Study of a strong inhibitory solid-free drilling fluid

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Abtract. The study on the problem of hydration and dispersion expansion of shale and the poor high temperature resistance and lubrication performance of mud with soil is carried out. The selection of viscosity enhancer, filter loss reducing agent, lubricant and inhibitor in solid-state drilling fluid was carried out through experiments. The formula of solid-free drilling fluid was 0.2% 1831+1% xanthan gum+1% phenolic resin and 1% sodium benzenesulfonate. The linear expansion rate of bentonite is less than 20%, which shows that the formulation has good inhibition performance. The mud ball in the drilling fluid after 48 h of storage did not undergo hydration expansion, which indicated that the formulation had strong inhibition on the hydration expansion of clay. Finally, after heating the formula in a roller heating furnace at 120 °C for 16 h, the plastic viscosity, dynamic shear force and apparent viscosity of the formula were determined as 14.00 mPa·s, 24.00 Pa and 39.50 mPa·s respectively, while FL (filtration loss) was 17 mL. In conclusion, the strong inhibition solid-phase drilling fluid formula is superior in both the inhibition of hydration expansion and the high temperature resistance of clay.

Key words: Drilling fluid; no solid phase; inhibition; reducing filtration loss; high temperature resistance.

1. Introduction

The solid-free drilling fluid is a kind of polymer water solution mainly prepared by water soluble polymer. Compared with the solid drilling fluid system, the system has many advantages, such as lower flow resistance, lower static shear force, good rheology and easy viscosity adjustment. In the drilling process, it has good ability of carrying cuttings, protecting well wall and preventing well collapse. It can protect oil and gas reservoir very well. Solid-phase drilling fluid is highly recognized and applied in oilfield drilling industry because of its advantages of better filtration reduction performance, high lubrication coefficient, low friction between drill bit and wellbore, simple operation and low production cost.[1-4] Generally, the solid-phase drilling fluid is used as viscosity enhancer with biopolymer, cellulose derivative, synthetic polymer and weak gel, and the modified starch, polyanionic cellulose (PAC), sulfonated phenol formaldehyde resin (SMP) are used to improve its filtration loss reduction, adjust the density with weighting agent and salt, and use corrosion inhibitor, anti collapse inhibitor. The mixture of other drilling fluid treatment agents such as bactericides is made.[5-8] In recent years, people have more and more demand for oil and gas production. Many kinds of conditions encountered during drilling process also promote the development of drilling technology, and the requirements on its performance are also more stringent. Well under different conditions and various complex drilling processes require drilling fluid to have good strong inhibition performance. Whether the well wall is stable or not, whether it has high temperature resistance stability, and whether it causes pollution to the oil reservoir is closely related to the strength and strength of the drilling fluid inhibition. The research on high performance strong inhibitory solid-phase drilling fluid and matching with different treatment agents to find the suitable single agent can better maintain the shale wall fixation, prevent borehole expansion, find out the simple formula with green environment protection and low cost, adapt to the current environment, and improve the drilling efficiency of various environments, reduce drilling cost and improve enterprise income and benefit.[9-10]

In this paper, the inhibitor with better inhibition was screened by linear expansion experiment, and the inhibition performance was tested by compounding with xanthan gum, HPAM, CMC Na and HV PAC. Through the high temperature evaluation experiment and salt resistance evaluation experiment, the viscosity enhancer with good anti high temperature and salt resistance is selected. The best concentration of viscosity enhancer and the screened inhibitor were used to optimize the filtrating loss agent. Finally, mud ball experiment and drilling fluid

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performance evaluation are carried out to evaluate the performance of drilling fluid formula.

2. Materials and methods

Materials used for the study are abtained from Changqing Oilfield. The rheological properties, filtration properties and lubrication properties of drilling fluid with inhibitor, tackifier, filtrating agent or lubricant such as AV (apparent viscosity), PV (plastic viscosity), YP (yield point), FL (API filtration) and TG (friction coefficient), were evaluated using a viscometer (ZNN-D6S, Hetongda Co. Ltd, Qingdao), medium-pressure filtration instrument (GJSS-B12K, Haitongda Co. Ltd, Qingdao) and viscosity coefficientin strument (Qingdao Hetongda Co. Ltd, Qingdao) according to the formulas in Chinese National Standard GB/T 16783.1-2006, followed by the thermogravimetry, mud ball experiment and SEM were carried out after the formula of solid-state drilling fluid was determined.[11-23]

3. Results and discussion

3.1 Screening of inhibitors

Linear expansion experiments were carried out in 1831, polydimethylammonium chloride and 1227 at different concentration gradients to investigate the inhibition of inhibitors on the hydration expansion of clay, so as to select the inhibitors in the final formula.The experimental results show that the linear expansion rate of 1831 solution with concentration of 0.2% is the lowest after 120 min, indicating that the clay expansion inhibition performance of 1831 solution with concentration of 0.2% is the best. Therefore, 0.2% 1831 solution is used as the inhibitor of the formula.

3.2 Tackifier screening

The viscosity increasing properties of CMC Na, xanthan gum, HV-PAC and HPAM were evaluated through experiments, and the optimal viscosity increasing agent with good viscosity and low filtration was selected.

3.2.1 Drilling fluid stability

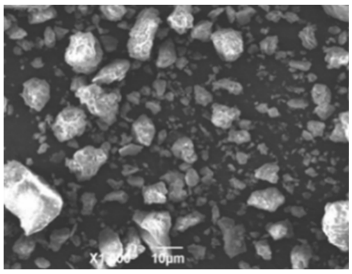
It can be seen from Table 1 that with the increasing dosage of tackifier, the plastic viscosity, dynamic shear force and apparent viscosity of other tackifiers fluctuate and are relatively unstable, except that the plastic viscosity, dynamic shear force and apparent viscosity of xanthan gum increase steadily.

Table. 1 Effect of different tackifier dosage on drilling fluid performance

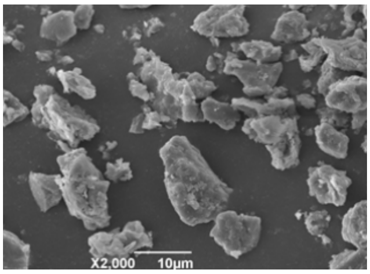
Tackifier	Dosage /%	AV /mPa·s	PV /mPa·s	YP /Pa	YP/PV /Pa/mPa·s	FL(API) /mL	TG
Xanthan gum	0.25	6.75	2.50	4.25	1.700	250.0	0.2962
	0.50	15.50	5.00	10.50	2.100	240.0	0.2126
	1.00	35.00	10.50	24.50	2.330	28.0	0.3443
CMC-Na	0.25	8.50	6.00	2.50	0.416	250.0	0.1853
	0.50	15.00	10.00	7.00	0.700	103 .0	0.1051
	1.00	16.50	12.50	1.25	0.100	66.0	0.2035
HV-PAC	0.25	13.50	8.00	5.50	0.688	171.0	0.3346
	0.50	34.00	18.50	15.50	0.838	44.0	0.2680
	1.00	78.00	33.00	45.00	1.363	26.0	0.2035
HPAM	0.25	19.00	11.50	7.50	0.650	6.0	0.7265
	0.50	37.50	25.00	12.50	0.500	5.6	0.2680
	1.00	85.00	50.00	35.00	0.700	5.0	0.2217

3.2.2 Scanning electron microscope

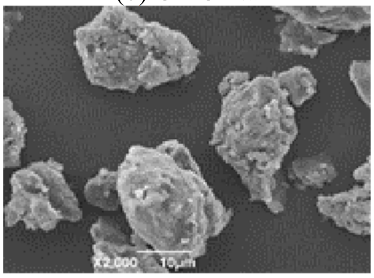
Scanning electron microscopy (SEM) was used to observe the micro morphology of the dried soil samples prepared by adding 1831 inhibitor to the clean water, and then adding CMC Na, xanthan gum, HV-PAC, HPAM, etc. as thickeners, respectively, and the dried soil samples prepared by adding thickener and only tap water, as shown in Fig. 1. It can be seen from Fig. 1 that through the microscopic analysis of soil samples before and after treatment with different thickeners by scanning electron microscope, 1831 inhibitor is added to the drilling fluid base slurry, and then sodium carboxymethyl cellulose, xanthan gum, HV-PAC and HPAM are added as thickeners respectively. The dried soil sample particles are significantly larger than those after hydration and drying of tap water,It can be shown that 1831 inhibitor can play a good inhibitory effect and inhibit the hydration and dispersion of clay.



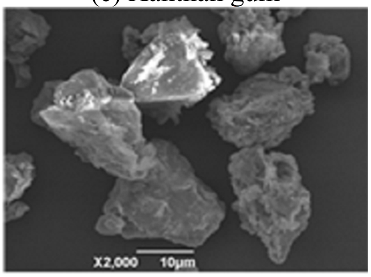
(a) Water



(b) CMC-Na



(c) Xanthan gum



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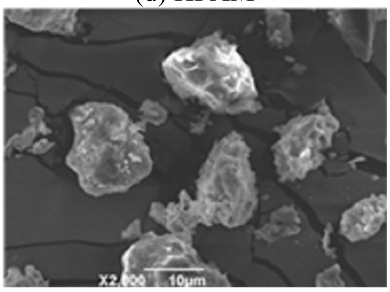
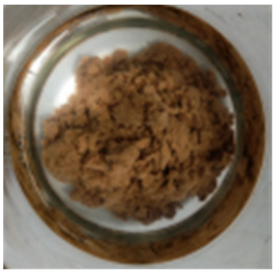
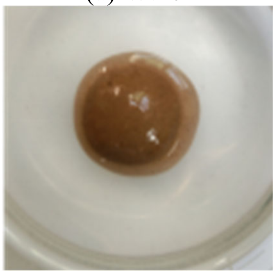

(e) HV-PAC

Fig. 1 Microstructure of clay before and after treatment with different thickeners

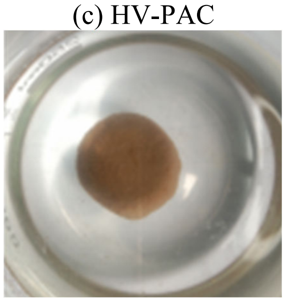
3.2.3 Mud ball experiment

Under the condition of room temperature, mix the sodium soil and clean water evenly in the proportion of 2:1 by mass, and then agglomerate into each mud ball with a mass of about 10 g. Put 1831 inhibitor into the solution prepared by adding xanthan gum, HV-PAC, CMC Na and HPAM as thickeners respectively, and observe the experimental phenomenon after standing for 48 h. The experimental results are shown in Fig. 2. It can be seen from Fig. 2 that the mud ball put into the clean water has completely collapsed, but the mud ball in the solution prepared by putting 1831 and adding xanthan gum, HV-PAC, CMC Na and HPAM as thickeners has no cracks on the surface and no hydration expansion.It shows that adding 1831 into the drilling fluid has a good inhibition on the hydration expansion of clay, which is consistent with the linear expansion rate of bentonite.


(a) Water


(b) XG


(c) HV-PAC


(d) CMC-Na

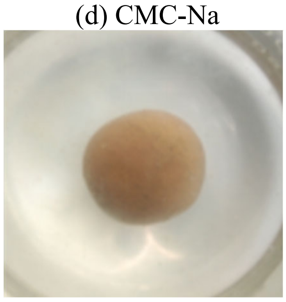

(e) HPAM

Fig. 2 Appearance of mud ball in aqueous solution with different inhibitors (48 h)

3.2.4 Evaluation of high temperature resistance[24]

After each thickener is prepared into a solution, it is put into a frequency conversion roller heating furnace and heated for 16 h at 80 ℃, 90 ℃, 100 ℃, 110 ℃ and 120 ℃ respectively. After the solution is cooled, the performance of drilling fluid is evaluated as shown in Table 2.

Table. 2 Performance evaluation of drilling fluids of various systems at different temperatures

Drugs	Temperature /℃	AV /mPa·s	PV /mPa·s	YP /Pa	YP/PV /Pa/mPa·s	FL(API) /mL	TG
XG	25	35.00	10.50	24.50	2.330	28.0	0.3443
	80	35.00	8.50	26.50	3.118	37.0	0.2035
	90	34.00	9.00	25.00	2.778	51.0	0.2680
	100	34 50	8.50	26.00	3.059	60.0	0.2773
	110	26.50	7.00	19.50	2.786	72.0	0.2586
	120	25.00	11.00	14.00	1.272	72.0	0.1584
CMC-Na	25	13.25	12.00	1.25	0.104	66.0	0.2035
	80	14.00	38.00	10.00	0.263	63.0	0.3443
	90	16.00	36.00	13.00	0.361	60.0	0.3057
	100	22.00	29.00	21.00	0.724	53.0	0.1317
	110	20.00	23.00	7.50	0.326	272.0	0.5317
	120	14.50	19.00	35.50	1.109	235.0	0.2035
HV-PAC	25	78.00	33.00	45.00	1.363	26.0	0.2035
	80	70.25	30.50	39.75	1.303	88.0	0.4663
	90	72.00	33.00	39.00	1.181	102.0	0.2680
	100	73.50	33.00	40.50	1.227	78.0	0.2586
	110	61.25	35.50	25.75	0.725	70.0	03057
	120	85.00	36.00	27.00	0.750	76.0	0.2680
HPAM	25	85.00	50.00	35.00	0.700	5.0	0.2217
	80	60.00	45.00	15.00	0.333	5.6	0.3153
	90	57.50	30.00	27.50	0.916	22.0	0.1317
	100	45.00	6.00	39.00	6.500	28.0	0.3640
	110	1.25	1.00	0.25	0.250	246.0	0.4663
	120	1.00	0.50	0.20	4.000	276.0	0.3057

It can be seen from the data in Table 2 that with the increase of temperature, the plastic viscosity, dynamic shear force, apparent viscosity and dynamic plastic ratio of xanthan gum gradually decrease, but the decrease range is not obvious, while the filtration loss gradually increases, but the increase range is not obvious, indicating that the drilling fluid has good high temperature resistance. For CMC Na, with the gradual increase of temperature, the plastic viscosity of drilling fluid first increases and then decreases, the dynamic shear force first increases and then decreases, and then suddenly increases, the apparent viscosity gradually increases, the dynamic plastic ratio first increases and then decreases and then increases, and the filtration rate gradually increases. The high temperature resistance of this type of drilling fluid is general. For HV-PAC, with the increase of temperature, the plastic viscosity of the drilling fluid does not change significantly, the dynamic shear force first increases and then suddenly decreases, while the apparent viscosity decreases, the filtration rate first increases and then suddenly decreases, and the temperature resistance is general. For HPAM, the plastic viscosity and plastic viscosity of drilling fluid decrease with the increase of temperature, the dynamic shear force and dynamic plastic ratio first increase and then decrease, and the filtration rate increases with the increase of temperature. At 110 ℃, the filtration rate changes suddenly, and the filtration reduction effect fails.

3.2.5 Evaluation of salt resistance

Salt layer and gypsum layer will inevitably be encountered in the process of drilling construction, so salt resistance is also a very important evaluation index of drilling fluid. Add KCl in different proportions such as 5%, 10%, 15%, 20%, 25% and 30% into each solution respectively, and then evaluate the performance of drilling fluid. The data are shown in Table 3.

Table. 3 Performance evaluation of drilling fluids of various systems under different concentrations

Drugs	Concentration /%	AV /mPa·s	PV /mPa·s	YP /Pa	YP/PV /Pa/mPa·s	FL(API) /mL	TG
Xanthan gum	5	43.25	14.00	29.25	2.089	10.0	0.6494
	10	44.25	16.50	27.25	1.651	10.0	0.2680
	15	45.50	16.50	29.00	1.757	8.0	0.3839
	20	45.25	15.50	29.75	1.919	8.0	0.1228
	25	64.50	24.00	40.50	1.687	8.0	0.1944
	30	70.00	34.00	36.00	1.058	10.0	0.1673
CMC	5	61.00	28.50	32.50	1.140	26.0	0.6249
	10	61.75	29.50	32.25	1.093	42.0	0.3640
	15	62.75	30.00	32.75	1.091	38.0	0.1228
	20	47.50	26.00	21.50	0.826	60.0	0.2126
	25	43.50	24.00	19.50	0.813	40.0	0.1763
	30	42.25	22.00	17.50	0.795	46.0	0.3249
HV-PAC	5	76.25	32.50	43.75	1.346	24.0	0.1584
	10	82.50	31.00	51.50	1.661	28.0	0.3153
	15	60.50	27.00	33.50	1.241	40.0	0.3249
	20	61.00	27.50	33.50	1.218	26.0	0.1584
	25	60.00	27.00	33.50	1.240	26.0	0.1944
	30	62.00	26.00	32.50	1.250	28.0	0.1228
HPAM	5	37.50	25.00	12.50	0.500	24.0	0.6371
	10	36.50	22.00	14.50	0.659	26.0	0.4663
	15	34.50	22.00	12.50	0.568	20.0	0.3346
	20	25.25	16.50	8.75	0.530	32.0	0.3939
	25	23.25	18.50	9.75	0.527	34.0	0.1673
	30	22.75	17.50	10.50	0.600	36.0	0.3640

It can be seen from the data in Table 3 that for xanthan gum, with the increase of salt concentration, the plastic viscosity, dynamic shear force, apparent viscosity and dynamic plastic ratio of drilling fluid remain stable, and the filtration rate is relatively stable. After adding 30% KCl, the filtration rate is only 10ml, indicating that this type of drilling fluid has good salt resistance. For CMC Na, the plastic viscosity, dynamic shear force, apparent viscosity and dynamic plastic ratio of drilling fluid decrease with the increase of salt concentration, and the filtration loss increases gradually. The salt resistance of this type of drilling fluid is general. For HV-PAC, the plastic viscosity and apparent viscosity of the drilling fluid first increase and then decrease with the increase of salt concentration, while the dynamic shear force decreases continuously, and the filtration loss first decreases and then suddenly increases. At 15%, the filtration loss suddenly changes to 40 mL, and the filtration reduction effect is invalid. For HPAM, the plastic viscosity and apparent viscosity of drilling fluid decrease with the increase of salt concentration, the dynamic shear force and dynamic plastic ratio first increase and then decrease, and the filtration loss increases slowly with the increase of salt concentration. In conclusion, through the above experiments, it can be found that among the four tackifiers, xanthan gum has the best comprehensive performance of high temperature resistance and salt resistance. Therefore, xanthan gum is used as the tackifier in the final solid-free drilling fluid system in this formula.

3.3 Determination of fluid loss reducer

The 1% xanthan gum solution was compounded with monoxanthate polymer, potato starch, phenolic resin and lignin respectively, and then its viscosity and filtration loss were measured respectively. The filtration reduction performance was compared, and the single agent with the best performance was selected.

Table. 4 Performance evaluation of 1% XG under different concentrations of filtrate reducer

Drugs	Concentration /%	AV/mPa·s	PV/ mPa·s	YP/ Pa	YP/PV /Pa/mPa·s	FL(API) /mL
Monoxanthate polymer	0.1	39.00	13.00	26.00	2.000	126.0
	0.3	42.50	14.00	28.50	2.040	108.0
	0.5	47.00	17.00	30.00	1.760	116.0
	0.7	46.50	19.00	27.50	1.450	100.0
	1	42.80	19.50	27.30	1.400	86.0
Potato starch	0.1	36.00	12.00	24.00	2.000	186.0
	0.3	35.50	11.00	24.50	2.230	144.0
	0.5	38.50	12.00	26.50	2.210	264.0
	0.7	40.00	13.00	27.00	2.080	184.0
	1	37.50	12.00	25.50	2.130	270.0
Lignin	0.1	16.30	11.00	26.00	2.360	76.5
	0.3	15.50	20.50	20.50	1.000	82.5
	0.5	13.50	6.50	13.50	2.080	60.5
	0.7	12.00	16.50	12.00	0.730	64.5
	1	17.00	2.00	17.00	8.500	70.0
phenolic resin	0.1	14.30	4.00	14.30	3.580	61.0
	0.3	14.80	3.00	14.70	4.900	61.5
	0.5	15.00	2.50	15.00	6.000	62.5
	0.7	13.00	4.50	8.50	1.890	47.5
	1	50.20	19.00	32.50	1.710	19.0

It can be seen from Table 4 that when the concentration of monoxanthate polymer increases gradually, AV and YP first increase and then decrease. The filtration loss is too large and the filtration reduction effect is general.With the increase of potato starch concentration, PV remains stable and basically unchanged. Compared with monoxanthic acid, the filtration loss is greater, and the filtration reduction effect is not ideal, so it is not considered.With the increase of lignin concentration, AV and YP decreased first and then increased, PV was also relatively unstable, and the filtration rate decreased compared with the previous two filtration reducing agents, but it was still not ideal.As the concentration of phenolic resin increases, the filtration loss decreases to the ideal range, and the PV increases steadily. Therefore, phenolic resin has good filtration loss reduction performance, so it is selected as the filtration loss reducer of the final formula.

3.4 Lubricant determination

Lubricant can reduce the friction between drilling tool and borehole wall, so as to reduce the rotating torque and additional tension, and avoid the occurrence of downhole complex accidents such as sticking. After compounding the optimal concentration of tackifier and fluid loss reducer with various lubricants, the viscosity coefficient and extreme pressure lubrication coefficient were measured respectively to select the best lubricant. The selected tackifier, i.e. 1% xanthan gum and filtration reducing phenolic resin, are compounded with three lubricants respectively, and their viscosity coefficient and extreme pressure lubrication coefficient are measured to determine their lubrication performance, as shown in Table 5.

Table 5 Performance evaluation of 1% XG and 1% phenolic resin under different lubricants

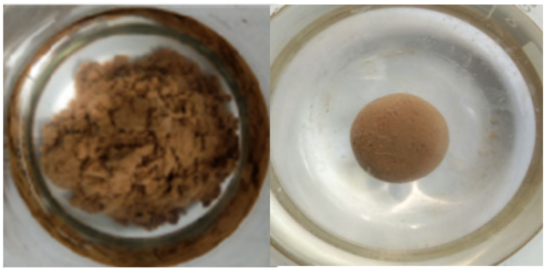
Lubricant	Dosage /%	Viscosity coefficient of mud cake	Extreme pressure lubrication coefficient
Vegetable oil	1.0	0.2309	0.2065
	2.0	0.2126	0.1864
	3.0	0.2673	0.1673
Sodium benzenesulfonate	1.0	0.2126	0.2144
	2.0	0.1944	0.2356
	3.0	0.1673	0.2845
KD-03	1.0	0.2126	0.0468
	2.0	0.1544	0.0546
	3.0	0.1944	0.0675

It can be seen from Table 5 that for vegetable oil, with the increase of dosage, the viscosity coefficient of mud cake first decreases and then increases, and the extreme pressure lubrication coefficient also decreases gradually, so the lubrication effect is not ideal. For sodium benzene sulfonate, with the increase of its dosage, the viscosity coefficient of mud cake decreases gradually, and the extreme pressure lubrication coefficient also increases gradually. Therefore, it can be seen that its lubrication performance is excellent. For KD03, with the increase of dosage, the viscosity coefficient of mud cake first decreases and then increases, the extreme pressure lubrication coefficient increases slowly, and the lubrication effect is not very ideal. To sum up, the lubricant with the best lubricating performance is sodium benzenesulfonate solution with a concentration of 1%. 3.5

Formulation determination and performance characterization of solid free drilling fluid The formulation of solid-free drilling fluid was determined, and the performance of strongly inhibitory solid-free drilling fluid system was characterized by thermogravimetric analysis, mud ball experiment and scanning electron microscope. After screening, the final formula of solid-free drilling fluid is determined as: 0.2% 1831+1% xanthan gum+1% phenolic resin+1% sodium benzene sulfonate.

3.4.1 Mud ball experiment

At room temperature, sodium bentonite was put into oven, adjusted to 105 ℃ and dried for 5 h. After mixing the sodium bentonite and tap water at a mass ratio of 2:1, the ball was weighed about 10 g. The balls were put into the formula solution and soaked in tap water for 72 h. The appearance of the mud balls was observed and photographed at 24 h intervals.Then the inhibition effect of each clay inhibitor is evaluated by the surface morphology of the expanded clay ball. The experimental results are shown in Fig. 3. It can be seen from Fig. 3 that the mud ball put into the clean water has completely collapsed, while the surface of the mud ball placed in the drilling fluid solution has no cracks and hydration expansion. It shows that adding 1831 inhibitor into drilling fluid has good inhibition on the hydration expansion of clay, which is consistent with the linear expansion rate of bentonite.



(a) Clear water (b) Drilling fluid solution

Fig. 3 Appearance of mud ball in clear water and drilling fluid formula (48 h)

4. Conclusions

Through the linear expansion experiments of 1831, 1227, polydiene dimethyl ammonium chloride and polymer thickener, the results show that 1831 has the best inhibition performance. Among them, the linear expansion rate of clay measured by 1831 with concentration of 0.2% is the lowest. 1831 is compounded with xanthan gum, HV-PAC, CMC Na and HPAM respectively for thermogravimetric experiment and clay ball experiment. It can be seen that 1831 has a strong effect on inhibiting the hydration expansion of clay. XG was selected as the single agent in the later compounding by the screening experiment, high temperature resistance experiment and salt resistance experiment, among which the xanthan gum with 1% concentration had the best performance. Xanthan gum was compounded with monosulfonate, potato starch, phenolic resin and lignin respectively, and phenolic resin was selected as a single agent with better filtration reduction performance. Then xanthan gum and phenolic resin were compounded with vegetable oil, KD03 and sodium benzenesulfonate respectively, and the single agent with better lubrication performance, namely sodium benzenesulfonate, was screened out. The best formula of viscosity enhancer and each treatment agent is 0.2% 1831+1% xanthan gum, 1% phenolic resin and 1% sodium benzenesulfonate.

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