Prevention and Countermeasures on Drilling Troubles: A Case of 3/7 Block Oilfield in South Sudan

Huiying Zhai[1,a,*], Baolin Liu[1], Zhen Nie[2], Qizhi Huang[2] and Min Feng[2]

[1]*School of China University of Geosciences, Beijing, China*
[2]*Research Institute of Petroleum Exploration & Development, Beijing, China*
a. zhaihy@cugb.edu.cn
**Huiying Zhai*

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Abstract: The lithology of the 3/7 oilfield in South Sudan is dominated by claystone and sandstone, during the drilling operation, the formation loss, tight hole and caving of the wellbore are prone to occur. This paper analyzes the formation lithology in this area, and summarizes four kinds of drilling problems such as formation loss, tight hole and collapse, bit balled up and stuck. Reasonable and effective treatment methods and preventive measures are proposed according to different drilling troubles, including leakage plugging technology while drilling, cement plugging technology, a progressive method from easy to difficult to solve the stuck, and so on. The drilling troubles technical countermeasures proposed in this paper provide an important technical reference for high efficient drilling in other similar blocks, and will help to reduce the non-production time, lower the drilling cost in the 3/7 area of South Sudan.

1. Introduction

The South Sudan 3/7 block is located in the M basin, which is the second largest sedimentary basin in the Central African Rift Valley. The basin is northwest-northwest, with a length of about 600km, a width of about 150km, an area of 3.3×104 km2, and a sediment thickness greater than 8000m is a Meso-Cenozoic passive rift basin developed under the background of right-lateral strike-slip activity in the Central-African shear zone. The entire oilfield is located in Upper Nile River, South Sudan, about 700 kilometers from the capital Juba[1].

At present, CNPC has been developing in the 3/7 block in South Sudan for about 18 years and is a model project for overseas cooperation of PetroChina. The oilfield development is dominated by the vertical wells, with a small number of horizontal and directional wells. The main reservoirs of the oilfield are Yabus and Samma, and the main reservoir depth is between 1300 and 1400 meters. The reservoir properties are generally good and the porosity is between 20-30%. The number of wells drilled has reached more than 900, but there are still many traps that have not been drilled or explored. According to the existing data, the remaining recoverable reserves are considerable, and the oilfield still has the value and significance of long-term development.

2. Analysis of Stratum Lithology and Characteristics

The lithology of the oilfield is dominated by claystone and sandstone. The formation Agor has poor diagenesis, low pore pressure and fracture pressure, and it is prone to formation loss and wellbore collapse during drilling operation. There are large sections of claystone from Daga to the upper strata of Yabus. In some sections, there are interbedded layers of claystone and shale. The shale is easy to hydrate and expand to reduce the well diameter. The shale is easily exfoliated, causing the wellbore to collapse and expand. From the lower Yabus Formation to the Samma Formation, the rock varies greatly, consisting of poorly cemented fine-sandstone, coarse sandstone and pebbly sandstone with claystone.

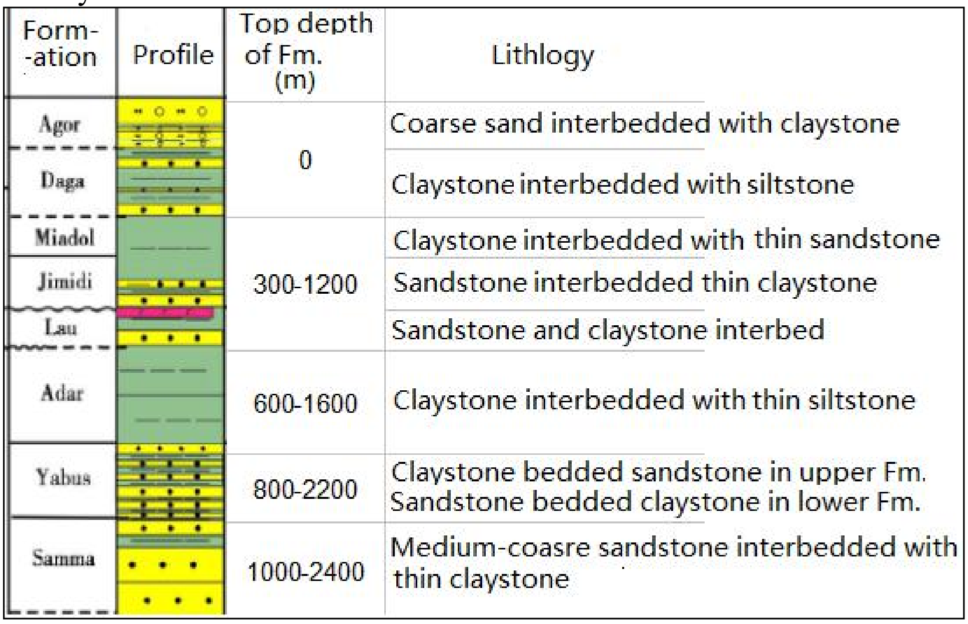

Figure 1: Stratigraphic lithology profile of the 3/7 block oilfield in South Sudan.

3. Risk Analysis of Drilling Complex

Through a detailed review of 90 wells' drilling datum, it is found that the drilling troubles of the 3/7 block in South Sudan are divided into four categories, namely, formation loss, tight hole and collapse, balled up and stuck.

3.1.Formation Loss

Formation loss occurs during drilling operation. This is a common drilling complex. Dealing with loss could take up drilling time and cause loss of drilling fluid. It is more likely to cause other drilling accidents such as stuck, blowout, wall collapse and so on. It even caused the wellbore to be scrapped, which ultimately caused huge economic losses. The three necessary conditions for leakage are that the pressure difference, the leakage channel and the space, and the size of the leakage channel are larger than the particle size of the solid phase in the drilling fluid.

Viewing the drilling datum of 90 wells drilled from 2008 to 2015, 16 wells of which were drilled in the formation, the total leakage volulme of drilling fluid was not less than 9705 bbls, and the leakage of 15 wells occurred in the formation Agor/Daga, only one well lost occurred in the lower formation Yabus. Therefore, the loss in this block mainly occurs in the formation Agor and Daga. These two formations are mostly composed of sandstone and coarse sandstone with thin claystone.

The cementation is poor, relatively loose, with large porosity and good connectivity. In the event of a loss, are mostly malignant leakage, no return at the wellhead; other formations may encounter loss if they encounter faults or fault fracture zones with large faults, such as FJ-27 wells, in the Yabus formation, drilled the fault of about 10 meters, loss occurred and 2516 bbls drilling fluid was lost.

Table 1: Statistics on leakage in the 3/7 block of South Sudan.

Well Name	Details	Loss Volume（bbl）	Formation
FE-34H	50-136m: many times total loss	850	Agor
FF-32H	292m: total/partial loss	629	Agor/Daga
FJ-33H	Surface hole: total/partial loss	1140	Agor/Daga
Fal-8H	80-110m: total /partial loss	627	Agor
FC-29	50-160m:total loss	750	Agor
FE-26	70-150m: loss	130	Agor
FE-32	67-78/260m; total loss	590	Agor
FJ-27	1190-1381m: total /partial loss	2516	Yabus
FJ-31	120-166m: total loss	600	Agor
FF-31	97m: total loss	600	Agor
FK-9	13-56m:partial loss	138	Agor
Ma-25	50-80m: total loss 109m/175m/193m/282m:loss	566	Agor/Daga
FM-19	Partial loss	126	Agor/Daga/Miadol
Ma-26	71m: total loss	298	Agor
As-15	272m: loss	145	Agor/Daga
FK-12	55m: loss	/	Agor

3.2.Wellbore Shrinkage and Collapse

In the 3/7 block of South Sudan, the complexities of wellbore shrinkage and collapse are common in drilling operations. Among the 90 wells viewed, 64 wells of them encounter tight hole or collaps. These complexities can cause overpull or drag. In the year of 2015, 25 wells were drilled, 20 wells of which showed different degrees of wellbore shrinkage, and the treatment time was about 475.85 hours, accounting for 58.5% of non-production time. The shrinkage and collapse of the wellbore mainly occur in the formation of Miadol, Jimidi, Adar and upper Yabus. The lithology of the formations is mainly claystone, and contain a large amount of clay minerals, Therefore, in addition to the mechanical factor, the reasons for the shrinkage and collapse of the wellbore in this area are also chemical factor or a combination of the two. From the caliper log, the position and degree of tight hole and collapse can be seen. It can be seen from Figure 2 that the borehole shrinkage and collapse in the Adar formation exist simultaneously. As can be seen from Figure 3, the formation Miadol and Jimidi have a serious collapse during the 600-850 m, and during the drilling operation of this section, circulation is frequent to keep the wellbore cleaning. drilling fluid.

At the same time, the strength of the wellbore shrinkage and collapse is related to the shale/claystone content in the formation, wellbore soaking time, the performance of the drilling fluid, the drilling measures and so on.

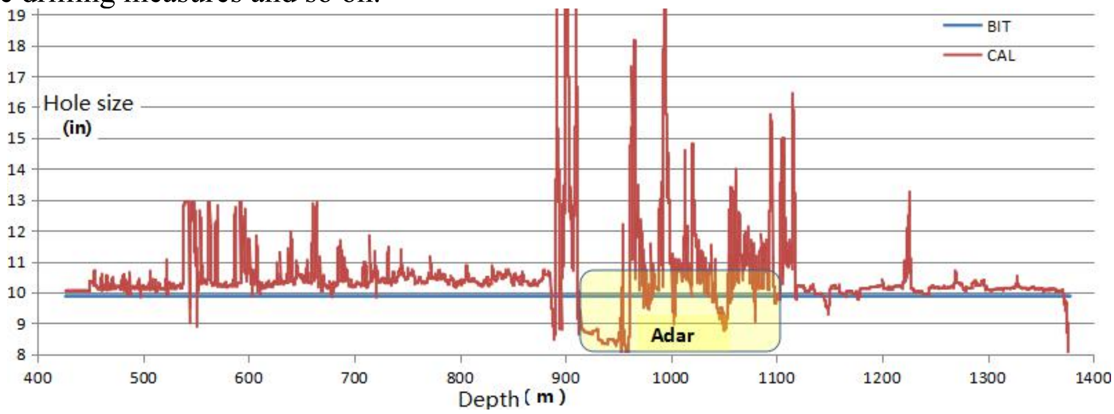

Figure 2: Caliper log of well FJ-27.

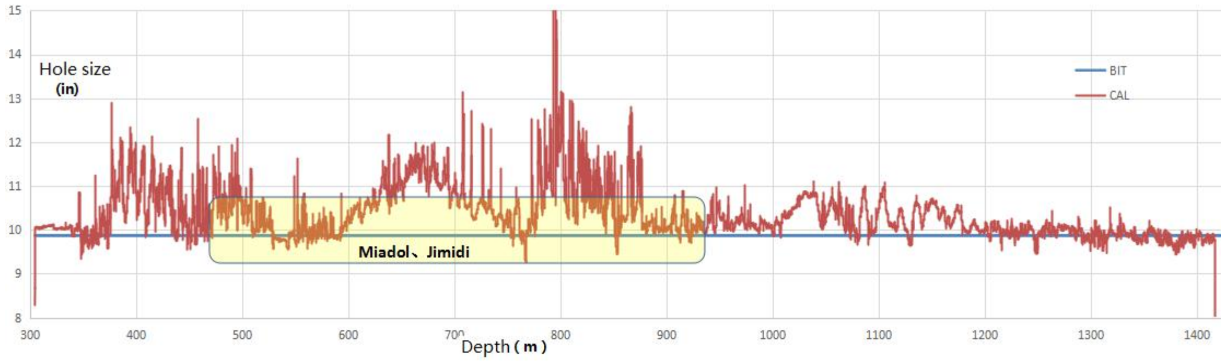

Figure 3: Caliper log of well FN-24.

3.3.Balled Up

Because the lithology of the middle and lower strata in this area is dominated by claystone, it is easy to collapse into the borehole, resulting in an increase in the solid phase content of the drilling fluid. If it is not removed in time, it will easily lead to bit balled up and bit nozzle blocked. In the year of 2015, 25 wells were drilled, and 7 wells of them encountered balled up. Treating time was 152.75 hours, mainly in the formation Adar and Yabus, as shown in Table 2.

Table 2: Details of trouble balled up in the 3/7 block of South Sudan.

Well Name	Detail	Treat Time（hrs）	Formation
Ha-22	Balled up	20	Yabus
Ha-26	Balled up	43.75	Adar
Ha-29	Balled up	16.5	Yabus
Ma-22	Balled up	16.25	Adar
Ma-24	Balled up	33	Adar
PS-13	Balled up	20.5	Jimidi
Mh-18	Balled up	2.75	Adar

3.4.Stuck

Stuck in this field is relatively less. In the 90 wells viewed, 3 wells encountered stuck in the second open well, and one of the wells stuck twice, as shown in the table 3. In the year of 2015, one well met the stuck namely As-15 well, and dealed with the stuck nearly 2 days. The cause of the stuck was shutting up the well for 10 days at 975 meters (Jimidi formation) due to safety factors. The wellbore is soaked by the drilling fluid for too long, causing the claystone hydration to expand and shrink. Another reason is that the pump stop time is too long, the cuttings are too much, and the drilling fluid is not circulated long time, its viscosity and shear value is higher. The other two wells are horizontal wells. It is easy to accumulate cuttings in the inclined section, and the claystone formation is easy to shrink. These two reasons are superimposed to increase the chance of a stuck.

Table 3: Stuck details in the 3/7 block of South Sudan.

Well Name	Details	Treatment TIme（hrs）	Formation	Remarks
FM-26H	stuck	19.5	Miadol/Yabus	shrinkage/cuttings
FD-33H	stuck	15.75	Adar	cuttings
As-15	stuck	41	Jimidi	shut up the well

4. Treatment Methods and Preventive Measures

In view of the drilling complexity situation in this area, combined with the lithologic characteristics of the block, the complexity of treatment and prevention can be started from three aspects: one is to select reasonable drilling parameters; the other is to increase the number of reaming and circulation in the claystone formation; the third is to adjust the density of drilling fluid (DF). The DF density has a great influence on ensuring safe drilling. The DF density should be greater than the pore pressure gradient and the shear failure gradient, which is less than the rock fracture pressure gradient; when the DF column pressure is seriously lower than the pore pressure, it will cause serious wellbore collapse; when the DF density is between the pore pressure gradient and the shear fracture gradient, the wellbore will be shrinked and shear fracture will be formed; when the DF density is greater than the fracture pressure gradient, it will lead to loss[4, 18, 19].

4.1.Treatment and Prevention of Formation Loss

There is a risk of well loss in the formation Agor and Daga in this area, and the leakage is serious generally. It often encounters no return at the wellhead. The treatment method is firstly to adopt the technology of plugging while drilling, adding the plugging material in the drilling fluid; if the plugging while drilling is not effective, the pumping cement plugging technology is adopted, using the drill pipe to inject rapid-solidification cement slurry into the loss formation, and then restart the drilling operation after the cement slurry is solidified, generally formation loss will not occur repeatedly.

The well loss in this area mainly occurs in the loose formation, and the risk of leakage can be further reduced through the preliminary prevention measurement. First, the high-viscosity drilling fluid is used to drill through loss formation quickly; secondly, sufficient plugging materials while drilling are prepared on well site; the mud engineer detects the total amount of drilling fluid, finds the leakage in time, graps the timing of plugging, adds plugging materials to the drilling fluid as soon as possible to prevent large leakage or malignant leakage; minimize the occurrence of agitation pressure during drilling; adjust drilling fluid performance in time[8, 11, 14, 15, 16, 17].

4.2.Treatment and Prevention of Shrinkage and Collapse

Both the shrinkage and collapse of the wellbore will cause over-pull or drag, but there is a little difference about the treatment method. To deal with the shrinkage of the wellbore, it is necessary to carry out short-wiper trip up/down, reaming, and circulating the drilling fluid to clean the wellbore. To deal with the collapse of the wellbore, it is necessary to adjust the performance of the drilling fluid, increase the density of the drilling fluid[12, 13].

There is wellbore shrinkage and collapse in this area, which is related to the lithology of the formation and the mineral composition of the rock, the density and performance of the drilling fluid, and the stress state of the formation. It is impossible to change and adjust the formation lithology and the mineral composition of the rock, but it can prevent the shrinkage and collapse of the wellbore through construction measures, adjusting the drilling fluid density and optimizing the drilling fluid performance.

There are large sections of claystone from the bottom of Daga to the top of Yabus in this area, and there is interlayer of sandstone. So the wellbore is easy to hydrate and expand to shrink, and there is a risk of the wellbore collapse. To this end, KCl drilling fluid is used to prevent wellbore instability, and its mechanism of action: First, the inhibition of the KCl drilling fluid makes the wellbore stable, non-absorption and non-expansion, maintaining the hardness of the borehole wall is the prerequisite for stabilizing the borehole wall; Second, adding anti-collapse agent GWJ, temporary plugging agent FT-1 to block the micro-cracks and prevent the water from entering the sandstone and claystone interlayers to cause cracking; Third, maintain a reasonable drilling fluid density, which is the key to stabilizing the wellbore wall, the reasonable drilling fluid density can not only balance the released ground stress, but also make blocking particles enter the micro-seam to form a dense shielding tape; the fourth is to control the pH value of the drilling fluid, best between 8.0-9.0, and the excessive pH value will promote the hydration and dispersion of the claystone[1, 2, 3].

In addition to technical precautions, some precautions can be taken during drilling operation to maintain wellbore stability. First, when drill about 300 meters, circulate drilling fluid, clean the hole, and carry out short wripe trip up/down; second, when pull BHA out of the hole to the wellhead, and once again run in the hole, circulating the drilling fluid at least one circle; third, during the drilling operation, try to use the upper limit of the drilling fluid density window.; fourth, strictly use solid control equipment, vibrating screen, sand remover, desilter, centrifuge, etc. to ensure that the drilling fluid meets the purification requirements[5, 6].

4.3.Treatment and Prevention of Balled Up

The balled up in this area can be judged from the following phenomena: the drilling speed is significantly reduced, about 1 m/hr; the torque is seriously fluctuated; the pump pressure is increased. After the nozzles of bit plugged and balled up, firstly, flush the bit and then replace it, that is, lift the bit off the well bottom, increase the displacement for cleaning; if the cleaning is invalid, pull the BHA out of the hole to the wellhead, clean or replace the bit.

The most important technical measure to prevent the occurrence of ball up is to maintain and adjust the performance of the drilling fluid. Especially for the claystone formation in this area, it is necessary to control the filtration of the drilling fluid, improve the inhibition and lubricity of the drilling fluid, and control the content of solid phase strictly. The engineering measure is to take the possible largest displacement, carry the cuttings out as soon as possible, prevent the formation of sludge and then balled up the bit; at the same time, it is better to optimize the bit type and the nozzles' size and number; run the bit evenly during the operation; the drilling pressure should not be too large[7, 9, 10].

4.4.Treatment and Prevention of Stuck

The strata in this area is mainly a claystone formation, which is prone to tight hole or the accumulation of cuttings from the collapse of the wellbore, resulting in stuck. Especially in the inclined well sections of directional wells or horizontal wells, the cuttings are easy to accumulate, and there is a risk of stuck. Solving the stuck is to use a progressive method from easy to difficult, that is, firstly start the pump to cycle the drilling fluid, clean the hole, and then work the pipe; if unable to work the pipe, the jar can be used to solve the stuck; if the jar is still invalid, soak pipe with a releasing stuck agent and gradually work the pipe; if the releasing stuck agent still cannot solve the stuck or find that the pump cannot circulate the drilling fluid after stuck, it is to use reversing pipe or the explosion loose buckle to pull the pipe out of hole above the stuck point, then mill the fish.

The well of A-15 was shut down for about 10 days, start the pump and circulate the drilling fluid gradually. It was not successful to work the drill pipe many times. After that, soaked the drill pipe with the releasing stuck agent, work the drill pipe gradually and solve the stuck. The formula for calculating the amount of the releasing stuck agent is as follows:

$$Q = K\frac{\pi(D^2 - d_O^2)H}{4} + \frac{\pi d_I^2 h}{4} \tag{1}$$

Q---the amount of the releasing stuck agent, m^3;

K---the factor of wellbore diameter expansion, 1.2-1.25;

D---bit diameter, m;

d_o---out diameter of dill pipe, m;

d_I---inner diameter of dill pipe, m;

H---height of the outside soaking of the drill pipe, generally required to be more than 100 meters above the stuck point;

h---height of the inner soaking of the drill pipe. It depends on the specific conditions of the stuck and the expected soaking time. Reserves should meet the replacement of long-term soaking(The wells with high density of drilling fluid, or with LCM, or with sand beds, or with stabilizers in BHA).

In order to prevent the occurrence of stuck in the area, during the drilling operation, test the parameters of drilling fluid and circulate the drilling fluid to clean the hole, prevent the accumulation of cuttings; optimize the performance of the drilling fluid and prevent the occurrence of tight hole; the drilling tool is equipped with a jar, and at the same time inspect, the drilling tool that is damaged is no longer run into the hole[10, 19].

5. Conclusions

1) The main complications encountered in the 3/7 block of South Sudan are formation loss, tight hole and collapse of wellbore, ball up, and stuck. The causes of their occurrence are analyzed one by one.

2) In view of the complex of formation loss, it is proposed to adopt the method of plugging while drilling and cement re-injection; for the tight hole and collapse of wellbore, it is proposed to adopt different methods, such as short wiper trip up/down, reamimg, circulating drilling fluid and increasing the density of drilling fluid; for the ball up, it is proposed to flush the drill bit first, replace the drill bit if it is invalid, and optimize the drilling fluid performance; for the stuck complex, it is proposed to adopt a progressive method from easy to difficult to solve the stuck.

3) This paper provides an important technical reference in the future drilling operation for the prevention of complex occurrences, timely deal with complex drilling with reasonable methods, improve drilling efficiency and reduce drilling cost.

References

[1] Guo Jiankang, Yan Jienian, Fan Weiwang, et al. The modification of KCl/polymer fluid system and its application in block 3/7, Sudan[J]. Petroleum Drilling Techniques, 2005, 33(6): 28-31.

[2] Wu Xianghong, Rao Liangyu, Li Xianbing, Li Xianglin. An Optimization Model to Determine Horizontal Well Location and Parameters for Strong Bottom Water Reservoir in Sudan. 2012, SPE 150865.

[3] Wael M. El Essawy, Rosli bin Hamzah, Mirghani Mohamed Malik, David Knox, Mohammed R. Monem, Reinhard J. Oswald. Novel Application of Sodium Silicate Fluids Achieves Significant Improvement of the Drilling Efficiency and Reduce the Overall Well Costs by Resolving Borehole Stability Problems in East Africa Shale. 2004, IADC/SPE 88008.

[4] Yin Shuai, Ding Wenlong, Yang Wenna, et al. Progress of Borehole Stability Considering Strata Anisotropy[J]. Advances in Earth Science, 2015, 30(11): 1218-1230.

[5] Mirghani Malik, Raj Deo Tewari, Sivaraman Naganathan. Rotary Steerable Systems Result in Step Change in Drilling Performance—A Case Study. 2006, SPE 103842.

[6] Ming Xiansen, Yuan Zhiping, Bin Chenggang. Drilling chanllenges and drilling fluid technologies for shale gas drilling in Changqing area[J]. Drilling Fluid & Completion Fluid, 2017, 34(5): 44-49.

[7] I. Hamoudi, K. Kartobi, P. Vieira, M. A. Saad, F. Torres, H. Qutob. Successful Application of Unique Polyamine High Performance Water- Based Drilling Fluid in Bohai Bay Shale Formations. 2013, IPTC 16721.

[8] Wang Zhonghua. The status and development direction of plugging technology for complex formation lost circulation. Sino-global Energy, 2014, 19(1): 39-48.

[9] Chen Xiuping, Zou Deyong. Bit balling mechanism and research progress in countermeasures for PDC bit drilling in mud shale formations. Natural Gas Industry, 2013, 34(2): 87-91.

[10] Li Zuobin. Well TasW-1 Complicated Condition Treatment Technique, Petroleum Drilling Techniques, 2010, 38(2): 88-90.

[11] El SAYED M, EZZ A, AZIZ M, et al. Successes in curing massive lost circulation problems with a new expansive LCM. 2007, SPE/IADC 108290 .

[12] Bi Bo. Research on borehole stability affected by shale penetration and hydration. Drilling Fluid & Completion Fluid, 2011, 28: 1-3.

[13] Zhao Haifeng, Chen Mian. Real-time prediction of borehole instability based on actual drilling data. Acta Petrolei Sinica, 2011, 32 (2):327-328.

[14] Akong Bassey, Adewale Dosunmu, Friday Otutu. An integrated approach to understanding wellbore stability in faulted and depleted sands while drilling challenging XYZ well Niger Delta. 2014, SPE-172461-MS.

[15] Zheng Youcheng, Li Xiangbi, Deng Chuanguang, et al. Techniques of treating seriously lost circulations in Northeast Sichuan[J]. Natual Gas Industry, 2003, 23 (6): 84-85.

[16] Jin Yan, Chen Mian. Wellbore stability mechanics[M]. Beijing: The Science Publishing Company, 2012.

[17] Jordan Gao, Tosin Odunlami, Nadine Osayands. Shale bedding impact on wellbore stability and drilling optimization. 2014, SPE-171601-MS.

[18] Lu Xiaochuan, Di Mingli, Wang Wei. Treating method for lost circulation in Bohai Oilfield[J]. Journal of Yangtze University (Natural Science Edition), 2017, 14 (11): 46-49.

[19] An Lei, Shen Guomin, Si Na. Releasing the stuck drill-pipe and cause analysis of 7-A well of block B in Niger Delta[J]. West-China Exploration Engineering, 2013, 9: 22-26.