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Drilling Fluids Microbial Impact and Mitigation

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Abstract: Microbial contamination and extensive growth of bacteria in water-based drilling fluids impact the overall drilling operation cost and performance and may affect reservoir integrity. To prevent microbial growth, drilling fluids should be treated with effective biocides for microbial control to prevent polymers biodegradation and loss of the mud rheological properties Make-up water and drilling mud samples from reserve fields and mud mixing tanks were collected from active drilling rigs. Baseline numbers of general aerobic bacteria (GAB) and sulfate-reducing bacteria (SRB) in the make-up water and the drilling mud being used were determined using the Most Probable Number (MPN) method. Microbial growth in the drilling mud and microbial control using glutaraldehyde-based biocide were evaluated under short-term (< 24 hours) conditions and long-term conditions, up to 7 days downtime of drilling operations. In short operational downtime, without biocide addition to the stagnate mud system, resulted in high number of GAB (105-107/ml) in the mud. In long operational downtime, addition of 1500 ppm of biocide (1/3 of normal dosage) at Day 3 was found to be effective in controlling GAB and SRB growth in drilling mud. Biocide performance was significantly affected by the mud sulfide content; higher dosage and more frequent treatment may be required to control the microbial growth in the drilling mud. The study indicated that biocide treatment is essential for microbial control, especially in the period of drilling operational downtime. Based on this evaluation study, Drilling mud treatment programs and field best practice have been developed and implemented in by all Saudi Aramco active drilling rigs.

Keywords: Xanthan gum, drilling fluids, microbial growth, impact.

1. Introduction

Xanthan gum and starch are high molecular weight polysaccharides with exceptional shear thinning properties and good suspension characteristics. They are widely used in oil industry for oil field drilling, workover and completion fluids [1-3]. Due to the biopolymer nature, they are susceptible to bacterial contamination and attack [4]. Drilling fluids and mud additives are generally acknowledged as potential sources of contamination in deep drilling programs [5-7]. Extensive bacterial growth during drilling mud preparation has been reported in Barnett Shale gas operations [8, 9]. Uncontrolled microbial growth in drilling mud can result in significant degradation of biopolymers of drilling mud leading to the loss of mud rheological properties [10, 11]. The metabolic by-products from biopolymer degradation and the various additives in drilling mud can serve as food sources and promote the growth of naturally occurring oil field microbes such as anaerobic sulfate-reducing prokaryotes (SRP) [9, 10, 12-15] Consequences of excessive SRP activity include microbiologically influenced corrosion, biomass plugging in injection wells and in the formation, and hydrogen sulfide (H2S) production deep in the formation, leading to reservoir souring and reduced product quality [11, 16-21]. One microbial control strategy used in drilling operations is the addition of biocides for suppression of vital microbial activities that would affect rheological properties of mud, and control of the introduction of resilient and high temperature tolerant microorganisms into the reservoirs [5, 22].

In this study, make-up water and drilling mud samples from reserve tank and mixing tank were collected from three drilling rigs in Saudi Aramco oilfields to determine the microbial contamination and effectiveness of glutaraldehyde-based biocide on microbial control of drilling mud under normal and

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abnormal (downtime) operations. The Most Probable Number (MPN) method was used for bacterial enumeration before and after biocide treatment. The method would take one week to enumerate the general aerobic bacteria (GAB), and up to four weeks to enumerate the slow growing sulfate-reducing bacteria (SRB) [23-25].

The paper presents a case study of assessing microbial contamination in the current drilling practices within Saudi Aramco. The study recommended the drilling mud operation and field best practice for microbial control to be implemented in all Saudi Aramco drilling rigs.

2. Sampling and Sample Description

The appropriate drilling rigs were selected based on its drilling depth and temperature at the time of sampling. The drilling mud and make-up water samples were collected on March 8, 2016, for microbial assessment from Rig X in Field A and Rigs Y and Z in Field B. All selected gas well rigs used water based drilling mud. In each drilling rig, three mud samples were collected from mixing tank (inlet and outlet to the drill pipe) and reserve tanks, designated as Mud-in, Mud-out, and Mud-reserve, respectively. To preserve sample integrity, all samples were delivered in ice igloos and stored at 4°C before analysis.

At the time of collection, the drilling depth was between 4585 and 8534 ft, and temperature between 82.2°C and 84.4°C (Table 1). Under the normal operation (Rig# X and Z), the pH of mud-in and mud-out samples was adjusted and maintained at 9-10 range, while the mud pH in reserve tank was around 8. At the operation downtime (Rig# Y during sampling), the pH of all mud sample dropped to below 8 due to bacteria growth. For color and texture illustration purposes, a small volume of mud samples was transferred to sterile glass vials and petri dishes (Fig. 1).

Make-up water samples were collected from three drilling rigs in the chosen oilfields. The geochemical composition of the water samples is shown in Table 2, with salinity equivalent to 5% to 15% of Arabian Gulf seawater. The pH of make-up water is at 7.7 to 8.3.

Table 2 Geochemical composition of make-up water samples.

	Make-up water		
Field	**A**	**B**	**C**
Bicarbonate	167	159	67
Carbonate	0	0	0
Hydroxide	0	0	0
Barium	< 1	< 1	< 1
Calcium	127	147	732
Chloride	772	707	3058
Conductivity@25°C	1625	2954	8885
Potassium	30	11	67
Magnesium	53	58	260
Sodium	253	230	1222
Total Dissolved Solids	1838	1635	7130
Strontium	< 1	3	< 1
Sulfate	466	334	1791
pH@25°C	8.1	8.3	7.7
Specific Gravity@60°F	1.0018	1.0018	1.0064
Close to SW salinity	5%	5%	10%

Table 1 Well and mud sample information.

	Field	**A**	**B**	
Rig/well info	Rig#	X	Y	Z
	Well Depth (ft.)	8534	4585	5680
	Well Temperature (°C)	84.4	82.2	82.2
Mud-in	pH	10.1	7.6	9.0
Mud-out		10.1	7.7	9.0
Mud-reserve		8.3	7.4	8.1

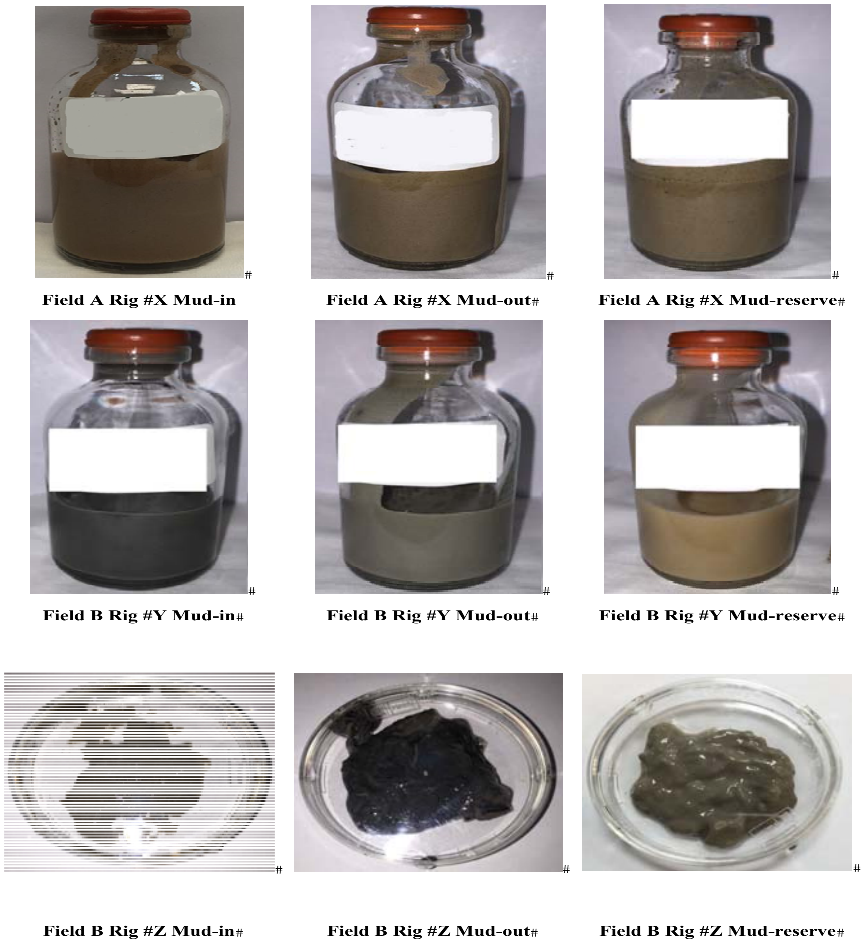

Fig. 1 Drilling mud samples.

3. Drilling Operation Conditions

According to drilling mud engineer, drilling mud are prepared using sweet water, and the pH is adjusted to and maintained at 9-11 during the operation. Starch and xanthan gum are commonly used as drilling additives in Saudi Aramco drilling operations. Only when starch is used as a drilling additive for shallow well drilling, biocide is added at the dosage of 0.2-0.3 gallon per barrel, which is equivalent to 4750 to 7150 ppm. More biocide is added every 1-2 hours depending on how much starch is used. In the sampled drilling rigs, the biocide (KCB-310A) is supplied by Champion, containing active ingredients glutaraldehyde (10-30%) and formaldehyde (1-10%).

Furthermore, the drilling engineer indicated that there are occasions when the drilling operation has to be stopped. When this happens, the wellbore mud will be stagnant; the mud in the mixing tank will be under low pressure mixing and move slowly. The operation halt can last for 12-24 hours, or as long as 7-10 days. In the latter case, biocide is added at 1/3 of the normal dosage every 2 days to maintain the concentration. The operational downtime provides a good condition for microbes to thrive and consequently contaminate the drilling mud system. It is observed that the pH of the drilling mud.

Samples collected from the Field B Rig# Y dropped to below 8 dues to operational downtime and microbial activities.

4. Experimental Design

Laboratory experiments were designed to simulate field operational conditions at the worst case scenario that is the operational downtime from 12-24 hours to one week. The Most Probable Number (MPN) method was used to determine the baseline GAB and SRB numbers in the make-up water and drilling mud samples, and the numbers in the mud samples after incubation for 12 hours to seven days with or without biocide addition. 50°C of incubation temperature was used to simulate the tank temperature in the drilling operation in Saudi Arabia. When biocide is added during incubation, 1500 ppm was used to mimic the 1/3 of normal dosage as practiced in the field.

The GAB and SRB media composition was listed in Table 3. The pH of the media was adjusted to 8.0, and the media were prepared in 10% of Arabian Gulf seawater, which simulates the salinity and pH of make-up water, and the pH of drilling mud samples during operational downtime. The experimental treatment matrix was summarized in Table 4.

Table 3 Composition of bacterial growth media.

GAB medium

Items	Amount
Bacteriological Peptone	0.5 g
Yeast Extract	0.5 g
Seawater (10%)	Make up to 1 liter

SRB medium

Items	Amount
Ammonium Chloride	1.0 g
Calcium Sulfate	1.0 g
Magnesium Sulfate	2.0 g
Sodium Lactate	3.5 ml
Yeast Extract	1.0 g
Ascorbic Acid	0.1 g
Resazurin Solution	4.0 ml
Sodium Thioglycollate	0.1 g
Ferrous Sulfate	0.5 g
Potassium Hydrogen Phosphate	0.5 g
Seawater (10%)	Make up to 1 L

Table 4 Lab experimental set-up for drilling mud samples.

Treatment	Conditions	Biocide
1	12-hour incubation at 50°C	No
2	24-hour incubation at 50°C	No
3	7-day incubation at 50°C	No
4	7-day incubation at 50°C	1500 ppm added at Day 3

After 12 and 24 hours of incubation of mud samples at 50°C, the samples were taken for MPN inoculation to determine the number of GAB and SRB, which mimics the short-term operational downtime without biocide addition. At seven day incubation, 1500 ppm of biocide KCB-310A was added at Day 3 to one of the treatments to mimic the field practice and determine the effectiveness of microbial control at long-term operational downtime.

5. Results

Table 5 summarized the results of microbial analysis in make-up water and drilling mud samples collected from three rigs in two oilfields.

The make-up water collected from three drilling rigs showed high microbial activities, containing 105-107/ml of GAB. SRB number in make-up water was very low as expected due to oxygen presence. In drilling mud samples collected in different tanks contained baseline GAB and SRB in range of 102-103/ml. The number of GAB and SRB in the drilling mud was affected by oxygen level, biocide treatment, and sulfide content in the mud. In the scenarios mimicking short-term downtime (< 24 hours and no biocide addition), GAB grew up to the level at 105-107/ml, while SRB number decreased to 101-102/ml due to depletion of oxygen in mud tanks. If no biocide was added in long-term downtime (7 days), the number of GAB decreased to 102-104/ml in most of the mud samples, and SRB increased to 102-104/ml. One addition of Biocide KCB-310A at Day3 at the dosage of 1500 ppm during long-term downtime was very effective in controlling GAB and SRB growth in drilling mud. GAB number at Day 7 remained at 101-102/ml level, and SRB at below detection level in the mud samples collected from two drilling rigs. In the mud samples collected from Field B Rig# Z, addition of biocide at Day 3 did not show an effective control of GAB and SRB, with GAB at 105-106 cells/ml and SRB at 102-103 cells/ml at Day 7. This ineffective microbial control of biocide

KCB-310A at Rig# Z may be dueto the presence of high concentration of sulfide in the mud samples, as indicated by black color (Fig. 1). Sulfide content in the drilling mud has significant negative impact on performance of glutaraldehyde-based biocide at high temperature and alkaline pH [5, 22, 26].

Table 5 Results for microbial assessment in drilling mud samples.

Treatment	Condition	Field	A		B			
		Rig#	X		Y		Z	
		MPN	GAB	SRB	GAB	SRB	GAB	SRB
Baseline	-	Make-up water	1.5E+06	2.3E+00	7.5E+05	2.3E+00	2.3E+07	<0.4
Baseline	0 hr, no biocide	Mud-in	4.3E+03	4.3E+03	7.5E+03	4.3E+03	4.3E+03	7.5E+03
		Mud-out	2.3E+02	9.3E+03	4.3E+02	2.3E+02	9.3E+03	4.3E+02
		Mud-res	4.3E+02	4.3E+02	4.3E+02	4.3E+02	4.3E+02	4.3E+02
1	12 hr, 50°C, no biocide	Mud-in	7.5E+04	4.3E+02	4.3E+06	4.3E+02	9.3E+06	9.3E+02
		Mud-out	1.5E+06	2.3E+02	9.3E+06	9.3E+02	9.3E+06	1.5E+02
		Mud-res	1.5E+06	9.3E+01	2.3E+07	1.5E+01	2.3E+07	4.3E+01
2	24 hr, 50°C, no biocide	Mud-in	2.3E+05	9.3E+01	9.3E+06	2.3E+02	2.3E+07	9.3E+01
		Mud-out	9.3E+06	4.3E+02	9.3E+06	2.3E+02	2.3E+07	4.3E+01
		Mud-res	2.1E+06	2.3E+02	7.5E+04	2.3E+01	2.3E+07	4.3E+01
3	7 days, 50°C, no biocide	Mud-in	9.3E+02	2.3E+02	2.3E+02	2.3E+02	9.3E+07	9.3E+04
		Mud-out	-	2.3E+03	2.3E+07	9.3E+03	-	2.3E+02
		Mud-res	4.3E+04	1.5E+04	2.3E+01	4.3E+02	2.3E+02	9.3E+07
4	7 days, 50°C, 1500 ppm biocide at Day 3	Mud-in	4.3E+02	<0.4	2.3E+02	<0.4	4.3E+06	4.3E+03
		Mud-out	4.3E+02	<0.4	2.3E+02	4.3E+01	2.3E+05	1.2E+02
		Mud-res	2.3E+01	<0.4	2.3E+01	<0.4	2.3E+02	2.3E+00

6. Conclusions

Under Saudi Aramco normal drilling operation conditions, addition of 0.2-0.3 gallon of biocide per barrel of drilling mud every 1-2 hours is expected to provide good microbial control in drilling mud. The short (< 24 hours) and long (up to 7 days) operational downtime presented a challenge for proper control of microbial activities in mud tanks. In short operational downtime, the current practice with no biocide addition resulted in high number of GAB (105-107/ml) in the mud samples, and this may have been due to the abundance of oxygen at the during the beginning of short-downtime operations. In the long operational downtime, the addition of 1500 ppm of biocide (1/3 of normal dosage) at Day 3 was effective in controlling GAB and SRB growth in drilling mud. In addition to biocide effect, the number of GAB and SRB in the drilling mud during operational downtime was significantly affected by oxygen and sulfide content. Oxygen presence promoted GAB growth, while oxygen depletion resulted in high number of SRB in the mud. High sulfide content in the mud significantly reduced the performance of glutaraldehyde-based biocide. As a result, higher dosage and/or more frequent treatment may be required to control the microbial growth in the drilling mud. The study indicated that biocide treatment is essential for microbial control in drilling operations, especially in the period of operation downtime.

7. Recommendations

As a result of this study, the following are the recommended drilling mud operation and field best practice for microbial control:

- Biocide must be added to the drilling mud, regardless of the mud formulation containing starch or xanthan gum.
- Biocide must be added to all tanks, including water tank and mud reserve tank.
- Maintain the current practice during normal drilling operation: 0.2 gallon of biocide (KCB-310A) per barrel of mud every 1-2 hrs.
- During short downtime (< 24 hours), add 0.12 gallon of biocide (KCB-310A) per barrel of mud every 12 hours.
- During long downtime (up to 7 days), add 0.12

gallon of biocide (KCB-310A) per barrel of mud every 2 days.

- With high sulfide content in the mud, higher dosage and more frequent addition of biocide are required.
- Perform appropriate on-site microbial analysis on drilling mud and make-up water to check microbial activities before starting or restarting (after downtime) the drilling operations.

References

[1] Nguyen, H. T., and LaFontaine, J. M. (1990). "Effect of Various Additives on the Properties of the Clarified XC Polymer System." Paper SPE 19404. *SPE Symposium on Formation Damage Control*. Lafayette, Louisiana, 22-23 February, 1990.

[2] Underdown, D. R., Calvert, A. L., and Newhouse, D. P., (1989). "Comparison of HEC and XC Polymer Gravel Pack Fluids." Paper SPE-19751. In: *SPE Annual Technical Conference and Exhibition*. San Antonio, Texas, 8-11 October.

[3] Zaitoun, A., Makakou, P., Blin, N., Al-Maamari, R. S., Al-Hashmi, A. R., Abdel-Goad, M., and Al-Sharji, H. H. (2012). "Shear Stability of EOR Polymers." *SPE J.* 17: 335-339. SPE-141113-PA.

[4] Schlumberger Oilfield Glossary, 1998. http://www.glossary.oilfield.slb.com/en/Terms/x/xanthan_gum.aspx, accessed 9 November 2017.

[5] Kahrilas, G. A., Blotevogel, J., Stewart, P. S., and Borch, T. (2015). "Biocides in Hydraulic Fracturing Fluids: A Critical Review of Their Usage, Mobility, Degradation, and Toxicity." *Environ. Sci. Technol.* 49: 16-32, doi: 10.1021/es503724k.

[6] Sunde, E., Thorstenson, T., and Torsvik, T. (1990). "Growth of Bacteria on Water Injection Additives." In: *65th Annu. SPE Tech. Conf.*, New Orleans, 9/23- 26, 1990. pp. 727-733, doi: 10.2118/20690-MS.

[7] Zhu, X. Y. (2016). "Microbial Communities in Drilling Mud Additive Xanthan Gum and Their Implications in the Oil Industry." In: *Proceedings of 16th MECC*, 2016, pp. 1-12, Bahrain.

[8] Davis, J. P., and Struchtemeyer, C. G. (2012). "Bacterial Communities Associated With Production Facilities of Two Newly Drilled Thermogenic Natural Gas Wells in the Barnett Shale." *Microbiol. Ecol.* 64: 942-954, doi: 10.1007/s00248-012-0073-3.

[9] Struchtemeyer, C. G., Davis, J. P., and Elshahed, M. S., (2011). "Influence of the Drilling Mud Formulation Process on the Bacterial Communities in Thermogenic Natural Gas Wells of the Barnett Shale." *Appl. Environ. Microbiol.* **77**: 4744-4753.

[10] Daly, J., Tomlin, J., and Read, N. W. (1993). "The Effect of feeding xanthan Gum on Colonic Function in Man: Correlation With in Vitro Determinants of Bacterial Breakdown." *Br. J. Nutr.* 69: 897-902.

[11] Wolicka, D., Borkowski, A., and Dobrzynski, D. (2010). "Interactions Between Microorganisms, Crude Oil and Formation Waters." *Geomicrobiol. J.* 27: 43-52.

[12] Cord-Ruwisch, R., Kleinitz, W. and Widdel, F. (1987). "Sulfate-reducing Bacteria and Their Activities in Oil Production." *J. of Petr. Technol.* 39: 97-106.

[13] Little, B. J., and Wagner, P. (2001). "Microbiologically Influenced Corrosion." In: R. L. Bianchetti (Ed.), *Peabody's Control of Pipeline Corrosion*, Houston, TX: NACE.

[14] Mavroudis, D. (2001). *Downhole Environmental Risks Associated with Drilling and Well Completion Practices in the Cooper/Eromanga Basins: Report Book 2001/00009*. Primary Industries and Resources SA, Adelaide, South Australia.

[15] Rajasekar, A., Anandkumar, B., Maruthamuthu, S., Ting, Y. P., and Rahman, P. (2010). "Characterization of Corrosive Bacterial Consortia Isolated From Petroleum-Product-Transporting Pipelines." *Appl. Microbiol. Biotechnol.* 85: 1177-1188, doi: 10.1007/s00253-009-2289-9.

[16] Bottero, S., Picioreanu, C., Enzien, M., Van Loosdrecht, M. C. M., Bruining, H., and Heimovaara, T. (2010). "Formation Damage and Impact on Gas Flow Caused by Biofilms Growing Within Proppant Packing Used in Hydraulic Fracturing." In: *SPE International Symposium and Exhibition on Formation Damage Control*, Lafayette, LA, USA; Society of Petroleum Engineers: Richardson, TX, USA.

[17] Chang, Y. J., Peacock, A. D., and Long, P. E., et al. (2001). "Diversity and Characterization of Sulfate-Reducing Bacteria in Groundwater at a Uranium Mill Tailings Site." *Appl. Environ. Microbiol. 67*: 3149-3160.

[18] Graves, J. W., and Sullivan, E. H. (1996). "Internal Corrosion in Gas Gathering Systems and Transmission Lines." *Materials Protection* 5: 33-37.

[19] Horn, J., and Jones, D. (2002). "Microbiologically Influenced Corrosion: Perspectives and Approaches." In: C. J. Hurst, R L. Crawford, G. R. Knudsen, M. J. McInerney, L. D. Stetzenbach (Eds.), *Manual of Environmental Microbiology*, Washington, DC, ASM Press, pp. 1072-1083.

[20] Pope, D. H., and Pope, R. M. (1998). *Guide for the Monitoring and Treatment of Microbiologically Influenced Corrosion in the Natural Gas Industry*. Gas

Research Institute, Des Plaines, Illinois, USA.

[21] Youssef, N., Elshahed, M. S., and McInerney, M. J. (2009). "Microbial Processes in Oil Fields: Culprits, Problems, and Opportunities." *Adv. Appl. Microbiol.* 66: 141-251.

[22] Kahrilas, G. A., Blotevogel, J., Corrin, E. R., and Borch, T. (2016). "Downhole Transformation of the Hydraulic Fracturing Fluid Biocide Glutaraldehyde: Implications for Flowback and Produced Water Quality." *Environ. Sci. Technol.* 50: 11414-11423, doi: 10.1021/acs.est.6b02881.

[23] Barton, L. L., and Fauque, G. D. (2009). *Biochemistry, Physiology and Biotechnology of Sulfate-Reducing Bacteria*, Vol. 68. New York: Academic Press, pp. 41-98, doi: 10.1016/S0065-2164(09)01202-7.

[24] Barton, L., and Hamilton, W. A. (Eds.) (2007). *Sulphate-Reducing Bacteria: Environmental and Engineered Systems*, Cambridge University Press.

[25] Salanitro, J. P., Williams, M. P., and Langston, G. C. (1993). "Growth and Control of Sulfidogenic Bacteria in a Laboratory Model Seawater Flood Thermal Gradient." In: *SPE Oilfield Chem. Int. Symp.,* New Orleans, 3/2-5, 1993, pp. 457-467.

[26] Kriel, B. G., Crews, A. B., Burger, E. D., Vanderwende, E., and Hitzman, D. O. (1993). "The Efficacy of Formaldehyde for the Control of Biogenic Sulfide Production in Porous Media." In: *SPE Oilfield Chem. Int. Symp., New Orleans*. 3/2-5, pp. 441-448, doi: 10.2118/25196-MS.