
LABORATORY EVALUATION OF BIOSURFACTANT SOLUTION FOR FILTER CAKE REMOVAL TO ENHANCE A MORE WETNESS CONDITION IN OIL RECOVERY

Emmanuel E. Aluola ¹., Samuel E. Ogbeide ¹., Kess O. Obahiagbon ¹.

¹Department of Chemical Engineering, Faculty of Engineering, University of Benin. Edo State, Nigeria.

ABSTRACT: *In order to regain wellbore permeability, several operators use synthetic surfactant, polymers and other chemical compounds to ensure interfacial tension reduction between oil-water/brine, mobility control, alteration of the wettability of the reservoir rocks, filter cake removal in wellbore cleanup and reservoir remediation operations. These synthetic surfactants are not biodegradable, they are expensive, toxic and are linked to products of petroleum origin. This accounts for the growing research interests in biosurfactants, environmentally friendly and cost effective remediation products of good compatibility with reservoir rocks, biodegradability and lower toxicity. A nonionic saponin extracts from indigenous plants were used to design a biosurfactant solution with mostly acid and solvent soluble materials. Formulation of reservoir drill-in fluid (RDIF) was carried out for the purpose of filter cake generation, using the American Petroleum Institute (API) high temperature/high pressure (HTHP) filter press. Appropriate evaluations and laboratory testing to determine the effectiveness and feasibility of the biosurfactant solution to remove the filter cake were carried out. Results showed that the biosurfactant solution formed was able to fluidize and remove the filter cake. It was able to solubilize the oil in the emulsion, leaving the solids and surfaces in a more water wet state to enhance injectivity and productivity in the reservoir.*

KEYWORDS: wettability, nonionic, biosurfactants, remediation, biodegradability.

INTRODUCTION

During any well construction, sustaining a stable wellbore without damage to the formation has always been one of the numerous challenges often encountered. Various grades of oilfield chemicals/materials are incorporated into the drilling mud to control fluid/filtrate leak off, ensure thin impermeable filter cake formation, balance formation pore pressure and enhance wellbore stability. Most often, the materials are incompatible with the reservoir rocks, they alter the porosity and permeability through penetrations into perforations and channels of oil flow. This can affect the storage potentials and reduce hydrocarbon recovery. Any such alterations in reservoir permeability and limitation in the flow of hydrocarbon to the wellbore or production facility is termed formation damage. Increase in positive skin factor has the susceptibility to disrupt oil extraction process. "Skin" is the reduction in the permeability of the reservoir rocks by introduced natural or induced materials. Filter cake is one of the materials that can compromise permeability of the formation.

The Filter cake is a tough, impermeable and flexible layer of solid particles from drilling fluids which is deposited on the surface of the wellbore (Aird, 2019). A poorly designed drilling fluid, with high rate of fluid loss into the formation will result in the formation of a thick, soft and incompetent mud cake across permeable formation. This can result in increase in the contact area between the drill string and formation, leading to wellbore instabilities and nonproductive time like differential sticking. A thick mud cake due to the high fluid loss to the formation, usually with drilled solids (low gravity solids) formed across a porous would lead to excessive torque and drag during drilling or tripping. Saladeen *et al.*, 2017 established that formation damage is more pronounced in horizontal wells than in vertical and deviated wells. The filter cake layer must be removed proficiently to allow for good cementing job after drilling operations, to attain lower completion costs and optimize hydrocarbon recovery rates without any limitations during production (Huang *et al.*, 2019). The removal of the impermeable filter cake that is produced would depend largely on the physical and chemical properties of weight-up additives (Elkatatny *et al.*, 2019; Caenn *et al.*, 2017). Oil well completions are usually divided into three types; open hole, perforated casing and liner completions. The retardation in hydrocarbon flow is more critical in open hole completions, with stand-alone and expandable screen application. The screens are easily plugged by the deposited filter cake (Quintero *et al.*, 2007). Minimizing alteration in reservoir permeability is critical and must be considered in all well operations, since it can occur during drilling, completion, production and workover phases of operation. During filter cake removal through wellbore cleanup, reservoir remediation and enhanced oil recovery processes, several operators make use of synthetic surfactants, polymers and other oilfield chemical compounds to ensure interfacial tension reduction between oil and water/brine, mobility control and alteration of the wettability of the reservoir rocks. These materials due to their non-biodegradability stay in the environment indefinitely when released. This brings about environmental degradation. They are detrimental to terrestrial plants, animals and aquatic species (Johnson *et al.*, 2020; Bachari *et al.*, 2019). The use of biosurfactants would help in curbing the nuisance of toxicity, environmental degradation and contamination. Pradhan and Bhattachayya, 2017 reported that biosurfactants are readily available and are promising biological alternatives to synthetic surfactants. They are ecologically adaptable with multi-functionality compared to the synthetic/commercial surfactants (El-Aziz *et al.*, 2019; Samal *et al.*, 2017; Sahu *et al.*, 2018; Akbari *et al.*, 2018; Bachari *et al.*, 2019). They can reduce the interfacial tension, enhance oil solubilization and fluidize the filter cake in the pores of the formation to stimulate/remediate damaged reservoirs.

MATERIALS AND METHODS

Reservoir drill-in fluid (RDIF) was designed exclusively for the purpose of filter cake generation in this study. This could be used to drilling through any reservoir section of a wellbore successfully, irrespective of formation. The aim of the drill-in fluid is meant to maximize drilling performance and reduce formation damage, thereby preserving well potentials, to facilitate the well completion type and enhance overall well delivery (Addagalla *et al.*, 2016).

All mud additives were obtained from OilChem Drilling Fluids Limited, Port Harcourt Nigeria. The formulated drill-in fluid was synthetic oil based mud (SOBM) system. This was weighted with various sizes of acid soluble CaCO_3 particles (5, 50 and 150 microns). Pure grade calcium carbonate (fine & medium) were used to ensure good filter cake removal during wellbore clean up and to ensure good hole cleaning, lubricity and inhibition. The drill-in fluid was specially designed to exclude additives that could migrate into the formation and plug the pores of the reservoir thereby creating further formation damage challenges. The sized CaCO_3 particles were carefully selected to provide the required weight and pore throat bridging/filtration properties to prevent whole mud and filtrate loss, while being small enough to pass through the aperture of the screen and completion equipment. Knowing that mud formulation could have a direct influence on flow characteristics of the reservoir. Prior to remediation operations, the reservoir drill-in fluids must be displaced efficiently and the treatment fluid spotted in the area of interest to achieve the desired results.

Chemical Composition of the RDIF

The following chemical additives and concentrations (table 3.1) were used in the composition of the reservoir drill-in fluid. Synthetic base fluid used provided enhanced rheological properties. It is ecofriendly, with almost 100% biodegradability, it acted as the external or continuous phase of the mud. Emulsifiers used were basically primary and secondary emulsifiers. They helped to lower interfacial tension between oil and water, which allowed the formation of stable emulsion. Lime ($\text{Ca}(\text{OH})_2$) was the source of calcium ion for emulsion stability and alkalinity control. It was meant to perform a chemical reaction with the fatty acid emulsifiers. Drill water served as the internal or dispersed phase of the mud. Calcium Chloride (CaCl_2), a divalent salt reduced the water activity of the mud (increased water phase salinity) for possible shale inhibition. 98% high grade was used for the purpose of this research work. Rheology modifier helped to enhance the low end rheology (6 dial reading) to the appropriate value in conjunction with optimized hydraulics for good hole cleaning.

Wetting Agent was introduced to help in the preferential oil-wetting of solids. Sized calcium carbonate (CaCO_3) ; 5, 50 and 150 microns served as weighting/bridging agents, for quick establishment of protective filter cake. Viscosifiers/gellants (organo clay) improved cuttings transport and reduced barite settling, thus reducing annular pressure build up and wellbore pressure differentials. From the formulation, the RDIF was made of diverse chemical compounds in an inverse emulsion of oil and water. An 8-speed viscometer was used to determine the rheological properties as shown in table 2.2. The yield point (YP) which was an indication of the carrying capacity of the mud and the plastic viscosity (PV) which denoted the level of solids in the mud and the gel strength of the mud were obtained from the viscometer dial readings using the API recommended standard procedure for field testing of oil-based drilling fluids (API RP 13B-2). The effect of volume ratio of oil to water in terms of emulsion stability of the mud was determined by

the oil-water ratio (OWR). The electrical stability (ES), the low shear rate yield point (LSRYP) and the fluid loss (FL) and the mud chemistry were determined (table 2.2).

Table. 2.1: Reservoir drill-in fluid (RDIF) formulation

Product	Concentration	Unit
Base Oil (EDC – 99)	0.514	bb1/bbl
Primary (1 ⁰) Emulsifier	2.5% (v/v)	gal/bbl
Lime	7.0	ppb
Secondary (2 ⁰)Emulsifier	2.5% (v/v)	gal/bbl
Drill water	0.277	bb1/bbl
Gellant (Organo clay)	5.0	ppb
Rheology Modifier	1.3% (v/v)	gal/bbl
CaCl ₂ @ 25 wt % (Salinity)	35.2	ppb
Wetting Agent	2.5% (v/v)	gal/bbl
CaCO ₃	168.0	
(UF, F, M)	(acid-soluble	ppb
5u, 50u, 150u,	weighting/bridging agent)	
(60: 20: 20 ratio)	(100.8 ; 33.6; 33.6)	

Table 2.2: RDIF parameters @ 120⁰f

Properties	Results	Unit
Mud Weight	10.5	ppg
PV	24	cP
YP	17	lb/100ft ²
Gels (10 sec/10 min)	10/13	lb/100ft ²
ES	560	volts
Excess Lime	1.3	ppb
LSRYP	10	lb/100ft ²
HPHT FL@500psi, 250 ⁰ F	2.0	ml
6rpm	10	Ib/100ft ²
OWR	65/35	-
WPS	250,000	ppm

Filter Cake formation.

The American Petroleum Institute (API) high temperature /high pressure (HTHP) heating jacket and fluid loss cell were used to generate the filter cake from the SOBM Drill-in-fluid (DIF) at 121⁰C (250⁰F) and 500psi differential pressure. The HTHP cell was used to denote the down hole conditions of the reservoir. The density of prepared mud sample was 0.546psi/ft (10.5ppg). The DIF mud sample was stirred for 10 minutes, using high speed beach mixer. The double ended cell was assembled and the heating jacket cord was plugged to the voltage source. A 500⁰F metal thermometer was placed in the hole on the outside of the heating jacket and the jacket preheated to 10⁰F above test temperature. While preheating the jacket, O-rings, high pressure regulator, lid/valve and cell body were inspected and worn seals/components were replaced. The HPHT filtration kit was cautiously set up (figure 2.2). With valves B and C closed, 100psi was applied to both the high and low pressure regulators. Valve B was opened; this was done to maintain 100psi back pressure in the cell body, while heating to the desired temperature. When the desired test temperature of 121⁰C (250⁰F) was reached, pressure on the high pressure regulator was increased to 600psi. Valve C was opened. The filtrate was collected for 30 minutes, maintaining the test temperature at +/- 5 ⁰F at the end of 30 minutes, valve C was closed carefully and valve D opened. Filtrate collected (figure 2.3) was 2 X 2.0mls = 4mls (all oil). A competent thin filter cake was carefully obtained from the cell (figure 2.3). The mud cake formed was subsequently subjected to the biosurfactant treatment solution to remove/destroy the cake and render it water wet. The time taken to remove/destroy the cake was recorded.

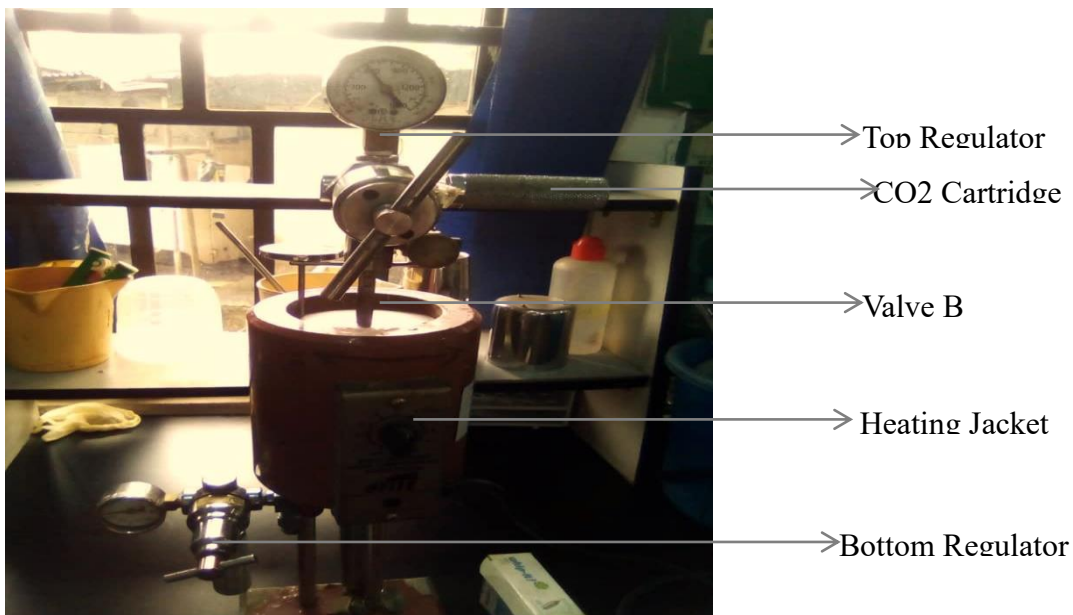


Figure 2.2: HPHT Filter Press.

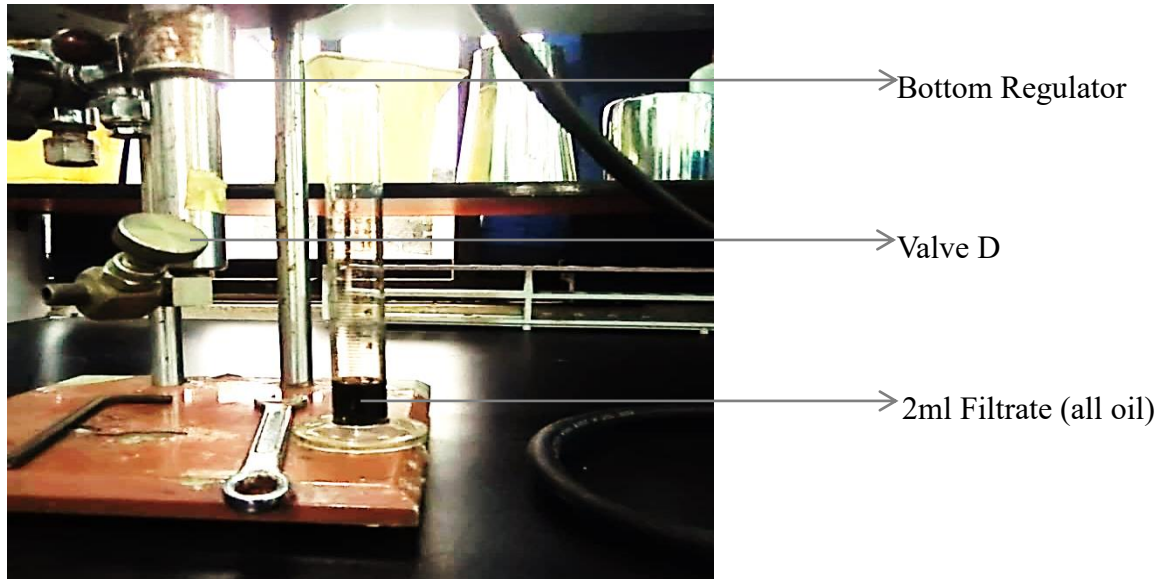


Figure 2.3: 2ml filtrate obtained (all oil)



Figure 2.4: Filter Cake obtained from HPHT Press.

Table 2.3: Surfactant Fluid Formulation for Sandstone Reservoirs.

Product	Concentration
Brine	63% to 77%
Primary Mesophase Surfactant Fluid	15% to 21%
Corosion Inhibitor	0.5% to 1%
Mesophase Cosurfactant	2.5% to 5%
Organic Acid	5% to 15%

(Adapted from Baker Hughes Dbabran R&D Center Laboratory, cited in Addagalla *et al.*, 2016).

Table 2.4: Single phase microemulsion formulation using saponin extract

Products	Concentration
Brine	64%
Saponin extract	20%
Cor – 16	1%
Isopropanol (IPA)	1%
Organic Acid	14%

Preparation of of saponin surfactant solution

Pietrangeli *et al.*, (2014) reported that open hole remediation fluid should contain between 10% - 30% of the surfactant blend, which is the major component for wellbore cleanup treatment. Biosurfactant (Saponin) treatment solution was prepared using the recipe in table 2.4; after several laboratory trials. Calcium chloride brine with the required density (0.546psi/ft) (10.5ppg) was used. Saponin, a natural surfactant from indigenous plants was used in the design owing to its solubilization potentials, to destabilize the emulsion and solubilize oil fractions. Raman *et al.*, 2003 asserted that the most desirable properties of microemulsions for detergency or cleaning applications are due to improved solubilization for both polar and non polar compounds. The corrosion inhibitor would help to reduce corrosion rates of both completion and production tools and equipment to acceptable level. A Co surfactant (Isopropanol) in the design helped to stabilize and enhance the effectiveness of the biosurfactant. This would preferentially water wets the surface of the wellbore, thereby mobilizing the solids that ordinarily would stick to the surface of the wellbore. The organic acid in the formulation assisted in the removal of calcium carbonate in the filter mud cake which were solubilized efficiently, having been freed and water wet. The biosurfactant soak solution with proper formulation using acetic acid, corrosion inhibitor and a co-surfactant would completely break up the emulsion-forces between the drill-in fluid (DIF) spilled inside & around the beaker, rendering the surface water-wet and consuming the acid soluble particles; resulting in the leaching of the mud particles from the body of the glass beaker with free flow, without any physical agitation (Zhou *et al.*, 2018).

Test Criteria

The tests below were carried out in the laboratory based on reservoir conditions to assess the quality and cleanup efficiency of the formulated biosurfactant intended to solubilize the oil and fluidize the filter cake formed. These tests criteria included single phase stability, compatibility, soaking, filter cake removal and detergency tests. The density of the formulated solution should be such that it should be able to hold back the influx of reservoir/formation fluid into the wellbore.

The reservoir density would determine the brine type. Knowing the reservoir bottom hole temperature before hand would help formulate efficient and effective solution. The type of base fluid used play critical role in the selection of surfactants. Ecofriendly, mineral oil (EDC-99) was used for this study.

Phase Stability

Phase stability evaluation tells the state of a mixture at specified conditions, in most cases at given temperature and pressure. The analysis is vital in petroleum and gas reservoirs, process systems, production and transport engineering (Nichita and Secuinu, 2020). 150ml of the biosurfactant solution was transferred into a glass beaker and was heated in a water bath to 65.56°C (150°F) for 48hours to check for phase stability. The thermal stability test is a simple test where the treatment fluid is placed in an oven at a predetermined temperature, representative of the expected reservoir temperature to ascertain if the treatment fluid would remain as a single-phase fluid at the reservoir condition (Quintero *et al.*, 2015). It is assumed that surfactant solutions are in instant equilibrium with respect to micelles, other structure or formation when changes in conditions such as degree of saturation, temperature, salt addition, etc are made (Marques and Silva, 2013). Addagalla *et al.*, 2016 had established that the reservoir bottom hole temperature and other reservoir properties should be known prior to remediation treatment formulation to enable a robust and healthy laboratory design.

Detergency Evaluation

Detergency tests were performed using the biosurfactant to show its efficiency and effectiveness in the removal of drill-in fluid and residues from the near wellbore region and return it to a water wet state (Pietrangeli *et al.*, 2014). 5ml of the Drill-in fluid was placed in a beaker and left for 20 minutes to allow the beaker become completely oil wet. 50ml of the biosurfactant solution was introduced avoiding agitation, and the beaker was left undisturbed in an oven at 65.56°C (150°F) for 24 hours.

Soaking Test

The soaking test was to evaluate the time it would take the biosurfactant solution to pass through the filter cake. This is referred to as “delay or break through time”. It is the time it takes the treatment solution to make a path through a filter cake. The delay time is very important because, it gives an idea on when to start experiencing losses. Meanwhile the open hole is isolated by activating the packer, while running the upper completion. The test also helps to determine the ability of the treatment solution to water wet the solids in the DIF. 100ml surfactant solution was carefully poured into the HPHT cell in order not to disturb the integrity of the filter cake. The HPHT cell was placed in the heating jacket and heated to 93.33°C (200°F), and 200psi was applied to the cell. The 200°F is the representative of the bottom hole temperature (BHT) of the candidate reservoir. The first 50ml was collected to check the designed delay time. The cell was refilled with

another 50ml of surfactant fluid (Addagalla *et al.*, 2016). The lower valve was closed for 48 hours to check for complete water wettability.

Destructibility Test

For cake destructibility test, the HTHP cell was re-assembled with the formed filter cake on the disc. 100mls of the treatment (biosurfactant solution), was added into the assembled cell and left for two hours. 40mls was removed and another 40mls added as replacement. This was left undisturbed at 150°F for 48hrs.

Compatibility Test

To verify the compatibility of the formulated treatment solution with reservoir fluids, some light crude was obtained from an existing well #9 Ughelli (East) field of the Niger Delta area; and 0.546psi/ft (10.5ppg) CaCl₂ brine was formulated (table 2.4.1). Both samples were heated in a water bath to 150°F differently. Equal amounts of the biosurfactant and the crude and biosurfactant and brine were poured into separate beakers (80ml), this was followed by shaking vigorous with a glass rod to allow for proper miscibility. The beakers were then left undisturbed at room temperature of 25.56°C (78°F) and observed for the formation of precipitates, emulsion or separation (Addagalla *et al.*, 2016).

Table 2.4.1: Composition of Saponin soak; for 0.543psi/ft (10.4ppg)

Product	Concentration Vol %	Volume mls	Density SG
Saponin	20.0%	70	1.145
CaCl ₂ brine	56.0%	196	1.390
Acetic Acid	15.0%	52.5	1.049
Water	8.0%	28	1.000
Corrosion Inhibitor	1.0%	3.5	0.892
	100%	350	1.25

Importance of pre-flush

Pre-flush is very significant in chemical enhanced oil recovery (EOR), reservoir remediation and simulation operations. It involves pumping of salinity fluid (water) ahead of surfactant (micellar) solution (Table 2.4.2). It aims at displacing the reservoir brine which may contain ions such as magnesium, Calcium and Potassium ions, capable of reacting with the surfactant solution. This can lead to further formation Damage, through scale and precipitate formation. Pre-flush helps to

prepare the reservoir by adjusting the salinity to accommodate the introduced surfactant solution (Schlumberger, 2021).

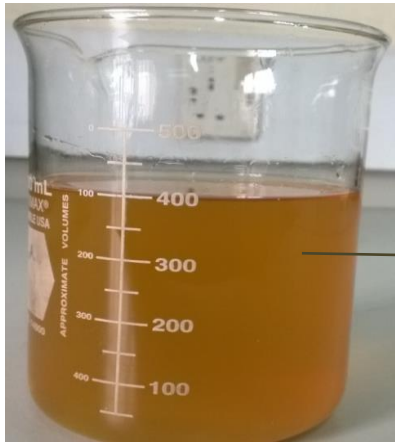
Table 2.4.2: Pre- flush composition:

Component	Concentration	Volume	Density
	%	mls	SG
Saponin Extract	20	32	1.145
CaCl ₂ brine	70	112	1.390
Water	10	10	1.000
Total	100	160	1.26

RESULTS AND DISCUSSIONS

Phase Stability

The results obtained from the RDIF formulation and subsequent filter cake generation were evaluated in a double-ended HPHT filtration cell to determine the efficiency of the biosurfactant solution by measuring physical properties on the basis of physical state, chemical composition and internal structure, was uniform and they met/show the test criteria for a single phase. Performance results were beyond the capabilities of conventional treatments (Zhou *et al.*, 2018; Quintero *et al.*, 2015). Upon addition of the surfactant solution, no visible phase separation was observed before (at room temperature of 78°F) and after heating to 150°F for 48hrs. As shown in sample 3.1A and sample 3.1B below. The predetermined temperature representing the expected reservoir temperature, to see if the treatment fluid will remain as a single-phase fluid at the reservoir conditions. The biosurfactant solution met the test criterion of a single phase. This result is similar to the results obtained from laboratory evaluation of reservoir remediation fluids prior to post-completion intervention on Block 17 wells in Rosa field, about 210km NW of Luanda Angola by Quintero *et al.*, 2015. The average increase in productivity index (PI) was 60%.



→ Biosurfactant Solution before heating to 150°F for 48hrs

Figure 3.1A: Biosurfactant at room temp at 78°F



→ Biosurfactant solution after heating to 150°F for 48hrs

Figure 3.1B: Biosurfactant solution after heating, maintaining a single phase.

Detergency of treatment (biosurfactant) solution

From the laboratory examination, the biosurfactant treatment solution with proper formulation with acetic acid, corrosion inhibitor and a co-surfactant completely broke up the emulsion-forces of the drill-in fluid (DIF) spilled inside & around the beaker, rendering the surface water-wet and consuming the acid soluble particles (3.2B). This results in the leaching of the mud particles from the body of the glass beaker with free flow, no physical agitation (Zhou *et al.*, 2018). This attests to the fact that biosurfactant solution has powerful detergency properties to remove oil mud damage. Similar to results of laboratory assessment of treatment fluids used on severely damaged

wells (A & B) of Khajif sandstone reservoir in Saudi Arabia by Addagalla *et al.*, 2016. Both wells showed great production improvements after treatment.

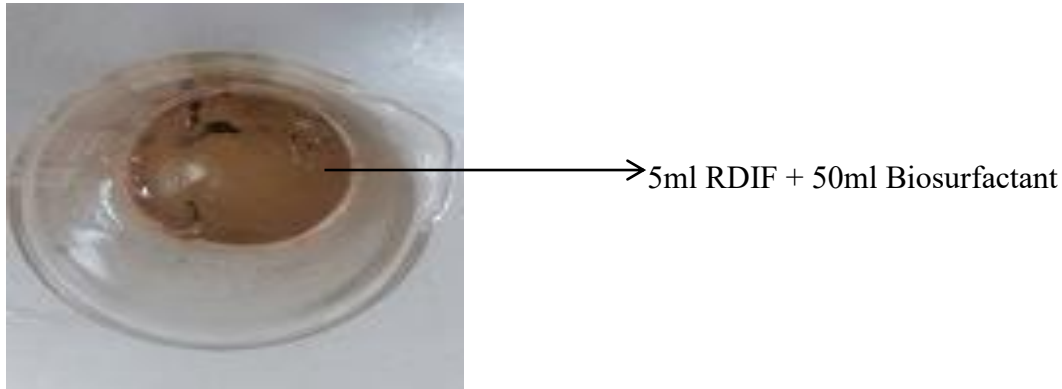


Figure 3.2A: RDIF + Biosurfactant in static condition.

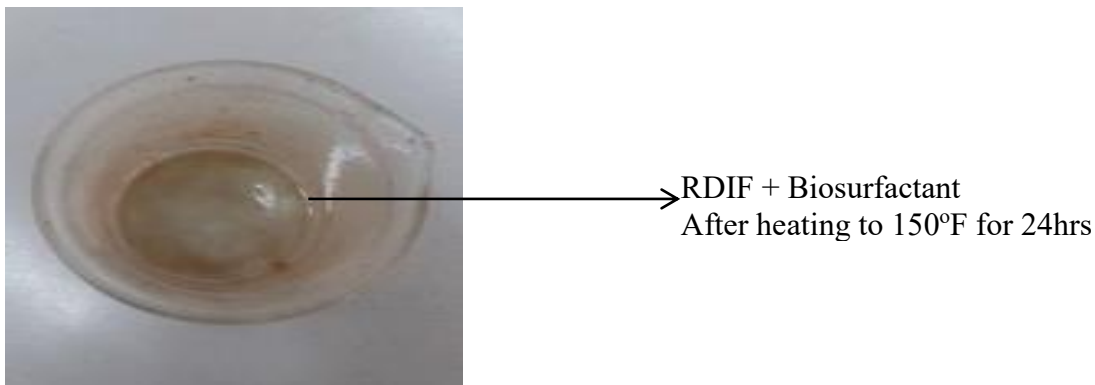


Figure 3.2B: Emulsion-forces of the RDIF completely broken by the biosurfactant solution.

Result of Cake Destructibility Test

The soaking time recorded for this study was between 7-9hrs. After the required amount of soaking time at 200 °F. When the HTHP cell was re-assembled and the destructibility test carried out at 150°F for 48hrs, the cake was almost completely consumed by the biosurfactant solution (fig. 3.3B), with the solids particles & Aloxite disc surface rendered completely water-wet. When the filter cake samples were dispersed in water no sheen was observed, meaning that all the oil has gone into the surfactant solution (Quintero *et al.*, 2007). The result (visual inspection) as shown in fig 3.3B below indicates cake destructibility of more than 70%.



Figure 3.3A: Oil-wet mud filter cake before treatment with biosurfactant solution.

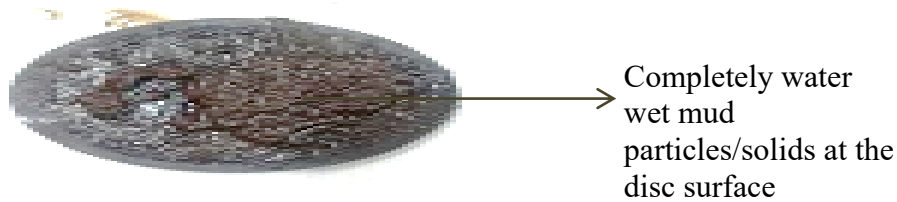


Figure 3.3B: water-wet mud filter cake after treatment with biosurfactant solution at 150°F for 48hrs.

Compatibility results

There was 100% separation in the cylinders (fig. 3.4- 3.6) without any precipitate formation. The biosurfactant showed compatibility, formed a homogenous blend with completion and formation fluid (crude oil, formation water/brine).

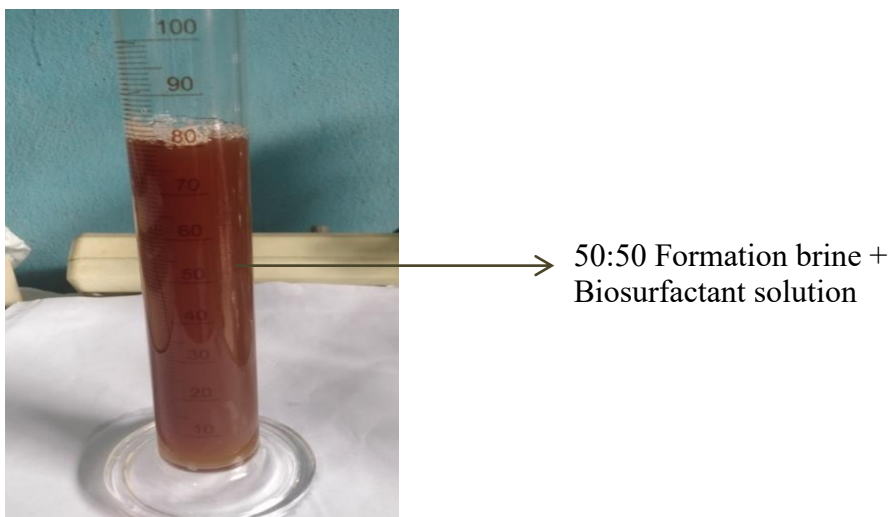


Fig. 3.4: Brine + Biosurfactant solution, no precipitate



→ 50:50 Formation Crude +
Biosurfactant solution: t =0

Fig 3.5: Formation crude + Biosurfactant after vigorous agitation



→ 50:50 Formation crude +
Biosurfactant solution; t=60mins

Fig. 3.6: Formation crude + Biosurfactant after vigorous agitation at t = 60mins

Table 4.6: Phase separation (%) versus time

Time (mins)	Separation (vol. %)
0	0
3	8
5	13
10	25
15	38
20	50
25	63
30	100
40	100
50	100
60	100

CONCLUSIONS

Application of the biosurfactant solution was to ensure clean flow paths/channels for optimum oil recovery performance and enhanced injection rate, since the biosurfactant solution had an ultra low IFT and was able to soak/penetrate the generated filter cake. Ultimately, destroying the filter cake that would have blocked the completions stand alone screens expandable sand screens and other completion equipment, thereby allowing for increased oil production. It solubilizes the oil in the emulsion and filter cake, leaving the solids and surfaces in in a water wet state. The sized CaCO_3 which served as bridging agents in the formation were removed by the acetic acid, while the remaining drill solids were completely dispersed and mobilized. These results compare favourably with findings of previous investigators, reported in the open literature. These results demonstrate the suitability of the derived biosurfactants in the remediation of near wellbore formation damage.

REFERENCES

- Addagalla, V. K., Kosandar, B. A., Lawal, I. S., Jadhav, P. B., Imran, A., El-Araby, M. S., Al-Saqer, Q. R., Al-Ansari, A. A., Pino Rojas, M. R., Gadalla, A.E., Olivares, T. D. (2016). Remediation of Severely Damaged Wells Using Mesophase Technology: Case Histories in Saudi Arabia. *Saudi Aramco Journal of Technology*, pp. 1 - 10
- Aird, P. (2019). Deepwater Drilling, Well Planning, Design, Engineering, Operations and

- Technology Application. Gulf Professional Publishing, pp. 643-658.
- Akbari, S., Abdurahman, N. M., Yunus, R. M., Fayaz, F., Alara, O. R. (2018). Biosurfactants – a new frontier for social and environmental safety: a mini review. *Biotechnology Research and Innovation*, 2(1): 81-90
- Bachari, Z., Isari, A. A., Mahmoudi, H., Moradi, S., Mahvelati, H. E. (2019). Application of Natural Surfactant for enhanced oil Recovery - Critical Review. IOP Conference Series, *Earth and environmental Science*, 221: pp. 1-14
- Caenn, R., Darley, H. C. N., Gray, G. R. (2017). Composition and properties of drilling and completion fluids; in the filtration properties of drilling fluids. 7th ed. Gulf professional publishing; Oxford, UK. pp. 367-460
- El Aziz, M., Ashour, A., Melad, A. (2019). A review on Saponins from Medicinal plants; chemistry, isolation and determination. *Journal of Nanomedicine Research*, 8(1): 282-288.
- Elkatatny, S., Mohammed, A., Basfer, F. (2019). One Stage Calcium Carbonate Oil-Based Filter Cake Removal using a New Biodegradable Acid System. *Sustainability*, 11 (20): 5715-5726
- Huang, S., Guo, X., Duan, W. (2019). Degradation of high molecular weight polysaccharide by alkali-activated Persulfate: Reactivity and potential application in filter cake removal before cementing. *Journal of Petroleum Science and Engineering*, 174, 51-61.
- Johnson, P., Trybala, A., Starov, V., Pinfield, V. J. (2020). Effects of Synthetic Surfactants on the Environment and the Potential for Substitution by Biosurfactants. *Advances in Colloid and Interface Science*, Vol. 288 (10): 1-11
- Marques, F. E., Silva, F. B. (2013). Surfactants, Phase behavior. In Book: Encyclopedia of Colloid and Interface Science, pp. 1290-1333
- Nichita, D. V., Secuianu, C. (2020). An Improved reduction method for phase stability testing in the single-phase region. *Open Chemistry*, 18(1): 1316-1322
- Pietrangeli, G., Quintero, L., Jones, T.A., Benaissa, S., Menezes, C.A., Aubry, E., Poitrenaud, H., Furgier, J.N. (2014). Overcoming Wellbore Cleanup Challenges in Deepwater Wells in West Africa. In Proceedings of the SPE International Symposium and Exhibition on Formation Damage Control, Lafayette, Louisiana, USA. pp. 1-11
- Pradhan, A., Bhattacharyya, A. (2017). Quest for an ecofriendly alternative surfactant: Surface and foam characteristics of natural surfactants. *Journal of Cleaner Production*, 150, 127-134
- Quintero, L., Passanha, W. D., Eric, A., Poitrenaud, H. (2015). Advanced Microemulsion Cleaner Fluid Applications in Deepwater Wells. Offshore Technical conference, Brazil. OTC 26344-MS. pp. 1-20
- Quintero, L., Thomas, A., David, J., Clark, E., Twynam, J. A. (2007). NAF Filter Cake Removal Using Microemulsion Technology. SPE 107499-MS. pp. 1-6
- Raman, I. A. B., Suhaimi, H., Tiddy G. J. T. (2003). Formation of microemulsions with palm-based oils stabilized by a non-ionic surfactant. *Journal of oil palm research*, 12(2): 50-61.
- Sahu, S. S., Ghandhi, I. S. R., Khwaira Kpam, S. (2018). State-of-the-art review on the characteristics of surfactants and foam from foam concrete perspective *Journal of The*

Institute of Engineers (India) Series A, 99, 391 – 405.

Salauudeen, I., Isehunwa, S. O., Dauda, D. A., Ayuba, I. (2017). Analysis of formation Damage during the Drilling of Horizontal Wells. *International Journal of Science and Technology Research*, 6(5): 56-63

Samal, K., Das, C., Mohanty, K. (2017). Eco-friendly biosurfactant saponin for the solubilization of cationic and anionic dyes in aqueous system. *Dye pigments*, 140, 100-108

Schlumberger, (2021), Oilfield Glossary, accessed 19th Oct. 2021, Preflush, {<http://glossary.oilfield.slb.com/terms/pre-flush>}

Zhou, J., Nasr-El-Din, H.A., Socci, D., Holcomb, J. A. (2018). Cost-Effective Application of New Surfactant/Oxidant System to Enhance the Removal Efficiency of Oil-Based Mud Filter Cake. Paper presented at the SPE Western Regional Meeting, Garden Grove, California, USA, SPE – 190115 – MS. pp. 1-19