Comparative assessment of *Mucuna solanniae* as an alternative fluid loss control material in synthetic drilling fluid design

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Abstract

In recent years, research using biomaterials in drilling fluid design has thrown light on their biodegradability, availability and low cost. Apart from these, they have in some cases shown properties superior to those of synthetic materials. This research assessed *Mucuna solanniae* as a fluid loss control agent, looking at its fluid loss, filter cake quality, rheology and comparing them with those of Sodium Asphalt Sulfonate, a commonly used drilling mud additive. It assessed the additives at varying concentrations of 2 ppb, 4 ppb, 6 ppb and 8 ppb. The results obtained were filtrate volumes of 5.5 against 4.8 at 2 ppb, 5.0 against 4.5 at 4 ppb, 4.5 against 4.2 at 6 ppb, and 4.1 against 3.8 at 8 ppb, all at 30 min. Field standard value is 5.0 ml fluid loss. Filter cake thickness was 1 mm for all concentrations of *Mucuna solanniae*. On rheology, plastic viscosity, yield point and yield stress were 27 cP against 28 cP, 19 Ib/100 ft² against 19 Ib/100 ft², and 5 Ib/100 ft² against 6 Ib/100 ft², showing slight difference in their rheological properties.

Keywords *Mucuna solanniae* · Sodium asphalt sulfonate · Synthetic mud · Fluid loss

Introduction

The world's energy needs increase each year and so does the search for more oil and gas deposits. This translates to drilling oil and gas wells even in difficult terrains like in ultra-deep offshore, over pressured formations, salt zones, troublesome clay formations, thief zones, etc. Finding oil sometimes requires drilling to great depths, or deviating to avoid obstacles. These bring up challenges that are not even considered in shallow wells in addition to safety and environmental concerns. Because drilling costs are high, mud performance must be optimum (Igwilo et al. 2016).

Mud is as vital as 'blood' to the drilling process (Meng et al. 2012). Its functions among other things include, removing cuttings from the well bore, balancing formation

pressures, maintaining wellbore stability, transmitting hydraulic horsepower to the bit, cooling and lubricating the bit, protecting the formation with an impermeable filter cake, helping in gathering data through cuttings, cores and logs (Heriot Watt 2005).

During the drilling operation, mud loses some fluid to the formation. This way it can have a residue 'filter cake' on the hole wall which helps protect the formation from more filtrate invasion. If this cake is not formed, mud particles can flow into the formation, impairing it (Suter et al. 2011; Allen and Roberts 1982). The filter cake should be impermeable. Its permeability is determined by the shape, size, and arrangement of the mud solids. Hence, particles that are small and irregular are best for good quality cake and they should be well compacted (Igwilo et al. 2017).

Problem statement

Formation damage is the biggest challenge to effective recovery. It could result from loss in formation permeability mostly due to infiltration of drilling and completion fluids into the formation. Hence, it affects the near wellbore region (Azar and Samuel 2007). Since we cannot eliminate the use of drilling and completion fluids, a good filter cake becomes

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necessary to protect the formation from further infiltration. If the filter cake is too thick, it exposes the well to the possibility of stuck pipes. Fluid loss characteristics of a drilling mud are determined by the materials used in mud preparation. So, for optimal mud performance, the right materials should be used to form a good quality filter cake that can protect the formation as well as avoid hole problems (Oloro 2017). *Mucuna solanlie* is a biomaterial that exhibits good rheological (Uwaezuoke et al. 2017) and fluid loss properties comparable to industry standards. The advantages of green materials over synthetic ones which include, low cost of procurement, availability, environmental friendliness and biodegradability, are the reasons they have featured in many research works (Centore et al. 2014; Ekeinde et al. 2018). The material is locally grown/harvested and sourced from Nigeria, Africa and other Asian countries. It is biodegradable because it is a green material. Biocides can be included to retard bacterial action. The presence of oil would retard bacteria action together with brine. Efforts are ongoing to determine if they are competent and safe to use and hence replace synthetic materials. Most materials that contain carbon exhibit characters valuable for specific applications (Román-Martínez and Salinas-Martínez de Lecea 2013). They include suitable surface chemistry, chemical inertness, mechanical resistance, high surface area, optimum porosity and ultimately thermal stability. *Mucuna solanlie* contains high percentage of carbon as shown by scanning electron microscope image (Igwilu et al. 2020), hence, is expected to exhibit these characteristics. Thermal stability of the material has been highlighted in the same material and other previous works.

Filtration loss theory

The mud base fluid is basically, a carrier for the mud additive which really determines the mud properties. Additives are used in mud formulations to achieve several purposes such as the filtration control, viscosity control, weighting control, rheology control, and emulsification (Amoco 2001). Filtration control is important especially in the payzone as mud fluid and particle infiltration can damage the pay, necessitating expensive stimulation jobs. This is why rate of filtrate loss should be studied as a guide to its overall impact on the formation (Kumar 2010). Three conditions must be met for filtration to occur; (a) a liquid/liquid solid slurry must be present, (b) a permeable medium must be present, (c) the fluid must be at a higher pressure than the permeable medium (Igwilu et al. 2019).

The loss of mud filtrate to the formation occurs if the formation permeability allows fluid to pass through the pore spaces. As fluid flows into the formation, the solid residue settles on the wall gradually restricting flow until it stops. The solid residue deposited on formation wall is called the

Table 1 Phytochemical composition of leaves of *Mucuna* (Trease and Evans 1989)

Phytochemical	% Composition
Alkaloids	9.60 ± 0.141
Flavonoids	4.90 ± 0.200
Saponins	24.60 ± 1.979
Cyanogenic glycosides	20.74 ± 0.452
Tannins	32.55 ± 0.778

Table 2 Proximate composition of leaves of *Mucuna* (Pearson 1976)

Nutrients	% Composition
Moisture	11.37 ± 0.632
Ash	0.11 ± 0.01
Crude protein	31.91 ± 2.6
Crude fat	2.97 ± 0.009
Crude fiber	14.80 ± 0.42

filter cake. Its characteristics are important as they help to prevent further fluid infiltration. The thicker the filter cakes the more stable at restricting flow. This is true for static filtration when the cake thickens with time. However, it is not ideal for the cake to be thick, as a thick cake reduces hole diameter and hence increases pressure (Chilingarian and Vrabutr 1983). According to (API 1969), static filtration volume varies with the square root of time. In dynamic filtration, cake erosion occurs with circulation, and pipe movement, countering the effect of deposition. So, shear stress exerted by circulation and pipe movement is balanced by the shear strength of the cake (Uwaezuoke et al. 2017).

Chemical analysis of *Mucuna solanlie*

Previous researches have chemically analyzed *Mucuna solanlie* leaves and seeds, and determined its composition in a bid to identify elements, oxides or compounds responsible for its behaviors at certain conditions such as its rheological properties at low shear rates. Presented in Tables 1, 2 and 3 are tables showing *Mucuna solanlie* compositions.

Materials and method

Apparatus and materials

The apparatus, materials and supplies used in this research include, weighing balance, Fann V-G meter, measuring cylinder, Hamilton beach mixer, HPHT filter press, conical flask, beakers, pH meter, jaw crushers, BS sieve, furnace,

Table 3 Mineral composition of leaves of *Mucuna* (AOAC 2000)

Mineral	Composition (mg/100 g)
Calcium (Ca)	108.68 ± 1.05
Phosphorous (P)	11.06 ± 1.51
Magnesium (Mg)	4.27 ± 0.17
Manganese (Mn)	0.22 ± 0.01
Iron (Fe)	0.95 ± 0.10
Zinc (Zn)	0.02 ± 0.01
Selenium (Se)	0.09 ± 0.002
Potassium (K)	177.50 ± 2.82
Sodium (Na)	16.50 ± 0.42

Fig. 1 *Mucuna solan* after harvesting

thermometer, stopwatch, API filter press, oven, spatula, sieving mesh and filter paper. Also shown is the seed of *Mucuna* (Fig. 1).

The *Mucuna solan* shell was removed, and the seeds were sliced into pieces, soaked in water for 3 h, then grounded into powder form, dried in an oven for 2 h at 120 °F which is an optimum temperature of retaining the chemical properties, and finally sieved and re-grounded until finer powder were recovered.

Method

This section is divided into four parts, namely: (a) mud formulation and weight measurement (b) filtration test at low pressure- low temperature (c) filtration test at high pressure-high temperature (d) mud rheology testing.

Mud formulation The mud was formulated according to Table 4. It was prepared with varying masses of the additives hence obtaining samples with various concentrations. Samples were prepared with two (2) grams of each additive in 350 ml which is one (1) laboratory barrel. This gives a concentration of 2 ppb. Samples were also prepared with four, six and eight grams of the additives giving concentrations of 4 ppb, 6 ppb, and 8 ppb. In all, eight samples were prepared; four for each additive. The mud density was measured.

Filtration test at low-pressure low-temperature

Static filtration test was carried out on four sets of measurements using 2 ppb, 4 ppb, 6 ppb and 8 ppb of *Mucuna solan* in accordance with API Standard. API recommended practice for field testing water-based drilling fluids (API 2010) of Fann LPLT Filter Press was strictly followed during the experiment. The filtration test was conducted for 30 min of filtration. Filtration control characteristics of the mud samples were demonstrated by the filtrate volume and the thickness and consistency of the filter cake (the residue) deposited on the filter paper after 30 min of filtration. The filtrate volume and filter cake characteristics for each of the samples tested were measured and recorded accordingly. The mud filter cake thickness is measured to the nearest millimeter.

HPHT fluid loss experiment

This is the test of the wall building properties in the mud which determines the rate at which fluid is forced through

Table 4 Synthetic mud formulation using *Mucuna solan* as fluid loss control agent of 10ppg and the oil/water ratio of 75/25

Product	Oil/water—75/25, Mud density—10ppg				Product concentration for 1 lab. bbl (350 mls)	
	SG	Unit size	Mixing order	Mixing time	g	mls
Base fluid (EDC-99)	0.805	BBL	1	4	174.9	217.3
Viscosifier	1.7	Lb			2.0	1.2
Lime	2.3	Kg			3.0	1.3
Primary emulsifier	0.9	Gal	2	2	8.5	9.4
Aqueous phase	1	Bbl			76.1	76.1
Brine phase	3.62	Kg	3	5	25.4	7.0
Barite	3.7	Kg	4	5	139.4	37.7
Fluid loss agent	1.07		5	6	4.2	3.9
Total					429.3	350.0

filter paper under specified conditions of time, temperature and pressure. This filter press simulates filtration against permeable formation at high temperatures and pressures. At the desired temperature, the sample is filtered across the filter media while pressure is applied to the top of the cell.

The HPHT filter press consists of a heating jacket with thermostat, primary and Carbon dioxide pressure assembly, back-pressure receiver, sample cell and stem thermometer. A back-pressure receiver is used to collect the filtrate. The test cell is encased in the heating jacket to ensure complete and uniform sample heating, thereby measuring the fluid loss in a sample.

High pressure-high temperature fluid loss test (Fig. 2) was carried out in accordance with (API 2010) standard. HPHT was done using 2 ppb, 4 ppb, 6 ppb and 8 ppb of the mud formulated with *Mucuna solannie* and Carbogel. The HPHT filter press comprises cylinder cell 3-inches internal diameter and 5-inches high to contain the formulated drilling fluid. The bottom of the cell was fitted with a sheet of hardened low ash grade filter paper, filled with the drilling fluid sample to be measured. After the required connections, a pressure of 600psi from Carbon dioxide cartridge was used as a source of input pressure and the bottom gauge was maintained at 100psi. HPHT filtration test commenced immediately the mud sample was heated up to 120 °F. With a 10 ml graduated cylinder placed beneath the cell, the filtrate through the filter paper was collected over a period of 30 min recorded in milliliters (ml). The recorded filtrate volume was doubled because of inner compartment of the filter area according to API standard, before reporting it as the HPHT fluid loss of the mud samples formulated with *Mucuna solannie*. The results of the filtrate loss volume obtained for each fluid loss control agent at various concentrations were measured after 30 min. The time was lowered to 5 min, 10 min, 15 min, 20 min and 25 min below the standard time of 30 min (Table 5). After each HPHT fluid loss test, the mud cell was dismantled to obtain the filter paper. The filter paper containing a layer of mud was

rinsed with water, measured in inches and later, the residual (cake) thickness of the mud sample on the filter paper was measured using Vernier caliper and recorded in millimeters (mm) as the mud cake thickness of the mud sample as shown in Table 6.

Rheology test

Rheology tests were carried out with the Fann V-G viscometer. The samples were tested at 120⁰ F, simulating down hole temperature condition. The reading obtained at the speeds of 3, 6, 100, 200, 300, and 600 rpm's were recorded in Table 7. The tests were carried out according to API standard (API 2010).

Results and discussion

Results

The results of the filtration test with 2 ppb concentration of the additives were plotted and shown in Fig. 3. The 2 ppb and 8 ppb concentrations that were used as lowest and highest for the test were points used to estimate the optimum concentration. There are no maximum and minimum values.

Discussion of results

Results of filtration test at various time intervals from 5 to 25 min of 2 ppb concentration of *Mucuna solannie* and Sodium Asphalt Sulfonate plotted in Fig. 3 shows that *Mucuna solannie* cake is more permeable, hence it allows more filtrate volumes. However, the volume difference between the two additives decreases with time and at 25 min has just a 0.9 ml difference. The trend of filtrate volume decreasing with time also shows that mud prepared with both additives will build a filter cake that will protect the formation from mud filtrate invasion. Figure 4 shows at a glance how both additives fare against industry standard of 5.0 ml fluid loss. Both additives showed excellent fluid loss

Fig. 2 HTHP filter press for oil-based mud

Table 5 Filtration volumes at other time intervals using 2 ppb optimum concentration of the additives

Additive Concentrations (ppb)	Other time Interval (mins.)	Filtrate volume (ml)	
		<i>Mucuna solannie</i>	Sodium asphalt sulfonate
2	5	13.38	10.34
4	10	8.96	7.60
6	15	7.61	6.37
8	20	6.77	5.65

Table 6 Filtration properties of HPHT fluid loss measurements of synthetic muds using *Mucuna solannie* and Sodium Asphalt Sulfonate as fluid loss control agents

Physical properties	Concentration of <i>Mucuna solannie</i>			
	2 ppb	4 ppb	6 ppb	8 ppb
Mud density(ppg)	10	10	10	10
Filtrate Volume (ml) of <i>Mucuna</i> Per 30 min Received	5.5	5.0	4.5	4.1
Filtrate volume per field standard across the reservoir (ml)	5.0	5.0	5.0	5.0
Filtrate volume of sodium asphalt sulfonate (ml)	4.8	4.5	4.2	3.8
Electrical instability of the Mud (mV) formulated using <i>Mucuna solannie</i>	327	331	336	340
Filter cake thickness (mm)	1	1	1	1

Table 7 Computed Results of *Mucuna solannie* of 10.6ppg mud weight

Mud properties	Fluid loss control agent " <i>Mucuna solannie</i> "				Shear rate (l/s)
	2 ppb	4 ppb	6 ppb	8 ppb	
Mud Weight, ppg	10	10	10	10	
600RPM	73	75	79	80	1022
300RPM	46	47	49	50	511
200RPM	32	34	37	40	341
100RPM	19	21	23	26	170
6RPM	6	7	7	7	10
3RPM	5	6	6	7	5
Plastic viscosity (cP)	26	27	30	31	
Yield point, (lb/100ft ²)	19	19	19	20	
Yield point: plastic viscosity	0.73	0.70	0.63	0.65	
Electrical stability (mV)	318	325	329	335	
Yield stress (lb/100ft ²)	4	5	5	7	

Fig. 3 Plot of filtrate volumes per time for 2 ppb concentration of both additives

control at higher concentrations of 4, 6 and 8 ppb. By standard, the fluid loss volume should not exceed say 5 ml. Higher values of filter cake thickness could result in problems such as stuck pipe, excessive drag from tight hole, increased pressure surges due to reduced hole diameter, and too thin high

permeability filter cake can result in excessive formation damage and evaluation problems with wireline logs.

Figure 5 indicates the filter cake thickness with filtrate volumes at the different concentrations. Both additives showed consistency in cake thickness. This shows that they

Fig. 4 Plot of filtrate volume at various concentrations of both additives against field standard

build stable cakes that can withstand drilling activities that would otherwise lead to cake erosion and deterioration. Also, the thin cake thickness means that wells drilled with *Mucuna solannie* additive will not be exposed to hole problems like pipe sticking that result from poor cake quality.

Figure 6 shows that for both additives, the mud's electrical stability increases with additive concentration, just as filtrate volume decrease with additive concentration (Fig. 4). Hence, muds prepared with *Mucuna solannie* will exhibit good fluid loss control as well as good hole sweep.

Figures 7, 8, 9, 10, 11 and 12 show the rheological properties of both additives showing similar trends. They have high viscosity values at all concentrations showing good viscosifying and hole cleaning tendencies. API rheology standards are a yield point/plastic viscosity of not more than three. Both additives fall within this standard according to Tables 7 and 8.

Whereas viscosity is the property of mud in motion, gel strength is exhibited by a mud that is static. During temporary suspension, mud gels and cuttings are suspended. Subsequently, it thins when circulation is restarted and

Fig. 5 Plot of filtrate volume and cake thickness against additive concentration

Fig. 6 Electrical stability of the Mud at different Additive Concentrations

Fig. 7 Comparison of Plastic viscosity of *Mucuna* against Sodium Asphalt at various concentrations

cuttings are transported as a result. The higher the yield point, the better the cutting carrying capacity. The yield points presented are adequate. The yield point of *Mucuna solannie* was constant with concentration until at 8 ppb. The yield stress however increased with concentration indicating higher cuttings carrying capacity and hence better hole cleaning at higher concentrations. The rheograms (Figs. 11 and 12) clearly show the non-Newtonian nature of mud prepared with these additives.

Conclusion

Mud prepared with *Mucuna solannie* gave filtrate volumes of 5.0 ml at 4 ppb, 4.5 ml at 6 ppb, and 4.1 ml at 8 ppb, all within acceptable range for good fluid loss control agent when compared against the field standard of 5.0 ml. Also, mud prepared with *Mucuna solannie* gave filter cake of 1 mm which is thin and of low permeability. This indicates that a well drilled with *Mucuna solannie* prepared will most likely not be exposed to drilling challenges like pipe

Fig. 8 Comparison of Fluid Yield point of *Mucuna* against Sodium Asphalt at various concentrations

Fig. 9 Comparison of Yield stress of *Mucuna* against Sodium Asphalt at various concentrations

sticking. Finally, muds prepared with both *Mucuna solan- nie* and Sodium Asphalt Sulfonate had yield stress values increasing with concentration pointing at better hole cleaning potentials of the muds at higher concentrations. This research established *Mucuna solannie* as a good fluid loss control agent according to API and field standards. It also indicated the adequate dosage of the additive to be used for mud preparation.

When a mud satisfies API specifications for fluid loss tests, potential for differential sticking and formation

damage is limited. Similarly, provision of borehole stability, reduction of tendency to have irreversible changes in fluid properties, reduced tendency for poor cementing jobs and tight hole incidents are achieved. The two data points in the API fluid lost test are the fluid loss volume and filter cake thickness. Since API fluid loss test can lead to errors since they are performed at surface conditions, HPHT fluid loss test is used to simulate downhole conditions. For the HPHT fluid loss test, the mud filter cake must be maintained below 2 mm thickness. Rheology helps to determine

Fig. 10 Comparison of Rheological properties of *Mucuna* against Sodium Asphalt at various concentrations

Fig. 11 Shear stress—shear rate plot of *Mucuna solanum* at various concentrations

cutting carrying capacity, suspension capability and circulating pressures. Whereas YP is used as indicator of carrying capacity of the mud, the gel strength determines suspension capabilities and both are related since the same

additives are used to control them. PV is an indicator of solids content. A high circulating pressure may be indicative of high solids content, hence, must be minimized by improving on the efficiency of solids control equipment.

Fig. 12 Rheograms of Sodium Asphalt Sulfonate at various concentrations

Table 8 Computed Results of Sodium Asphalt Sulfonate of 10.6ppg mud weight

Mud properties	Fluid loss control agent “Sodium Asphalt Sulfonate”				Shear rate (1/s)
	2 ppb	4 ppb	6 ppb	8 ppb	
Mud Weight, ppg	10	10	10	10	
600RPM	73	75	80	81	1022
300RPM	46	47	50	51	511
200RPM	33	35	38	41	341
100RPM	20	23	26	29	170
6RPM	7	8	8	8	10
3RPM	6	7	7	8	5
Plastic viscosity (cP)	27	28	30	30	
Yield point, (lb/100ft ²)	19	19	20	20	
Yield point:Plastic viscosity	0.70	0.68	0.67	0.67	
Electrical stability (mV)	320	326	331	336	
Yield stress (lb/100ft ²)	5	6	6	8	

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Compliance with ethical standards

Conflict of interest No conflict of interest has been declared by the authors.

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