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Study on the effect of polymeric rheology modifier on the rheological properties of oil-based drilling fluids

C Ma[1, 5], L Li[2], Y P Yang[2], W W Hao[2], Q Zhang[3] and J Lv[4]

[1] Jiangxi Science & Technology Normal University, Nanchang 330013, China
[2] CNPC Drilling Research Institute, Beijing 100083, China
[3] Petrochina Tarim Oilfield Company, Kuerle 841000, China
[4] CNPC Guangzhou Training Center, Guangzhou 510000, China

[5] E-mail: macha001@126.com

Abstract. A new type of polymeric rheology modifier was synthesized by suspension polymerization, and the effect of rheology modifier on the rheological properties of oil-based drilling fluids was investigated. The results indicated that the obtained polymer had good capacity of improvement of shearing force of oil-based drilling fluids under high temperature and high pressure conditions. Moreover, the obtained polymer can improve the stability of oil-based drilling fluids greatly. As a result, the obtained polymer is a good rheology modifier for oil-based drilling fluids, and it can optimize oil-based drilling fluid system with good rheological properties, good static suspension ability for cuttings and environmental protection function. It can play an essential role in safe drilling jobs and improvement of drilling efficiency.

1. Introduction

Due to the contribution from shale gas plays, estimated gas reserves in South China have risen greatly in the last few years. These new shale plays have been developed in recent years by the application of advanced horizontal drilling techniques. In order to maintain wellbore stability of the horizontal section, oil-based drilling fluids are often the first choice of drilling fluids in the drilling operation of unconventional shale plays [1-5]. Despite the differences amongst shale plays, oil-based drilling fluids are flexible enough to be used across the majority of the unconventional shale gas reserves. Excellent shale formation stabilization, lubricity, and anti-contamination ability are just a few of the benefits of oil-based drilling fluid system [6-10]. However, compared with water-based drilling fluids, the rheological properties of oil-based drilling fluids are more difficult to control, and there is a lack of suitable additive to adjust the rheological properties of oil-based drilling fluids [11-16].

In order to meet the requirement of drilling operation in the deep formations, a new type of polymeric rheology modifier for oil-based drilling fluids is developed, and the effect of obtained polymer on the rheological properties of oil-based drilling fluids is tested in details. The experimental results indicate that the obtained polymer could improve the shearing force of oil-based drilling fluids greatly. In addition, it has good temperature resistance property.

The rheology modifier has good capacity of improving the shearing force and viscosity of oil-based drilling fluids, which is conducive to improving the capacity of carrying cuttings of drilling fluids and wellbore stability.

2. Experiment

To a 500 mL, four-necked flask equipped with a nitrogen inlet and a magnetic stirrer, methyl methacrylate, methyl styrene, octadecyl acrylate, dimethyl azobis isobutyrate and 300 mL THF are added. The mixture is stirred at 80 ºC for 16 h in nitrogen.

After the solvent is removed at reduced pressure, the product is washed by distilled water for several times to remove residual THF, dried in vacuum at 100 ºC for 24 h, pulverized through a 80~100 mesh sieve, and then the polymeric rheology modifier (PRM) is obtained as a white powder. The chemical structure of PRM polymer is showen in figure 1.

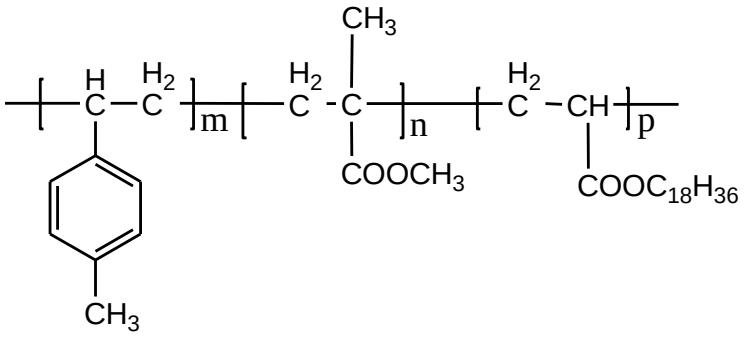

Figure 1. The structural formula of polymeric rheology modifier.

3. Results and discussion

3.1. Mechanism of the effect of PRM on the rheology of oil-based drilling fluids

Based on the similarity-intermiscibility theory, due to its long alkyl chain, PRM has good oil solubility, so PRM molecular chain could spread freely in the oil phase. PRM has two kinds of strong polar groups, including ester group and ether group. So the space grid structure with certain intensity could be formed through the hydrogen bonding interaction by the combination of PRM molecular and water drop in invert oil-emulsion drilling fluids, which could play an important role in improving the shearing force of oil-based drilling fluids.

As the shear value of drilling fluids is depended on the number of structure chain in unit volume fluid and the strength of single structure chain, the space grid structure will increase the strength of structure chain, which can improve the static suspension property of drilling fluids.

3.2. The effect of dosage of PRM on the rheological properties of oil-based drilling fluids before and after rolling at 120ºC

Table 1 illustrates the influence of the dosage of PRM on the rheological properties of oil-based drilling fluid formula before and after rolling 16 h at 120 ºC. The results indicate that PRM has good capacity of improving the shearing force and viscosity of oil-based drilling fluids at 120 ºC, and the capacity of improving shearing force of oil-based drilling fluids is better and better with the increase of dosage of PRM.

In addition, the shear strength of oil-based drilling fluids becomes better and better, too. PRM has very certain capacity of depressing fluid loss of oil-based drilling fluids. The rheological properties of oil-based mud change little before and after rolling 16 h even when the dosage is 3%.

PRM has good effect of thickening and improving shear strength. All things considered, the optimum dosage of PRM at 120 ºC is 1%. In addition, PRM could increase the emulsion-breaking voltage of drilling fluids after rolling 16 h at 120 ºC, which could improve the stability of oil-based drilling fluids.

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

Dosage of PRM/%	Aging condition	AV/mPa s	PV/mPa s	YP/Pa	GEL/Pa/Pa	FL_{API}/mL	FL_{HTHP}/mL	ES/V
0	before roll	23.5	19	4.5	3.5/4	1.2	-	1280
	after roll	22	19	3	2.5/3	-	5.0	603
1%	before roll	27	20	7	4/4.5	0.7	-	1123
	after roll	28.5	23	5.5	3.5/4	-	3.0	936
2%	before roll	32.5	24	8.5	4.5/5	0.5	-	1301
	after roll	39	31	8	4.5/5	-	2.9	960
3%	before roll	48	33	15	7/7.5	0.3	-	1268
	after roll	51.5	39	12.5	5.5/6	-	3.2	1160

[a] Formula for preparing oil-based drilling fluids: 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 + 0-3% PRM + 1% calcium oxide + barite (The density of mud is 1.20 g/cm^3).

[b] The rolling condition is 120 ºC × 16 h, HTHP filtration condition is 120 ºC × 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.

3.3. The effect of dosage of PRM on the rheological properties of oil-based drilling fluids before and after rolling at 150 ºC

Table 2 illustrates the influence of the dosage of PRM on the rheological properties of oil-based mud. From table 2, the experimental results indicate that PRM has good capacity of improving the shearing force and viscosity at 150 ºC. The effect of thickening and improving shearing force and becomes better and better with the increase of dosage of PRM. Moreover, the rheological properties of oil-based mud change little before and after rolling.

All things considered, mainly on account of the cost and the capacity of improving shear strength, the optimum dosage of PRM at 150 ºC is 1%. Moreover, PRM can increase the emulsion-breaking voltage of oil-based drilling fluids after rolling at 150 ºC, so the stability of drilling fluids could be improved greatly.

Table 2. Influence of dosage of PRM on the properties of oil-based drilling fluids before and after rolling 16 h at 150 ºC.

Dosage of PRM /%	Aging condition	AV/mPa s	PV/mPa s	YP/Pa	GEL/Pa/Pa	FL_{API}/mL	FL_{HTHP}/ mL	ES/V
0	before roll	23.5	19	4.5	3.5/4	1.2	-	1280
	after roll	16	16	0	0.25/0.5	-	37	420
1%	before roll	27	20	7	4/4.5	0.7	-	1123
	after roll	28.5	24	4.5	2.5/3	-	18.4	698
2%	before roll	32.5	24	8.5	4.5/5	0.5		1301
	after roll	36.5	30	6.5	3/3.5	-	40	960
3%	before roll	48	33	15	7/7.5	0.3	-	1268
	after roll	47.5	36	11.5	4/4	-	20	1000

[a] Formula for preparing oil-based drilling fluids: 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 + 0-3% PRM + 1% calcium oxide + barite (The density of mud is 1.20 g/cm^3).
[b] The rolling condition is 150 ºC × 16 h, HTHP filtration condition is 150 ºC × 3.5 MPa.

3.4. The effect of dosage of PRM on the rheological properties of oil-based drilling fluids before and after rolling at 180 ºC

Table 3 indicates the influence of the dosage of PRM on the rheological properties of oil-based mud before and after rolling 16 h at 180 ºC. From table 3, the results indicate that PRM has good capacity of improving the shearing force and viscosity at 180 ºC. PRM has very certain capacity of depressing fluid loss of oil-based drilling fluids. The effect of improving the shearing force and viscosity becomes better and better with the increase of dosage of PRM.

Table 3. Influence of dosage of PRM on the properties of oil-based drilling fluids before and after rolling 16 h at 180 ºC

Dosage of PRM /%	Aging condition	AV/mPa s	PV/mPa s	YP/Pa	GEL/Pa/Pa	FL_{API}/mL	FL_{HTHP}/ mL	ES/V
0	before roll	23.5	19	4.5	3.5/4	1.2	-	1280
	after roll	15	15	0	0/0.25	-	84	406
1%	before roll	27	20	7	4/4.5	0.7	-	1123
	after roll	20.5	20	0.5	1/1.5	-	64	698
2%	before roll	32.5	24	8.5	4.5/5	0.5	-	1301
	after roll	33	28	5	2.5/3	-	66	816
3%	before roll	48	33	15	7/7.5	0.3	-	1268
	after roll	38	22	16	3/3	-	72	900

[a] Formula for preparing oil-based drilling fluids: 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 + 0-3% PRM + 1% calcium oxide + barite (The density of mud is 1.20 g/cm^3).
[b] The rolling condition is 180 ºC × 16 h, HTHP filtration condition is 180 ºC × 3.5 MPa.

The rheological properties of oil-based mud have little change before and after rolling at 16h at 180 ºC. All things considered, mainly on account of the cost and the capacity of thickening and improving shear strength, the optimum dosage of PRM at 180 ºC is 2%. In addition, PRM can increase the emulsion-breaking voltage of drilling fluids after rolling at 180 ºC, so the stability of drilling fluids could be improved.

4. Conclusions

1) PRM has good capacity of thickening and improving the shearing force of oil-based drilling fluids at HTHP conditions.

2) PRM has little influence on the properties of oil-based drilling fluids, and it can optimizate the rheological properties of oil-based drilling fluids. PRM can solve the problem that the rheological properties of oil-based mud are difficult to adjust.

3) PRM can improve the stability of oil-based drilling fluids greatly under HTHP conditions.

4) PRM has good temperature resistance properties under 180 ºC. The optimum dosage of PRM for oil-based drilling fluids is less than 1% under 150 ºC.

PRM could play an essential role in improving hole cleaning, maintaining borehole stability, and avoiding severe drilling problems. It is a good rheology modifier for oil-based mud, and it could meet the requirement of drilling operation under extreme condition. PRM is expected to possess a wide prospect of application in drilling operations.

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