CSCanada
Advances in Petroleum Exploration and Development
Vol. 10, No. 1, 2015, pp. 38-43
DOI:10.3968/7502

ISSN 1925-542X [Print]
ISSN 1925-5438 [Online]
www.cscanada.net
www.cscanada.org

Study on Damage Characteristics and Formation Protective Drilling Fluids in Dongying Formation Low Permeability Reservoir of Chengbei Oilfield

SUN Jianxiang[a],*; HAN Laiju[b]; JIA Jianghong[b]

[a] College of Petroleum Engineering, China University of Petroleum, Qingdao, China.
[b] Drilling Technology Research Institute, Shengli Petroleum Engineering Co., Ltd, Sinopec, Dongying, China.
*Corresponding author.

Received 19 August 2015; accepted 16 September 2015
Published online 28 September 2015

Abstract

On account of the poor protection of the Dongying formation low permeability reservoir of Chengbei oilfield, this paper researched the damage characteristics of Dongying formation low permeability reservoir, by reservoir sensitivity test, water locking damage test, TC model clogging test, and so on. Studies showed that the factors causing damage included water block, water sensitivity, and solid particles invasion. A kind of high quality pollution-free sea-drilling fluid was developed to deal with the potential damage, which had a better performance and protected the reservoir well.

Key words: Low permeability reservoir; Damage characteristics; Water sensitivity damage; Water block damage; Drilling fluid for protection reservoir

Sun, J. X., Han, L. J., & Jia, J. H. (2015). Study on damage characteristics and formation protective drilling fluids in Dongying formation low permeability reservoir of Chengbei oilfield. *Advances in Petroleum Exploration and Development*, *10*(1), 38-43. Available from: URL: http://www.cscanada.net/index.php/aped/article/view/7502 DOI: http://dx.doi.org/10.3968/7502

INTRODUCTION

The low permeability reservoir accounted for up to 72.8% of the China's oil reservoir. This kind of reservoir generally had the characteristics of low permeability, small pore throats, large surface area, high sensitive mineral content, developed fracture, and other, tending to cause solid particlesinvasion, water sensitivity, water block, emulsions blockage, by the drilling fluid's invading the formation, which resulted ina poorreservoir protectionand economiceffects[1-2]. The Dongying formation reservoir was classed as the low permeability reservoir on the basis of exploration results. Due to the lack of analysis and experimental research, the pertinence of the reservoir protection was not as expected. Meanwhile, the producing energy was mainly provided by the formation, and not replenished by water injection, subject to the construction conditions. For the foregoing reasons, the formation pressure was generally low, which could easily cause leakage to damage the reservoir[3-4]. Therefore, the author analyzed the damage of the Dongying formation low permeability reservoir of Chengbei oilfield, and optimized the drilling fluid for reservoir protection, in order to provide the basis of future development and protection.

1. GEOLOGIC ASPECTS

The Dongying formation reservoir of Chengbei oilfield was at a depth of about 3,450 m. Its lithology mainly contains gray-green, gray sand stone containing feldspar on glomerate crumbs. The mineral maturity was low. The cement type based mainly in pore cementation. Based on the analysis of the laboratory test data, the Donying formation reservoir were classed as low permeability reservoirs, of which the reservoir porosity (12%~20%) and permeability ((1~110) $\times 10^{-3}$ μm^2) were both low. The reservoir pore throat was narrow, with strong heterogeneity. The largest connected pore throat radius ranged from 0.3 to 18 μm, with an average of 7.67 μm. The pore throat radius ranged from 0.3 to 4 μm, with an average of 2.02 μm. The variation coefficient of pore throats ranged from 0.83 to 1.03, with an average of 0.95. The uniformity coefficient ranged from 0.20 to 0.39, with an average of 0.27. The kaolinite was the main component of reservoir clay mineral, accounted for 80%, and followed by the illite/montmorillonite interlayer, accounted for 12%.

2. THE POTENTIAL FORMATION DAMAGE CHARACTERISTICS

2.1 The Analysis of Solid Particles Invasion

The pressure of the Dongying formation low permeability reservoir of Chengbei oilfield was generally low, because of the absence of water injection, thereby the developing mainly relied on natural energy. In an overbalanced pressure condition, the solid phase of the drilling fluid could easily invade into the reservoir to clog the pore throats. There were two main sources of solid particles[5]. The first was foreign solid, which was brought into during the process of development, and the second was the large amount of solid particles existing in the reservoir itself[6].

Considering the technique difficulties and economic benefits, currently, the wide used drill-in fluid was still mud, of which the main solid particles were mainly the clay and weighting materials. To determine the relationship between the diameter of particles that caused clogging, and the radius of pore throats, an TC model clogging test was proceeded using standard particle sized plastic pellets flouting liquid. The results was shown in Table 1.

Table 1
The Damage Caused by Solid Particles

Solid particle diameter of suspensionμm	Pore throat diameter of TC modelμm	Particle diameter /throat diameter	Test pressure $\times 10^{-1}$ MPa	Test temperature ℃	λ%	Depth that particles invaded into the TC model
<2	5	<1/5	0.15	21	34.11	Passed
<2	5	<1/5	0.55	21	36.52	Passed
<2	10	<1/10	0.12	21	14.63	Passed
<2	10	<1/10	0.50	21	95.2	Passed
6-10	5	3/5-1	0.50	21	95.2	0.03
6-10	5	3/10-1	2.55	21	99.0	0.1
6-10	10	3/10-1/2	0.51	21	96.1	7.0
6-10	10	3/10-1/2	2.50	21	99.0	10
6-10	15	1/5-1/3	0.51	21	71.9	Passed
6-10	15	1/5-1/3	2.55	21	54.4	Passed

Note. The diameter of standard plastic pellets was < 2 μm，6～10 μm，16～25 μm. Corresponding to the pellets diameter, the pore radius should be selected among 5 μm, 10 μm, 15 μm.

The results showed that the solid particles impacted significantly on the permeability of low permeability reservoir. According to the relationship between the diameters of particles causing clogging, and pore throat radius, on one hand, the content of solid particles in the drilling fluid could be reduced to protect the reservoir; on the other hand, temporary clogging agent could be appropriately chosen theoretically. Kaolinite accounted for up to 80% of the mineral component of the Donying formation reservoir of Chengbei oilfield. It could easily break up and migrate when contacted with water, accordingly to aggregate in narrow throats, causing clogging and filling the pores. Besides, the montmorillonite of the illite montmorillonite interlayer would expand in water, resulting in clogging the pores and throats.

2.2 The Analysis of Reservoir Sensitivity

The existence of sensitive minerals in the reservoir was the cause of chemically sensitive damage that occurred in the low permeability reservoir. If the external fluid was not compatible with the sensitivity minerals, interactions between the two would occur, such as water sensitivity, velocity sensitivity, salt sensitivity, acid sensitivity, alkali sensitivity and the like.

In order to analyze the sensitivity of the Dongying formation low permeability reservoir, the cores of the well CB326 were experimented, to test its water sensitivity, velocity sensitivity, salt sensitivity, acid sensitivity, and alkali sensitivity. The data was showed in Table 2.

Table 2
Well CB326 Water Sensitivity Experiment Data

Scores	KW 10^{-3} μm^2	K0.5W10^{-3} μm^2	K·W 10^{-3} μm^2	Water sensitivity index RK·W / KW	Water sensitivity degree
1#	33.8	25.7	18	0.53	Middle
2#	5.75	5.45	4.13	0.72	Under middle
3#	42.8	40.5	33.7	0.79	Under middle

Note. Evaluation criteria: R = 0~0.2, strong water sensitivity; R = 0.2~0.4, middle water sensitivity; R = 0.4~0.6, middle water sensitivity; R = 0.6~0.8, under middle water sensitivity; R = 0.8~1.0, weak water sensitivity.

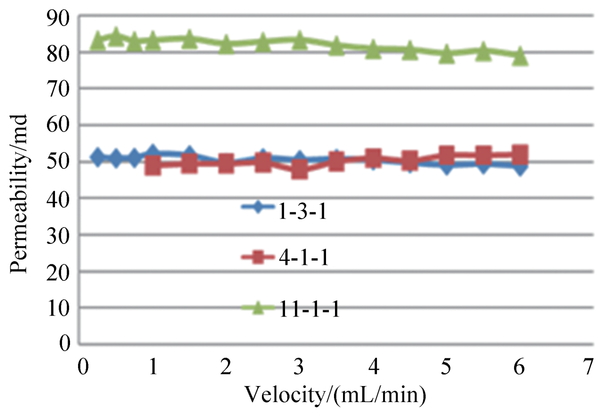

Figure 1
The Velocity Sensitivity of Well CB326

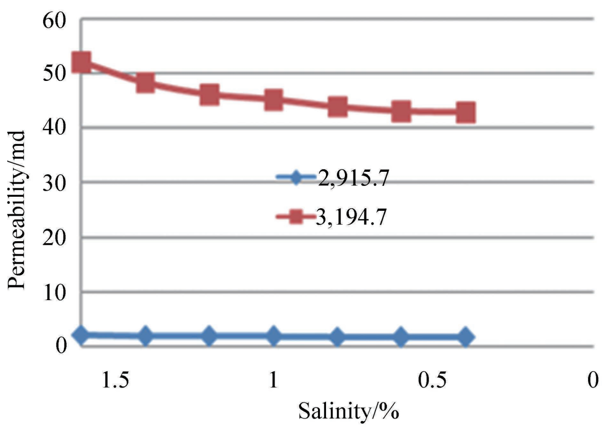

Figure 2
The Salt Sensitivity of Well CB326

Table 3
Well CB326 Acid Sensitivity Data

Cores	Layers	Original permeability $\times 10^{-3}$ μm^2	Permeability after acidification $\times 10^{-3}$ μm^2	Return permeability %
1#	Ed8	33.8	33.2	98.2
2#	Ed9	41.6	41.1	98.8

Table 4
Well CB326 Salt Sensitivity Data

Cores	Permeability with different pH ($\times 10^{-3}$ μm^2)					
	pH = 7	pH = 8	pH = 9	pH = 10	pH = 11	pH = 13
1#	33.8	33.6	33.5	33.2	32.9	32.6
2#	41.6	41.4	41.1	40.9	40.6	40.2

The above tables and figures indicated that the Donying formation low permeability reservoir of Chengbei oilfield exhibited low under middle water sensitivity, no velocity sensitivity, weak salt sensitivity, no acid sensitivity, no alkali sensitivity. Thereby, the reservoir damage was mainly caused by water sensitivity.

2.3 Analysis of Water Block

During the development of the reservoir, when external fluid entered the pores, force would occur on the curved interface that formed by oil-gas and water, that is the capillary pressure. If the starting pressure of reservoir could not overcome the capillary pressure generated by the phase changing, the aqueous phase clog would clog the pores, and ultimately affected the oil and gas recovery[7]. This damage was called water block. Capillary imbibition and water phase retention were the primary causes of serious water phase trapping of the low permeability reservoir.

2.3.1 Capillary Imbibition

Capillary imbibition was defined as a kind phenomenon, that the foreign fluid was siphoned into the capillary pores in the oil and gas reservoir, when the original water saturation of the reservoir was lower than the irreducible water saturation.

The expression of the capillary force is as follows:

$$p_c = \frac{2\sigma\cos\theta}{r} \tag{1}$$

Where p_c is for the capillary force, σ is for the interfacial tension, r is for the pore radius, and θ is for the contact angle.

By Equation (1) it can be concluded, when pore throatdiameter decreases, water interfacialtension increases, or the rock hydrophilicity boosts, the capillaryforceincreases, thusthe water block will be more serious. Table 5 shows that the Dongying formation lower reservoir of Chengbei oilfield could be easily injured by the water block that caused by capillary siphon due to its hydrophilic wettability.

Table 5
Well CB326 Dongying Formation Rock Wettability

Layer	Well section m	Rock properties	Water absorption %	Oil absorption %	Wet type
Ed6	3,205.78～3,213.06	Yellow-gray oil-immersed fine sandstone	25.68	0	Hydrophilic
	3,205.78～3,213.06	Yellow-gray oil-immersed fine sandstone	37.86	0	Hydrophilic

2.3.2 The Aqueous Phase Retention

The permeability's reducing caused by the aqueous phaseretentionwas one of thefactors causingthe most severedamagein low permeabilitygas reservoirs. The main sources of the retained water were original formation water, invading water, the condensate water generated by gas around the bottom. The water block in the reservoir would be more severe, as the rocks were more hydrophilic, as the throats were more narrow, as the permeability was lower, and as there were the more absorbed water[8].

The gas permeability of the low permeability reservoir cores was tested with variable saturation of water in the laboratory. Figure 3 indicated that with the same water saturation, as the permeability decreased, the relative permeability decreased, which lead to severer water block. Generally, the water block problems were very serious in the low permeability reservoir. Figure 4 indicated that as the permeability and the original water saturation decreased, the water block index increased, and the liquid phase trapping were more serious.

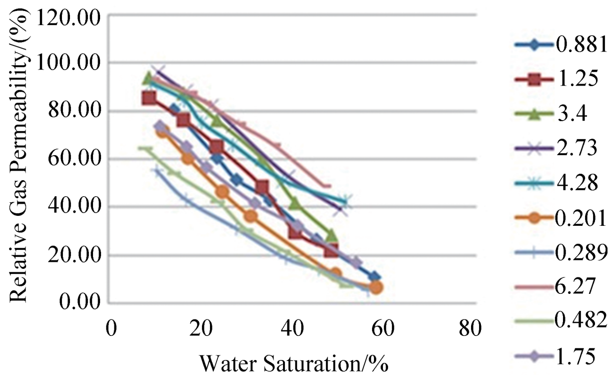

Figure 3
Permeability vs Water Block Index

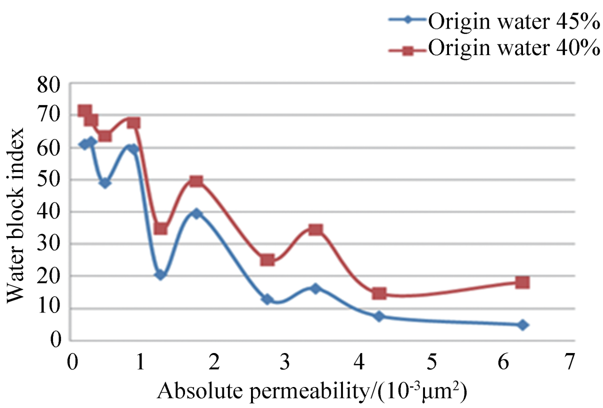

Figure 4
Permeability vs Water Block Index

Based on laboratory test, it was found the potential damage on the Dongying formation low permeability reservoir of Chengbei Oilfield was mainly characterized by solid-phase invasion, water sensitive and water block caused by liquid phase invasion.

3. OPTIMIZATION AND PERFORMANCE EVALUATION OF DRILLING FLUID FOR RESERVOIR PROTECTION

To develop drilling fluid for reservoir protection, that was designed to solve the damage problem of the Donying formation low permeability of Chengbei oilfield, reasonable packing method should be chosen to form thin and tough mud cakes rapidly, which can reduced the solid phase invasion, and reasonable agent should be optimized to reduce the water block, meanwhile, the systemic inhibitory should be enhanced to control the hydration and expansion of the shales, in order to reduce the water sensitivity.

3.1 Optimization of the Agent for Reducing the Water Block

The self-priming experiments of cores is an important means to optimize the agent. Self-priming usually occurred in the dual role of capillary forces and gravity. For low permeability rocks, the capillary force was much larger than gravity, so the effects of gravity was ignored in the process of self-absorption. The larger capillary force described by the more significant self-priming effect, would cause more severe water block.

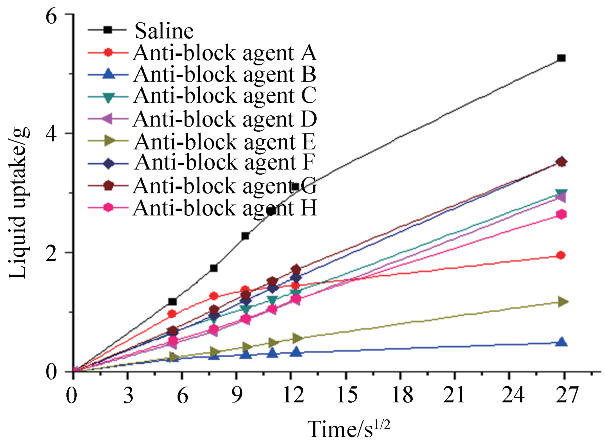

Figure 5
Aspiration Quality vs Time

Figure 5 indicated that using different types of agents, the decline of liquid uptake varied. What's more, the effects were significantly different from each other with longer time. Apparently, the self-absorption of agent B was the smallest, so its performance was the best.

The drilling fluid was finally determined as high quality pollution-free sea-drilling fluid system. With ideal packing method, the system could form dense cakes, reduce dynamic filtration, reduce filtrate invasion, and could decrease the interfacial tension with agent added to reduce the water block, as well as could decrease clay swelling by adding polyalcohol to improve the inhibition of the drilling fluid, which could reduce water sensitivity.

3.2 General Performance Evaluation

The general performance of high quality pollution-free sea-drilling fluid was shown in Table 6.

Table 6 indicated that the system had some yield value and preferred gel strength, which demonstrated that the system had enough suspending ability to carry cuttings. Also, the system showed excellent inhibitory to avoid clay swelling. What's more, the filtration of the system was less than 5 mL, which could form tough and dense mud cakes rapidly to reduce solid phase invasion. Obviously, the system could satisfy the need of offshore drilling.

Table 6
The General Performance of High Quality Pollution-Free Sea-Drilling Fluid

Items	Data
Apparent viscosity (mPa·s)	32
Plastic viscosity (mPa·s)	18
Yield value (Pa)	12
API filtration (mL)	3.8
Initial/ final yield value (Pa/Pa)	2.0/4.0
Recovery (%)	93
Lubricating factor	0.05

3.3 Performance Evaluation of Anti-Contamination

The performance of anti-clay, anti-NaCl, and anti- $CaCl_2$ were shown in Figure 6. The experimental conditions was 120 ℃, and scrolling for 36h.

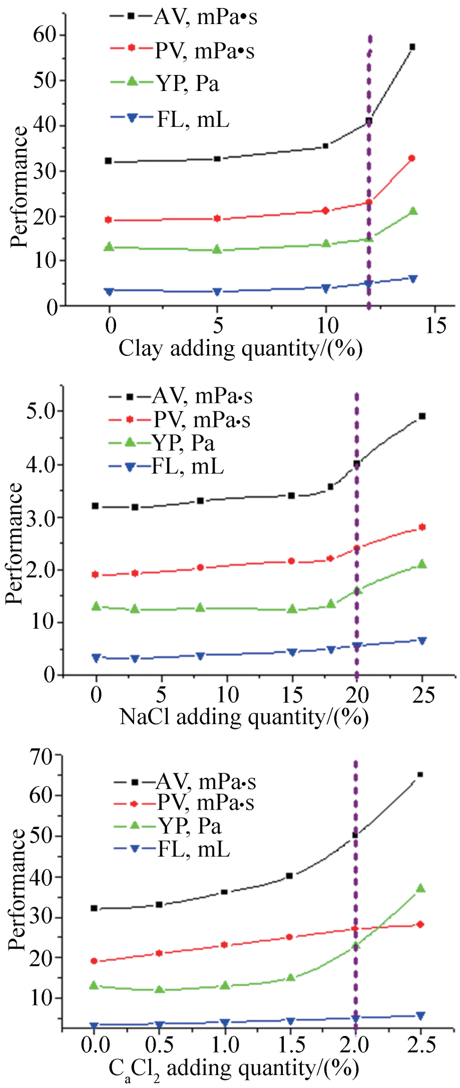

Figure 6
Performance Evaluation of Anti-Contamination

From Figure 6, as the content of bentonite increased, apparent viscosity, plastic viscosity, yield value, and filtration had all increased, but slightly, indicating that the system had strong ability to resist clay contamination (up to 12%). With larger amount of invasive NaCl, general performance parameters of the system increased, but slightly, indicating that the system had strong ability to resist NaCl contamination. With larger amount of $CaCl_2$, the whole general performance parameters increased, but not significantly, indicating that the system has some ability to resist $CaCl_2$ contamination (up to 2.0%).

3.4 Evaluation of the Protection of the Reservoir

The performance of using the optimized high quality pollution-free sea-drilling fluid to protect the reservoir were evaluated by reservoir damage evaluation system. The dynamic contaminating experiments were adopted to test the cores of well 326 with the optimized high quality pollution-free sea-drilling fluid. As it's shown in Table 7, the permeability of the system recovered well, the rates all above 90%.

Table 7
The Permeability Recovery Rate in the Dynamic Contaminating Experiment

Core number	Initial permeability/μm^3	Recovered permeability /μm^3	Recovered rate/%
1	42.5	39.6	93.2
2	41.9	38.7	92.3
3	40.5	38.2	94.3

Note. The experimental conditions weretemperature at 120℃, velocitygradient at 250 s^{-1}, pressure at 3.0 MPa, confining pressure at 5.0 MPa.

On basis of the dynamic filtration experiment results in Figure 7, the filtration of 3 groups of cores ranged from 2.0 ml to 2.5 ml, and were still small after 2 hours, which demonstrated that the final dynamic filtration rate was small. This indicated that the system could form mud cakes rapidly, after opening reservoir, which could prevent the reservoir being invaded by foreign solid and liquid phases.

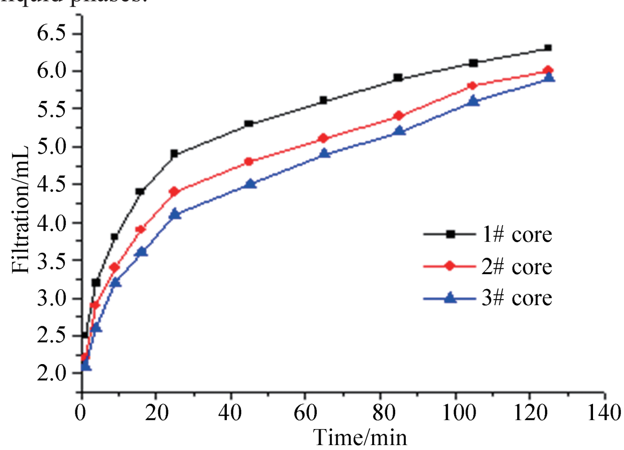

Figure 7
Dynamic Filtration Experiment Time/min

4. APPLICATION

The high quality pollution-free sea-drilling fluid was actually a kind of naturalpolymerpolyalcohol non-permeable drilling fluid system. This system performed very well in the drilling of CB326A-1, CB326A-2, CB326A-3, and other 17 wells, by reasonably choosing packing agent and anti-block agent and others. In 2010, this technology achieved the quick drilling target of "one month, one well", for 3,500 m ~ 4,000 m in the CB326 block. Some wells were tested, and the daily production was average 86.82 m^3 for liquid, and 56.5 m^3 for oil, both far beyond expectation.

CONCLUSION

(a) The laboratory test demonstrated that the damage of Dongying formation low permeability reservoir of Chengbei oilfield were characterized by under middle water sensitivity, water block, and solid phase invasion.

(b) The high quality pollution-free sea-drilling fluid performed well in the Donying formation low permeability reservoir. This drilling fluid system were non-toxic by inspection. It had preferred inhibitory to prevent collapse, preferred lubricity, enough suspending ability to carry cuttings. What's more, it can form cakes rapidly, also could resist clay, NaCl, and $CaCl_2$ significantly, which could protect the reservoir well.

REFERENCES

[1] Cai, J. G., Xie, Z. H., & Liu B. J. (2001). Type sand characteristics of deep sandstone reservoirs in Shengli petroleum province. *Acta Petrol Sinica*, *22*(5), 34-37.

[2] Huang, L. X., & Zhang, G. M. (1999). Mechanism of pore throat's clogging due to solid particles in a formation. *Journal of Jianghan Petroleum Institute*, *21*(2), 41-43.

[3] Zhang, Z. H., Han, H. S., & Wang, S. Q. (2000). Preparation of drilling and completion fluids used for pre-venting the formation from damage of the high-pressure and low-permeability sandstone reservoirs. *Journal of Daqing Petroleum Institute*, *24*(1), 31-34.

[4] Yang, Y. X., Wu, Z. H., & Yan, Y. T. (2005). The analyses of Shanshan Oil-field low permeability reservoir damage. *Xinjiang Geology*, *23*(2), 213-214.

[5] Zhang, Y. Z., & Zhang, Z. H. (2004). Development of acirculating micro-foam drilling system and its performance evaluation. *Journal of Jianghan Petroleum Institute*, *26*(2), 103-105.

[6] Hajdo, L. E. (1994, February). *Formation damage of an unconsolidated reservoir during steam flooding*. Paper presented at SPE Formation Damage Control Symposium, Lafayette, Louisiana.

[7] Waren, B. K., Skea, K., Johnson, S., Smithinsky, S., & Lunan, B. (1998, April). *Development of the pekisko dolomite in the Bigoray field*: *Issues in formation damage mechanisms, drilling fluid selection and well stimulation*. Paper presented at SPE Rocky Mountain Regional/Low-Permeability Reservoirs Symposium, Denver, Colorado.

[8] Jiang, G. C., Ji, C. F., & Ma, X. P. (2009, May). *Study and application of reservoir protection fluid system for drilling & completion using oil-film method*. Paper presented at 8th European Formation Damage Conference, Scheveningen, The Netherlands.

