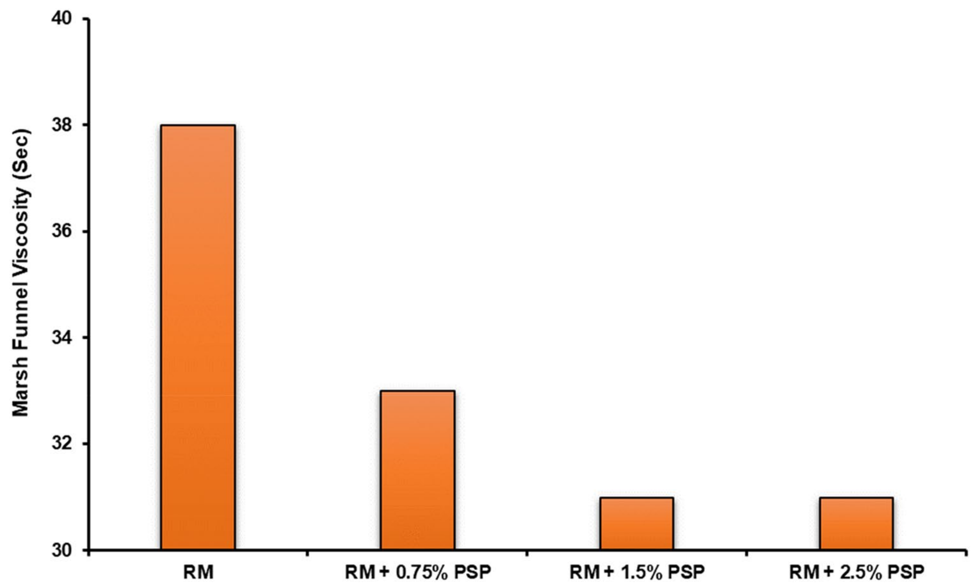

Fig. 8 Influences of PSP on viscosity of marsh funnel at fresh conditions (15 °C (60 °F))

possibility of PSP to be employed as a thinner agent for the type of water-based fluids. In other words, PSP can deliver the same aims as conventional thinner additives can achieve in the field. Nevertheless, PSP must be inspected at various downhole conditions to emphasize that PSP is functional at hostile conditions. For that reason, more checking must be implemented in hostile environments in addition to gathering peanut shells rather than disposing of them.

Can the PSP be employed as a filtration control agent?

According to the lab findings at fresh conditions, both LTLP and HTHP experiments of the seepage loss characteristics were improved when compared to the base fluid. For LTLP outcomes, by 27%, 31%, and 33% at 0.75%, 1.5%, and 2.5% of PSP blends, respectively, the filtrate (cc/30 min) was reduced. In the same context, the thickness specifications of the filter cake were remarkably enhanced. While for alteration in HTHP filtration (250 ºF and 500 psi) tests, the findings were as well impressive in ameliorating the specifications of both mud thickness and fluid loss, where introducing 0.75%, 1.5%, and 2.5% of PSP additives minimized the HTHP filtrate by 23%, 24%, and 25%, respectively. In the same vein, the thickness characteristics of the mud cake were also improved impressively. To elucidate these positive effects on the filtration characteristics as compared to RM at fresh terms (LTLP and HTHP), Figs. 11 and 12 were plotted.

According to the lab findings at the aged terms for 30 h and at 79 °C (175 °F) terms, lab data clarified that aged

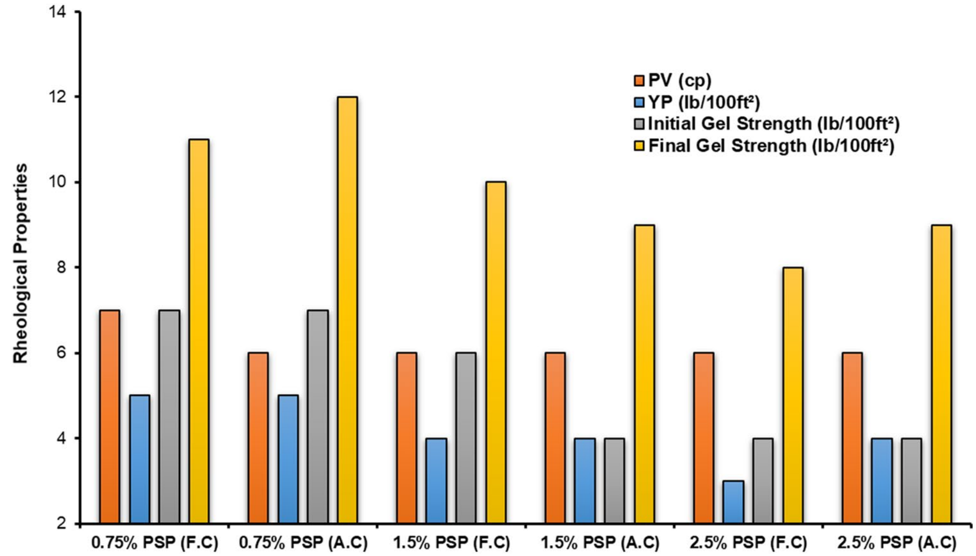

Fig. 9 Influences comparison of PSP on rheological properties at fresh conditions (15 °C (60°F)) and aged conditions (79 °C (175 °F) & 30 h of aged time))

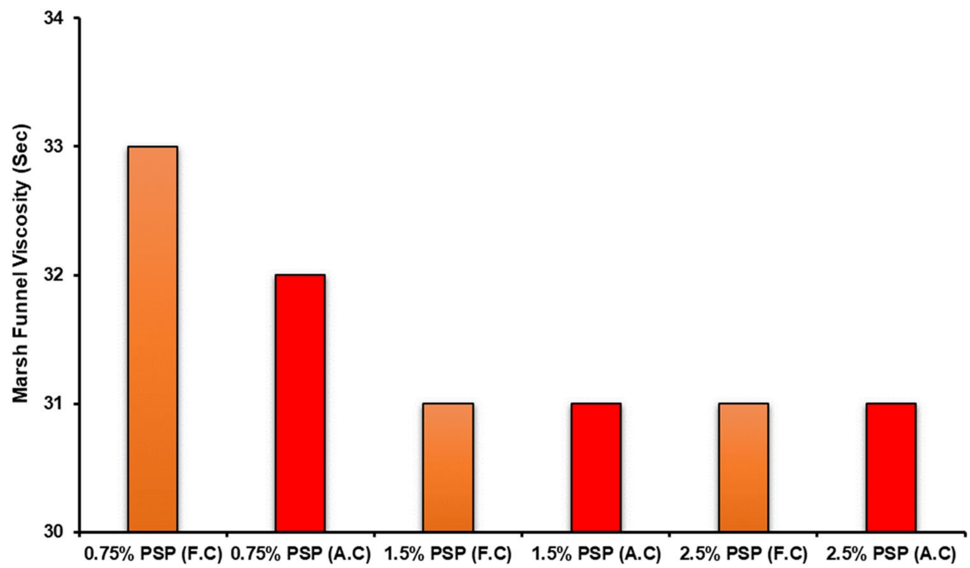

Fig. 10 Influences comparison of PSP on viscosity of marsh funnel at fresh conditions (15 °C (60 °F)) and aged conditions (79 °C (175 °F) & 30 h of aged time))

terms minimized filtration loss as compared to fresh terms and for all blends of the PSP at LTLP filtration control experiments conducted at 75 ºF and 100 psi. In the same context, the HTHP tests stated that mud loss (cc/30 min) was insignificantly altered by the aged conditions. However, the mud cake thickness changed, and it was minimized for all concentrations by comparing them to the fresh terms. To highlight the performance comparison between fresh and aged terms and for both LTLP and HTHP conditions, Figs. 13 and 14 are plotted.

To summarize, all concentrations of PSP boosted the properties of filtration at both surface and downhole environments and for both LTLP and HTHP. Also, the lab data exhibited that PSP additives were not influenced by hostile conditions. On the contrary, aged terms reinforced the mud loss characteristics when compared to lab conditions for LTLP. Likewise, the lab data revealed that an increase in the concentration of PSP additives had little effect on the specifications of mud cake thickness and mud loss. Therefore, suggesting 0.5–1% additives to be employed as a filtration agent for a functional accomplishment in the drilling process.

Can the PSP be employed as a treatment in partial loss?

Mud loss might also happen at any zone in the drilling operation. If a fluid loss happens while penetrating the formation, the focal point of the remedy is to mitigate or plug off the thief zone in order to complete the drilling process as a corrective approach. Also, controlling key drilling parameters

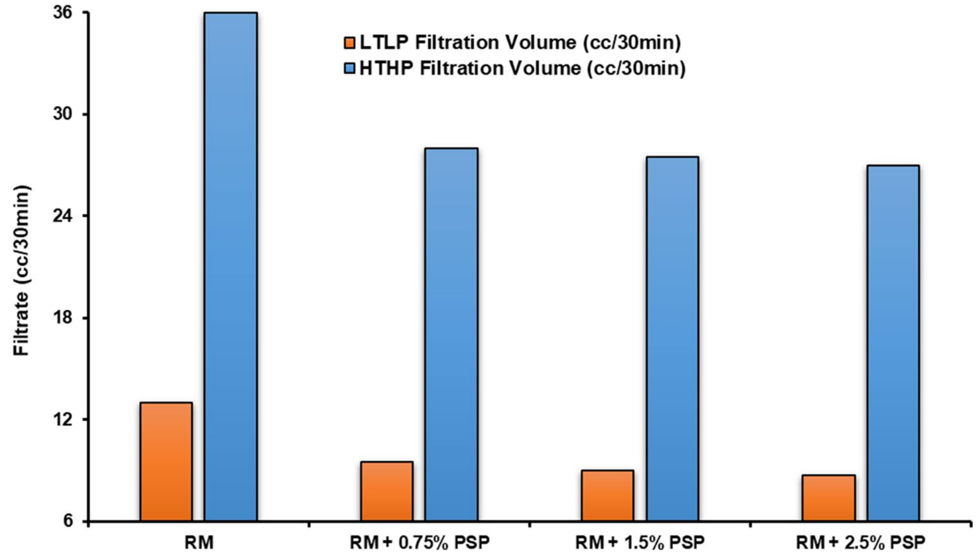

Fig. 11 Influence of PSP on filtrate at fresh conditions (15 °C (60 °F)) (LTLP (60 °F and 100 psi) and HTHP (250 ºF and 500 psi))

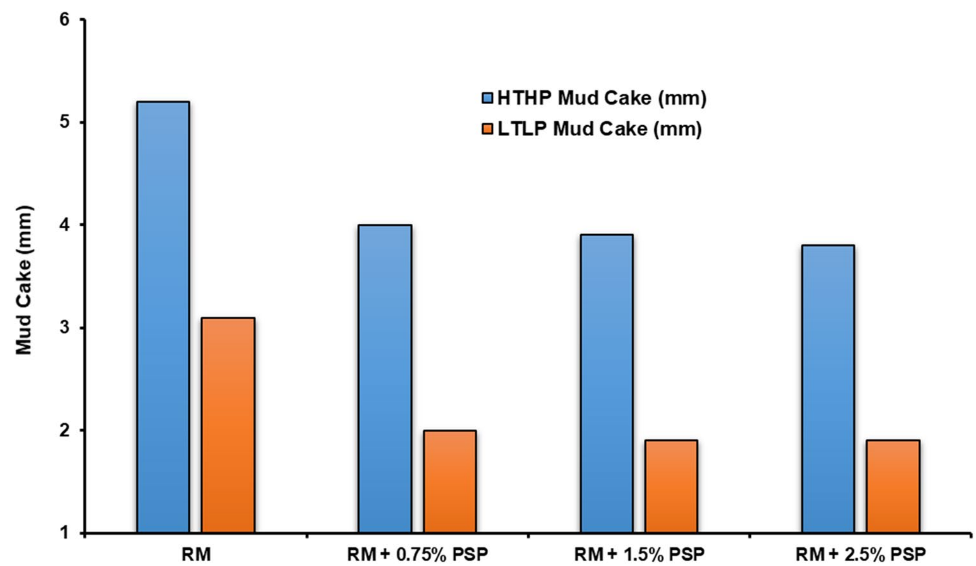

Fig. 12 Influence of PSP on mud cake fresh conditions (15 °C (60 °F)) (LTLP (60 F and 100 psi) and HTHP (250 ºF and 500 psi)))

give the potential to bypass or at least lessen mud loss as a preventive way. However, avoiding or mitigating fluid loss in thief formations requires the crew to have a very good experience and knowledge which is mostly not obtainable. That is why the industry depends largely on investing in corrective techniques of minimizing these troublesome issues after they occur (Al-Hameedi et al. 2017, pp. 4–8; Al-Hameedi et al. 2018, pp. 2–7).

The most popular remedies utilized to regulate partial mud losses are flaky, granular, and fibrous materials as well as high viscosity pills (Alkinani et al. 2019, pp. 3–9). Low-density drilling fluid mixed with any of the LCM additives can be used to treat partial loss. The lab data at fresh and aged environments showed that PSP had the feasibility to be exploited as an additive for mitigating partial loss. Mud balance measurements as well as LTLP and HTHP filtration control experiments, provided insights for PSP materials to be employed as a corrective approach to stop partial loss. The aim of including and debating fluid density in this part is because all remedies that are commonly invested to control partial fluid loss or any type of lost circulation are highly recommended to have a low density to avoid any increase in the effective circulation density. The main target of having low density remedial pills is to bypass excessive bottom-hole pressure in front of depleted formation (Basra oil Company, 2016). In summary, the concentrations of PSP did not influence density at fresh and aged terms. Additionally, the lab data elucidated that PSP was not impacted by sub-surface circumstances as shown in Tables 1 and 2.

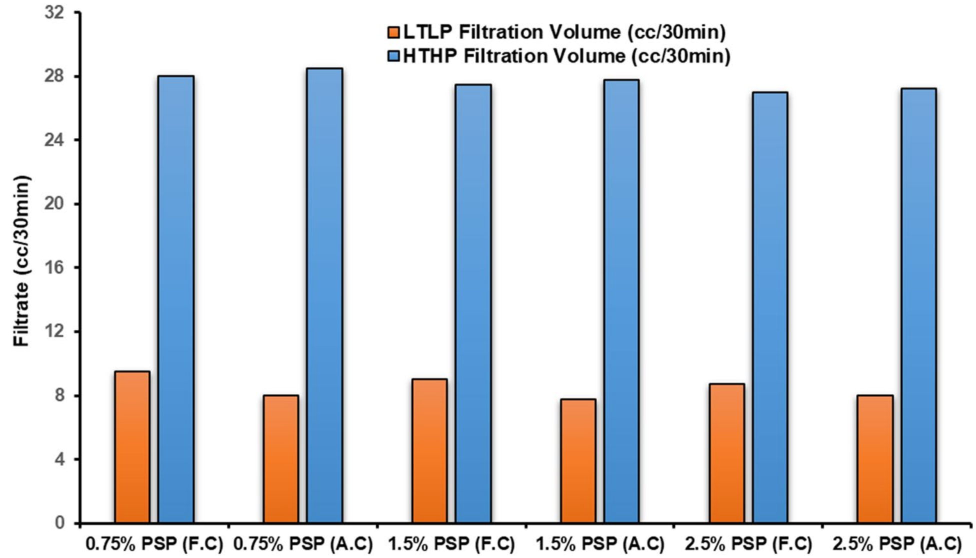

Fig. 13 Comparison of PSP influence on filtrate at fresh conditions (15 °C (60°°F)) and aged conditions (79 °C (175 °F) & 30 h of aged time))

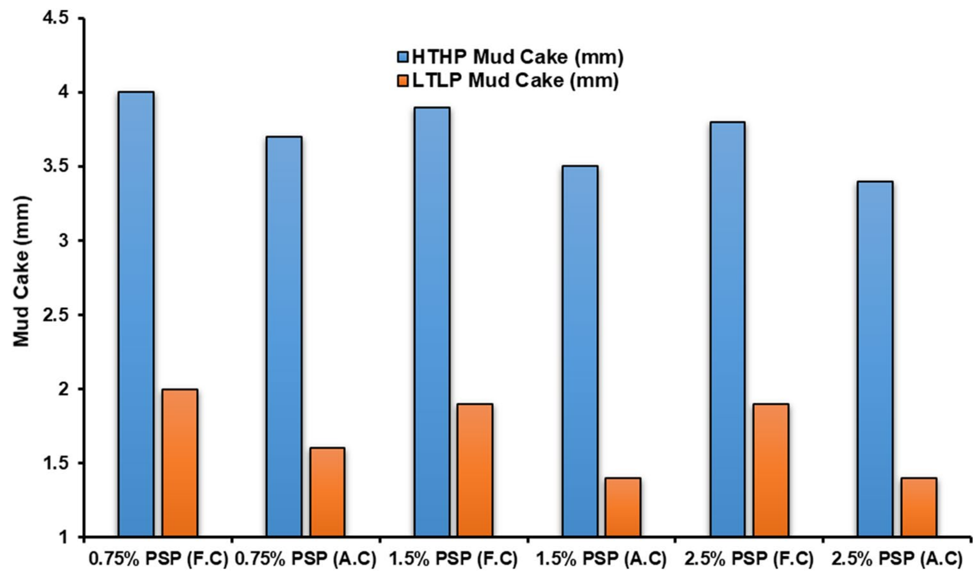

Fig. 14 Comparison between PSP influence on mud cake at fresh conditions (15 °C (60 °F)) and aged conditions (79 °C (175 °F) & 30 h of aged time))

Can the PSP be employed as a pH reducer?

The pH is vital for drilling fluid for many reasons such as preventing corrosion of equipment, providing a good environment of chemical additive used in the drilling operations, and stability during shale drilling. After adding three concentrations of PSP, the findings showed that PSP decreased pH as compared to RM by 9%, 19%, and 22% at 0.75% 1.5%, and 2.5% concentrations for fresh conditions, respectively. In the same context, pH minimized by 16%, 20%, and 23% at 0.75% 1.5%, and 2.5% concentrations for aged condition, respectively. Hence, the experimental results demonstrated that PSP additives can reduce alkalinity. Hence, it can be invested to be used as a pH reducer, especially during drilling cement. Figure 15 illustrates the influence of three PSP concentrations on alkalinity as compared to RM under fresh and aged terms.

Conclusion

This study aims to distinguish peanut shell powder (PSP) and how it can be employed as a substitutional or supportive material for conventional drilling fluid additives. Where this shift from conventional to unconventional can revolutionize the petroleum industry, and the transformation of food waste products into valuable commercial additives will introduce as a robust catalyst for the evolution of local and international manufacturers and generating of new job scopes; in addition to inspiring the eco-friendly

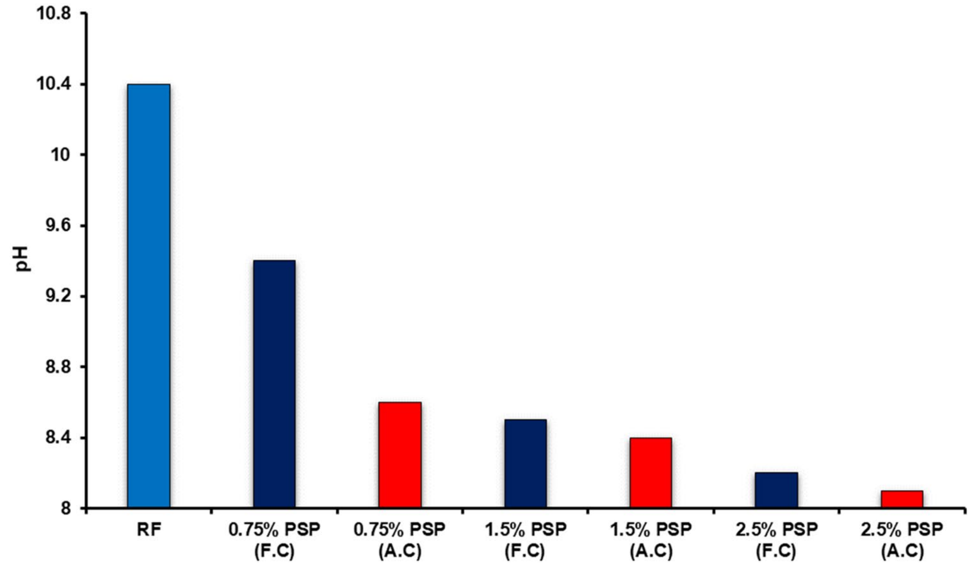

Fig. 15 Comparison between the influences of PSP on the pH at fresh conditions (15 °C (60 °F)) and aged conditions (79 °C (175 °F) & 30 h of aged time))

wastes materials manufacturer as one of the most appealing mercantile sectors of the worldwide. The following points were made based on this work:

- PSP has a lower specific gravity when juxtaposed to LCMs (e.g., $CaCO_3$) and due to its outstanding performance in terms of enhancing the seepage loss specifications, PSP particles tend to suspend in drilling fluid and thus can present minimal settlement-related problems. Also, PSP can be an additive for partial loss treatment because it has a neutral effect on mud weight, which makes PSP an excellent candidate to be utilized in high concentrations without any detrimental effects on the drilling fluid density.
- Bit nozzles plugging problems can be minimized when utilizing PSP due to its particulates being fine in size when juxtaposed to granular or fibrous commercial materials.
- The results of the experimental work showed an efficient and excellent performance of PSP when used as a multi-role additive to control filtration, minimize viscosity, and limit alkalinity.
- Aging the PSP samples did not affect PSP effectiveness. Thereby, PSP can potentially be utilized in the oilfield under sub-surface conditions.
- Since peanut shells are biodegradable, environmentally friendly, non-toxic, widely available, and have no bacterial issues, they are appropriate for various green fluid applications in the petroleum industry.
- The large-scale utilization of peanut shells and their economical contribution may inspire the peanut agricultural industry to be one of the most attractive worldwide.

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