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Effect of Particle Size Distribution on Fluid Rheology of High Density Drilling Fluid

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Abstract

The control and maintenance of rheological properties is the key technical problem that needs to be solved for high density drilling fluid. The influence of particle size distribution on the rheology of high density drilling fluid is analyzed. In order to identify the best particle size distribution of barite and iron ore, the influence of distribution modulus on the rheology of high density drilling fluid weighted by barite and iron ore is investigated based on the Aflred distribution equation. The experimental results show that weighting materials particle distribution has great effect on rheological properties of high density drilling fluid. When the barite particle distribution modulus n=0.4 and iron ore powder particle distribution modulus n=0.6, the rheology of high density drilling fluid is best, while the low settlement density difference and low HTHP filtrate loss is maintained.

Key words: Particle size distribution; High Density drilling fluid; Rheology; Distribution modulus

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INTRODUCTION

With the increasing depth of oil and gas drilling, the research and application of high density drilling fluid are becoming more and more extensive.[1-2] The control of rheology of high density drilling fluid has become the key technology of deep well drilling.[3-5] At present, the grain distribution theory is mainly used to improve the fluidity of coal water slurry [6] and the degree of research on improving the rheology of high density drilling fluid is not enough.[7-8] According to the Alfred distribution equation, the percentage of particles in each grain size interval of traditional weighting materials (barite and iron ore powder) of high density drilling fluid is calculated for various modulus of distribution, and then the rheological properties of high density drilling fluid formulated according to the calculation results is investigated, which provides a reference for controlling the rheology of high-density drilling fluid.

1. THEORETICAL BASIS OF PARTICLE DISTRIBUTION

The Alfred equation is a classical continuous stacking theory, and is a distribution theory based on continuous size distribution of particles. The Alfred equation was used to develop high concentration coal water slurry in 1970s. The Andresen equation was corrected by Dinger and Funk by introducing a finite minimum particle size into the distribution, and the Alfred equation[9] was proposed:

$$y=(d^n-d_s{}^n)/(d_L{}^n-d_s{}^n) \quad .$$

In the formula, y is the content for the particle size less than d, %; d_L is the maximum particle size; d_s is the smallest particle size; n is the modulus.

According the distribution theory, when the high density experimental mud has less fine particles and more coarse particles, the fine particles can not fully fill the gap between the coarse particles, and the packing of the particles is poor, which reduces the volume fraction of the effective flow phase of the experimental mud. When the fine particles are more and the coarse particles are less, the extra fine particles will enter the effective flow zone, which enhances the concentration of the effective mobile phase. Both of the two aspects will cause the viscosity of the high density experimental mud to increase and the rheological property of the slurry to be worse. Therefore, under the condition of certain density, drilling fluid has an optimum particle size distribution, so that the right amount of fine particles is completely filled in the intergranular space to achieve a close packing.

2. EXPERIMENT

2.1 Theoretical Calculation of Grain Distribution

According to GB/T5005, 75 µm, 45 µm and 6 µm were identified as particle size nodes of weighting materials. Combined with field experience, it was determined that the maximum particle size of weighting material was 106µm and the smallest particle size was 0.3 µm.[10-11] Using the Alfred equation, the percentage of particles in each grain size interval of n=0.1-0.8 is calculated, as shown in Table 1.

Table 1
Particle Size Distribution of Weighting Material Under Different Modulus of Distribution

Distribution modulus	Particle size distribution /%			
n	≥75µm	45~75µm	6µm~45µm	≤6µm
0.1	8	10	38	44
0.2	10	13	40	37
0.3	12	15	43	30
0.4	14	18	44	24
0.5	17	20	43	20
0.6	19	22	44	15
0.7	22	24	42	12
0.8	24	26	41	9

2.2 Performance Test of Weighted Drilling Fluid

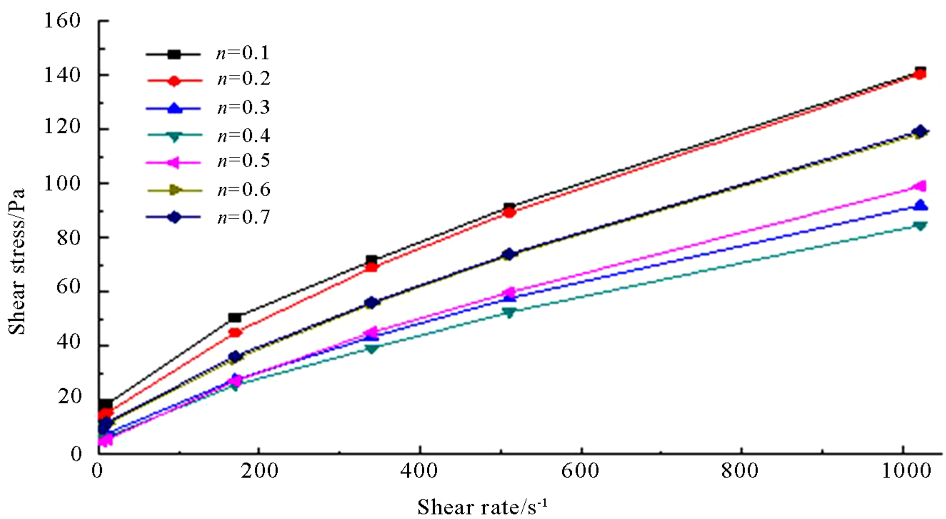
A common polysulfonated drilling fluid used in deep well and ultra-deep well is selected. Its basic formula is 3% bentonite +0.35%NaOH + 0.5%PAC-LV + 0.3%span-80 + 4%SPNH +2%SMP-1 + 3.5%SMC+ 1.2% SF-260 + 2.5% FT-A + 2% Lube. The density of drilling fluid is weighted to 2.4 g/cm^3 by adding barite and iron ore powder of different size according to the calculated value in table 1. After aging for 16h at 150°C, the properties of the experimental mud were measured.

3. RESULTS ANALYSIS

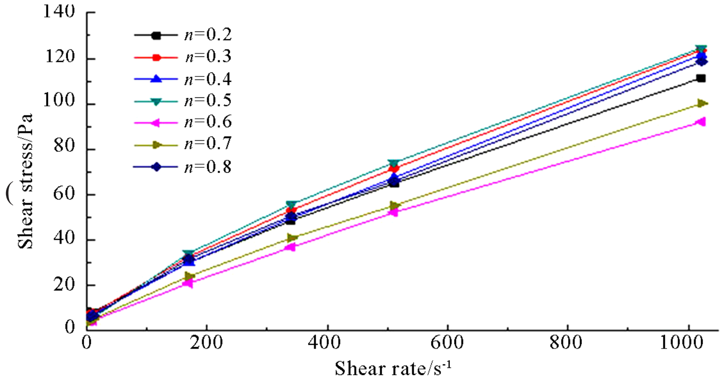
3.1 Effect of Particle Size Distribution on Rheological Properties

The aged experimental mud was cooled to room temperature, and the rheology was tested after fully stirring. According to the test data of the six speed rotary viscometer, rheological curve of drilling fluid weighted by barite and iron ore powder with different modulus of size distribution was drawn as shown in Figure 1.

According to Figure 1, the rheological curves of the high density drilling fluid weighted with barite and iron ore powder show the characteristics of the typical plastic fluid. Under the different distribution modulus n, the rheology curves of the high density drilling fluid weighted with barite and iron ore powder are different. When barite particle distribution modulus n=0.4 and iron ore particle distribution modulus n=0.6, the corresponding shear stress of the respective weighted drilling fluids is relatively low at the same shear rate. The effect is more obvious especially at the high shear rate.



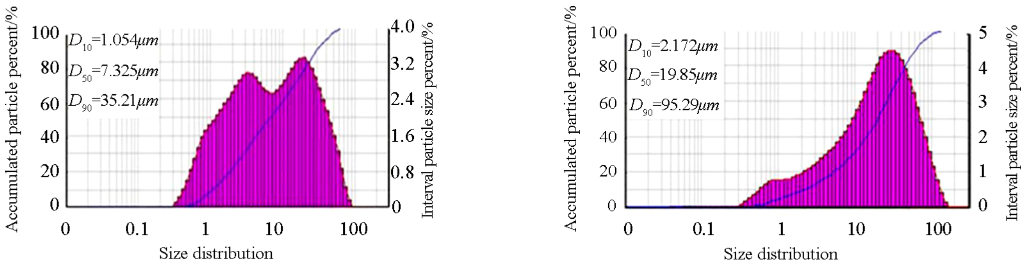
(a) Barite



(b) Iron ore powder

Figure 1
Rheological Curves of High-Density Drilling Fluids Weighted According to Different Distribution Modulus

Analysis: With the increase of distribution modulus *n*, the content of coarse particles of barite and iron ore powder with the diameter of more than 45 μm is increased, and the content of fine particles with particle size below 6 μm is decreased. When the distribution modulus of barite particles is 0.4 and the distribution modulus of iron ore particles is 0.6, the effect of particle size distribution is better. At this point drilling fluid particle size distribution is shown in Figure 2. Figure 2 shows that drilling fluid particle size distribution is wide, with D_{10} being around 2 μm and D_{50}/D_{90} being less than 1/3. The content of coarse and fine particle is appropriate. The small particles that are located in the gap between the large particles play a role of bearing, large particles are easy to flow due to the support of small particles thus improve the rheology of drilling fluid remarkably.



(a) Barite (distribution modulus *n*=0.4)

(b) Iron ore powder (distribution modulus *n*=0.6)

Figure 2
Particle Size Distribution of High Density Drilling Fluid

The rheology of high density drilling fluid is determined by physical and chemical properties of solid and liquid phases. Moreover, the geometry, density and surface properties of weighting materials affect the rheology of drilling fluids. Therefore, the optimum particle size distribution modulus of barite and iron ore particles is different.

3.2 Effect of Particle Distribution on Settlement Stability

The density difference between the upper and lower parts of the experimental mud was measured after being fully stirred for 24 h. The result is shown in Figure 3. Figure 3 shows that with the increase of distribution modulus n, the sedimentation density difference of high density drilling fluid weighted by barite and iron ore basically decreases first and then increases. When the distribution modulus is *n*=0.3 to 0.4, the density difference of the barite drilling fluid maintains at 0.01 g/cm^3.

When the distribution modulus is from *n*=0.5 to 0.6, the density difference of drilling fluid weighted by the iron ore powder maintains at 0.02 g/cm^3. Therefore, under the optimal distribution modulus of barite and iron ore, the stable stability of the high density drilling fluid can be maintained well.

3.3 Effect of Particle Size on HTHP Filtrate Loss

Test of high temperature and high pressure (150 /3.5MPa) filtrate loss and thickness of mud cake was carried out for experimental mud weighted by barite and iron ore powder. The results are shown in Table 2. From Table 2, it is known that under the different distribution modulus *n*, the HTHP filtrate loss and the thickness of the mud cake are rather different between the barite weighing material and iron ore powder weighting material. When the distribution modulus of barite particles is *n*=0.3 to 0.4 and the distribution modulus of iron ore particles is *n*=0.6, the particle size distribution of the drilling fluid is wide and the filling effect of small particles to large particles is obvious, and the accumulation degree of mud cake is high and thus, HTHP filtrate loss of high density drilling fluid is low and the thickness of mud cake is thin, respectively.

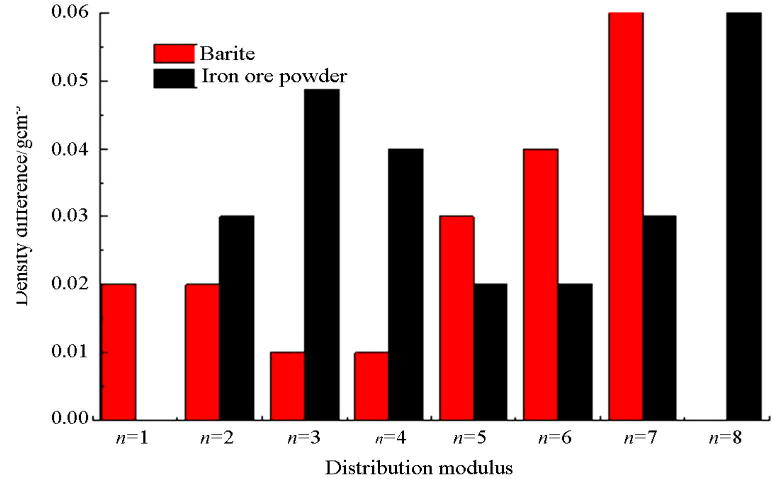


Figure 3
Settlement Density Difference of High Density Drilling Fluid Under Different Distribution Modulus

Table 2
High Density Drilling Fluid Weighted by Additives of Various Distribution Modulus

Distribution modulus	FL_{HTHP}/mud cake thickness, mL/mm	
	Barite high density drilling fluid	Iron ore powder high density drilling fluid
n=0.1	20.4/9.2	-
n=0.2	16.8/9.7	26.8/10.2
n=0.3	8.4/5.4	22.4/9.8
n=0.4	10.8/6.0	24.4/8.4
n=0.5	14.4/6.2	20.6/7.6
n=0.6	16.6/8.0	10/6.2
n=0.7	16.8/7.8	14.2/8.2
n=0.8	-	19.8/9.5

CONCLUSION

The appropriate particle distribution of the weighting material can significantly improve the rheology of high density drilling fluid. When the weighting material particle distribution follows Aflred distribution equation, and when barite particle distribution modulus *n*=0.4 and iron ore powder particle distribution modulus *n*=0.6, the weighted high density drilling fluid has good rheological property, and a low sedimentation density difference and low HTHP filtrate loss can also be ensured.

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