01 Dec 2020

Utilizing a New Eco-Friendly Drilling Mud Additive Generated from Wastes to Minimize the Use of the Conventional Chemical Additives

Abo Taleb T. Al-Hameedi

Husam H. Alkinani

Mohammed M. Alkhamis

Shari Dunn-Norman
Missouri University of Science and Technology, caolila@mst.edu

Journal of Petroleum Exploration and Production Technology (2020) 10:3467–3481
https://doi.org/10.1007/s13202-020-00974-6

ORIGINAL PAPER-EXPLORATION ENGINEERING

Utilizing a new eco-friendly drilling mud additive generated from wastes to minimize the use of the conventional chemical additives

Abo Taleb T. Al-Hameedi[1] · Husam H. Alkinani[1] · Mohammed M. Alkhamis[1] · Shari Dunn-Norman[1]

Received: 5 March 2020 / Accepted: 4 August 2020 / Published online: 27 August 2020

Abstract
The cost of the drilling operation is very high. Drilling fluid presents 15 to 30% of the entire expense of the drilling process. Ordinarily, the major drilling fluids additives are viscosity modifiers, filtration control agents, and partial loss treatments. In this experimental work, full-set measurements under fresh and aged conditions, as well as high-temperature and high-pressure (HTHP) API filtration, were conducted to study the impacts of adding 0.5%, 1.5%, 2.5%, and 3.5% of black sunflower seeds' shell powder (BSSSP) to spud mud. BSSSP of various grain sizes showed their ability to be invested for viscosity modifying, seepage loss controlling, and partial loss remediation. In addition to BSSSP eminent efficiency to be used as a multifunctional additive, the BSSSP is cheap, locally obtainable in commercial quantities, environmentally friendly additive and easy to grind into various desired grain sizes. Besides its outstanding strength to behave under conditions up to 30 h aged time and under 50 °C (122 °F) temperature, the utilization of powdered waste black sunflower shells in the drilling process and other industrial applications can reduce the effects of food waste on the environment and the personnel safety. To sum it up, experimental findings revealed that BSSSP can be used for multiple applications as a novel fibrous and particulate additive. The results elucidated BSSSP suitability in substituting or at least minimizing some of the traditional chemical materials utilized in the petroleum industry such as salt clay, polymers, and lost circulation materials (LCM).

Keywords Eco-friendly additives · Drilling fluid · Sunflower shells · Food product

Introduction

Waste materials refer to the materials that are discarded by people and are considered unwanted or no longer useable. Waste materials are diverse and unique as they can cover many aspects in many different areas. Globally, the waste materials accumulate and pose a threat to the environment. The sources of waste are abundant and can be generated from multiple sources such as households, food waste, hazardous waste, construction waste, wastewater, radioactive waste, and many others as summarized below (John Hopkins University 2006):

- Household wastes are manifold and can be composed of hazardous and non-hazardous materials. Examples include paper, bottles, cans, oils, batteries, household cleaners, etc.
- Food wastes are any unwanted part of the food that is inedible. Examples include banana peels, potato peels, orange peels, etc.
- Hazardous wastes are wastes that endanger the health and environment of the public. Examples include chemical additives, pesticides, solvent-based paints, etc.
- Construction wastes are wastes that are caused by constructions and building industries. The most common types include wood, bricks, concrete, etc.
- Wastewater is the water that has been affected by some sort of waste. They can be generated from households or industries.
- Radioactive wastes are wastes generated by radioactive material due to nuclear generation.

✉ Abo Taleb T. Al-Hameedi
ata2q3@mst.edu

✉ Husam H. Alkinani
hhappf@mst.edu

1 Missouri University of Science and Technology, Rolla, MO, USA

Waste materials as described above are diverse and there are many different types of waste ranging in numerous areas each with their own set of unique functions (Environmental Protection Agency 2019). From this list of different types of waste, it can be assessed which type can be useful or applied in the gas and oil industry. Logically, not all waste materials can be used for petroleum-related implementations. Thus, a thorough investigation of the waste materials that can be employed in the gas and oil industry is required. To attain this, it is important to examine the applicability of waste materials in the gas and oil industry. The goal is to use wastes that are not harmful and friendly to the environment and the safety of the public. This does not mean any type of non-hazardous waste is acceptable, as some cannot be applied to the petroleum industry. For example, some household wastes such as paper, bottles, and cans have no known use in the petroleum industry.

Hazardous wastes can be disregarded because they are toxic and can endanger the lives of humans and the environment. Any form of nuclear or radioactive wastes should also be avoided in the gas and oil industry as they can pose threats as well. The types of waste that can be applied in the petroleum industry include food waste, biodegradable waste, and construction waste.

Wastes are a rising global issue in modern society as they can lead to many unwanted consequences that can affect peoples' health and the environment. To minimize these problems, it is important to develop an alternative solution to solve these issues. These wastes have the capability to be exploited in petroleum operations by using them for various uses instead of disposing them to the environment. For example, food wastes can be used for other applications such as mud additives (Al-Hameedi et al. 2019a). Various authors have conducted studies and experiments on food waste to be used as alternative additives for drilling fluid. Waste materials can be applied to other petroleum areas such as enhanced oil recovery, stimulation fluid, and many more.

Several authors have researched the feasibility of using these waste materials in various applications in drilling fluid. Al-Hameedi et al. (2019b) did laboratory experiments utilizing mandarin peels powder to enhance rheology and seepage loss properties. Potato peels powder was investigated by Al-Hameedi et al. (2019c), the authors added potato peels powder to the reference mud and measured several properties such as rheology and filtration properties. Their findings revealed that potato peels powder can be exploited as a mud thinner. Moreover, Amadi et al. (2018) performed several experiments by using food waste products such as banana peels and potato peels to control filtration properties and mud rheological properties. Grass waste can be used to control filtration properties and mud rheological properties (Hossain and Wajheeuddin 2016). Wastes generated from trees can be applied to drilling fluids and they can be employed as a mud loss material to control seepage loss (Ramasamy and Amanullah 2018). Al-Hameedi et al. (2019d) used grass powder to conduct laboratory experiments to treat seepage losses. The results of grass powder were compared with starch, a common drilling fluid additive. The grass powder decreased the fluid loss and improved the filter cake properties, and provided better results in comparison with the starch as an additive. Al-Hameedi et al. (2020) tested the feasibility of utilizing palm tree leaves powder (PTLP) as an eco-friendly mud additive. Their findings showed that PTLP reduced alkalinity and seepage loss while improved the mud cake. The PTLP can reduce the viscosity as well when ground into a very fine powder. However, the results showed that PTLP affected the yield point and it was significantly reduced, suggesting PTLP has the potential to be used as a mud thinner additive. Other areas of petroleum besides drilling fluids can use waste materials such as production and well completion. Al-Hameedi et al. (2019a) showed some of the conventional drilling fluid additives with their potential danger to the personnel and environment. Among these materials, caustic soda, lime, and sodium chloride are the most toxic drilling fluid additives.

In this work, the interaction of eco-friendly black sunflower seeds' shell powder (BSSSP) and freshwater bentonite mud was examined under surface and downhole conditions. Experimental tests were conducted to evaluate the effects of adding BSSSP to drilling fluids. The evaluation tests include pH, density, rheological behavior, and fluid loss characterizations for both fresh and aged drilling fluids. The BSSSP shows its feasibility to be utilized as multifunctional material to improve the mud characteristics such as fluid loss, viscosity, and partial loss treatment in thief formations.

Background of black sunflower industry

The plant of sunflower is a yearly herb that has a large plate formed with yellow, ray flower petals arranged on the outer edge of the disk. Each sunflower head has around 1000–2000 tiny flowers connected at the base of the sunflower. The shell, which is also called hull, surrounds a little seed made out of about 20% protein and 30% lipids. In addition, it consists of a significant level of iron and dietary fiber (Madehow.Com 2019). The following subsequent paragraphs will be concentrated on the black type of the sunflower seeds since it has been used as additives in this experimental investigation.

The black sunflower seeds are grown in the middle of the bright yellow flower and are considered a good source of nutrition. Sunflowers are commonly used as food for humans and birds, but their byproducts including cooking oil, biodiesel fuel, and medicine are also being used in daily life. In addition, sunflower shells, which are considered waste materials, are being exploited in construction and agriculture industries instead of being discarded. In general, utilizing a natural, renewable resource such as sunflower seed shells to replace chemical-based materials has a potential benefit on the environment from a protection standpoint (Allonsy 2019). The shells are high in fiber and therefore are often exploited as a food source for animals. Shells have additionally been utilized as poultry litter, fireplace logs, and fillers for plastics. These applications have been restricted, and the shells are widely burned by the factories for energy generation (Madehow.Com 2019). Sunflower shells, supplied by local markets, are usually processed to remove any sticking dirt by washing, and then be air-dehydrated at the surface circumstances for 36 h. Chemically, the black sunflower seeds have "31.9% cellulose, 29.3% lignin, and 27.2% pentosane". The seeds have also a mean "surface area of 1.55 cm^2 and a mean pore area of 244.98 m^2" (Osma et al. 2007).

The largest sunflower seeds producing countries are Ukraine and Russia, which produce about a half portion of the world's sunflower seeds supply. In 2013, Ukraine generated about 11 million tons of sunflower seeds, which accounts for 24.8% of the world's yearly production, whereas Russia produced 10.6 million tons representing 23.7% of the world's production. Other world's major sunflower seeds producing countries include Argentina, China, Romania, Bulgaria, and Tanzania (Misachi 2019). The United States is also considered a large producer of sunflower seeds. It is estimated that 85% of the North American sunflower seeds are being produced in Minnesota North and South Dakota (Putnam et al. 1990). Most sunflower plants grown in the U.S. are utilized to produce oil (Feed Planet Magazine 2019).

Statistical data from the U.S. Department of Agriculture Foreign Agricultural Service (USDA FAS) showed that in the 2015/2016 season, the total world's sunflower seed production was 40.4 million tons, while in 2016/2017 season the production increased to 44.8 million tons (Feed Planet Magazine 2019). In the same context, Europe is considered as the largest and the most important producers of sunflower seeds in the world. During the 2016/2017 season, Europe produced an estimated 8.5 million tons of sunflower seeds with an increase of 7.4% compared to the 2015/2016 season (Cbi.Eu 2019). Most of that seeds production in Europe is dedicated to sunflower oil, but the market for confectionery/bakery- grade seeds is booming rapidly. Although sunflower seeds are utilized largely in bakery products, the seeds are utilized in other various products such as healthy snacks and directly consumed by humans as kernels or in-shell. In 2017, Europe imported about 3.4 million tons of sunflower seeds which worth €1.4 billion (Cbi.Eu 2019).

As for the U.S., the majority of sunflower production comes from Minnesota, North and South Dakota, Kansas, Nebraska, Colorado, and Texas with minor contributions from other states. Two types of sunflowers are grown in the U.S.: (1) oilseeds, intended to produce vegetable oil, are black-seeded with a thin hull that connected to the kernel, and (2) non-oilseeds which are dedicated as food for humans and animals, and such seeds are usually large and white striped with a thick shell. Most of the harvested sunflower acreages go for oil production instead of non-oilseeds purposes. In 2004, the amount of the U.S. oilseed sunflower production was 1763 million pounds, while the amount of non-oilseed production was 286 million pounds. The USDA reported in 2005 that 2,032,000 acres of oil sunflower and 578,000 acres of non-oil sunflowers were harvested. In addition, the annual average sunflower yield was 1564 lb per acre for oilseed sunflower and 1455 lb per acre for non-oilseed sunflower for 2005 (Berglund 2007).

Approximately 3 million acres of sunflowers are grown annually in the U.S., and up to 90% of these sunflowers are of oilseed type, which is finally processed into vegetable oil. About a third of the seeds processed for oil are deshelled, partially deshelled or left with shells on. Once the shells are removed from sunflower seeds, they become a very low-value byproduct, and they end up burned for fuel (Myers 2019). The main applications of the black sunflower shells (BSS) in various industries are (Allonsy 2019):

- *Plant fertilizers* Following the process of extracting oil from sunflowers, a massive volume of shells, which is considered as waste materials, can be used in plant growing process as cost-effective fertilizers. The chemical composition of sunflower shells indicates that they contain excellent plant nutrients such as nitrogen, phosphorus, and potassium. Utilizing the surplus shells as plant nutrients or fertilizers is considered one of the alternative options in lieu of disposal (Deibert and Lizotte 2019).
- *Construction material* BSS have also been utilized as construction material in the structure of natural-fiber wood paneling. This type of wood has the advantage of being eco-friendly compared to other wood products because the shells are renewable and can be recycled. Some of the applications of shells-based wood include wall paneling, cabinetry, and furniture. Another construction application of BSS is using the ash of sunflower shells as an additive in concrete to enhance its strength and minimize cracking (Allonsy 2019).
- *Animal food* BSS can provide a good nutrition source for cattle and sheep. The composition of shells consists of ash, protein, lipid material, reducing sugars and carbohydrates. Even though the shells have low values in protein and nutrition, the high fiber and carbohydrate contents make hulls suitable food for ruminants when mixed with other nutrients of higher value. For animals to digest the hulls easily, it should be finely ground and mixed in the feed (Allonsy 2019).

- *Fuel* BSS are considered a good fuel source and are commonly used to generate heat since its heat value is 19.2 megajoules per kilogram. The shells can be directly burnt by themselves, or they can be mixed with other wood waste products and pressed together to form fuel logs. Barnesville High School in Minnesota is an example of utilizing BSS to heat the entire school, which demonstrates the effectiveness of BSS fuel application. In 2019, the school consumed 450–600 tons of sunflower pellets during one heating season (Allonsy 2019).

BSS were also exploited for special purposes other than the ones mentioned above. Examples are oil for ceremonial body painting and pottery, medicinal crop, source of dye, etc. (Berglund 2007). Because of their good chemical properties, such as semi-drying without color modification, sunflower oil has been successfully applied in certain paints, varnishes, and plastics. In Russia and Eastern Europe, sunflower oil is ordinarily utilized to produce soaps and detergents. Moreover, the sunflower oil application in the chemicals industry has been explored (Putnam et al. 1990).

It is known that all organic materials whether their source is from plants or animals, are susceptible to decomposition. The plants and animals composed commonly of organic substances that are considered biodegradable once decomposed. As such, since the source of BSS is from a plant, it is considered degradable. Regarding the possible toxicity of BSS, they have intensively been searched in the literature and has been found no reported health problems related to the toxicity of BSS, and they are considered as environmentally friendly material. Therefore, BSS are considered very safe for humans. It can be concluded that the uses of BSS in the gas and oil processes can cause no health hazards to humans and the environment (Kirschner 2017).

Materials and methods

Materials

The bentonite utilized in this study was obtained from Haliburton Company. The sodium hydroxide (NaOH), employed to control the alkalinity of the mud, was obtained from Bulk Apothecary. The black sunflower seeds' shell powder (BSSSP) was prepared in-house.

Collection and preparation of BSSSP in-house

First, the black sunflower shells (BSS) were compiled in-house as shown in Fig. 1a. The BSS were left to dehydrate for several days. Then, the dehydrating procedure was speeded up by placing the BSS in an oven at 94 °C (200 °F) for 1 h. Subsequently, BSS were put in a dry place for 4–5 days under ambient laboratory conditions. Once again, BSS were placed in an oven at the same temperature 94 °C (200 °F) for 30 min to assure an entire drying process. Once dried, a food processor was used to ground the BSS into a fine powder. Figure 1b, c present the fine powder of BSS and the food processor, respectively. In addition, Fig. 2 summarizes the procedure of gathering and preparing the BSSSP.

Finally, a manual sieve test was implemented to locate the size of the BSSSP. The particle size distribution of the BSSSP is clarified in Fig. 3. The size of around 90% of the BSSSP particles is 0.4 mm (400 µm) or smaller; while 75% of the BSSSP particles are 0.2 mm (200 µm) or smaller. Around 50% of the particles are smaller than 0.088 mm (88 µm). Additionally, 25% and 10% of the BSSSP particles are 0.069 mm (69 µm) and 0.052 mm (52 µm) or smaller, respectively. Generally, the BSSSP particle size ranges between 52 and 400 µm (300—50 US Mesh size).

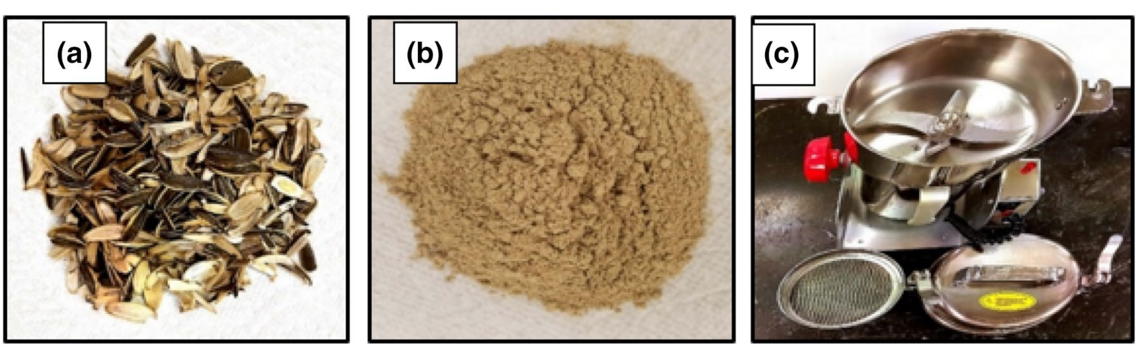


Fig. 1 **a** The raw waste of black sunflower shells (BSS), **b** the black sunflower shells' powder (BSSSP), and **c** the food processor

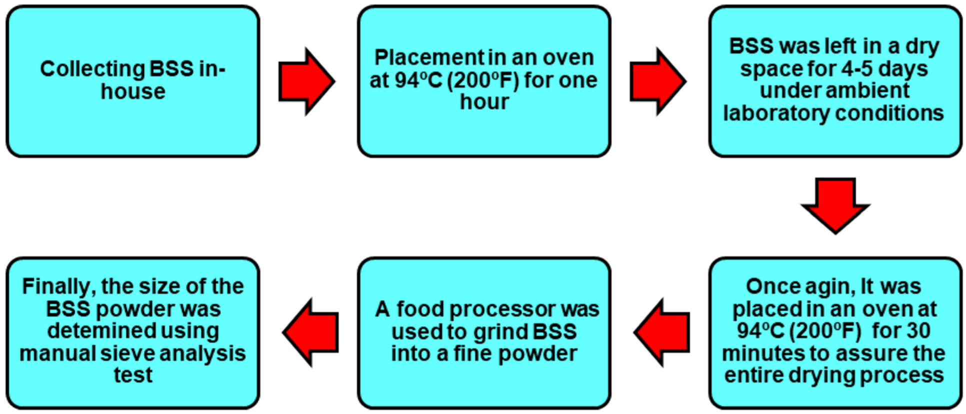


Fig. 2 The process of gathering and preparation of the BSSSP

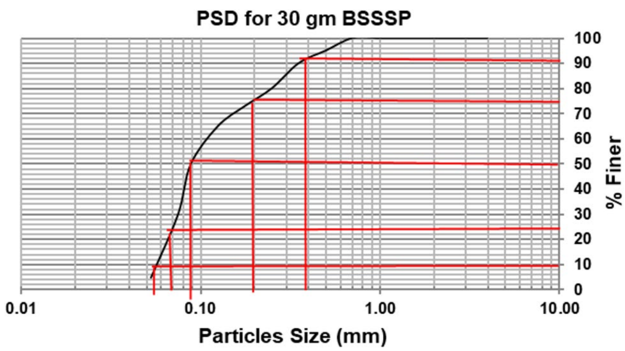


Fig. 3 The particle size distribution of the BSSSP

Density and pH measurements

One of the focal duties of the mud is maintaining the pressure in the wellbore. The subsurface formations are under pressure from the weight of the overlying layers. This weight compresses the formation's pores and pressurizes the pores' fluids to be higher in pressure than the hydrostatic head. If the drilling fluid does not balance the pressurized fluids, drilling through these formations can result in flow into the well (kick) or uncontrolled flow to the surface (blowout). For this, one of the important measurements is the mud density. In this study, an unpressurized mud balance was used to conduct the density measurements and the effect of adding BSSSP on the mud weight. In addition, having a suitable pH in the drilling mud is essential to hinder corrosion on the drilling tools, provide a suitable environment for the drilling fluid additives, and prevent chemical instability of shales. A digital pH meter was utilized in this study to report the pH of the drilling mud before and after adding the BSSSP additive.

Rheological measurements

Drilling fluids are considered Non-Newtonian fluids and the viscosity of Non-Newtonian fluids has two components; yield point (YP) and plastic viscosity (PV). PV is presented as the resistance of a fluid to flow; it is caused by the interaction between the solid particles with themselves, the liquid particles with themselves, and the liquid and solid particles with each other. YP is defined as the attractive force among colloidal particles in drilling fluid, and YP is in charge of the lifting and suspension of the cutting in the mud and presenting efficacious wellbore cleaning. Increasing the viscosity of the drilling fluid is important for cuttings removal. To increase viscosity, clay particles such as bentonite clay and polymers are introduced to the mud. However, due to the complex interaction among the key drilling parameters affecting hole cleaning, it is not simple to achieve efficient hole cleaning. The two viscosity components PV and YP during pump on situation and the gel strength during the pump off situation are the responsible parameters for an effective hole cleaning and an efficient cuttings suspension. YP of the drilling fluid demonstrates the relationship between the pump power and the flow rate. In different words, the initial flow of fluid or the shear stress will be impeded to move the fluid due to YP resistance. Therefore, the YP represents the size of the pressure top on the kickoff. If the YP is too high, it may be unattainable to re-start. In the same context, the drilling fluid will not flow until the applied shear stress surpasses the YP. To fulfill that target, the flow rate has to be boosted to supply the capability to move and pump the drilling fluid. Hence, the mud engineer will plan to maximize the thickening ratio (YP/PV) of the fluid in case the hole cleaning is not effective.

It is necessary to conduct rig site measurements at both fresh and aged conditions for the viscosity using marsh funnel as easy-to-use equipment to check the viscosity of the mud. In addition, utilizing Model 800 Viscometer as an accurate test for more analysis for the drilling fluid viscosity components to acquire a cohesive conclusion regarding the desired treatment and to guarantee that the mud maintains the designed properties after being circulated through the wellbore in order to provide an adequate hole cleaning.

Fluid loss measurements

It is common during drilling to lose some of the drilling fluid to the formation due to the difference between the hydrostatic pressure and the pore pressure (over-balanced drilling phase). Mud cake formation on the borehole wall is essential for formation stability. By constructing a filter cake, the drilling mud will carry out its functions in sealing the formations and minimizing the mud invasion. Most importantly, how quickly the mud cake forms, its thickness, and its permeability, all the aforementioned factors have a vital role in critical drilling issues such as mechanical stuck pipe, hole enlargement, drags, and well-logging analysis misinterpretations (Basra Oil Company 2007).

As wells are drilled through permeable layers, the weight of the mud column can exert enough pressure to cause some of the mud to be lost into the formation, unless a barrier is introduced to keep the mud in the wellbore. This process is called fluid loss. Fluid loss is a major concern when drilling through permeable layers. Since drilling muds are designed to control the flow of formation fluids into the wellbore during the drilling process, the hydrostatic pressure exerted by the mud at any point must at least equal the formation pressure. Because it is difficult to match the formation pressure, it is common to use drilling mud, which will provide somewhat more pressure than the formation. When this is the case, wellbore fluids (mud) will begin to enter the formation. A filtration process is used to build a thin impermeable layer inside the wellbore. This layer, if properly designed, can prevent the loss of drilling mud to surrounding rock layers, resulting in lower mud costs and better well control. There are many additives utilized to control the filtration properties of drilling muds. Among the most common filtration additives is bentonite clay (Basra Oil Company 2008; MI-Drilling fluids 2000). The most common way to control fluid loss is by using mud that forms a filter cake at the interface between the zone and the borehole wall. A mud cake forms because the solid particles suspended in the mud are too large to pass through the pores of the formation. As more fluid enters the formation, more solid particles build up on the formation. Eventually, the solid particles begin to build upon themselves and the cake itself becomes the filter. When enough particles have collected on the formation surface, the cake becomes essentially impermeable. The fluid that passes through the mud cake is referred to as filtrate. This initial loss is called spurt loss (Basra Oil Company 2008; MI-Drilling fluids 2000).

An ideal drilling mud will quickly form a very thin, impermeable filter cake. A thick filter cake increases the contact area between the drill stem and the filter cake, which can lead to the possibility of differential sticking of the drill stem. In addition, a thicker mud cake requires more torque to drill and causes more drag while tripping the drill string. If the cake is too permeable then the mud can deeply invade the formation, which can affect the results of well logs and hinder formation evaluation. High fluid loss into the target formation can also reduce the formation's productivity (high skin factor). Because of the dynamic conditions found in the downhole environment, it is hard to predict fluid loss in actual conditions (Basra Oil Company 2008; MI-Drilling fluids 2000). In order to have some means of comparing the fluid loss characteristics of drilling muds, simple tests that measure the spurt loss and filtration rates of mud have been developed. In this study, HTHP and LTLP Filter Press were utilized to characterize the seepage loss of the tested drilling fluid following the American Petroleum Institute (API) standards.

Experimental results and analysis

This section was divided into two sub-sections, surface and downhole conditions. Each sub-section has its own procedure. The ultimate aim of dividing this section into sub-sections is to furnish a coherent image and a cohesive insight into the major differences between the ambient laboratory conditions and field conditions in terms of the experimental procedures and laboratory results.

Fresh conditions (FC)

To understand the effectiveness of introducing different concentrations of BSSSP on the features of the base mud, reference mud (RF) was made, composed of 700 cc of water, 0.5 gm of NaOH, and 42 gm of bentonite. Next, all tests were performed and measured for the RF to be juxtaposed to the outcomes of introducing BSSSP. For example, mud density was examined using unpressurized fluid balance and marsh funnel viscosity utilizing marsh funnel; while the rheology involving; gel strength, yield point, and plastic viscosity were tested using a Viscometer. In addition, the filtration specifications involving filtrate in cc/30 min and mud cake thickness were addressed utilizing the standard LTLP API Filter Press at 75 °F and 100 psi, the HTHP API Filter Press at 250 °F and 500 psi, and digital and manual vernier calipers, respectively.

0.5% (3.5 gm), 1.5% (11 gm), 2.5% (18 gm), 3.5% (24.5 gm) concentrations of BSSSP were added independently to RF. Because of the biodegradability characteristic concern for the BSSSP as well as to guarantee there are no bacterial problems associated with BSSSP, the drilling fluid samples were left in the laboratory for 30 h under ambient conditions to explore the bacteria influences. There was no remarkable change in the pH of the drilling fluids, no smell change, no signs of foam formed at the surface, and there were no changes in the properties of the drilling fluids. These are common indications of bacterial effects. Hence, there were no bacterial

Table 1 The findings of the reference fluid and four concentrations of BSSSP (fresh conditions)

Property	RF	0.5% BSSSP	1.5% BSSSP	2.5% BSSSP	3.5% BSSSP
Mud density (ppg)	8.6	8.6	8.6	8.6	x
Marsh funnel viscosity (s)	33	56	102	96	x
PV (cp)	7	7	8	8	x
YP (Ib/100ft^2)	7	22	35	32	x
Initial gel strength (Ib/100ft^2)	9	23	31	30	x
Final gel strength (Ib/100ft^2)	15	27	35	35	x
pH	10.4	9.9	9.6	8.3	x
7.5 min filtrate (cc) (LTLP)	6	4.25	4	3.5	x
30 min filtrate (cc) (LTLP)	12.5	9.75	9.5	8.5	x
Filter cake thickness (mm) (LTLP)	3	2.3	2.5	2	x
7.5 min filtrate (cc) (HTHP)	18	13.25	13	12	x
30 min filtrate (cc) (HTHP)	34	25.5	25	24	x
Filter cake thickness (mm) (HTHP)	4.7	4	4.1	4	x

x indicates that no readings were observed due to the high concentration of BSSSP

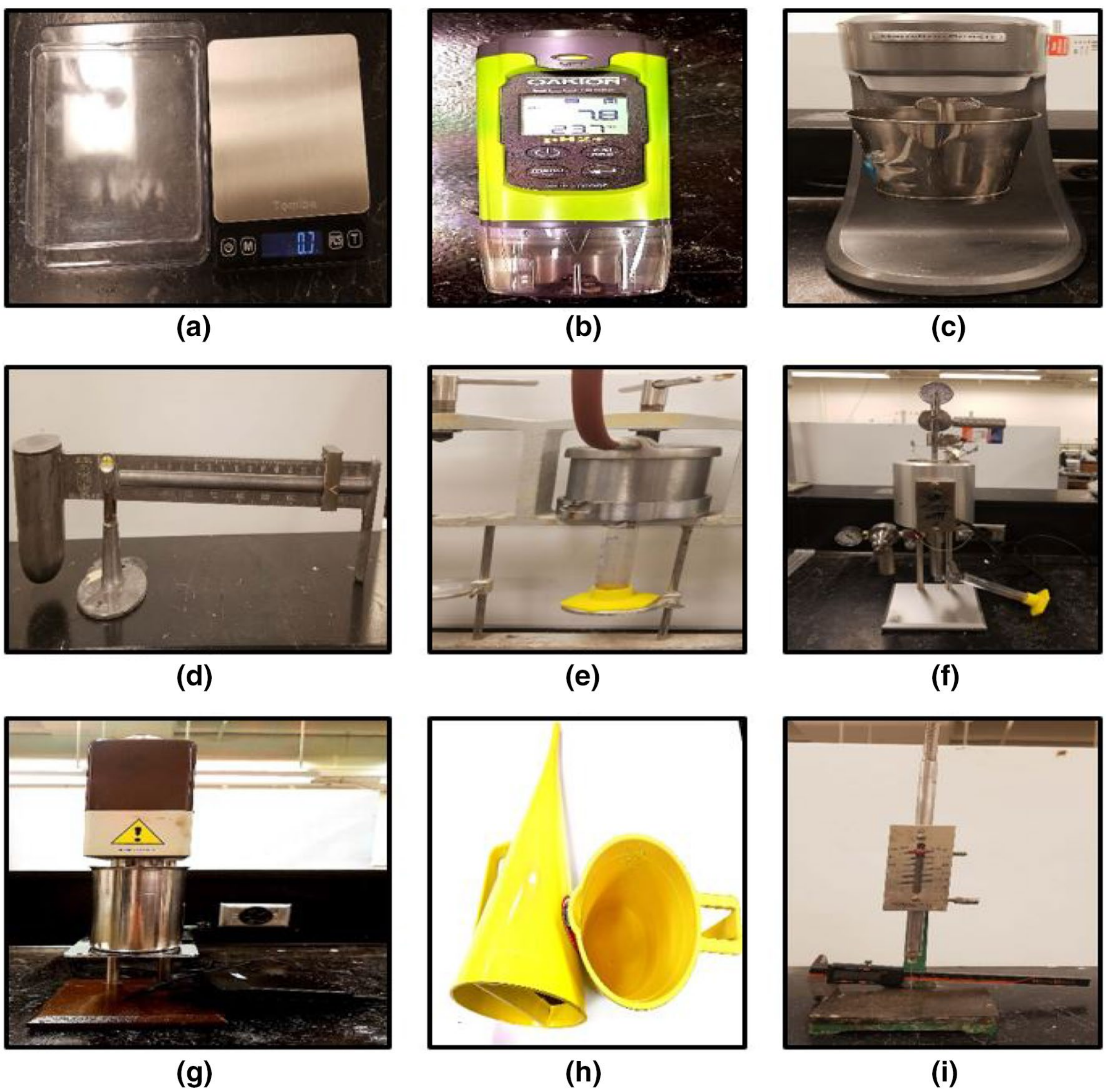


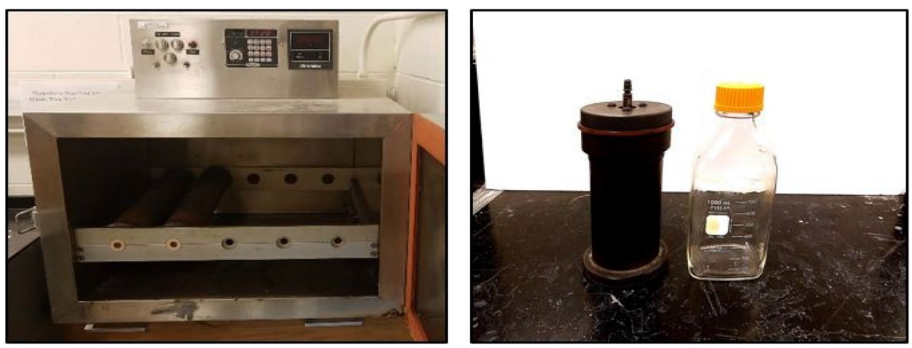
Fig. 4 All mud tests Equipment

issues with BSSSP. After that, the same full-set measurements and the fresh conditions that were performed to the reference fluid have exactly been conducted after adding the BSSSP in order to understand the effects of presenting the BSSSP additives on the physical properties and comparing it to the reference fluid. Table 1 illustrates the variation of the results due to adding four concentrations of BSSSP material under the fresh surface conditions; while Fig. 4 symbolizes all the equipment used to execute this experimental study.

Aged conditions (AC)

"Drilling fluid aging is the process in which a drilling fluid sample, previously subjected to a period of shear, is allowed to more fully develop its rheological and filtration properties. The time period needed to more fully develop properties varies from as little as several hours (usually 16 h and moderate temperature aging up to 122 °F (50 °C)) to as much as several days. The aging can be done at either ambient or elevated temperatures. Aging is done under conditions which vary from static to dynamic and from ambient to highly elevated temperatures"(Fann Instrument Company 2005). Because of the significant effects of temperatures, the chemical additives must be constantly observed and examined under the field conditions when executing an experimental study. Obviously, ambient conditions do not mirror the genuine stabilization of the mud characteristics, and do not mimic sub-surface circumstances. In other words, the drilling fluid properties will be altered due to aging and temperature. Consequently, critical issues may be faced during drilling (Basra Oil Company 2007). Thus, aged conditions were implemented for the three samples of BSSSP by placing them in a roller oven (dynamic condition) under 50 °C (122 °F) for 30 h to compare the findings of the fresh and aged conditions, and to guarantee the efficacy of BSSSP under sub-surface conditions utilizing the same full-set measurements shown in Fig. 4.

In addition, the roller oven and aging cell were used to simulate the sub-surface conditions are shown in Fig. 5. After aging, the three mud samples with BSSSP were allowed to sit in a dry space for 30 h under ambient conditions to recognize any bacterial issues. The results showed that BSSSP was not affected by bacteria and it was very



(a) (b)

Fig. 5 **a** Roller oven and accessories, and **b** aging cell and accessories

Table 2 The findings of introducing of BSSSP additives the reference fluid (aged conditions) 50 °C (122 °F) for 30 h

Property	0.5% BSSSP	1.5% BSSSP	2.5% BSSSP	3.5% BSSSP
Mud density (ppg)	8.6	8.6	8.6	x
Marsh funnel viscosity (s)	62	107	102	x
PV (cp)	7	13	13	x
YP (Ib/100ft^2)	26	47	45	x
Initial gel strength (Ib/100ft^2)	28	41	38	x
Final gel strength (Ib/100ft^2)	33	46	42	x
pH	9.5	9.1	8	x
7.5 min filtrate (cc) (LTLP)	4	3.5	3	x
30 min filtrate (cc) (LTLP)	8.5	8	7.5	x
Filter cake thickness (mm) (LTLP)	2.2	2.2	2	x
7.5 min filtrate (cc) (HTHP)	12.75	12	10.5	x
30 min filtrate (cc) (HTHP)	23	22	20.5	x
Filter cake thickness (mm) (HTHP)	3.95	3.9	3.7	x

x indicates that no readings were observed due to the high concentration of BSSSP efficacious under the aged conditions when comparing it to the fresh conditions as shown in Table 2.

Discussion

Due to the multifunctional effects of BSSSP on the reference fluid properties and according to its potential applicability, the interpretation of the findings was divided into three separate sub-sections, which are viscosity additive and filtration loss as well as partial loss treatment in the thief formations in order to understand the feasibility of using BSSSP in the petroleum industry.

Can BSSSP additives be utilized as a viscosifier in water-based drilling fluid?

Starting with the fresh conditions experimental findings, the effect of introducing 0.5% (3.5 gm), 1.5% (11 gm), 2.5% (18 gm), and 3.5% (24.5 gm) of BSSSP on the rheological characteristics of the drilling fluid was judged by comparing the measured values with the RF readings. The findings showed that BSSSP has a negligible impact on PV when compared to RF and no effect for the concentration variation was observed. However, BSSSP additives significantly increased the yield point; whereas 1.5% (11 gm) of BSSSP concentration increased YP by 400%; while 2.5% (18 gm) of BSSSP additive was less efficient than 1.5% (11 gm) of BSSSP and maximized YP by 357% when compared to RF. The 0.5% of BSSSP increased the YP by around 214%. In the same vein, increasing the concentrations of BSSSP also highly boosted the initial and final gel strengths when comparing them to RF and the effect of the concentration variation was almost insignificant. Figure 6 illustrates the impact of the three BSSSP concentrations on the rheological properties as compared to the reference fluid under fresh conditions. For 3.5% of BSSSP, there were no results as the liquid phase in the drilling fluid was not sufficient, the solids started to coagulate, and part of the additive was dry. In other words, the high concentration of BSSSP (3.5%) absorbed the free water, and a clotting phenomenon was experienced. In addition, the extreme reduction of pH caused the mud to fail for any measurement.

On the other hand, the aged conditions for 30 h and under 50 °C (122 °F) temperature had a positive impact on the rheological properties for the three concentrations of BSSSP when comparing them to the same concentrations of BSSSP under the fresh conditions. PV has increased by 63% for both concentrations of BSSSP (1.5% and 2.5%) and remained the same for 0.5%; while 0.5%, 1.5%, and 2.5% of BSSSP concentrations maximized YP by 18%, 35%, and 41%, respectively. Similarly, BSSSP additives considerably boosted the initial and final gel strengths under aged conditions. Moreover, 1.5% of BSSSP was more efficient than 2.5% of BSSSP in enhancing YP and gel strength, and there was no effect of the variation of the concentration on PV. Figure 7 shows the effect of the three BSSSP concentrations on the rheological properties under aged conditions (A.C) as compared to the three BSSSP concentrations under the fresh conditions (F.C).

Consequently, the three concentrations of BSSSP positively improved the rheological characteristics under both aged and fresh conditions. Additionally, experimental findings revealed that BSSSP was not affected by the aged time and temperature. The aged conditions reinforced the fluid rheology as compared to the fresh conditions. Furthermore, the results showed that a higher concentration of

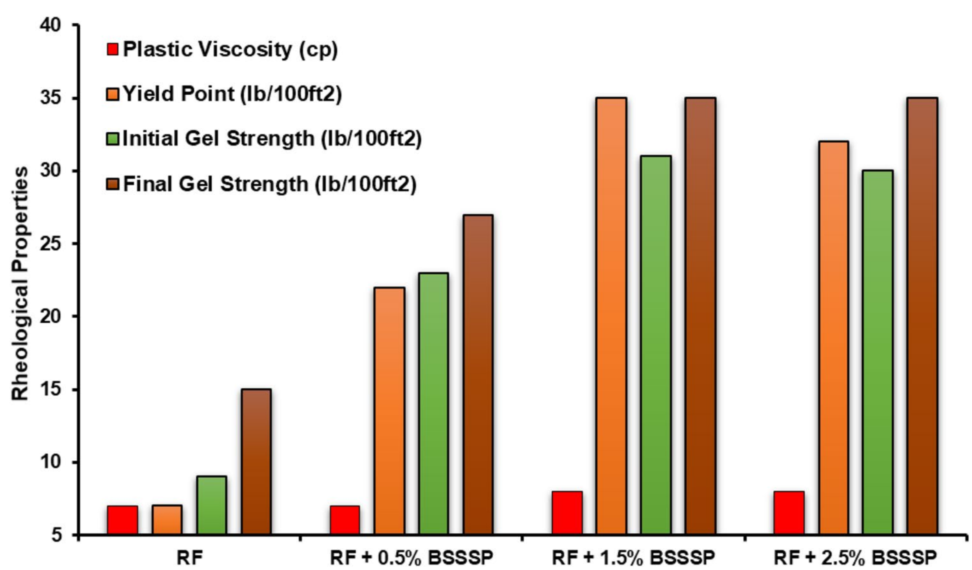
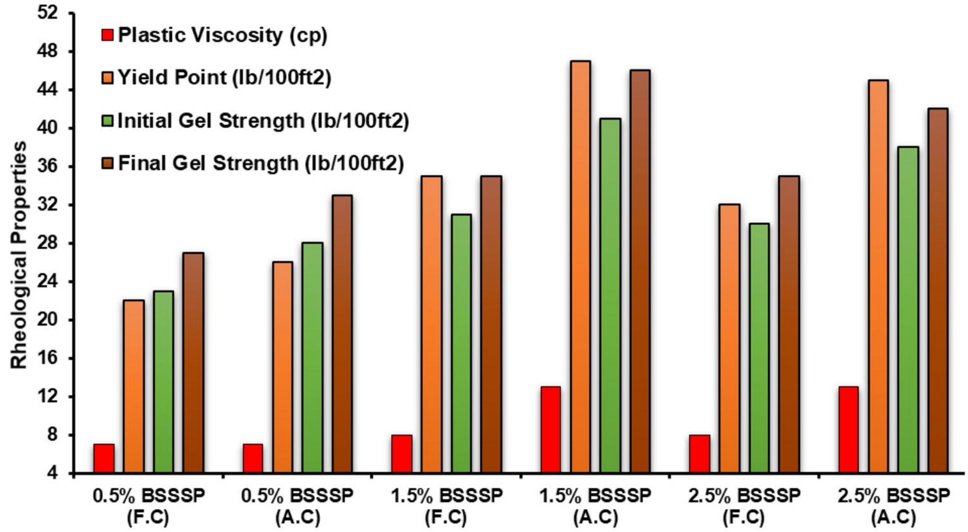


Fig. 6 The effects of BSSSP on the rheological properties (fresh conditions)

Fig. 7 Comparison between the effects of BSSSP on the rheological properties under fresh and aged conditions

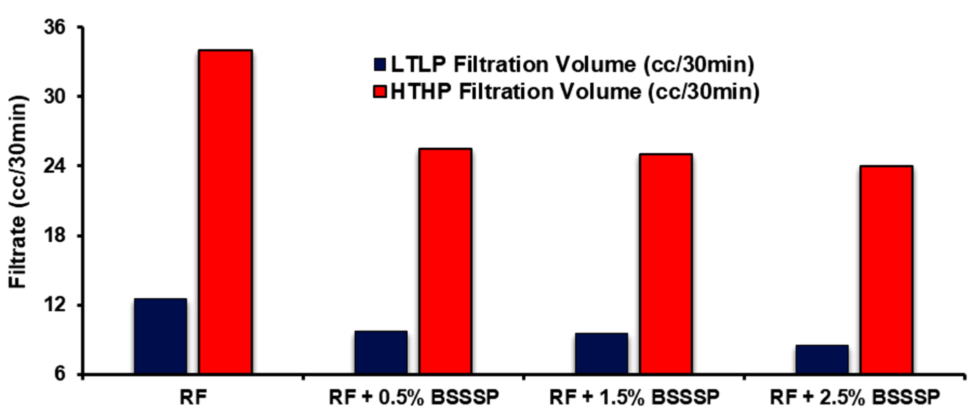


the BSSSP did not provide a proportionate enhancement in rheological properties. Hence, a lower concentration of 0.5–1% should be utilized as a viscosifier for optimal performance during normal drilling operations. As a result, the laboratory findings showed the possibility of utilizing BSSSP as a viscosity modifier. In other words, BSSSP has the capability to fulfill the same goals that conventional chemical additives can attain in the oilfield. Nevertheless, before BSSSP can be applied in the field, it should be examined under various pressures and temperatures using different aged times to assure that BSSSP is viable in the sub-surface conditions. Accordingly, more examinations should be executed under the wellbore conditions and hostile environment.

Can BSSSP be utilized as a seepage loss control material in water-based drilling fluid?

For the fresh conditions, LTLP filtration (75 °F and 100 psi) and HTHP filtration (250 °F and 500 psi) experiments were implemented for each concentration of BSSSP to precisely appraise the effect of 0.5%, 1.5%, and 2.5% additives on the seepage loss properties when juxtaposed to RF. It can be obviously observed that the filtration characteristics were enhanced for both LTLP and HTHP measurements when comparing to RF. Starting with LTLP findings, the filtrate (cc/30 min) was minimized by 22%, 24%, and 32% at 0.5%, 1.5%, and 2.5% BSSSP concentrations, respectively. Additionally, the filter cake thickness (mm/30 min) was remarkably decreased by 23%, 17%, and 34% at 0.5%, 1.5%, and 2.5% BSSSP concentrations, respectively. For HTHP filtration (250 °F and 500 psi) experiments, BSSSP was also efficacious in reinforcing the filtration properties; where HTHP filtrate was minimized by 25%, 27%, and 0.3% at 0.5%, 1.5%, and 2.5% concentrations of BSSSP, respectively. Similarly, mud cake thickness (mm/30 min) was notably improved by 15%, 13%, and 15% at 0.5%, 1.5%, and 2.5% concentrations of BSSSP, respectively. Figures 8 and 9 clarify the effect of the three BSSSP concentrations on seepage loss properties compared to RF under fresh conditions (LTLP and HTHP

Fig. 8 Effect of BSSSP on the filtrate (fresh conditions; LTLP and HTHP conditions)



conditions). Once again, there were no results for the 3.5% of BSSSP for the same reason mentioned earlier.

The second part of this sub-section is related to the effect of aged conditions for 30 h and under 50 °C (122 °F) temperature on the performance and effectiveness of BSSSP. The aim is to closely simulate the wellbore conditions and to verify the efficiency of BSSSP additives on the filtration characteristics using a more hostile environment. The experimental results revealed that aged conditions boosted the seepage loss properties as juxtaposed to fresh conditions and for all the concentrations of BSSSP; where the LTLP fluid loss (cc/30 min) was reduced by 13%, 16%, and 12% at 0.5%, 1.5%, and 2.5% BSSSP concentrations, respectively. In addition, the mud cake (mm/30 min) was moderately reduced at 0.5% and 1.5% and it did not change at 2.5% BSSSP concentrations.

On the other hand, the HTHP filtration showed that the filtrate (cc/30 min) was decreased by 10%, 12%, and 15% at 0.5%, 1.5%, and 2.5% BSSSP concentrations, respectively. In addition, the filter cake thickness was also reduced for both concentrations of BSSSP (1.5% and 2.5%). Figures 10 and 11 elucidate the impact of the three BSSSP concentrations

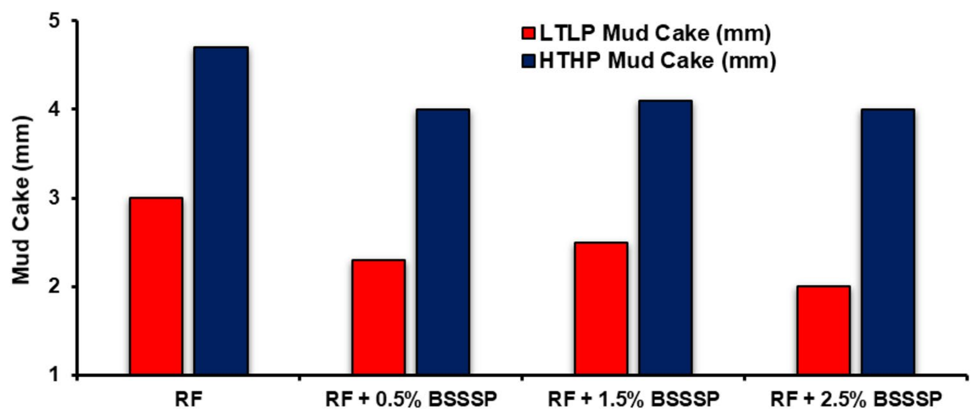


Fig. 9 Effect of BSSSP on the filter cake (fresh conditions; LTLP and HTHP conditions)

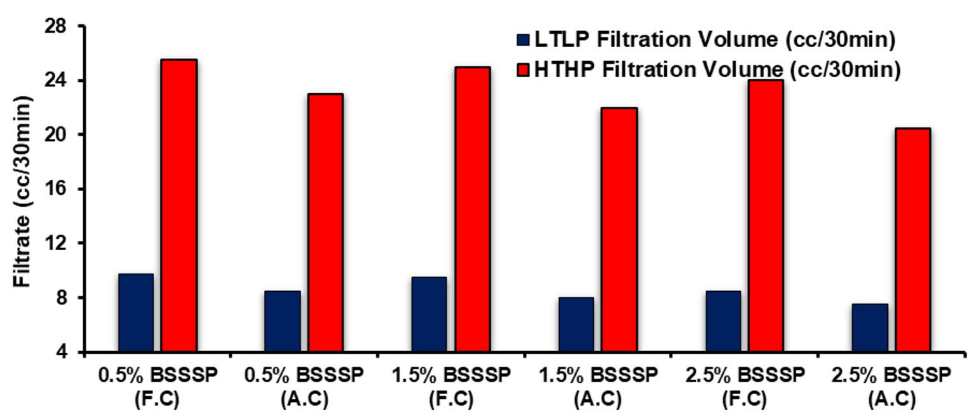


Fig. 10 Comparison between the effects of BSSSP on the filtrate under the fresh and aged conditions

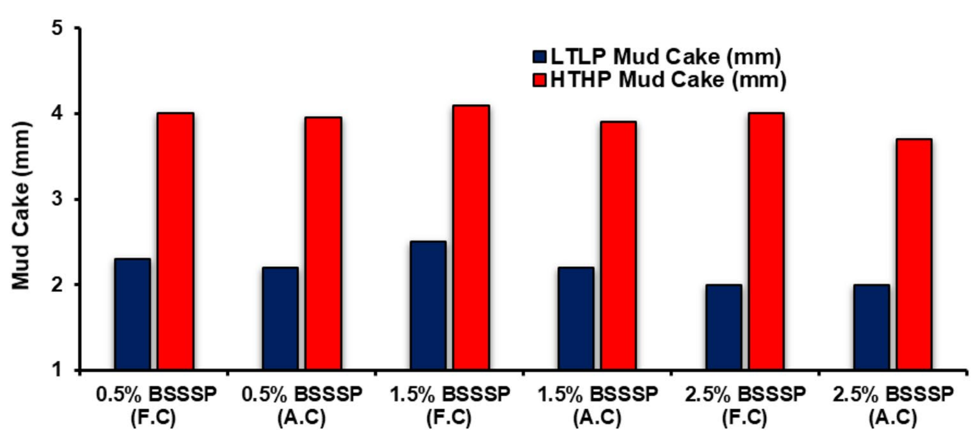


Fig. 11 Comparison between the effects of BSSSP on the filter cake under the fresh and aged conditions

on the seepage loss properties under the aged conditions when comparing them to the same BSSSP concentrations under the fresh conditions (LTLP and HTHP conditions).

To sum it up, it can be observed that the three concentrations of BSSSP emphatically ameliorated the seepage specifications under aged and fresh conditions and for both LTLP and HTHP filtration. Moreover, the experimental findings showed that BSSSP was not impacted by the aging time and temperature. Contrarily, the aged conditions enhanced the filtration characteristics as juxtaposed to fresh conditions. Furthermore, the outcomes showed that higher concentration of the BSSSP had a small impact on enhancing the filtrate and filter cake thickness, accordingly a lower concentration of 0.5–1% should be utilized as a fluid loss control agent for optimal fulfillment during normal drilling operations. Plainly, BSSSP has the applicability to achieve the same targets as the conventional chemical additives used in the oilfield.

Can BSSSP additives be utilized as a partial loss treatment in the thief formations?

Lost circulation may also occur at any point in the drilling operation. If mud losses occur while drilling a long section of the well, the objective of the treatment will likely be to plug off or limit the losses to allow drilling to continue. In other situations, the goal may be to limit the losses and cement the well. Given sufficient experience in drilling a particular type of formation, it may be possible to avoid or significantly minimize lost circulation events by controlling mud properties, drilling rate, or other field parameters. However, this requires a high level of experience and study, which is generally not available. For this reason, the industry relies heavily on using methods of mitigating lost circulation events after they occur.

There are many lost circulation treatments used to stop or control mud loss. Plainly, the most common treatments that are used to control partial losses are high viscosity patch and lost circulation materials (LCM) such as granular, fibrous and flaky additives. Starting with high viscosity patch, this remedy is high viscosity drilling mud (patch) with low mud density. Ordinarily, the viscosity is maximized using lime, bentonite, or salt clay. In calculated and sufficient quantities, this pill is pumped in front of the thief zone, to plug the losses zone, especially in partial losses.

The marsh funnel viscosity for this pill is roughly 90–110 s. Moreover, one of the LCM can be used to combat the partial loss such as drilling mud (low density) plus one of the fibrous materials, drilling mud (low density) plus one of the granular materials, or drilling mud (low density) plus one of the flake materials. The experimental findings for aged and fresh conditions revealed that BSSSP had the feasibility to be utilized as a partial loss treatment; where all of

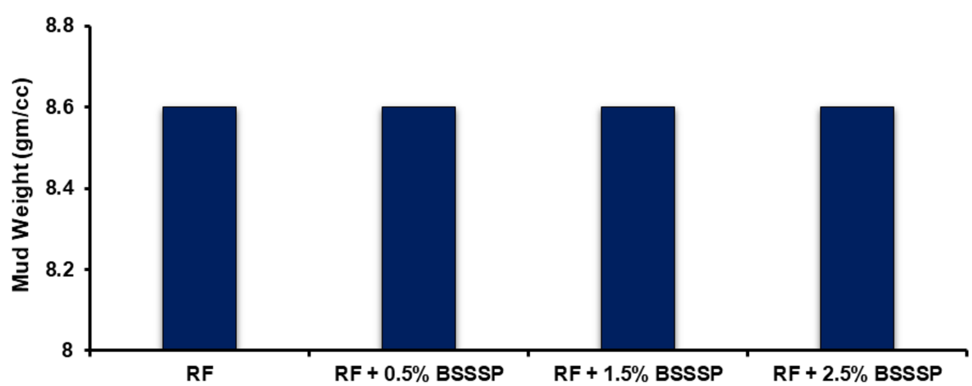


Fig. 12 The effects of BSSSP on the mud weight (fresh conditions)

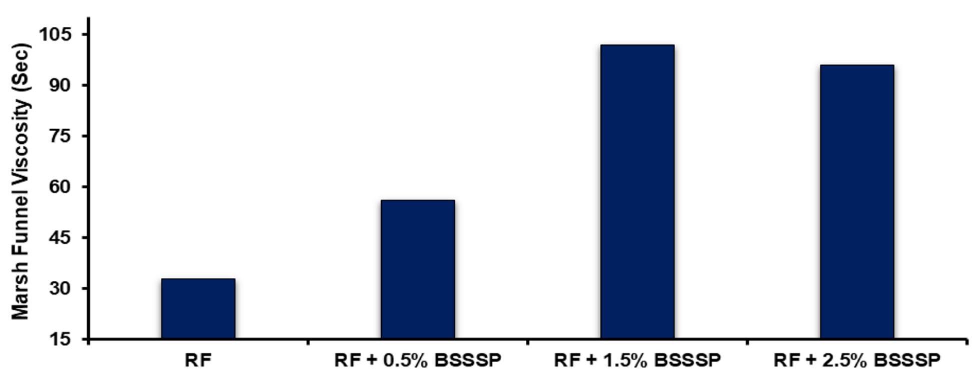


Fig. 13 The effects of BSSSP on the marsh funnel viscosity (fresh conditions)

Model 800 Viscometer, marsh funnel viscometer, and mud balance measurements provided a positive hint for BSSSP additives to be utilized for stopping partial loss. The goal of involving and discussing the mud weight in this sub-section is because all pills that are used to cease partial losses or any kind of mud loss should be low mud weight. The ultimate objective of having low mud weight pills is to avoid excessive equivalent circulation density in the annulus in front of the depleted formation and to prevent aggravating the problem. In return, unwanted consequences and side effects will be avoided (Basra Oil Company 2007).

For fresh conditions, concentrations of BSSSP had no impact on mud density; however, marsh funnel viscosity increased by 70%, 209%, and 191% at 0.5%, 1.5%, and 2.5% concentrations of BSSSP, respectively. Figures 12 and 13 illustrate the influence of the three BSSSP concentrations on the mud weight and marsh funnel viscosity properties as juxtaposed to RF under fresh conditions, respectively.

The aged conditions for 30 h and under 50 °C (122 °F) temperature for the three concentrations of BSSSP were investigated to guarantee BSSSP applicability under subsurface conditions as compared to the same concentrations of BSSSP under fresh conditions. The experimental findings showed that aged conditions had no impact on the mud weight, and it had the same values as fresh conditions for all the concentrations. On the other hand, the laboratory outcomes exhibited that aged conditions effectively increased the marsh funnel viscosity when compared to fresh conditions and for all the concentrations of BSSSP; where marsh funnel viscosity increased by 11%, 5%, and 7% at 0.5%, 1.5%, and 2.5% BSSSP concentrations, respectively. Figures 14 and 15 demonstrate the effect of three BSSSP concentrations on mud weight and marsh funnel viscosity under aged conditions when comparing them to the same BSSSP concentrations under fresh conditions, respectively.

In summary, the three concentrations of BSSSP significantly improved marsh funnel viscosity under aged and fresh conditions and did not affect the mud weight. Additionally, the experimental results clarified that BSSSP was not affected by aging time and temperature. The aged conditions enhanced the marsh funnel viscosity when compared to fresh conditions. Moreover, the findings showed that a higher concentration of the BSSSP had a negative effect on the improvement of marsh funnel viscosity, and it had no impact on the mud weight. Accordingly, a concentration of 1.5–2% should be utilized for optimum performance to mitigate partial losses. Obviously, BSSSP has the possibility to accomplish the same aims that high viscosity pills can perform in the field in combating the partial losses.

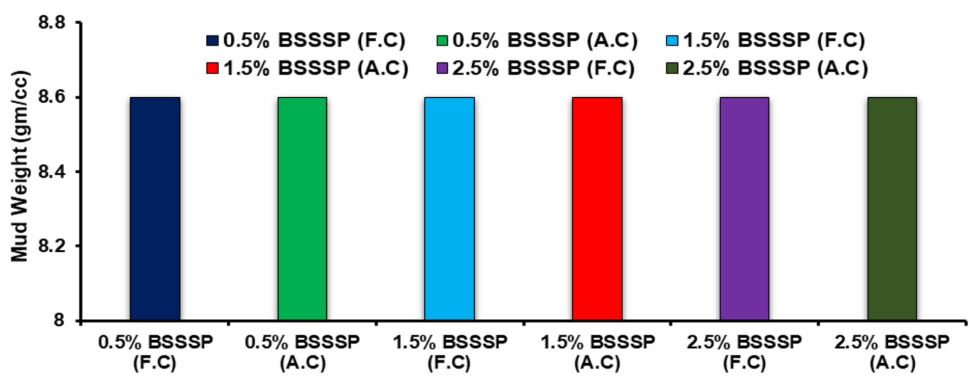


Fig. 14 Comparison between the effects of BSSSP on the mud weight under the fresh and aged conditions

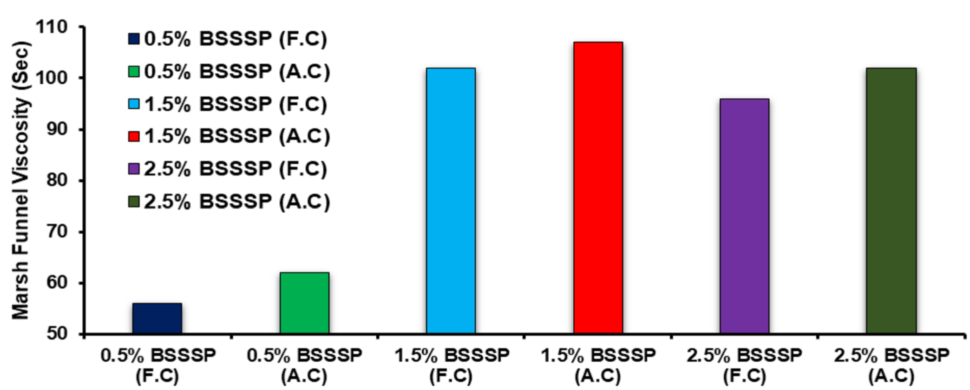


Fig. 15 Comparison between the effects of BSSSP on the marsh funnel viscosity under the fresh and aged conditions

Conclusions

Based on the experimental work performed in this research, the following conclusions can be drawn:

- Black sunflower shells are largely abundant all around the globe. This waste can be collected in large amounts and prepared to be exploited in petroleum applications. Thus, the large resources of the black sunflower shells industry guarantee a permanent source of providing a new eco-friendly mud additive.
- BSSSP can be used at low concentrations (0.5–1%) in normal drilling operation as a viscosifier and filtration control agent. However, BSSSP can be used at higher concentration (1.5–2%) for partial losses especially that the additive had no effect on the density of the drilling fluid.
- Because of the low specific gravity of BSSSP compared to LCMs products such as sized calcium carbonate, the BSSSP particles can readily stay suspended in the drilling mud and therefore can exhibit no or negligible settling issues.
- The BSSSP has fine-sized particles as compared to other commercial lost circulation materials such as granular or fibrous. Consequently, bit nozzles plugging issues will be avoided.
- Experimental findings showed an efficient performance for BSSSP to be used as a multifunctional additive such as increasing the viscosity, regulating the filtration characteristics, and controlling the partial losses.
- The aged conditions have a positive influence on BSSSP effectiveness. Hence, BSSSP can be potentially applied in the oilfield under sub-surface circumstances.
- Because of eco-friendly, non-toxic, biodegradable nature, and non-bacteria issues of black sunflower shells, these raw materials are substantially appropriate for different green product development for petroleum industry applications.
- The processing of black sunflower shells wastes into worthy profit-oriented products will represent a vigorous catalyst for the evolution of domestic and international industries and the creation of new job opportunities.
- The supplementary economic contribution of the utilization and industrial scale of black sunflower shells waste products may inspire the black sunflower shells agriculture industry as one of the most appealing commercial sectors of the worldwide.

References

Al-Hameedi ATT, Alkinani HH, Dunn-Norman S, Albazzaz HW, Alkhamis MM (2019a) Insights into eco-friendly and conventional drilling additives: applications, cost analysis, health, safety, and environmental considerations. Soc Petrol Eng. https://doi.org/10.2118/195398-MS

Al-Hameedi ATT, Alkinani HH, Dunn-Norman S, Al-Alwani MA, Alshammari AF, Alkhamis MM, Al-Bazzaz WH (2019b) Experimental investigation of environmentally friendly drilling fluid additives (mandarin peels powder) to substitute the conventional chemicals used in water-based drilling fluid. J Pet Explor Prod Technol (0123456789). https://doi.org/10.1007/s13202-019-0725-7

Al-Hameedi AT, Alkinani HH, Dunn-Norman S, Alashwak NA, Alshammari AF, Alkhamis MM, Albazzaz HW, Mutar RA, Alsaba MT (2019c) Environmental friendly drilling fluid additives: can food waste products be used as thinners and fluid loss control agents for drilling fluid? Soc Petrol Eng. https://doi.org/10.2118/195410-MS

Al-Hameedi ATT, Alkinani HH, Dunn-Norman S, Al-Alwani MA, Alshammari AF, Albazzaz HW, Alkhamis MM, Alashwak NF, Mutar RA (2019d) Insights into the application of new eco-friendly drilling fluid additive to improve the fluid properties in water-based drilling fluid systems. J Pet Sci Eng 183:106424. https://doi.org/10.1016/j.petrol.2019.106424

Al-Hameedi ATT, Alkinani HH, Dunn-Norman S, Al-Alwani MA, Al-Bazzaz WH, Alshammari AF, Albazzaz HW, Mutar RA (2020) Experimental investigation of bio-enhancer drilling fluid additive: Can palm tree leaves be utilized as a supportive eco-friendly additive in water-based drilling fluid system? J Petrol Explor Prod Technol 10:595–603. https://doi.org/10.1007/s13202-019-00766-7

Allonsy A (2019). https://www.hunker.com/12588918/uses-for-sunflower-seed-shells. Accessed 29 June 2019

Amadi K, Alsaba M, Iyalla I, Al Dushaishi, Al-Hameedi AT, Alkinani HH (2018) Empirical studies of the effectiveness of bio-enhancers (food waste products) as suitable additives in environmental friendly drilling fluid systems. Paper AADE-18-FTCE-105, presented at the 2018 AADE fluids technical conference and exhibition held at the Hilton Houston North Hotel, Houston, Texas, April 10–11, 2018

Basra Oil Company. Various daily reports, final reports, and tests for 2006, 2007, 2008, 2009 and 2010, 2011, 2012, 2013, 2016. Several Drilled Wells. Basra Oil Fields, Iraq

Berglund DR (2007) 1331 Sunflower Production. Fargo, North Dakota. https://www.ag.ndsu.edu/extensionentomology/recent-publications-main/publications/A-1331-sunflower-production-field-guide

Cbi.Eu (2019) Exporting sunflower seeds to Europe | CBI—Centre for the promotion of imports from developing Countries. https://www.cbi.eu/market-information/oilseeds/sunflower-seeds/europe/. Accessed 29 June 2019

Deibert EJ, Lizotte D (2019) Soil applications of sunflower meal as potential fertilizer sources. https://library.ndsu.edu/ir/bitstream/

handle/10365/4665/farm_39_06_05.pdf?sequence=1. Accessed 13 Aug 2019
Environmental Protection Agency (2019) Guide to the facts and figures report about materials, waste and recycling for 2015 and 2016. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/guide-facts-and-figures-report-about-materials. Accessed 25 June 2019
Fann Instrument Company (2005) Aging of water based drilling fluids. https://www.fann.com/fann/default.html. Accessed 18 June 2019
Feed Planet Magazine (2019) World sunflower seed and sunflower meal market. https://www.feedplanetmagazine.com/english/world-sunflower-seed-and-sunflower-meal-market/.html. Accessed 29 June 2019
Halliburton (2018) Products data sheet. http://www.halliburton.com/. Accessed 24 Feb 2019
Hossain E, Wajheeuddin M (2016) The use of grass as an environmentally friendly additive in water-based drilling fluids. J Pet Sci 13:292–303. https://doi.org/10.1007/s12182-016-0083-8
John Hopkins University (2006). Municipal, industrial, and hazardous waste. http://ocw.jhsph.edu/courses/EnvironmentalHealth/PDFs/Lecture15.pdf. Accessed 16 June 2019
Kirschner C (2017) Is it safe to eat sunflower seeds whole? MNN, Mother Nature Network, 5 June 2017. www.mnn.com/food/healthy-eating/stories/is-it-safe-to-eat-sunflower-seeds-whole. Accessed 29 June 2019
Madehow.Com (2019) How sunflower seed is made-material, used, processing, components, procedure, product, design. http://www.madehow.com/Volume-5/Sunflower-Seed.html. Accessed 29 June 2019
MI-Drilling Fluids (2000) Drilling fluids manual
Misachi J (2019) The top sunflower seed producing countries in the world. Worldatlas 2019. https://www.worldatlas.com/articles/the-top-sunflower-seed-producing-countries-in-the-world.html. Accessed 29 June 2019
Myers RL (2019) Sunflower: a native oilseed with growing markets. https://www.extension.iastate.edu/alternativeag/cropproduction/pdf/sunflower_crop_guide.pdf. Accessed 29 June 2019
Osma JF, Saravia V, Toca-Herrera JL, Couto SR (2007) Sunflower seed shells: a novel and effective low-cost adsorbent for the removal of the diazo dye Reactive Black 5 from aqueous solutions. J Hazard Mater 147:900–905. https://doi.org/10.1016/j.jhazmat.2007.01.112
Putnam DH, Oplinger ES, Hicks DR, Durgan BR, Noetzel DM, Meronuck RA, Doll JD, Schulte EE (1990) Sunflower. https://www.hort.purdue.edu/newcrop/afcm/sunflower.html. Accessed 29 June 2019
Ramasamy J, Amanullah Md (2018) A novel superfine fibrous lost circulation material derived from date tree for seepage loss control. In: Society of Petroleum Engineers, SPE Kingdom of Saudi Arabia annual technical symposium and exhibition held in Dammam, Saudi Arabia, 23–26 April 2018