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PERFORMANCE ANALYSIS OF SURFACTANTS IN WELLBORE CLEAN-UP OPERATIONS

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Abstract

Preparing drilled well for completion and production requires comprehensive wellbore clean-up operation for all sections of the drilled well. Ineffective wellbore clean-up can result in formation damage and reduce the productive life of the well resulting in remedial and workover operation. Complete wellbore clean-up solution usually consists of a set of mechanical tools (scrappers, brush, junk basket, deburr tools, BOP jetting tool etc.), chemicals (cleaning surfactant spacer, transition spacer, etc), filtration equipment, and modelling software for the operation. An efficient wellbore cleaning solution would resolve wellbore cleaning challenge for the specific well within a considerable time frame leading to cost saving for the operator. To achieve this, different parameters and factors affecting wellbore clean-up are optimised experimentally and/or through modelling. Among these factors is the cleaning efficiency of the surfactant used for spacer formulation for well clean-up. These research analysis the performance of surfactants in wellbore clean-up operations considering contaminated and non-contaminated spacer condition. This work employed experimental approach to study the effect of the type of surfactant, RPM and flow rate, time and contamination in relation to the cleaning efficiency of the surfactant in unit of mud removal efficiency (%). Different surfactant samples were used for spacer formulation and their cleaning efficiency for cleaning/removing mud, varying the mentioned factors and analysing its effect on the surfactant cleaning efficiency. The study revealed that increasing the RPM, flow rate and reducing contamination results to higher cleaning efficiency with time. The different surfactant samples (A, B, C and D) also exhibited different cleaning efficiency with sample C yielding 98% and 95% mud removal after 4 minutes and 8.5 minutes contact time for non-contaminated and contaminated wellbore clean-up (WBC) test while Sample D cleaner surfactant resulted in 100% mud removal after 1.5 minutes for non-contaminated test. Sample C and D where the best performing surfactant sample among the alternatives.

Introduction

The process of drilling and completing wells for production is cost demanding and all operations that affects the productive performance of completed wells are carefully planned to guarantee success. According to Waskoenig et al., (2002) and Ohia et al., (2018), an often-overlooked operation after drilling is wellbore clean-up operation. However, its consequences can result to Non-productive rig time and threat to production in future due to formation damage. A clean wellbore is a precursor to successful completion of the well and prevent unnecessary workover work when properly done prior to production (Nsingi, 2018).

Debris, junks and solids left in the well after drilling or milling activities can cause mechanical failures, formation damage and prevent further drilling and completing the well to total depth resulting in NPT and cost of remedial operation. This undesired scenario in oil and gas industry can be reduced or eliminated by designing and carrying out proper wellbore clean-up with the right system that address the needs of the well involved. The wellbore clean-up is carried out after drilling by implementing designed wellbore displacement aided with mechanical systems and filtration unit for thorough cleaning of the wellbore. Different components, factors and conditions are critically considered when planning wellbore clean-up such as the type of displacement, properties and condition of the mud already in the wellbore, Pump rate and pressure, mechanical assistance, spacers, and need for filtration (Nsingi, 2018). A typical wellbore solution will likely consist of mechanical tools such as packers for positive or negative testing of casing, A bypass/circulation tool for boosting circulation rate and mud conditioning, brush and scrappers for polishing and removing mud cake or film and other restrictive material from the casing walls, deburr milling tool for removing perforation burrs from the ID of a perforated casing, junk basket for removing large debris and solids, magnets for removing ferrous materials or magnetic induced materials, BOP jetting tool for flushing debris from subsea BOP, etc (Weatherford 2016). The spacer system is dependent on the type of the mud in the system and the completion fluid that follows after the spacer fluid. For Oil or synthetic based mud, it usually consists of a base oil for thinning/conditioning, transition fluids and a specific surfactant for cleaning (Nsingi, 2018). The clean-up operation is usually designed to allow for sufficient contact time between the spacer and the wellbore components because debris and other solid removal occurs gradually.

Some authors have studied and analysed different aspect of wellbore (drill-string, completion-string, formation wall etc) clean-up and the mechanical aiding systems and factors responsible for the cleaning. Curtis & Kalfayan (2003) studied the effect of an environmentally friendly surfactant as a neutral pickling solution for tubing cleanout. The case surfactant and other alternatives were compared for rust removal efficiency on the tubing and its reaction mechanism to prevent liberation of poisonous hydrogen sulphide gas. The surfactant proved effective for the clean-up operation. Nwoke et al (2003) reviewed case histories of clean-up operation with cleaning efficiency of less than 20NTU within 2 hours pumping time. They identified factors such as detergent flow regime, drill string rotation and reciprocation as pivotal to the success of the operation. Javora et al (200) highlighted the limitation of different techniques such as increasing hydraulic horsepower, backpressure schedules, addition of solids to increase spacer weight etc., to overcome the density limitation of cleaning fluids. They formulated and implemented a new high density, brine-based solid-free surfactant/spacer fluid for displacement in deep water wells which proved effective compared to the previous techniques in reducing the pumping pressure needed for displacement without reducing cleaning efficiency. Al-Kitany et al (2008) formulated bio-enzymes (A and B) to be incorporated in wellbore clean-up fluids for higher cleaning efficiency. The efficiency was compared with other clean-up formulation using simulated Reservoir condition core flow (RCCF) and permeability measurement from laboratory and field result. The field trials were a mix of satisfactory and unsatisfactory results due to issues in some wells. Van Zanten & Ezzat (2010) investigated the efficiency of nanotechnology-based surfactant spacer formulation (SP-A, SP-B and SP-C) in removing Oil-Based Mud and filter cakes. The efficiency was measured based on mud removal, filter cake removal and return permeability. The surfactant gave mud removal efficiency exceeding 98% for all surfactants while permeability return was about 100% for SP-A and SP-C and 75% for SP-B. Field trials were done using SP-A in over 100 wells for cementing displacement. Similar studies were performed by See et al (2011) using Nano Emulsion surfactant which yielded higher efficiency compared to tradition surfactant. They also studied the impact of temperature, pressure, electrolytes, briding agents, acidity and polymers on cleaning efficiency. Pernites et al (2018) examined the cleaning efficiency of novel formulated surfactants (Spacer A, B, and C). Temperature (up-to 275^0F) and Time were varied and its effect on the viscosity of the surfactant during cleaning was evaluated. The surfactants showed a flat viscosity variation over time and temperature. Studies by Gbadamosi et al (2018) demonstrated that adding nano-silica to water-based mud increases its Hole cleaning efficiency by enhancing its viscosity. Sharma et al (2020) evaluated the efficiency of a new enzyme in wellbore clean-up compared to conventional drill-in-fluid. The new enzyme helped resuscitate a dead well (well-A) to production (43% decrease in water cut and 262% increase in oil production) again after treatment with the enzyme.

This work studies the factors affecting the performance of surfactant used for spacer formulation and evaluates the results to optimise the factors for best cleaning efficiency performance for wellbore clean-up and also compares some available surfactant for mud removal efficiency under contaminated and non-contaminated test conditions.

Materials and Methods

The study was carried out through a wellbore clean-up test setup. The purpose of the test is primarily to identify the best surfactant (spacer) among some alternatives to clean-up the wellbore and the drill string and also the conditions and factors affecting the performance of surfactants and optimizing the factors for best results. During wellbore clean-up operations, the spacer pill is initially concentrated and free from contamination by mud before contacting the wellbore and down-hole completion equipment, implying higher mud removing and cleaning potential. However, as more mud (drilling fluid) is removed, the spacer becomes contaminated and less concentrated. This increases the likelihood of reduced performance, which is not desirable; hence, a good spacer pill is expected to have high cleaning potential when non-contaminated and during a contaminated scenario. This test also simulates such scenario and allows for iterating some factors for optimisation of the best performing condition. The contaminated and non-contaminated scenario test set-up was designed in this work.

Materials and Equipment

1. Oil-base Mud (10.5+ppg)
2. Samples Clean-up surfactant (A, B, C, and D)
3. Rotational Viscometer
4. Thermometer
5. PH meter
6. Digital density/relative density meter (for SG measurement)
7. Water
8. Measuring cylinder
9. beakers
10. Spacer preparation (200 ml spacer volume).

Properties of the surfactants

The physical properties of the surfactants were measured and the results is given in table

Table 1. Physical properties of the surfactants

TEST	Surfactant			
	A	B	C	D
SPECIFIC GRAVITY @ 25^{O}C	1.011	1.015	1.02	0.97

COLOUR: VISUAL INSPECTION	**Yellowish**	**Pink**	**Pinkish**	**Colourless**
APPEARANCE: VISUAL INSPECTION	**Clear**	**Clear**	**Clear**	**Clear**
FORM: VISUAL INSPECTION	**Liquid**	**Liquid**	**Liquid**	**Liquid**
pH @ 25^{O}C	**10.4**	**9.4**	**7.4**	**4.0**

Procedure

1. The spacer fluid (Contaminated and Non-contaminated) was prepared using each surfactant and differentiated into contaminated and non-contaminated using the following mixing volumes
   Non-contaminated (0% Contamination): 170ml freshwater, 30ml surfactant (15% v/v)
   Contaminated (25% Contamination): 127ml freshwater, 50ml mud, 23ml surfactant (11.5% v/v)
2. The drilling mud was poured into the thermo-cup and the rotating cylinder/sleeve of the viscometer was immersed into thermo-cup up-to the inscribed line and set for 6 RPM for 30 seconds to ensure the rotating sleeve is covered with mud.
3. The sleeve was removed and time was allowed for mud dripping to stop.
4. The thermo-cup was emptied of the mud and cleaned-up.
5. The spacer fluid (non-contaminated) was poured into the thermo-cup and the temperature regulated at 150^{0}F
6. The sleeve with mud was inserted into in the thermo-cup containing the spacer fluid and rotated at 100RPM each for 30secs and stopped. The sleeve was removed and pictures of the sleeve was taken.
7. Procedure 6 was repeated in a cumulative manner for 60secs (additional 30s), 90secs (additional 30s), 2.5min, 4min, 5.5min, and 8.5mins.
8. After 8.5mins of testing, any remaining mud is wiped off from the sleeve and the thermocouple emptied of the spacer and cleaned.
9. Procedure 5 to 8 is repeated at 200RPM and 300RPM for each of spacer A, B, C and D. However due to the limited quantity of surfactant A and D, surfactant A was tested for 200RPM and 300RPM while surfactant D was tested for 300RPM only.
10. Procedure 5 to 9 was repeated for each of spacer A, B, and D with 25% contaminated fluid as discussed in procedure 1. However contaminated spacer A was test at 200RPM and 300RPM due to limited quantity.

Results and Discussion

The results of the test (non-contaminated and contaminated) for each surfactant are given in Tables 2 – 4. Some images (Fig. 1) of the cylinder sleeve are also shown with the mud removal efficiency to serve as visual guide to the tabular data.

Non-Contaminated (NC) Test

Table 2: Mud Removal Efficiency for Spacer A & B (NC)

Spacer A			Spacer B			
Non-Contaminated			Non-Contaminated			
TIME	RPM-200 (%)	RPM-300 (%)	TIME	RPM-100 (%)	RPM-200 (%)	RPM-300 (%)
0	0	0	0	0	0	0
0.5	5	5	0.5	55	53	98
1	5	10	1	85	90	98
1.5	5	10	1.5	85	90	98
2.5	5	10	2.5	85	85	98
4	5	10	4	83	83	98
5.5	5	10	5.5	83	83	95
8.5	5	10	8.5	83	83	95

Table 3: Mud Removal Efficiency for Spacer C & D (NC).

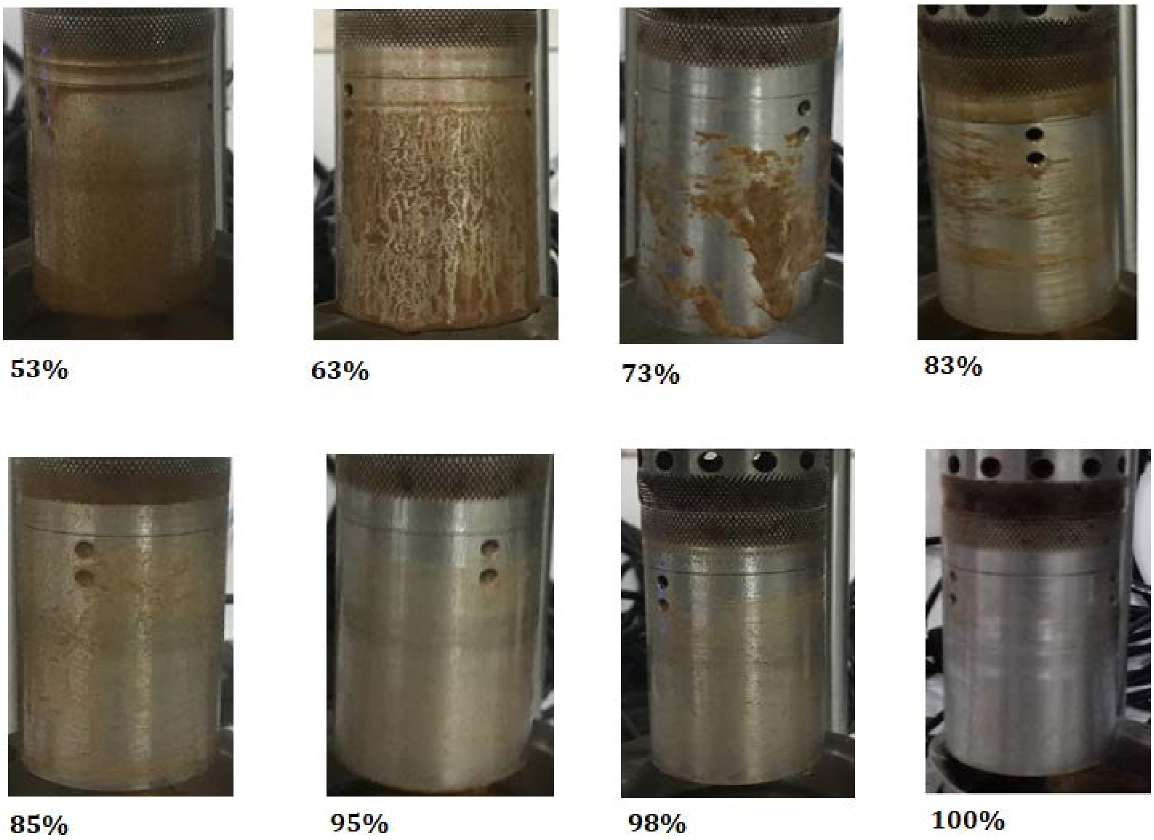
Spacer C				Spacer D	
Non-Contaminated				Non-Contaminated	
TIME	RPM-100 (%)	RPM-200 (%)	RPM-300 (%)	TIME	RPM-300 (%)
0	0	0	0	0	0
0.5	25	25	30	0.5	63
1	15	35	95	1	83
1.5	15	60	95	1.5	100
2.5	15	73	95	2.5	100
4	15	90	98	4	100
5.5	15	90	98	5.5	100
8.5	15	90	98	8.5	100

Contaminated (C) Test

Table 4: Mud Removal Efficiency for Spacer A, B & C

Chemical A			Chemical B				Chemical C			
Contaminated			Contaminated				Contaminated			
TIME	RPM-200	RPM-300	TIME	RPM-100	RPM-200	RPM-300	TIME	RPM-100	RPM-200	RPM-300
0	0	0	0	0	0	0	0	0	0	0
0.5	15	15	0.5	50	20	65	0.5	5	10	20
1	15	20	1	58	60	83	1	25	20	30
1.5	15	20	1.5	63	73	80	1.5	30	45	60
2.5	15	20	2.5	62	78	82	2.5	30	45	65
4	15	40	4	62	80	82	4	35	45	73
5.5	15	40	5.5	58	80	80	5.5	62	50	85
8.5	15	40	8.5	58	73	83	8.5	70	75	95

Visual Representation for Mud Removal Efficiency


53% 63% 73% 83%

85% 95% 98% 100%

Figure 1: Mud Removal from Cylinder Sleeve after Contact with Cleaning Spacer

Factors Affecting the Cleaning Efficiency of the Spacer

Effect of Variation of RPM and Flow Rate with Time

Fig. 2 – 7 shows the variation of RPM and flowrate with time for non-contaminated and contaminated surfactant in the spacer. From Fig. 2 - 7, the mud removal volume increases slightly from 200rpm to 300rpm but have a notable increase from 100rpm to 300rpm both for contaminated and non-contaminated test. From the non-contaminated test, Spacer A, B, C, and D gave a mud removal of 10%, 95%, 98% and 100% at 300RPM and 5%, 83% and 90% at 200RPM for A, B and C. Surfactant B and C gave 83% and 15% respectively at 100RPM. Similar results were obtained for contaminated test with spacer A and B having 40% and 83% mud removal at 300RPM while at 200RPM Spacer A, B, and C gave 15%, 73% and 75% mud removal.

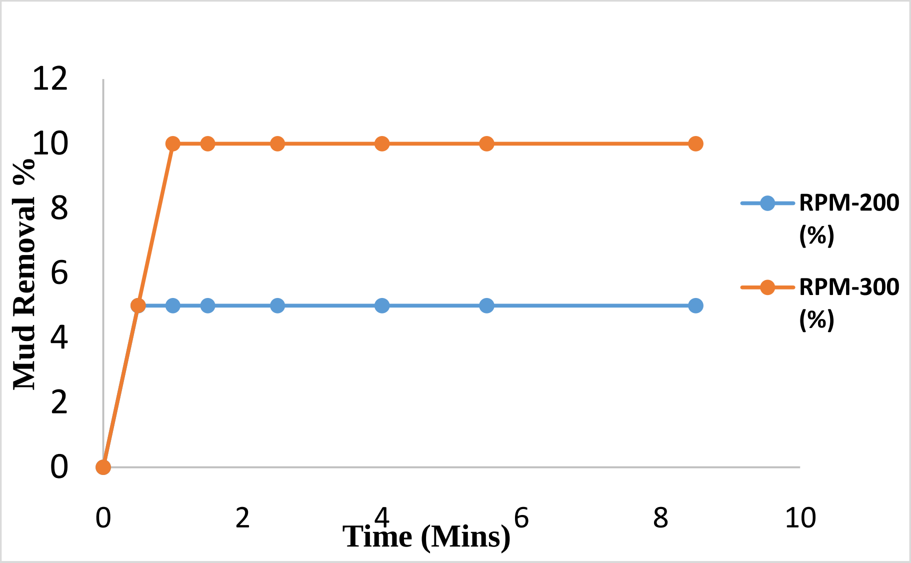


Figure 2: Effect of RPM on Cleaning Efficiency of Spacer A (NC)

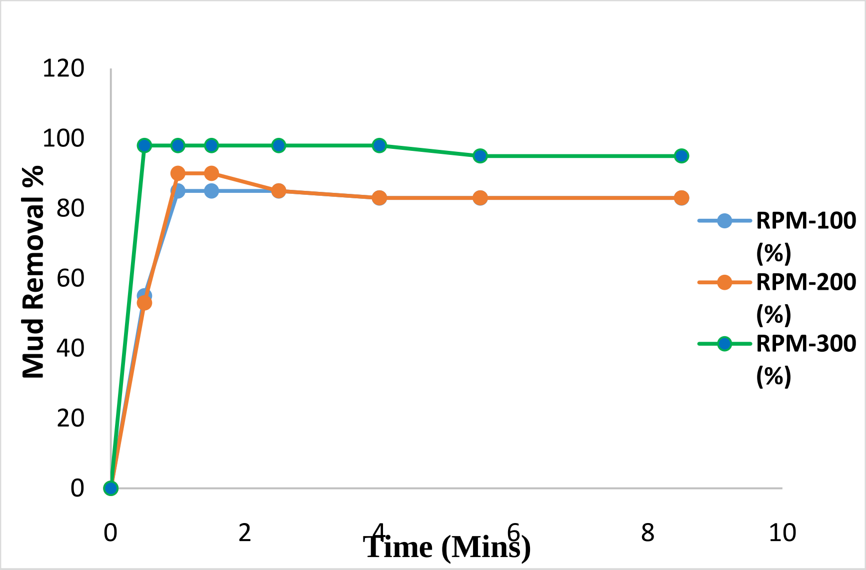


Figure 3: Effect of RPM on Cleaning Efficiency of Spacer B (NC)

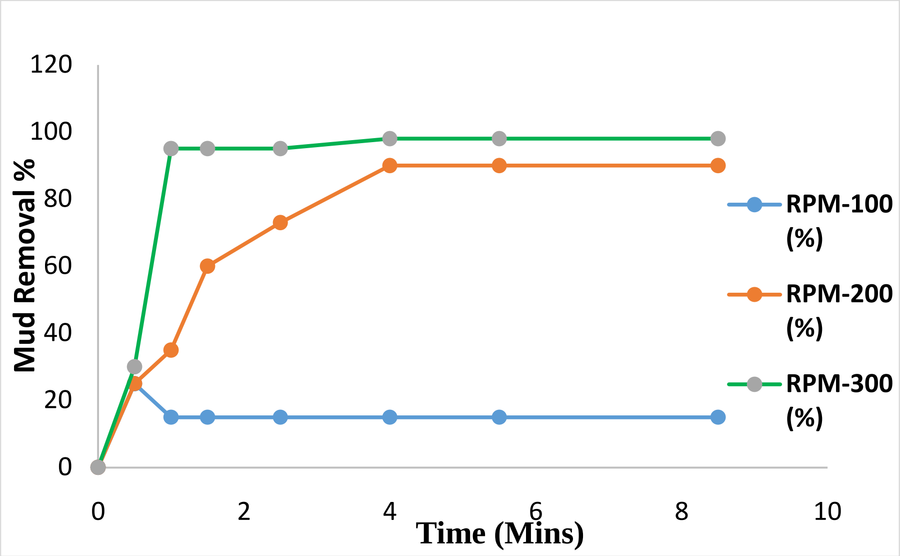


Figure 4: Effect of RPM on Cleaning Efficiency of Spacer C (NC)

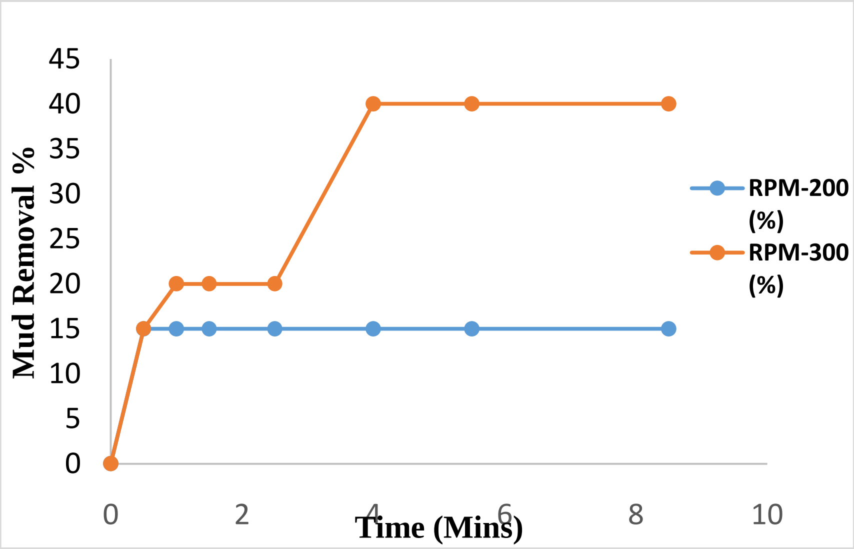


Figure 5. Effect of RPM on Cleaning Efficiency of Spacer A (C)

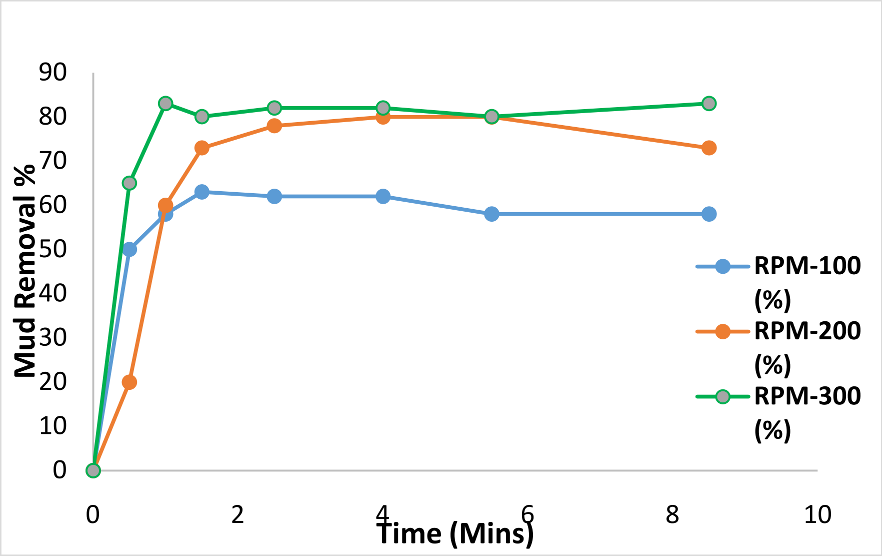


Figure 6: Effect of RPM on Cleaning Efficiency of Spacer B (C)

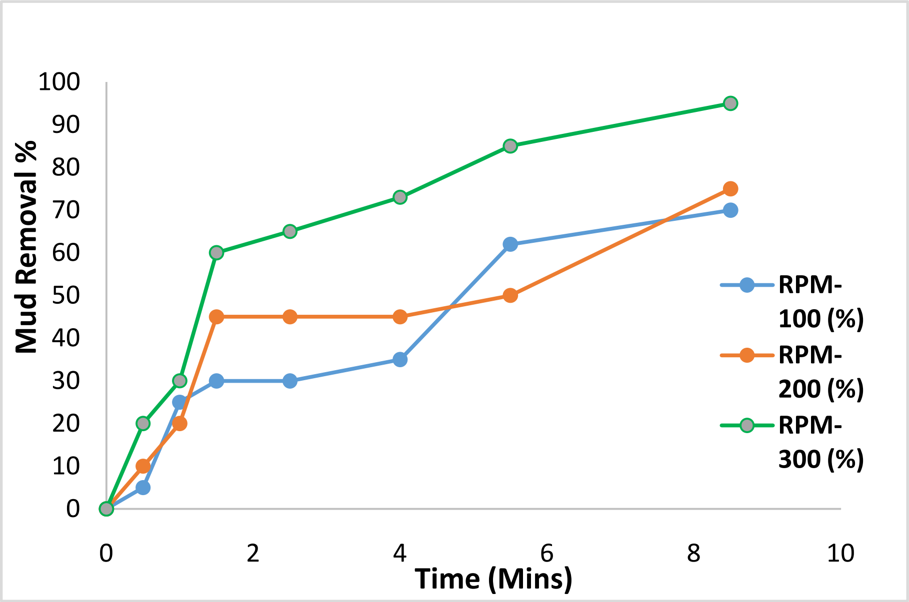


Figure 7: Effect of RPM on Cleaning Efficiency of Spacer C (C)

The increase in mud removal efficiency due to increase in rotation from 100RPM to 300RPM as seen in Fig. 2 – 7 was due to increased agitation between the spacer and mud on the sleeve caused by turbulence flow which increases the efficiency of the surfactant/chemical in the spacer. The sleeve (similar to drill-string) rotation induces rotational motion to the static spacer in the thermocouple creating a turbulent flow regime in the spacer similar to high flow rate which increases cleaning efficiency. Hence the greater the flow rate and RPM, the higher the cleaning efficiency (mud removal) of the spacer whether used downhole for cleaning the wellbore or at the surface for cleaning drill string equipment. Higher RPM also reduces the optimum contact time for the spacers.

Effect of Time

The cost of drilling activities and service companies' rental equipment are usually tied to time hence optimising process time is desirable to safe cost. From Fig. 2-6, the mud removal increased with time up-to some values (optimum contact time) and then becomes constant irrespective of increase in contact time of the spacer with the sleeve. From fig. 2 – 4, for non-contamination test, the optimum contact time for spacer A is 1.5 minutes for 200RPM and 300RPM with 5% and 10% mud removal efficiency. Spacer B has 1.5 minutes optimum contact time at 100RPM and 200RPM with 85% and 90% mud removal efficiency and also 1 minute contact time at 300RPM with 98% efficiency. Spacer C has 4 minutes contact time at 200RPM and 300RPM with 90% and 98% efficiency. Spacer D has 1.5 minutes contact time at 300RPM with 100% mud removal efficiency.

The contact time allows for sufficient cleaning up-to the maximum ability of the spacer. The higher the contact time the higher the mud removal (cleaning) up-to the optimum contact time. This call for a balance between the flow rate, RPM and contact time to get the best result. Software to model the well operations can help optimise the result for particular wells based on specific/particular conditions of the case wells.

Contamination

The spacer pill for clean-up is usually fresh and free from mud contamination when pumped downhole. However, as cleaning occurs and the removed mud, wax etc enters the spacer pill fluid, the system becomes contaminated with the drilling fluid which has a tendency to reduce the cleaning efficiency of the spacer clean-up fluids (Javora et al., 2011, Nsingi, 2008). For continuous cleaning for the designed/allowed contact time, the surfactant is expected to clean the wellbore and the casing/drill/completion string effectively with high mud removal rate or clean-up index. The evaluation of the result for contaminated test in Fig. 5 – 7, shows that at 300RPM, spacer formulation with surfactant A, B, and C gave 40%, 83%. 95% mud removal while at 200RPM the surfactants gave 15%, 73%, and 75% mud removal for contaminated test. Surfactant C had the highest mud removal rate for both 200RPM and 300RPM followed by B and A.

Surfactant

Excluding the above factors, the type of surfactant used for the spacer formulation determines the mud removal efficiency as seen in Figure 8 -11.

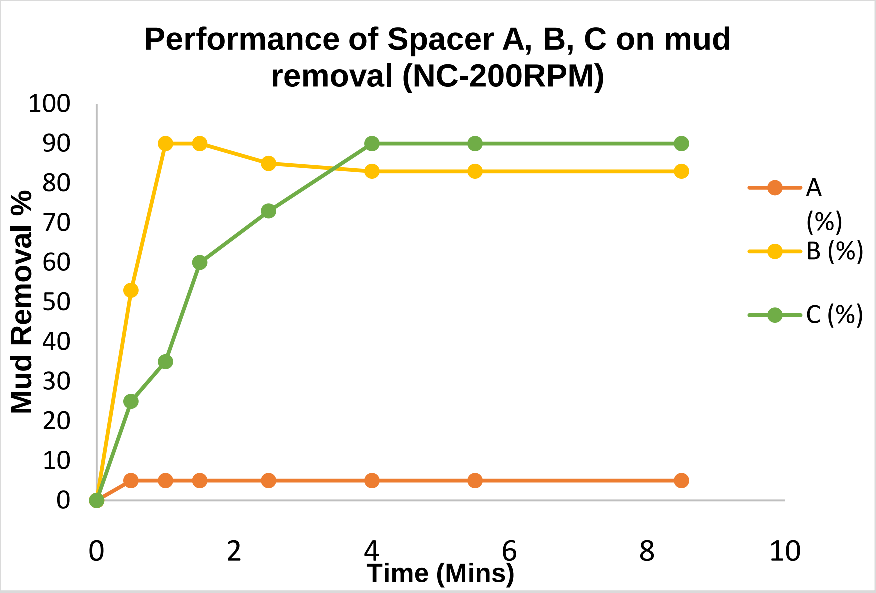


Figure 8: Comparing Mud Removal Efficiency of Surfactants, A, B, & C at 200RPM (NC)

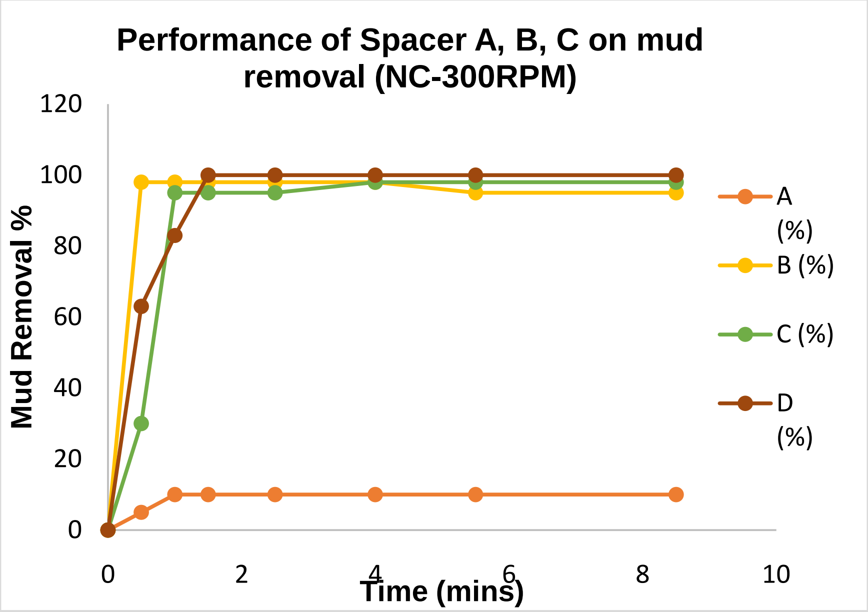


Figure 9: Comparing Mud Removal Efficiency of Surfactants, A, B, & C at 300RPM (NC)

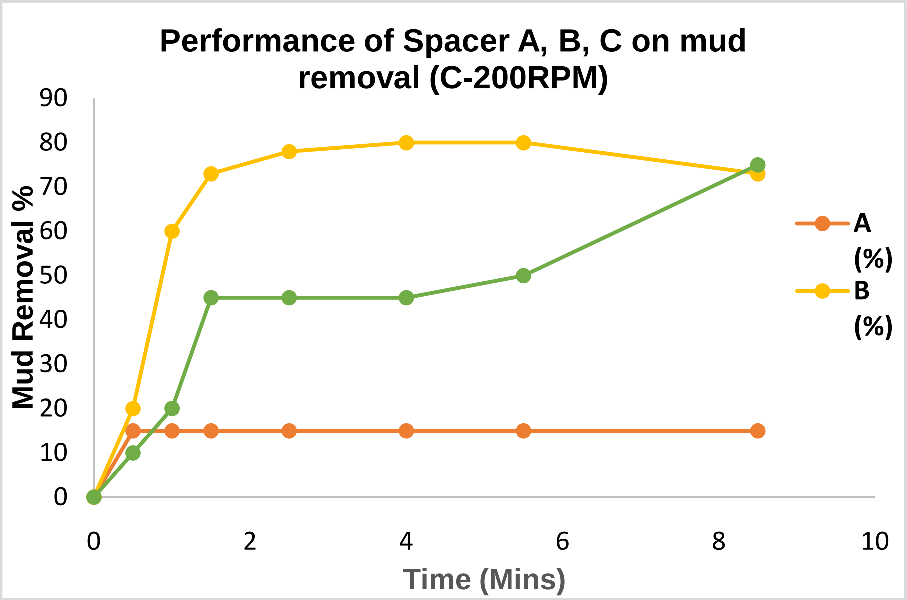


Figure 10: Comparing Mud Removal Efficiency of Surfactants, A, B, & C at 200RPM (C)

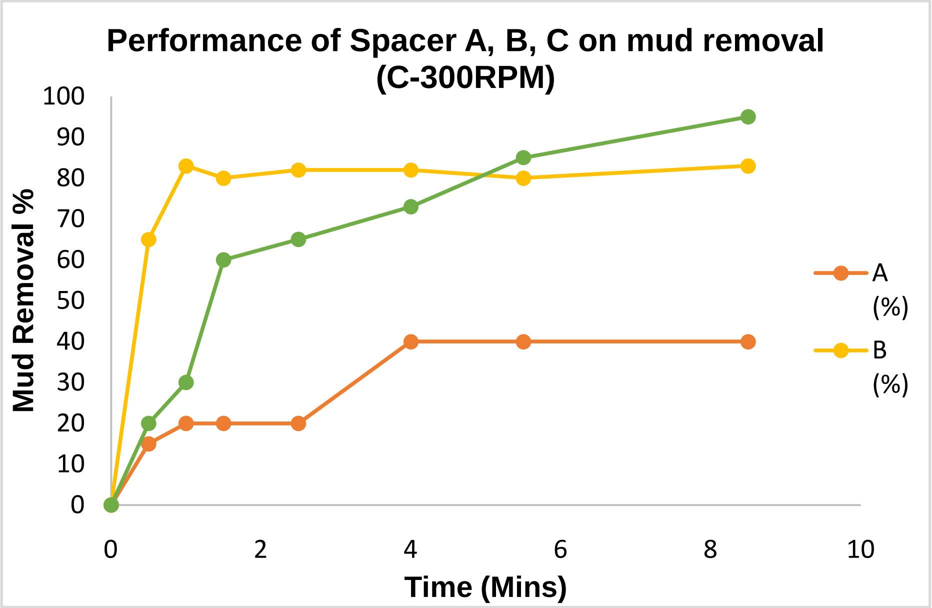


Figure 11: Comparing Mud Removal Efficiency of Surfactants, A, B, & C at 300RPM (C)

From Fig. 8 -11, at 200RPM NC test, 5%, 83%, and 90% mud removal were obtained from Surfactant A, B, and C, 10%, 95%, 98% and 100% mud removal are obtained from surfactant A, B, C and D. Similar results were obtained from contaminated test at 200RPM yielding 15%, 73%, and 75% for surfactant A, B and C. The spacers were not used for all RPM measurement for non-contaminated and contaminated test due to the available quantity of surfactants. The best performing spacer formulation was obtained from surfactant D as 100% mud removal was obtained after 1.5mins contact time for NC test. Surfactant C also gave 98% and 95% after 4mins contact time at 300RPM and 200RPM for non-contaminated test while it gave 75% and 70% mud removal after 8.5mins for contaminated test for 200RPM and 100RPM. Depending on the cost, the surfactant concentration can be increased above 15%v/v which logically will result in higher mud removal at a shorter contact time although this analysis was not performed for confirmation.

Case Histories

Case studies of wellbore and drill string clean-up operation which resulted in considerable savings in cost and time of operation have been obtained by using surfactant with high mud removal rate. Surfactant D used for this study was one of BaraKlean wellbore cleaners and the case histories below Gives a brief summary of some success case studies using this surfactant and other clean-up surfactants.

United Arab Emirates

An operator drilling ERD wells was approaching completion phase and planned utilizing an effective casing and drill-string cleaner which is expected to reduce the volume of contaminated fluid due to the limited waste storage capacity in the offshore site. One of Baraklean cleaners was deployed for the operation and resulted in 300% volume reduction of contaminated brine and a cost saving of $25000 for each drilled well. In addition, the displacement operation was reduced by 30 minutes valued at $5,000 for each well Halliburton (2019b).

South Coast, United Kingdom

An Operator performing workover operation had issues with wax deposit (large quantity) on its completion assembly which restricted circulation and movement resulting in pulling the assembly out of the well. Scraper was deployed with the hope of removing the wax but it smeared it instead, hence a clean-up solution was required to dissolve and remove the wax from the completion string. Baraklean casing cleaner together with base oil was applied after series laboratory confirmatory test and simulation, resulting in complete removal of the wax deposit and the completion operation resumed without any further issues Halliburton (2019a).

Offshore Brazil

The operator initially planned carrying out indirect displacement of Synthetic based mud (SBM) with completion brine (Sea-water was to be used first to displace the SBM before running the brine). The operation time was estimated to 12 hours which wasn’t effective for time and cost of the operation. A Baroid based cleaning surfactant which was compatible with the synthetic based mud and other spacers was deployed for the operation using direct displacement method was recommended by Baroid’s team which resulted in time savings of 10hours valued at $150,000 *Halliburton (2016a).*

Gulf of Mexico

A filter cake breaker was needed to remove filter cake formed by drill-in-fluids for a planned injection well drilling in the Gulf of Mexico. This challenge was primarily was to remove filter cake formed and prevents solids from plugging the injection zone of the well. One of Baraklean cleaners was deployed with other fluids and systems for the operation. The filter cakes were removed and was confirmed through a flow-through testing with reservoir drill in fluid and beaker samples Halliburton (2016b).

Conclusion

From the results and analysis, higher RPM, flow rate and allowed optimum contact time results in higher cleaning efficiency of the wellbore spacer fluid system. The operation should be designed and simulated to operate at the optimum RPM, flowrate and contact time allowable for the safe operation of the wellbore clean-up process. In addition, surfactants with high mud removal efficiency especially after mud contamination should be selected as part of the clean-up fluid for the operation. This can be achieved by evaluating different wellbore clean-up surfactant/spacer formulation using similar test used in this research. The concentration of the surfactant used for the spacer formulation can also be increased and the effect of concentration on cleaning efficiency evaluated to justify the cost of increased concentration. This research showed that surfactant C has higher cleaning efficiency than B and A at both contaminated and non-contaminated test at the RPM values considered.

References

Al-Kitany, N. A., Ghosh, B., Fakhreldin, Y. E., Bemani, A. S., Al-Hadrami, H. K. H., & Al-Wahaibi, Y. M. (2008). Performance evaluation of wellbore clean up fluids: Laboratory test results and field production data. In *Abu Dhabi International Petroleum Exhibition and Conference*. Onepetro.

Curtis, J., & Kalfayan, L. (2003). Improving wellbore and formation cleaning efficiencies with environmental solvents and pickling solutions. In *SPE Latin American and Caribbean Petroleum Engineering Conference*. Onepetro.

Ferreira, E. J. S. (2012). *Hole cleaning performance monitoring during the drilling of directional wells* (Doctoral dissertation).

Gbadamosi, A. O., Junin, R., Oseh, J. O., Agi, A., Yekeen, N., Abdalla, Y., & Yusuff, A. S. (2018). Improving hole cleaning efficiency using nanosilica in water-based drilling mud. In *SPE Nigeria annual international conference and exhibition*. Society of Petroleum Engineers.

Halliburton (2016a). Direct Displacement Using Baroid Casing Cleaner and CFG ™ Modeling Saves 10 Hours on Deepwater Operation. Halliburton.

Halliburton (2016b). BaraKlean® -648 casing cleaner helps remove wax in wellbore cleanout limited by low pit and pump rate capacities. Halliburton.

Halliburton (2019a). *Baraxcel ™ Drill-In Fluid And Baraklean ® -648 Additive Optimize Deepwater EOR Project. Halliburton.*

Halliburton (2019b). *BaraKlean ® -926 Casing Cleaner Delivers Fast, Effective Results, Saving USD 30,000 Per Well in Costs and Rig Time*.

Holland, B., Cooksley, T., & Malbrel, C. A. (1994). Polymeric Flocculants Prove Most Effective Chemicals for Wellbore Cleanup Operations. In *SPE Formation Damage Control Symposium*. Onepetro.

Javora, P. H., Baccigalopi, G. D., Sanford, J. R., Cordeddu, C., Qu, Q., Poole, G. L., & Franklin, B. M. (2006). Effective high-density wellbore cleaning fluids: brine-based and solids-free. In *IADC/SPE Drilling Conference*. Onepetro.

Javora, P. H., & Adkins, M. (2011). Optimizing the Displacement Design-Mud to Brine. In *SPE European Formation Damage Conference*. Onepetro.

Nsingi, M. A. (2008). Wellbore Clean up as a case study. Institut Français du Petrole.

Nwoke, L., Uchendu, C., Arukhe, J., & Mamman, A. (2003). Optimum Wellbore Cleanup of Drilling-fluids Enhanced by Drill-string Rotation, Reciprocation and Detergents. SPE-85658. In *27th Annual SPE International Technical Conference and Exhibition, Abuja* (pp. 4-6).

Pernites, R., Padilla, F., Clark, J., Gonzalez, A., & Fu, D. (2018). Novel and High Performing Wellbore Cleaning Fluids with Surprisingly Flat Viscosity over Time and Different Temperatures. In *SPE Western Regional Meeting*. Onepetro.

Ohia, N. P., Anyadiegwu, C. I., & Muonagor, C. (2018). Assessment of the Risks and Challenges Encountered During Well Clean Up and Test on Niger Delta Gas Wells-Based on Practical Experience on Cases. *Science and Engineering*, *2*(2), 60-68.

See, C. H., Saphanuchart, W., Nadarajan, S., & Lim, C. N. (2011). Nanoemulsion for non-aqueous mud removal in wellbore. In *SPE/DGS Saudi Arabia Section Technical Symposium and Exhibition*. Onepetro.

Sharma, H. K., alkhalifah, Q., Al-Mulhim, A. K., & Al-Shammari, M. J. (2020). Successful Wellbore Cleanup Using Environmentally Friendly Chemicals to Enhance Well Productivity. In *SPE International Conference and Exhibition on Formation Damage Control*. Onepetro.

Van Zanten, R., & Ezzat, D. (2010). Surfactant nanotechnology offers new method for removing oil-based mud residue to achieve fast, effective wellbore cleaning and remediation. In *SPE International Symposium and Exhibition on Formation Damage Control*. Onepetro.

Waskoenig, H. H., Langhans, G., Miljenko, C., Heil, M., Antink, G. H., & Toskey, E. (2002). A Method for Real-Time Well Clean-up Optimization. In *SPE Annual Technical Conference and Exhibition*. Onepetro.