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Novel plugging agent for oil-based drilling fluids to overcome the borehole instability problem in shale formations

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Novel plugging agent for oil-based drilling fluids to overcome the borehole instability problem in shale formations

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Abstract. Based on borehole instability problems, a new kind of composite plugging agent for oil-based drilling fluids was developed, and the influence of plugging agent on shale stability was evaluated. The results indicated that the oil-based drilling fluids containing composite plugging agent could produce an ultra-thin, tight and relatively impenetrable mud cake, and consequently provided an excellent sealing effect. The core displacement experiment indicated that this plugging agent could reduce the shale permeability by a significant amount, and thus stop fluid invasion and improve wellbore stability. Using this plugging agent to seal the shale is a very powerful and economical approach to address borehole instability problem in troublesome shale formations. This plugging agent is suitable for the drilling of long sections of horizontal laterals. In the future, this plugging agent might hold great promise to resolve shale instability problem.

1. Introduction

Due to the significant contribution from shale gas plays, estimated gas reserves in South China have risen greatly in the last few years. In order to maintain wellbore stability of the horizontal section, oil-based mud (OBM) are often the first choice of drilling fluids in the drilling operation of unconventional shale plays [1-5]. OBM has strong inhibitive ability, which can prevent shale formations from hydration and swelling, and thus is often used in the development of shale gas reservoirs in China [6-9].

Maintaining borehole instability is the most critical aspect of drilling operations of horizontal well intervals [10-13]. However, most of OBM could not prevent filtrate invasion into micropores and microfractures on shale surface, and subsequent cause borehole instability problems. The main reason is that conventional drilling fluid particles are too large to seal the micropores or microfractures in shales, and thus could not stop fluid invasion [14, 15].

A new type of composite plugging agent (CPA) is developed, and added to OBM, and their influence on shale stability is evaluated. The results indicate that CPA-based drilling fluids can produce an effective internal mud cake possessing low permeability on shale surface, and can reduce filtrate invasion into formations and hence minimize fluid-induced damage. In addition, CPA could also possess the small sized pores to block throats and interact with the clay particles, and consequently provide an excellent sealing effect and improve wellbore stability.

CPA can reduce fluid losses to the formation significantly, and consequently provide an excellent sealing effect, so CPA are an effective plugging agent for strengthening wellbore stability. Using these oil-based drilling fluids containing CPA to seal shale formations is a very powerful and economical



approach to address borehole instability problems in troublesome shale formations. So these CPA-based drilling fluids are suitable for the drilling of long sections of horizontal laterals. In the future, these CPA-based drilling fluids might hold great promise to resolve shale instability problems.

2. Preparation of plugging agent

Conventional drilling fluid particles are too large to seal the micropores and microfractures in shales, and thus could not stop fluid invasion. The actual size of micropores and microfractures is not yet clear, so four kinds of sealing materials with different size distribution are selected. The first is colloid particles, and it can seal the micropores and capillary fracture. The second is rigid skeleton material, and it can play an important role in bridging and blocking for microfractures. The third is deformable material, and it can enter the channel of micro-fractures. The last is natural polymers with suitable softening point, and it could soften and deform at high temperature.

2.1. Colloid particles

A kind of humic acid acetamide compound is synthesized [16-18]. This humic acid acetamide compound has good dispersity in the oil-based drilling fluids. The particle size of humic acid acetamide is tested by the laser particle analyzer. The particle size distribution of humic acid acetamide is showed in Figure 1.

The medium diameter of humic acid acetamide is $0.1056\ \mu\text{m}$, D_{10} is $0.0667\ \mu\text{m}$, and D_{90} is $5.538\ \mu\text{m}$. Therefore, the particle size of most humic acid acetamide particles is less than $0.1\ \mu\text{m}$. Almost all humic acid acetamide particles are less than $10\ \mu\text{m}$, so these polymer materials can fall within this range of colloid particles. When the opening of micropores and capillary fractures is less than $10\ \mu\text{m}$, humic acid acetamide particles can easily enter and seal the micropores and capillary fractures on the borehole wall.

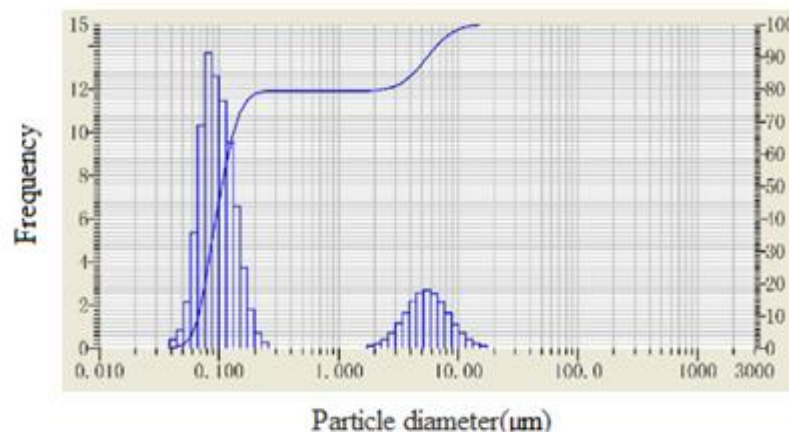


Figure 1. The particle size distribution of humic acid acetamide

2.2. Rigid skeleton particles

The rigid granular material should have enough compressive strength, shear strength and hardness. The skeleton particles should have good bridging effect for the microfractures. Based on high strength, crush resistance, tensile strength and no-deformation, a new kind of superfine rigid material is developed, and the particle size distribution of rigid granular material is showed in Figure 2. The medium diameter of rigid material is $6.6585\ \mu\text{m}$, D_{10} is $4.0038\ \mu\text{m}$, and D_{90} is $10.9093\ \mu\text{m}$. The diameter of rigid material is in the range of $5\ \mu\text{m}$ to $66\ \mu\text{m}$, so it can accord with 1/2~2/3 bridging theory. The rigid granular material could enter the microfractures, and play an important role in bridging and blocking. In addition, this superfine rigid material has no effect on rheological properties of drilling fluids, and they are environmentally friendly, too.

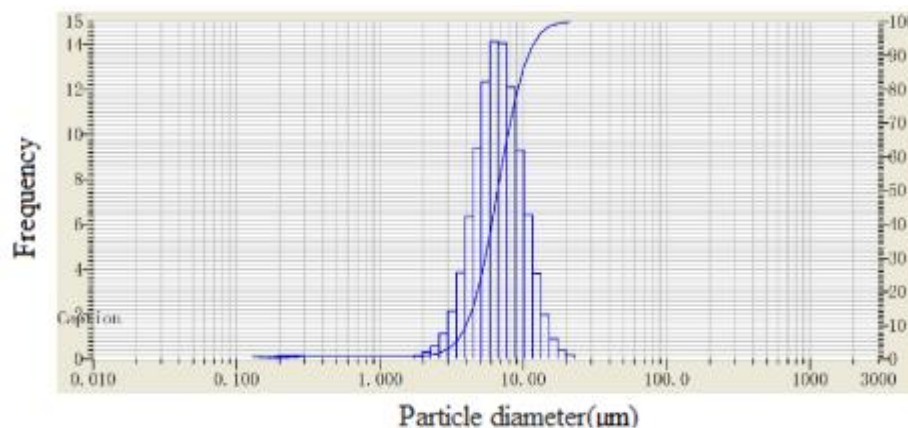


Figure 2. The particle size distribution of superfine rigid materials.

2.3. Deformable materials

The deformable materials should have enough elasticity and toughness. In addition, the deformable materials should have good dispersity in the oil-based drilling fluids, and high pressure deformation, so they could be squeezed into the channels of microfractures at high pressure. They could be expanded upon imbibing oil, so they can be tightly integrated with sides of fracture.

A kind of oil absorption material is added to diesel oil, and the oil-absorbing ability is evaluated. The experimental results indicate that the expansion ratio of oil absorption material is 58%. Therefore, this oil absorption material has good oil-absorbing expansion ability, so it can enter the microfractures in shales and seal the microfractures by oil-absorbing expansion. The particle size distribution of deformable materials is showed in Figure 3. The medium diameter of rigid material is 26.0641 μm , D_{10} is 14.3532 μm , and D_{90} is 47.6026 μm . This oil absorption material is a new kind of deformable particles to meet the requirement of OBM.

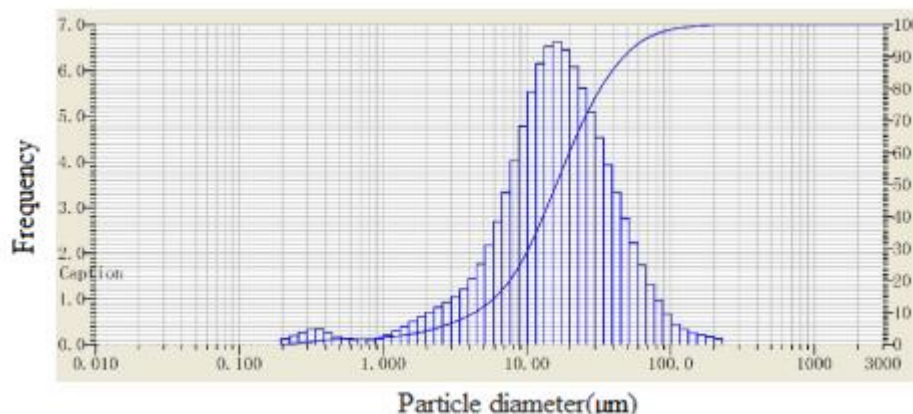


Figure 3. The particle size distribution of deformable materials.

2.4. Natural macromolecule polymer

To reduce the permeability of plugged zone, improve the adsorption capacity of plugging material with microfracture wall, and strengthen the plugging effect, a new kind of natural macromolecule polymer is developed. This natural polymer has a certain softening point, and it could be softened and deformed at high temperature, so it could be absorbed on the surface of microfractures. The isolating membrane could be formed on the borehole wall, so the residual tiny pores could be sealed. The particle size distribution of natural polymers is showed in Figure 4. The medium diameter of natural polymers is 49.2830 μm , D_{10} is 6.1478 μm , and D_{90} is 167.5421 μm .

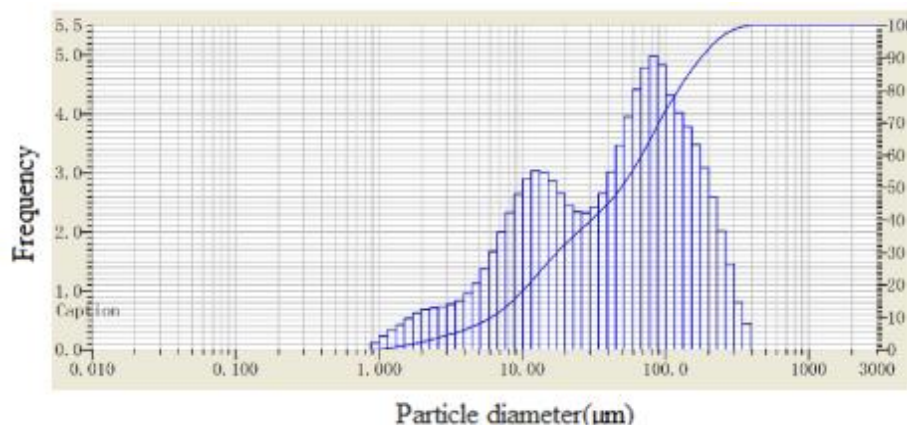


Figure 4. The particle size distribution of natural polymers.

2.5. Composite plugging agent for OBM

Based on the characteristics of shale micropores and microfractures, a new kind of composite plugging agent for oil-based drilling fluids is composed by different proportions of humic acid acetamide polymer, rigid skeleton material, deformable material and natural polymers, and it has the multiple characteristics of blocking pores, bridging plugging, deformable plugging and low penetration. These composite plugging agents are added to OBM, and the plugging ability of drilling fluids containing CPA is evaluated. A series of oil-based drilling fluid formulas with good plugging properties are developed, and they are used to seal different classes of micro-pored and micro-fractured low permeability shale reservoirs.

3. Results and discussion

3.1. The effect of CPA on the rheological properties of oil-based drilling fluids before and after rolling at 120 °C

Table 1. Influence of dosage of PRM on the properties of oil-based drilling fluids before and after rolling 16 h at 120 °C.

Formula	Aging condition	AV/mPa s	PV/mPa s	YP/Pa	GEL/Pa/Pa	FL _{API} /mL	FL _{HTHP} /mL	ES/V
Basic mud	before roll	27	23.5	3.5	3.5/4	2.3	-	1210
	after roll	29	23	6	3.5/4	0.7	12.8	800
Basic mud+1%CPA	before roll	30	26	4	3/3.5	-	-	516
	after roll	28.5	23	5.5	3.5/4	-	2	936
Basic mud+2%CPA	before roll	32	25	7	4/4.5	0.4	-	760
	after roll	29.5	25	4.5	3/3.5	-	1.6	490

^a Formula for preparing basic mud: 240 mL diesel oil + 60 mL calcium chloride aqueous solution with concentration of 20% + 2% organic clay + 2% primary emulsifier + 2% auxiliary emulsifier + 1% wetting agent + 1% calcium oxide + barite (The density of mud is 1.20 g/cm³).

^b The rolling condition is 120 °C × 16 h, HTHP filtration condition is 120 °C × 3.5 MPa.

^c AV—Apparent viscosity.

^d PV—Plastic viscosity.

^e YP—Yield point.

^f GEL—Initial gel strength/Final gel strength.

^g FL_{API}—API fluid-loss value.

^h FL_{HTHP}—HTHP fluid-loss value.

ⁱ ES—Emulsion-breaking voltage.

Table 1 illustrates the influence of CPA on the rheological properties of oil-based drilling fluid formula before and after rolling 16 h at 120 °C. The results indicate that the rheological properties of OBM change little before and after rolling 16 h even when the dosage is 2%. Meantime, CPA has less influence on the emulsion-breaking voltage of drilling fluids. CPA has good capacity of improving the viscosity of OBM, too. Both API filtration and HTHP filtration of drilling fluids have been reduced significantly when CPA is added to drilling fluids, so CPA has good capacity of depressing fluid loss.

3.2. HTHP core sealing plugging experiment

The plugging performance of drilling fluids containing CPA is evaluated by HTHP core plugging experiments. Two types of core with different permeability, including 15 mD and 50 mD, are used to test the plugging ability of drilling fluids containing CPA. Table 2 indicates the change of filtration of drilling fluids containing CPA over time. Figure 5 and Figure 6 is the displacement pressure curve of drilling fluids containing CPA.

As showed in Figure 5 and Figure 6, when the cores with different permeability are contaminated by oil-based drilling fluids containing CPA, the positive displacement breakthrough pressure of two different cores are more than 18 MPa (Instrument detection limit value). Therefore, CPA could improve the pressure bearing capacity of formations with the permeability of 15 mD and 50 mD greatly. The peak value of reverse displacement breakthrough pressure is only 0.8 MPa (15 mD) and 0.1 MPa (50 mD), respectively, so the plugged zone could be easily removed by reverse fluids, and the seepage capability of reservoir could be recovered effectively.

Table 2. The change of filtration of drilling fluid formulas over time.

Core number	Displacement condition	5 min	10 min	15 min	20 min	25 min	30 min
L15-1	Positive displacement	0	0	2	2.7	2.6	2.7
	Positive displacement after pollution	0	0	0.03	0.03	0.03	-
	Reverse displacement	0	0.9	2.6	2.6	2.6	2.6
L50-6	Positive displacement	4.2	5.2	5.2	5.2	5.2	5.2
	Positive displacement after pollution	0	0	0	0	0	0
	Reverse displacement	2.6	2.7	2.6	2.6	2.6	2.6

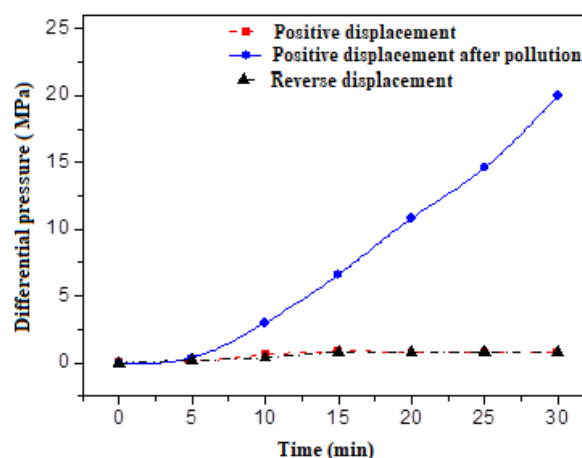


Figure 5. The displacement pressure curve of drilling fluids containing CPA (15 mD core).

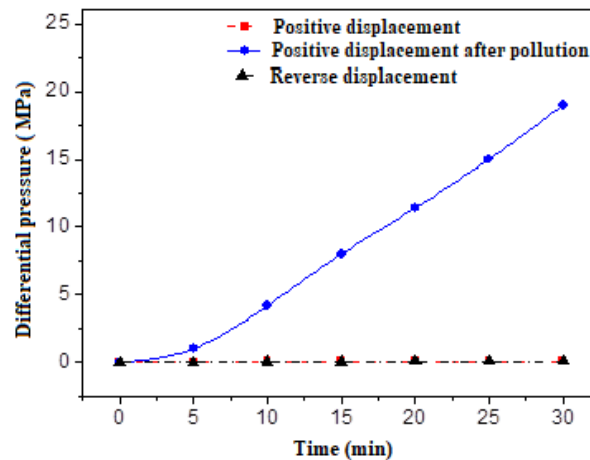


Figure 6. The displacement pressure curve of drilling fluids containing CPA (50 mD core).

Table 3. The plugging ratio and return permeability of oil-based drilling fluids containing CPA.

Core number	L/cm	D/cm	K_a /mD	K_0 /mD	K_1 /mD	K_2 /mD	R_1	R_2
L15-1	8.207	2.524	15	1.5	7.3×10^4	1.42	99.95%	94.6%
L50-6	4.815	2.540	50	13.2	0	13.1	100%	99.8%

From Table 3, the plugging ratio of oil-based drilling fluids containing CPA for two cores are close to 100%, so the drilling fluids containing CPA have better sealing ability in comparison with basic mud. Meanwhile, almost no filtrate could be discharged in the process of positive displacement after pollution, so this OBM formula has excellent sealing effect for 15 mD and 50 mD core. The return permeability is 94.6% (15 mD), 99.8% (50 mD), respectively, so the drilling fluids containing CPA have good reservoir protection effect, too.

4. Conclusions

1) A new type of composite plugging agent is prepared, and it could seal the micropores and microfractures on the shale formations effectively.

2) CPA can reduce the shale permeability, stop fluid invasion, prevent pressure transmission, and thus improve wellbore strength greatly.

3) Oil-based drilling fluids containing CPA have good rheological properties, good mud filtrate control capacity and plugging ability under HTHP conditions, and it can meet the requirement of drilling engineering in shale formations.

CPA could play an essential role in reducing fluid invasion, maintaining borehole stability, and avoiding severe drilling problems. The CPA-based drilling fluid technology can solve borehole instability problem effectively. In the future, these CPA-based drilling fluids might hold great promise to resolve shale instability problems.

Acknowledgments

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