Research On Oil-based Plugging Technology In A Horizontal Well Section Of The Fuling Shale Gas Field

Yu Liu[1,2], Qingshan Xiong[1,2*], Rong An[1,2], Hao Geng[1,2], and JiaHuan Xu[1,2]

[1] Hubei Key Laboratory of Oil and Gas Drilling and Production Engineering (Yangtze University)
[2] School of Petroleum Engineering, Yangtze University: National Engineering Research Center for Oil & Gas Drilling and Completion Technology
[*] Corresponding author. E-mail: 1403266446@qq.com

Received: Apr. 11, 2023; Accepted: Jul. 12, 2023

To address the serious issues of leakage, challenging plugging, and significant friction related to the long horizontal section construction in the Fuling shale gas field, a study was conducted to develop a suitable leak-proof agent OBMCP for oil-based drilling fluid. The difficulties of preventing leakage and plugging oil-based drilling fluid were analyzed, and the amount of reactively consolidated polymer HY-1 was controlled at 6.25 – 7.5% while considering the plugging strength requirements and plugging costs. The enhancer ZQJ was controlled at 0.4 – 0.6% to achieve high-strength rapid plugging, and the gelation time was controlled under the premise of safe construction to achieve a controllable curing time. Consequently, the oil-based drilling fluid leakage prevention and plugging technology were formed and applied in the J1 and J2 wells. The field test showed that the optimized drilling fluid had stable performance, a good plugging effect from the consolidation plugging agent, a stable borehole wall, small leakage, and strong anti-pollution ability, thereby achieving high-strength rapid plugging and a controllable curing time.

Keywords: Oil-based drilling fluid; plugging while drilling; consolidation plugging agent; wellbore instability; fuling shale gas

http://dx.doi.org/10.6180/jase.202405_27(5).0003

1. Introduction

Based on a statistical analysis of the leakage of oil-based drilling fluid in the target layer of 76 wells drilled in the Fuling Phase II and Nanchuan areas in 2016 – 2017 [1–4], it was found that 22 out of the 76 wells experienced oil-based drilling fluid leakage, resulting in a leakage ratio of 28.9%. The total amount of leakage was 4,558.6 m^3, with an average single well leakage of 207.2 m^3 and a maximum single well leakage of 1,060.2 m^3 (Jiaoye 6). The average number of single well leakages in the peripheral wells of Jiaoshiba was found to be more than twice that of the main structure of Jiaoshiba, particularly in the southern working area of Jiaoshiba and the Baima block near the Wujiang River, where the well leakage was particularly severe. Some exploration wells even experienced over 20 leakage layers.

According to the number of leakage wells and leakage amount in different block areas in Fig. 1 and Fig. 2 [5–7], it can be found that the leakage is mainly concentrated in the three blocks of Jiangdong, Baima and Heping Bridge. Among them, the number of drilling wells in the Jiangdong block area is the largest, reaching 33, and the number of out-of-circulation wells is also the largest, with 9; The proportion of out-of-cycle in the Baima block area was the highest, with an average leakage of 520.4 m^3 per well.

In the area of the Pingqiao block, the crack gas leakage of the Longmaxi Formation of the junction 8HF well has been blocked for 7 days with the same layer of the well. The crack leak in the Xiaohe Dam-Longma Creek Formation

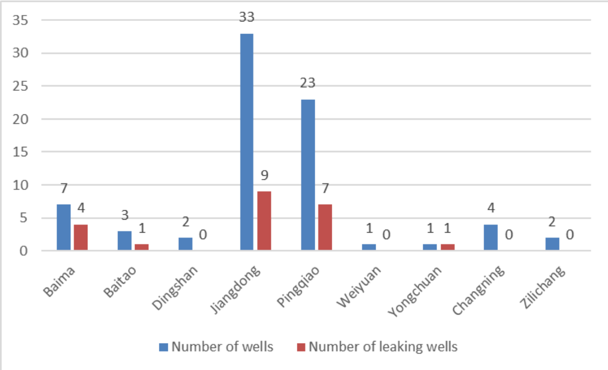

Fig. 1. Distribution of wells numbers and lost circulation wells in different blocks

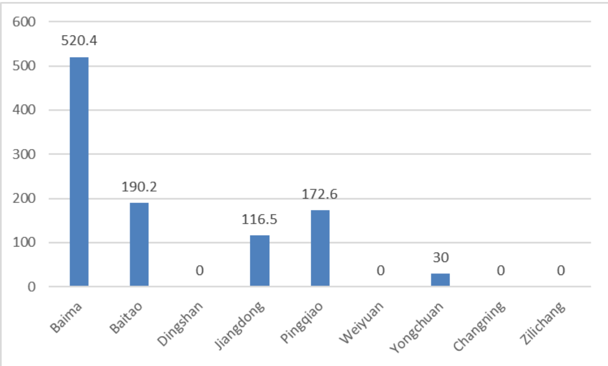

Fig. 2. Average single well leakage diagram

has been going on for 13 days. In the area of Jiangdong block, the three-stage perforation leakage of the Longmaxi Formation of the junction 81-2HF well, and the downhole cementing was blocked; In the area of Baima block, the third exit of well 106-1HF at the junction was 11 times out of circulation, the amount of lost circulation reached 359.55 m^3 and the plugging overflow point was located at 4694 m, and a lot of time was wasted during the completion period due to the treatment of lost circulation.

Constructing long horizontal section wells in shale gas fields often encounters numerous difficulties. Shale gas fields are typically characterized by highly permeable and fractured formations, leading to the filtration and leakage of drilling fluid. This, in turn, causes instability in the borehole and increases construction risks. The interaction between the fracturing fluid injection process and the drilling fluid can result in failure or reduced performance of the blocking agent, consequently affecting the subsequent blocking effect. In high-temperature and high-pressure environments, both the drilling fluid and plugging agent need to exhibit resistance to ensure a stable and long-lasting plugging effect. In comparison to traditional water-based plugging techniques, oil-based plugging techniques offer advantages such as improved high-temperature stability, impermeability, and broad applicability. By utilizing the appropriate oil-based plugging agent, not only can the stability of the well wall be enhanced and drilling fluid filtration and leakage reduced, but also the integrity and stability of the borehole can be maintained, ensuring the durability of the plugging effect.

In the Fuling shale gas field, formation leakage is a frequent occurrence during drilling operations. However, there has been relatively limited research conducted in China on plugging materials specifically designed for oil-based drilling fluids. Currently, the commonly used plugging materials in the field primarily consist of hydrophilic materials. These materials have lower compatibility with oil-based drilling fluids and can potentially impair their performance when used over an extended period of time. Therefore, in order to effectively solve the problems of serious leakage, difficult plugging and high friction resistance under the construction conditions of long horizontal wells in Fuling shale gas field, the compatibility and plugging experiments of indoor composite leakage prevention materials and oil-based drilling fluids were carried out, and the formula of oil-based drilling fluid leakage inhibitors was optimized [8–11]. By studying the consolidation strength of the plugging material HY-1 and the curing time of ZQJ, an optimal consolidation and plugging agent was developed [12–15]. Furthermore, it has been successfully implemented in the Fuling shale gas field, yielding positive outcomes in effectively sealing cracks, reducing leakage, and enhancing the stability of well walls.

2. Difficulties analysis of oil-based drilling fluid leakage prevention and plugging

2.1. Causes of oil-based drilling fluid leakage

Oil-based drilling fluids have good filtrate permeability. Therefore, when drilling in stratified and micro-fractured formations, the oil-phase filtrate can easily penetrate deeper into the formation under a positive pressure differential. This penetration causes a change in the fracture's wetting properties, transitioning from hydrophilic to oleophilic. As a result, the fracture is unable to "heal" automatically under the effects of filtration loss until the borehole pressure is reduced or the fracture is sealed. Additionally, oil-based drilling fluids exhibit higher compressibility compared to water-based drilling fluids. Consequently, the actual density of oil-based drilling fluids at the bottom of the well under high temperature and pressure will exceed the designed drilling fluid density. This disparity in density poses a greater risk of leakage, particularly when drilling in low-pressure, high-permeability formations, or fractured formations.

2.2. Leak prevention and plugging difficulties analysis

After collecting a large amount of field drilling data and analyzing the distribution pattern of well leakage in the reservoir layer of the Fuling shale gas field, as well as considering the formation pressure-bearing capacity and the characteristics of well leakage, and taking into account the current status of leakage plugging technology at both domestic and international levels, we have summarized the challenges in implementing leakage plugging technology in the reservoir layer of the Fuling shale gas field.

(1) In the horizontal well section, lost circulation often occurs. To shorten the drilling cycle and reduce plugging costs, the downhole screw + directional tool is generally used for the first plugging, and the particle size of the plugging material is limited to a maximum of 1-3 mm. During the plugging and squeezing process, drilling can be resumed as long as there is no leakage in the circulation. However, the depth of the plugging slurry and squeezing pressure may be insufficient. In later construction, due to factors such as pressure excitation and mud performance, leakage is prone to occur, making it difficult to identify the leakage point and reducing the success rate of plugging.

(2) The formation has a low bearing capacity and is sensitive to pressure. In the case of low well control risk and stable wellbore, reducing the density of drilling fluid has a good effect on leakage prevention and plugging. However, the leakage layer is sensitive to the excitation pressure of the wellbore liquid column, and the leakage rate is easy to re-leakage. Based on the plugging situation analysis, it was found that various plugging materials with different particle sizes did not achieve significant plugging effect, and the pressure easily rose after plugging. Furthermore, even though the plugging material plugged the fracture surface, it was still difficult to form an effective plugging in the fracture, leading to recurrent leakage after some drilling time.

(3) In the case of overflow and leakage coexisting, plugging treatment becomes even more challenging and expensive. For instance, in the Jiaoye 85-5HF well, active gas layers were encountered at depths of 4,457 m and 4,488 m. The throttling cycle exhaust time was prolonged, and the shut-in pressure was high. Increasing the drilling fluid density from 1.52 g/cm^3 to 1.67 g/cm^3 caused the gas layer to gush and leak. It was difficult to determine the appropriate drilling fluid density. After the plugging operation, there was significant backflow of plugging slurry, and the desired effect was difficult to achieve. Similarly, in the Jiaoye 8HF well, there was fracture gas leakage in the Longmaxi Formation, and it took 7 days to kill the well and perform plugging.

(4) Compared with new leakage layers, it is more difficult to plug leakage caused by plugging or pressure induction. For instance, in Well Jiaoye 51-4HF, 17 leakages occurred during the drilling of oil-based drilling fluid in the Longmaxi Formation and Wufeng Formation, of which two were lost circulation events. The causes of lost circulation were mainly attributed to fault fractures developed in the Longmaxi and Wufeng formations of the well, with strong induced ductility. As the drilling depth increased, the degree of leakage generally increased, and the leakage rate kept rising until lost circulation occurred. Early on, plugging while drilling could be effective, but with the increasing formation fracture induction, the fractures widened and extended to the fault. Although attempts to reduce the density of drilling fluid and increase the amount of plugging agent while drilling were made, conventional drilling tools were the only solution to plug the leakage.

(5) The reason for the ineffectiveness of plugging materials is that they typically exhibit strong hydrophilicity and lack compatibility with oil-based drilling fluids. This hinders their ability to effectively enhance the filter cake quality and improve the pressure-bearing effect of the formation. Additionally, these materials often have limited adaptability to the particle size and leakage channel, resulting in suboptimal plugging effects. Fig. 3 illustrates different plugging particles.

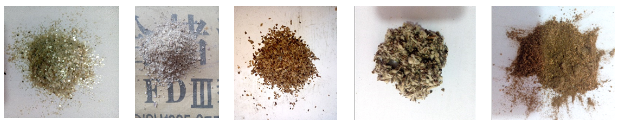

Fig. 3. Different plugging particle shapes

3. Oil-based leak preventer obmcp while drilling

Conventional bridge plugging materials have limited adaptability when it comes to achieving an effective plugging effect. This is mainly due to the fact that the accumulation of micro-nano particles during the formation of a plugging layer is just as important as the bridging effect itself. As a result, the conventional bridging mechanism is unable to meet the design requirements for powder micro-nano particle size gradation. To effectively bridge and plug micropores and microcracks, a certain bridging mechanism must be met by the rigid bridging particles.

The basic formula of OBMCP is: rigid particles/QS (10

∼ 74 μm) + oil-wet fiber/ZMB (20 ∼ 2,000 μm) + flake filling material/EG (47 ∼ 74 μm).

The effect of the ratio of composite anti-leakage materials on the rheology of oil-based drilling fluid was studied to assess the compatibility and sand bed plugging effect:

(1) The effect of the ratio of composite anti-leakage materials on the rheology of oil-based drilling fluid was investigated to evaluate the compatibility and sand bed plugging effect. The ratio of 1# composite leakproof material was 45% HPS, 50% QS, and 5% ES. The results in Table 1 show that the 1# composite anti-leakage material had a certain influence on the rheology of the oil-based drilling fluid, apparent viscosity, compatibility, filtration loss, and plugging ability. This could be due to the small proportion of expansion material as filling material, which had a significant impact on the filtration loss. Additionally, the larger sieve size of the plugging particles resulted in a poor plugging ability.

(2) The ratio of 2# composite anti-leakage material is 35% HPS + 50% QS + 15% ES. From Table 2, it can be observed that the 2# composite anti-leakage material has a certain effect on the rheology of oil-based drilling fluid, leading to a certain increase in apparent viscosity, compatibility, and filtration loss, and poor plugging ability. This may be due to the small proportion of expansion material used as filling material, which has a significant impact on the filtration loss. However, the plugging ability gradually improved with the increase of the amount of material used.

(3) The ratio of 3# composite leakproof material was 40% HPS, 50% QS, and 10% ES. The results in Table 3 show that the 3# composite anti-leakage material had a certain influence on the rheology of the oil-based drilling fluid, including the apparent viscosity, compatibility, filtration loss, and plugging ability.

(4) From Table 4, it can be observed that the 4# composite anti-leakage material does not affect the rheological properties of the oil-based drilling fluid, including the apparent viscosity, and exhibits good compatibility. Additionally, the filtration loss decreases initially and then increases, while the plugging ability is good.

According to the laboratory-optimized formula for oil-based drilling fluid leakproof agent, 30 tons of product were produced, and a sample of 30 tons of composite leakproof material OBMCP produced during the pilot test was taken for particle size analysis, as shown in Fig. 4.

(1) The Winner 3001 laser granularity analyzer test revealed that the primary particle size distribution ranged from 17.85 to 96.08 μm, with an average particle size of 26.30 μm.

(2) The OBMCP material, after being dried at 100 °C for 12 hours, was analyzed for particle size using a sample sieve. Fig. 4 shows that the material is primarily distributed between 200-160 mesh (75-96 μm).

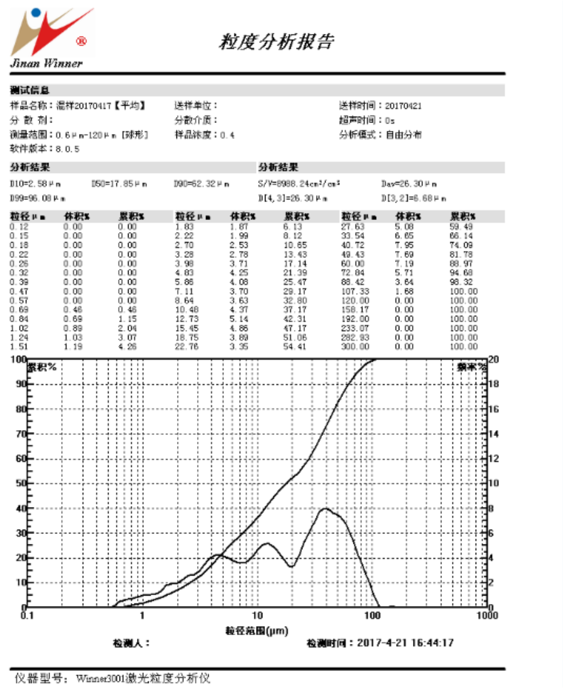

Fig. 4. Particle size distribution of OBMCP composite leak proof agent for oil-based drilling fluid

4. Development of consolidated plugging agent

While the fast loss and enrichment properties of the quick seal plugging agent are fully utilized, the slurry is prepared with diesel fuel, resulting in the inability of the quick seal plugging agent to cement and cure after the formation of the plugging layer. This leads to weak resistance to the breakage of the plugging layer and a short plugging period. To achieve the purpose of fast filtering and curing in oil-based drilling fluids, HY-1, a reactive cementing polymer, was introduced into the quick seal plugging agent. Its cementing performance under temperature conditions is utilized to achieve high-strength plugging in oil-based drilling fluids. Simultaneously, the amount of reinforcing agent ZQJ is controlled to achieve the desired controlled curing time.

The first consideration when selecting a cementing and plugging agent is the characteristics of the formation. For formations with high permeability, a plugging agent with high plugging capacity is required. Secondly, the cementing and plugging agent should have high viscosity and adhesion, which can enhance the stability of the well wall and prevent collapse and borehole closure. Therefore, bore-

Table 1. Compatibility and plugging property of 1# composite leak proof material with oil-based drilling fluid

Adding amount/%	AV/(mPa·s)	PV/(mPa·s)	YP/Pa	Gel/(Pa/Pa)	FL/(mL)	0.7 MPa leakage (20-40 mesh sand bed)
0	56.5	43	12.5	6/8	2.4	0.3 MPa full bleed
1	59.5	45	13.5	7/8	2.4	0.3 MPa full bleed
2	56	42	14	6/7.5	3.2	0.3 MPa full bleed
3	61	46	15	6/6	4	0.3 MPa full bleed

Table 2. Compatibility and plugging property of 2# composite leak proof material with oil-based drilling fluid

Adding amount/%	AV/(mPa·s)	PV/(mPa·s)	YP/Pa	Gel/(Pa/Pa)	FL/(mL)	0.7 MPa leakage (20-40 mesh sand bed)
0	51	40	11	5.5/5.5	3.6	0.3 MPa full bleed
1	44.5	38	5.5	5.5/6	3.6	0.5 MPa full bleed
3	53	39	14	5.5/6	5.2	15 cm soak 14 cm
5	56	43	13	6/6.5	5.6	15 cm soak 7 cm
7	65	47	18	6/7	6.0	15 cm soak 4 cm

Table 3. Compatibility and plugging property of 3# composite leak proof material with oil-based drilling fluid

Adding amount/%	AV/(mPa·s)	PV/(mPa·s)	YP/Pa	Gel/(Pa/Pa)	FL/(mL)	0.7 MPa leakage (20-40 mesh sand bed)
0	56.5	43	12.5	6/8	2.4	0.3 MPa full bleed
1	57.5	45	12.5	6/6	3.2	15 cm soak 6 cm
3	58	42	16	6/6.5	3.6	15 cm soak 6 cm
5	66	50	16	6.5/7	5.2	15 cm soak 5 cm
7	70	52	18	7.5/8	5.2	15 cm soak 4 cm
9	68	53	15	6.5/7	6.5	15 cm soak 4 cm

Table 4. Compatibility and plugging property of 4# composite leak proof material with oil-based drilling fluid

Adding amount/%	AV/(mPa·s)	PV/(mPa·s)	YP/Pa	Gel/(Pa/Pa)	FL/(mL)	0.7 MPa leakage (20-40 mesh sand bed)
0	51	40	9	4.5/5	4.8	15 cm soak 8 cm
1	51	41	10	4.5/5	3.6	15 cm soak 10 cm
3	50	38	12	4.5/6	2.4	15 cm soak 7.5 cm
5	52	41	11	5/5.5	6.4	15 cm soak 3 cm
7	52.5	41	11.5	5/5.5	7.2	15 cm soak 3.5 cm

hole stability is a key factor to consider when selecting and formulating a cementing and plugging agent. Additionally, it is important to ensure that the cementing and plugging agent meets environmental standards to minimize the risk of environmental pollution.

4.1. Mechanism of HY-1

HY-1 is a thermoplastic resin with thermosetting properties that can exist in both liquid and solid forms. It can solidify under the action of a reinforcing agent and can be bonded with the mineral components in the quick plugging agent. As the reaction is an intermolecular condensation reaction, it does not need to be dissolved, making it resistant to the effects of diesel carrier liquid.

Simultaneously, this reaction can also take place on the surface of the plugging agent and the formation rock, allowing it to address the cementation of the plugging agent and formation, as well as the cementation of the fractured leakage layer in an oil phase environment.

4.2. Investigation of the curable reactivity of different plugging materials

The commonly used plugging materials and ZYSD in the field of oil-based drilling fluid were selected, and the reaction-consolidation ability of the oil-based drilling fluid was investigated under the conditions of a certain amount of reaction-consolidation polymer HY-1 and enhancer ZQJ. The results are shown in Table 5.

Based on the results shown in Table 5, it can be concluded that ZYSD, limestone, and mineral powder II exhibit good reactive consolidation ability, while shell and plant fiber do not produce any consolidation reaction ef-

Table 5. Investigation of reactive consolidation ability of different plugging materials

Plugging agent formula	HY-1/(g)	fracture strength/(MPa)
400g 5#diesel oil + 200g ZYSD + 35g HY-1 + 1g reinforcing agentZQJ	0	Unconsolidated
	35	**10.67**
400g 5#diesel oil + 200g limestone (1∼2mm) + 35g HY-1 + 1g reinforcing agentZQJ	0	Unconsolidated
	35	**1.25**
400g 5#diesel oil + 200g Mineral powder I (100 μm) + 35g HY-1 + 1g reinforcing agentZQJ	0	Unconsolidated
	35	**6.27**
400g 5#diesel oil + 200g Mineral powder II (10 μm) + 35g HY-1 + 1g reinforcing agentZQJ	0	Unconsolidated
	35	**12.32**
400g 5#diesel oil + 200g shell (1∼2mm) + 35g HY-1 + 1g reinforcing agentZQJ	35	Unconsolidated
400g 5#diesel oil + 200g plant fiber (1∼2mm) + 35g HY-1 + 1g reinforcing agentZQJ	35	Unconsolidated

fect. Therefore, ZYSD and mineral powder II are selected as the primary plugging materials for oil-based drilling fluid. Among them, ZYSD is a well-established formula-type material, while mineral powder II is not a standalone bridging material. Therefore, ZYSD is chosen as the main material for plugging, and mineral powder II is utilized as a selective auxiliary material.

4.3. Investigation of HY-1 adding amount

The laboratory evaluated the effect of different amounts of reactive consolidation polymer HY-1 on the curing strength of the plugging agent.

Evaluation method: A fixed formula was used, and different amounts of HY-1 were added to the mixture. The mixture was then sealed and aged at 80 °C after filtration. The anti-breaking strength of the resulting filter cake was tested. The results are shown in Table 6.

It is evident from Table 6 that the consolidation strength of the plugging agent gradually increases as the amount of HY-1 increases. However, when the dosage reaches 30 g, the increase in consolidation strength is not significant. Considering the strength requirements and cost of plugging in the field, the dosage of HY-1 is determined to be 25-30 g, which is equivalent to a concentration of 6.25-7.5%.

4.4. Investigation of the amount of reinforcing agent ZQJ

Further investigation was conducted to determine the effect of the same reinforcing agent ZQJ on the curing time. The results are presented in Table 7.

Based on Table 7, it is evident that the curing time gradually decreases with the increase in the dosage of the enhancer ZQJ under the same conditions. Therefore, the dosage of the enhancer can be controlled at 0.4 ∼ 0.6% during field construction to achieve high strength and rapid plugging, while ensuring safe construction in accordance with the downhole temperature and field conditions.

Two wells, Jiaoye J1 and Jiaoye J2, were drilled in the Jiaoshiba area using oil-based drilling fluid with a density of 1.34 - 1.45 g/cm^3. The construction of both wells was safe and stable, without any leakage. This success demonstrates the advantages of oil-based drilling fluid, including its stable performance, inhibition and anti-collapse properties, and ability to maintain a stable wellbore. An overview of the test wells is presented in Table 8 and Table 9.

5. Applications in the field

According to the information you provided, from 2018 to now, two wells, Jiaoye 53-6HF and Jiaoye 45-5HF, have been applied in the Jiaoshiba area, using long horizontal oil-based drilling fluids with a density of 1.34-1.45 g/cm^3. The construction of these wells is safe and stable, and no leakage has occurred. This reflects the advantages of oil-based drilling fluids in terms of performance stability, inhibition and collapse resistance, and wellbore stability. Specific well tests are provided in Table 8 and Table 9.

The field test shows that the oil-based drilling fluid system solves the problems of large friction and poor emulsion stability, reduces the downhole complexity, and has no downhole complexity during the construction of long horizontal wells. The drilling cycle is shortened, the comprehensive cost of shale gas formation drilling is reduced, and the needs of field construction are met. The main application effects are as follows:

(1) The drilling fluid has stable performance, strong anti-pollution ability, a long maintenance cycle, and does not need to adjust the performance frequently.

(2) The plugging effect is good and the leakage is small. The developed oil-based LWD leak proof agent OBMCP is combined with rigid materials with different particle size gradations, micron-level plugging agents with elastic deformation function, and oil-based special mineral fiber materials for effective plugging. Effectively block pressure

Table 6. Investigation on dosage of reactive consolidation material HY-1

Test order numer	Testing instrument	HY-1/(g)	Gel time at 100 °C/(h)	Fracture strength/(MPa)
1		0	~	0
2		10		3.9
3	400g 5#diesel oil + 200g ZYSD	20		4.8
4	+ 1g reinforcing agentZQJ + HY-1	25	2~2.5	9.2
5		30		10.0
6		35		11.2

Table 7. Effect of different enhancer ZQJ addition on the bonding strength of filter cake

Test order numer	Testing instrument	Reinforcing agentZQJ/(g)	Gel time at 100 °C/(h)	Fracture strength/(MPa)
1		0	~	
2		0.2	6 ~ 8	
3	400g 5#diesel oil + 200g ZYSD	0.4	5 ~ 6	
4	+ 20g HY-1 + reinforcing agentZQJ	0.6	3 ~ 5	4.5 ~ 5.0
5		0.8	2 ~ 4	
6		1.0	1 ~ 3	

Table 8. Engineering conditions of oil-based drilling fluid test well for long horizontal well

Well number	Well depth(m)/vertical depth(m)	Horizontal section/(m)	Third section cycle/(day)	Mechanical drilling speed/(h/m)
Jiaoye J1	5850/2768	2700	28	11.6
Jiaoye J2	5625/2728	2432	43	6.74

Table 9. Performance of oil-based drilling fluid for test wells

Well number	Density (g/cm^3)	FV (s)	PV (mPa·s)	YP/Pa	Gel/Pa	HTHP (mL)	Oil to water ratio	ES/V
Jiaoye J1	1.43 - 1.45	57-68	29-42	7-10	3-4/5-6	2-3	75:25 - 80:20	910-990
Jiaoye J2	1.39 - 1.42	82-95	36-49	5-12	3-4/5-9	2-3	80:20 - 85:15	780-1196

transmission, avoid the generation of induced cracks, reduce leakage, and stabilize the wellbore. The wellbore of the test well is stable without leakage.

6. Conclusion and suggestion

1) The oil-based drilling fluid with stable performance, strong anti-pollution ability, and high strength plugging can be formed by adding 6.25 - 7.5% reactive consolidation polymer HY-1.

2) The amount of reinforcing agent ZQJ is controlled at 0.4 ~ 0.6%, and the gelation time is controlled to achieve the purpose of high-strength rapid plugging and controllable curing time under the premise of safe construction.

3) The oil-based consolidated plugging agent has a good plugging effect, stable borehole wall, and small leakage, and has a good application prospect.

4) The study is applicable to other shale gas fields or long horizontal well construction in similar geological conditions. Field trials can be conducted to evaluate the performance of cementable plugging agents under specific geological conditions and establish partnerships with other developers to share experiences and data, thereby accelerating the dissemination and application of cementing plugging technology.

5) Nanomaterials can enhance the sealing effectiveness and stability of oil-based plugging agents, while bio-based materials can offer environmentally friendly and biodegradable alternatives. With technological advancements and ongoing innovation, these novel oil-based plugging materials are expected to deliver improved plugging results and process enhancements for long horizontal well construction.

References

[1] C. Shiping, W. Shenyao, Z. Jiaxin, J. Minjia, and Z. Yaping, (2020) *"Evaluation and Application of a Plugging Agent for BK910 Oil-based Drilling Fluid"* **Drilling & Production Technology** ***43***(6): 97. DOI: 10.3969/J.ISSN.1006-768X.2020.06.28.

[2] L. Kaihe, W. Chenye, L. Shaofei, S. Jinsheng, B. Yingrui, W. Jintang, W. Ren, and W. Jianlong, (2022) *"Dynamic behavior and mitigation methods for drilling fluid loss in fractured formations"* **Journal of China University of Petroleum** ***46***(2):

[3] L. Wenli, S. Jinchu, C. Zhiyuan, L. Jing, and M. Luqiang, (2016) *"Oil base drilling fluid for drilling shale gas wells in Fuling"* ***33***(5): 19–24. DOI: 10.3969/j.issn.1001-5620.2016.05.004.

[4] L. Wenzhe, Y. Xingchuan, L. Yan, L. Houbin, W. Wen, Z. Zhen, and W. Shenyao, (2022) *"Lost Circulation Mechanism and Main Controlling Factors in Deep Brittle Shale Wells"* ***29***(162-169): DOI: 10.3969/j.issn.1006-6535.2022.03.024.

[5] G. Yi, L. Tianyu, W. Kaikai, B. Hanyong, W. Jin, J. Aimin, L. Zhanghua, and L. Mengyao, (2020) *"Fuling Shale Gas Field, Wufeng Formation-Longmaxi Formation Evaluation of shale gas preservation conditions"* ***25***(253-262):

[6] W. Jiahe, L. Yaqiu, L. Jie, L. Bang, W. Yu, and L. Qiang, (2018) *"Low-grade fault recognition technology and its application in Wufeng-Longmaxi formations in Jiaoshiba area, Fuling, Sichuan Basin"* ***40***(1): 51–57. DOI: 10.11781/sysydz201801051.

[7] N. Haikuan, L. Pei, D. Wei, D. Jianghui, S. Chuanxiang, L. Mi, W. Jin, D. Wei, Z. Peixian, L. Donghui, et al., (2022) *"Enrichment characteristics and research directions of deep shale gas: A case study of the Ordovician Wufeng-Silurian Longmaxi shale in the Sichuan Basin and its surrounding areas, China"* **Petroleum Exploration and Development**: 20220814.

[8] L. Wenze, F. Dong, W. Xiang, G. Qinghua, W. Jingheng, et al., (2021) *"Research and Application of Micron Anti-leak and Plugging Technology in Changningweiyuan Longmaxi Formation"* **Drilling & Production Technology** ***44***(6): 111.

[9] Y. Jinbiao, Y. Yashao, C. Xuxuan, G. Keming, J. Gufeng, and L. Qiangui, (2020) *"Shale gas oil-based drilling fluid plugging technology and its application in Changning block"* **Drilling & Production Technology** ***43***(4): 133. DOI: 10.3969/J.ISSN.1006-768X.2020.04.37.

[10] S. Man, Z. Mingkun, and X. Mingbiao, (2017) *"Plugging while drilling technology using oil-based drilling fluid in Fuling Shale Gas Field"* ***45***(3): 21–26.

[11] L. Ke, J. Jianghong, Y. Lei, and L. Haibin, (2022) *"Mechanisms of Lost Circulation and Technologies for Mud Loss Prevention and Control in Shale Oil Drilling"* **Drilling Fluid & Completion Fluid** ***39***(4): DOI: 10.12358/j.issn.1001-5620.2022.04.008.

[12] W. Zaiming, X. Jing, Z. Yixin, S. Yuanyuan, X. Xiaofeng, and L. Xiangyin, (2021) *"Performance Evaluation and Field Application of Self-Consolidating Plugging Agents"* ***49***(6): 62–66. DOI: 10.11911/syztjs.2021044.

[13] X. Jing, W. Zaiming, Z. Yixin, and H. Yi, (2021) *"Application of a Self-Solidifying Lost Circulation Material in Well G21X3 in Jidong Oilfield"* ***38***(1): 89–92. DOI: 10.3969/j.issn.1001-5620.2021.01.015.

[14] W. Xianbing, X. Xinghai, et al., (2021) *"Performance evaluation and application process of environment-friendly plugging agent AT-SPS in shale gas drilling"* **Chemical Engineering of Oil and Gas** ***50***(5): 71–74.

[15] Y. Xin, Z. Zhen, G. Mengyang, L. Lei, F. Jin, and D. Zhengqiang, (2021) *"Development and application of high temperature resistant oil-based drilling fluid plugging agent: taking shale gas well W204H of Longmaxi Formation as an example"* **Fault-Block Oil & Gas Field** ***28***(2): 168–172.