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Research and application of anti-leakage drilling fluid

Y. Hao

China University of Geosciences (Beijing), Beijing 100083, China

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Micro-foam drilling fluid can effectively lower the pressure of liquid columns and seal the reservoir space in a good way. Through the strict control of water loss and enhancement of sealing, it can effectively reduce the damages to reservoir strata. The technical research is carried out towards the geological conditions and reservoir characteristics of K Oil Field. The research starts from the two aspects--cementing fluid design and cementing construction process design. And design the low-density anti-leakage slurry system meeting the requirements on the on-site construction ,which is micro-foam drilling fluid. This system boasts the features of great rheological and thickening performance, high compressive strength, strong anti-leakage and channeling prevention ability. This technology has been applied to three wells for trial in K Oil Field. The process of cementing construction is smooth and with no leakage. The percent of pass for the cementing quality reaches 100%, the high-quality rate reaches 80%, and rate of the cement returning height during the well cementation reaching the standard is 100%, and test results are good. It has reached the anticipated objective of the project.

Keywords:Micro-foam drilling fluid;Anti-Leakage;Optimal selection of the Formula;Foam performance;Field application.

INTRODUCTION

As for the Jurassic oil deposits of the main development layers of K Oil Field, the values of the current formation pressure are only 2.9MPa and 3.2MPa. The pressure maintenance levels are only 48.3% and 53.3% of the original formation pressure (6.0MPa). The pressure in the local areas is only 1.5MPa and the pressure maintenance level is only 25%. At present, the actually measured pressure coefficients of Jurassic reservoir layers have decreased to the range between 0.32 and 0.93. The formation deficit is serious. The oil deposits in cretaceous system and Jurassic system of K Oil Field belong to the oil deposits with bottom water. The formation permeability and connectivity are relatively good. The strata are loose and the loading capacity declines. The formation porosity is relatively large. K Oil Field belongs to typical low-pressure oil reservoir easy to leak. During the process of development, it is quite easy to pollute the reservoirs. During the process of drilling operation, under the influence of differential pressure, the drilling fluid may permeate into the reservoirs; and under the influence of extremely high differential pressure, the malignant leakage may be aroused, thus making a large amount of drilling fluid and solid contents enter the reservoir pores, which will result in severe contamination. The protection of low-pressure reservoirs usually starts from the reduction of differential pressure of the operations in the well bottom and the improvement of the operation fluids and underlying compatibility [1]. It is to reduce the differential pressure of operations in the well bottom, reduce the risks of leakage, and decrease the entry of the external fluid into the formation. When the entry of the external fluid is inevitable during the development of low-pressure reservoirs, it needs to improve the operational fluids and underlying compatibility, to reduce the pollution to the oil reservoirs. The micro-foam drilling fluid has distinctive low-density effects and foam plugging effect [2~4]. It is the drilling fluid system applicable to the development and protection of low-pressure reservoirs. It can save time and equipments so that bring benefits [5].Considering the geological conditions and reservoir characteristics of K Oil Field. , It chooses micro-foam dilling fluid and optimizes the dilling flluid, The test of the micro-foam drilling fluid in K Oil Field has obtained good effects.

THE STABILITY AND THE MECHANISM OF MICRO-FOAM DRILLING FLUID

The stability of Micro-Foam

The factors influencing the stability of the micro-foam drilling fluid are divided into internal cause and external cause, Internal cause is mostly drainage of liquid film and diffusion function of gas through the liquid film;The external cause includes temperature, pressure and the intrusion of outside materials and so on [6 ~7].

In terms of the micro-foam,is not irreplaceable

* To whom all correspondence should be sent:
E-mail: yanghao@cugb.edu.cn

by ordinary foams [8]. due to the differences between it and the ordinary foams in microstructure, the main factor causing the burst of micro-bubbles is the action of gravity [9]. The fluid descends due to its own gravity, which makes the liquid films become thinner and thinner and finally leads to the burst of the bubbles; therefore, the properties of the liquid films are the main factor influencing the stability of the foam. Besides, when the external conditions including temperature and pressure change or the foam is shocked or vibrated by the external forces, it will accelerate the process of rupture.

Action Mechanism of the Micro-Foam Drilling Fluid

Firstly, low-density effect. When the density of the micro-foam drilling fluid is lower than the ordinary water-based drilling fluid, the fluid column pressure at the well bottom can be effectively lowered, the water loss can be reduced, the leakage can be decreased, the pollution can be lessened and the reservoirs can be protected.

Secondly, Jamin Effect [10]. During the permeation of micro-foam into the strata, the micro-foam is captured in the pore throat. The superimposition of Jamin Effect largely increases the resistance of the foam drilling fluid to flow into the strata, and prevent the further permeating or draining of the drilling fluid to the strata.

Thirdly, the mechanism to resist the pressure transmission. The foams in the micro-foam drilling fluid can resist the transmission of the fluid column pressure of the drilling fluid to the strata, thus slowing down the increase of the formation pore pressure.

OPTIMAL SELECTION OF THE FOAMING AGENT AND THE FOAM STABILIZER

Optimal Selection of the Foaming Agent

Compared to the ordinary foam drilling fluid, the micro-foam drilling fluid proposes stricter requirements on the foaming agent. It requires the foaming agent in use to boast relatively high foaming ability, but not generate too many bubbles. The generated bubbles must be tiny and even, and have good stability; meanwhile it shall possess relatively good resistance to salt, calcium and temperature.

Tilt-pour method is the method commonly used to evaluate the foaming performance in production and experiments. This method is relatively convenient and accurate. The equipment adopted is Ross-Miles Foaming Apparatus, which is shown in the following figure 1.

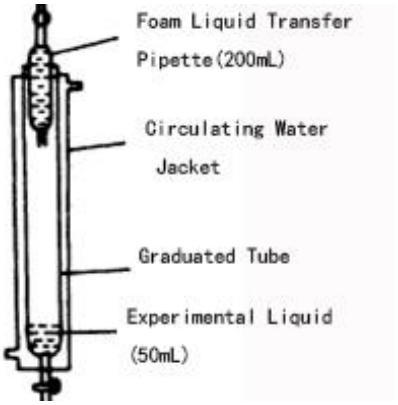

Fig. 1. Ross-Miles foaming apparatus.

The tilt-pour method is applied to evaluate many kinds of foaming agents. The added volume is all 0.4% and the results are shown in Table 1.

Table 1. The Evaluation of the Foaming Agent.

Title	Foaming Height（mm）	Half-Life Period（min）
ASB	178	45
DSB	168	51
F871	358	133
JP-2	308	109
SJ－6	188	131
TSB-2	264	134

From the experimental data it is known that the foaming agents F871, JP-2, SJ-6 and TSB-2 all have great foaming ability, and their half-life period is relatively long. They are all relatively good foaming agents.

Table 2. The Evaluation of the Foam Stabilizer.

Foam Stabilizer	Added Volume (%)	Foaming Height (mm)	Half-Life Period (min)
CMC	0.5	502	196
HEC	0.5	352	183
XC	0.5	410	245
PAC	0.5	321	246
XC+PAC	0.25+0.25	378	286

The Evaluation of the Foam-Stabilizer

Through the theoretical research and the mechanism analysis, the evaluation test has been conducted on the foam stabilizing effects of the treating agent of the drilling fluid. 0.5% TSB-2 is taken as the foaming agent of the test. The results of the test are shown in Table 2.

The experimental data suggest that PAC, XC and CMC are all the great foam stabilizers. The foam fluid made by them is high in foaming volume and great in stability.

THE RESEARCH OF THE MICRO-FOAM DRILLING FLUID FORMULA AND ITS PERFORMANCE EVALUATION

The Research of the Formula

The micro-foam drilling fluid is the multi-phase disperse system with the phases of gas, liquid and solid. Its stability depends on the stable existence of the micro-foam as well as the stability of the drilling fluid system; while the stability of the micro-bubbles mainly depends on the stability of the liquid foams; meanwhile, it renders the liquid films with relatively low liquid drainage rate [11]; therefore when selecting the base mud of the micro-foam drilling liquid, the base mud shall satisfy the following conditions: firstly, appropriate solid contents; secondly, a certain liquid viscosity; thirdly, the stable drilling fluid performance.

Flow Pattern Adjustment.

Formula 1:
4%bentonite+0.2%Na2CO3+0.1%NaOH+0.1% XC+0.5%Na-HPAN +0.3%CMC +0.1%PAC+2%SMP-II+0.25%TSB-2

Formula 2:
4%bentonite+0.2%Na2CO3+0.1%NaOH+0.2% XC+0.5%Na-HPAN +0.3%CMC +0.1%PAC+2%SMP-II+0.25%TSB-2

Formula 3:
4%bentonite+0.2%Na2CO3+0.1%NaOH+0.1% XC+0.5%Na-HPAN +0.3%CMC +0.3%PAC+2%SMP-II+0.25%TSB-2

Formula 4:
4%bentonite+0.2%Na2CO3+0.1%NaOH+0.2% XC+0.5%Na-HPAN +0.3%CMC +0.2%PAC+2%SMP-II+0.25%TSB-2

The results of the test are shown in Table 3.

The optimal selection of the inhibitor

The adding of the inhibitor of inorganic salts, may affect the stability of micro-foam liquid films in the micro-fo am drilling liquid [12], thus lowering the stability of the micro-foam drilling fluid system. The test evaluates the inhibitory effects of the commonly-used polymer inhibitors on the clay expansion.

The study shows that compared to K-PAM and FA367, the inhibitory effects of tackifying inhibitor YFKN on the mudstone dispersion are more significant. Its compatibility with the micro-foam drilling fluid system is good and there are no adverse effects on the stability of the micro-foam.

According to above test results and analysis, the micro-foam drilling fluid system is to choose the one with appropriate base fluid viscosity, good foaming ability, strong anti-pollution capacity, and inhibiting ability to the shale, which is easy to prepare and can totally meet the requirements on the on-site construction. The finally determined formula of micro-foam drilling fluid is listed below:

4%bentonite+0.2%Na_2CO_3+0.1-0.2%NaOH+0.1-0.3%XC+0.5-1%Na-HPAN+ 0.2-0.5%YFKN+0.3-0.5%CMC+0.1-0.3%PAC+2-3%SMP-II+0.2-0.5%TSB-2.

The performance evaluation of the drilling fluid

Temperature Resistance Test

The 1st Formula +0.2%YFKN is selected to conduct the aging tests at different temperatures, and the test results are shown in Table 5.

Table 3. The Performance test of the drilling fluid.

Formula	Density (g/cm^3)	Plastic Viscosity (mPa•s)	Yield Point (Pa)	Yield Point and Plastic Viscosity Ratio	FLAPI (mL)
1	0.71	20	11	0.55	4.5
2	0.71	19	10.5	0.55	4.5
3	0.74	24	18.5	0.77	3.5
4	0.73	21	14.5	0.69	4.1

Table 4. Drilling fluid performance table.

Density (g/cm^3)	Viscosity (s)	FLAPI (mL)	Mud Cake (mm)	pH Value	Sand Content (%)	FLHTHP (mL)	Static Shear Force (Pa)		Plastic Viscosity (mpa•s)	Yield Point (Pa)
							Initial Shear	Final Shear		
0.8-1.0	45-80	< 5	< 0.5	8-9	< 0.3	< 15	1-3	2-6	10-25	8-15

Table 5. Temperature Resistance Test

Temperature	Density (g/cm^3)	Plastic Viscosity (mPa.s)	Performance Dynamic Shear Force (Pa)	Yield Point and Plastic Viscosity Ratio	Filter Loss (mL)
20˚C	0.725	21	15	0.71	4.1
80˚C /8h	0.775	24	17	0.71	3.9
100˚C /8h	0.779	22	15	0.70	4.1
120˚C /8h	0.808	24	16	0.68	4.5
130˚C /8h	0.824	21	14	0.67	5.5

Table 6. Physical properties of the cores of the oil reservoir for the dynamic experiment.

No.	Length（cm）	Diameter （cm）	Porosity（%）	Permeability （$10^{-3}\mu m^2$）	Phase Reversal Permeability （$10^{-3}\mu m^2$）	Recovery Value （%）
1	5.75	2.18	13.6	11.66	10.7	91.8
2	5.49	2.17	14.7	17.65	16.0	90.1

The test results show that the rise of the temperature plays a certain role on the stability of the micro-foam, but the influence is not huge. With the rise of the temperature, the base liquid tends to be sparse, the half-life period becomes shorter and the filter loss volume is slightly increased. However, during the on-site construction, according to the actual situations, with the changes of the well temperature, it shall appropriately adjust the viscosity of the base liquid, increase the volume of the film stabilizer, and choose the appropriate micro-foam liquid formula.

Anti-Pollution Capacity

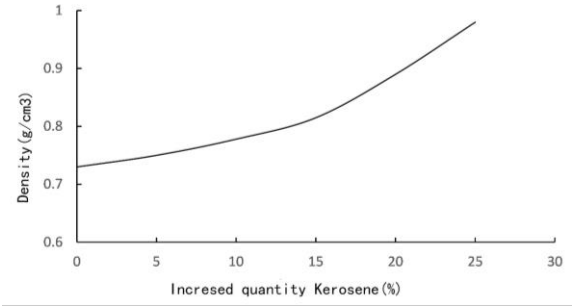

Fig. 2. The density fluctuation curve chart with the increase of the quantity of kerosene.

The influence of kerosene on micro-foam drilling fluid is expressed as: with the increase of of the quantity of kerosene, the foaming ability of the foaming agent presents the declining trend but its density is on the rise. When the oil reservoir is discovered during the on-site drilling, it shall increase the quantity of the foaming agent, so as to increase the stability of the micro-foam drilling fluid.

Density Characteristics

Low density is one of the outstanding characteristics of the foam drilling fluid[13], as for which, there are a large quantity of gas. Under the influence of the factors like temperature and pressure, the variation range of density is large. The method generally used to express the fluid density in the two phases of solid and liquid as well as the gas density cannot describe the density fluctuation rules of the micro-foam drilling liquid; therefore the relation among the density, pressure and temperature of micro-foam drilling fluid shall be rendered by the experimental method.

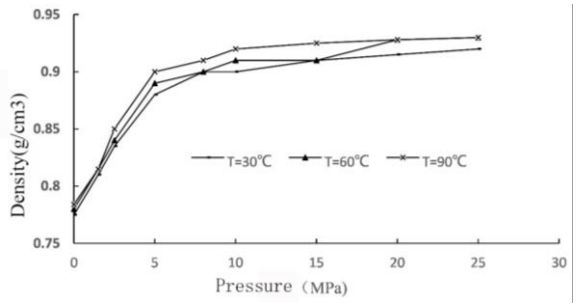

Fig. 3. Temperature-pressure-density curve of the micro-foam drilling fluid.

From the above figure, it can be seen that the influence of pressure on the density of the micro-foam drilling fluid is relatively huge, but the influence of temperature on it is relatively small; among which, before 5MPa, the change rate of the density curve is relatively high, while after 5MPa, the change rate of the density is relatively low. Density slightly increases with the rise of the temperature, but the increasing rate is relatively small.

Protective Effects on Reservoir

The micro-foam drilling fluid is applied to conduct the pollution evaluation experiment towards the sandstone cores in the reservoirs of two blocks. The results are shown in Table 6.

From the test data, it can be seen that the recovery value of the micro-foam drilling fluid permeability rate is above 90%, and it has relatively good protective effects on the oil reservoir.

FIELD APPLICATION

According to the stratigraphic characteristics of K Oil Field, the characteristics of micro-foam drilling fluid and the domestic application conditions, the corresponding technical measures are formulated, to guarantee the smooth implementation of the construction.

Site operation.

K1 Well is a vertical well with one opening and three spuddings. The design well depth is 1350m. According to the design, surface drilling can reach the depth of 30m. The micro-foam drilling fluid can be tested in the well section below 374m of the 2nd spudding. Attention shall be paid to the lower reservoir leakage and actions shall be taken to prevent the lower reservoir leakage. The construction difficulty of this well lies in that there are the lower Jurassic reservoir belongs to abnormal low-pressure reservoir. The difference of pressure coefficients is large and the leakage risk is huge. The density of the drilling fluid decreases from 1.20g/cm^3 to 1.10g/cm^3. The blistering is smooth, and the micro-foam in the drilling fluid is tiny and uniform with good foam stabilizing effects. During the operations of drilling, pipe trip, wireline logging, well clearing, casing and well cementing, the downhole conditions are all normal and have realized the anticipated leakage-proof effects of micro-foam.

K2 well is a vertical well with one opening and three spuddings. The design well depth is 1350m. According to the design, the 2nd spudding drilling can reach the depth of 375m. The micro-foam drilling fluid can be tested in the well section below 400m of the 3rd spudding. Actions shall be taken to prevent the lower reservoir leakage., it is required to implement the 3rd spudding at the drilling well fluid density of 1.17g/cm^3, and then adopt the micro-foam technique to prevent the leakage. During the construction, the minimum density of the drilling fluid can reach 1.12g/cm^3, which can successfully prevent the well leakage.

K3H well is a horizontal well with one opening and three spuddings. The design well depth is 1655m. The 2nd spudding drilling can reach the depth of 375m. The micro-foam drilling fluid can be tested in the 3rd spudding. Actions shall be taken to prevent the lower reservoir leakage. In the position at the well depth of 1354.81m, the vertical depth is 1252.54m. Compared to the adjacent wells, the gas cap of the gas reservoir may exist in the vertical depth of 1252.54m. It shall not directly adopt the low-density drilling fluid in the 3rd spudding. The oil gas indication shows when drilling to the well depth of 1351.48m; however when the pump is stopped, there is no overflow by the observation, and it begins to test the micro-foam drilling fluid. The density of the 3rd drilling fluid of well decreases from 1.19g/cm^3 to 1.12g/cm^3. When the drilling is completed, the density of the drilling fluid is 1.12g/cm^3, the signals of the directional instrument are normal, and the well leakage is successfully prevented.

Application Effects

The performance of the micro-foam drilling fluid is stable, and the decreased density range is approximately 0.08g/cm^3. The performance of the drilling fluid is stable. The correlation data of the low-density microsphere drilling fluid and the polymer drilling fluid are listed in Table 7.

The density of the micro-foam drilling fluid is lower than the conventional water-base drilling fluid, and equal to the low-density microsphere drilling fluid. The filter loss of the drilling fluid is low, and can reduce the damages to the strata. The viscosity shear force is high and the rock-carrying ability is strong, which can effectively get rid of the rock debris at the well bottom. The solid content is low, which makes it easy to control the rheological property. There is no need to use the air compressor and other gas injection equipment or nitrogen generator, and it can be used in a recycled manner.

The test of the micro-foam drilling fluid in K Oil Field has obtained good effects and is successful in the leakage prevention of the low-pressure strata. The statistics of the relevant data are listed in Table 8.

In the well section with high pressure and low pressure in the same formation, that the micro-foam enters the formation and blocks the pores can effectively prevent the leakage of the low-pressure formation. The minimum drilling density is decreased to 0.10 g/cm^3, which prevents the well leakage.

Through the survey of the perforation and oil extraction in the test wells of K1 well and K2 well, the correlation data are listed in Table 9.

Table 7. The comparison between the performances of different drilling fluids.

Drilling Fluid System	Density (g/cm³)	Viscosity (s)	API Filter Loss (mL)	Plastic Viscosity (mPa.s)	Yield Point (Pa)	Solid Content （%）
Micro-foam	0.80-1.0	45~55	4~5	15~25	8~12	1~5
Low-Density Microsphere	0.86~1.0	40~50	5~8	10~20	5~10	10~20
Polymer	1.02~1.09	40~45	5~8	10~15	5~8	1~5

Table 8. The statistical table of the test conditions of the micro-foam drilling fluid.

No.	Well No	Well Section of Application （m）	Formation Pressure Coefficient	Density of the Drilling Fluid (g/cm³)	Leakage (m³)
1	K1	374~1355	0.83~0.95	1.10~1.20	0
2	K2	375~1350	0.85~0.92	1.12~1.17	0
3	K3H	375~1657	0.87~0.97	1.12~1.19	0

Table 9. The comparison between the test well and the well in oil production data.

No.	Well No	Test Well/Contrast Well	Daily Oil Production Volume (m^3/d)	Number of Perforation	Production Volume Per Hole (m^3/d)	Improvement Rate（%）
1	K1	Test Well	23.5	176	0.132	29.4
	K4	Contrast Well	17.8	177	0.102	
2	K2	Test Well	27.5	244	0.116	81.3
	K5	Contrast Well	16.2	265	0.064	

Compared to the adjacent wells, the daily oil production volume of K1 well is larger than that of the K4 by 5.7m^3, and the daily oil production volume of K2 well is larger than that of the K5 well by 11.3m^3. The average oil production volume per hole improves by 29.4% and 81.3% respectively, which suggests that the protective effect of the micro-foam drilling fluid system on the low-pressure reservoirs is significant, which is conducive to improving the recovery efficiency of single well.

CONCLUSIONS AND SUGGESTIONS

1. Firstly, the micro-foam drilling fluid has the property of low density, and its performance is stable during drilling, which solves the well leakage problem encountered in the low-pressure reservoir drilling previously and avoids the damages to reservoir caused by leakage;

2. Secondly, the micro-foam drilling fluid can effectively protect the low-pressure reservoir, facilitate the fluid's flow-back and improve the recovery efficiency;

3. Thirdly, the micro-foam drilling fluid has relatively strong carrying capacity. It is normal to see the rock debris flowing out of the wellhead during drilling, which satisfies the requirements on geological mudlogging and drilling engineering;

4.Fourthly, a new drilling fluid system has been provided to the drilling construction on the low-pressure oil reservoirs. The on-site application suggests that the leakage-proof effects of the micro-foam drilling fluid are good, and the protective effect on the reservoir is significant. It is worthy of popularization and application.

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