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RESEARCH PAPER

Research and preparation of ultra-heavy slurry

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Abstract: In order to resolve the technical problem of cementing when drilling super high-pressure gas layers or saltwater layers of Guandu structure in Chishui region, Guizhou province, an ultra-heavy slurry was developed by optimizing weighting materials and designing particles, and applied to well Guanshen1 for liner cementing. According to the needs of preparing ultra-heavy slurry, the weighting additive MicroMAX in spherical particles was selected and combination of weight additives—reduced iron powder, iron powder, MicroMAX—was chosen for optimization. The particle size-distribution of the slurry was designed on the basis of the theory of tight packing, and the actual particle size-distribution is close to the ideal condition of tight packing. The ultra-heavy slurry with a density of 2.70-3.00 g/cm^3 was designed, which is good in basic performance, flow ability and stability. In the simulated mixing test on the ground, a slurry with an average density of 2.71 g/cm^3 was prepared by using conventional one-time cementing process. In the liner cementing of well Guanshen 1, the slurry with a density of 2.80 g/cm^3 was used to successfully seal the super high-pressure saltwater layer: the average density of the slurry pumped into well was 2.78 g/cm^3 and the maximum density was 2.82 g/cm^3; amplitude log showed that the cementing quality was good; the well bore kept stable in follow-up drilling when the density of drilling fluid was reduced from 2.77 g/cm^3 to 2.00 g/cm^3.

Key words: titania; photocatalysis; ceramic membrane; coupling reactor; methyl orange; degradation

Introduction

The gas-bearing strata in the Carboniferous Maokou Formation of the Guandu Structure, Chishui, Guizhou Province, has been under close attention all the while, but drillings have all failed to reach the target because the extra-high pressure saltwater layer or gas layer (the formation pressure coefficient exceeds 2.7[1]) in the Jialingjiang Formation could not be sealed for lack of ultra-heavy cement slurry. In the 1990s, well Guan-3 encountered high pressure gas layer at the depth of 3 808 m during drilling, and ultra-heavy drilling fluid with density ranging from 2.87 g/cm^3 to 2.92 g/cm^3 successfully killed the well. Nevertheless, conventional cementing and completion could not be done due to lack of ultra-heavy slurry, and the well was plugged without other choices[2]. Well Guan-7 was plugged for the same reason in 2005[3].

To develop ultra-heavy cement slurry, many attempts have been made from slurry design to equipment improvement. For instance, a secondary weighting slurry-preparing tank has been manufactured to prepare slurry with density of 2.65 g/cm^3 by researchers in Xinjiang Oilfield, the slurry density reached 2.61 g/cm^3 and 2.62 g/cm^3 respectively in well Huo-10 and well An-4 [4]. But the method does not work when encountering high formation pressure. This paper presents ultra-heavy slurry developed by optimizing weighting materials and designing particles. The practical applicability of the slurry is checked by simulation mixing test on the ground and it is applied to cementing of well Guanshen-1 in the Guandu Structure.

1 Ultra-heavy slurry design

1.1 Selection of spherical weighting additive

Particle shape of weighting additive has a great effect on its properties, such as friction angle and contact angle, which significantly influence the mixing ability between weighting additive and slurry, and the stability and mobility of slurry. Theoretically, the particle size of weighting agent should be kept as small as possible to avoid settlement. But ultra-fine particles got by grinding and pounding are characterized by irregular shape, multiple edges and corners, big specific surface, which are likely to cause particle gathering and large friction. High dosage of this kind of weighting additives would result in high consistence and poor mobility of the slurry, non-uniform adsorption of other slurry additives, degradation of slurry properties and even sensitivity. For example,

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retarder would be over-adsorbed owing to large dosage of micro-silicon, and a nonlinear relationship between thickening time and dosage of retarder would occur. To extend slurry's thickening time, much more retarder than normal has to be added [5]. In view of above-mentioned reasons, spherical weighting additive is selected, and its advantages include [6]: padding may be maximized, which is beneficial to the increase of slurry density; spherical particles have small friction factor, so they will not cause the rise of consistence, and the slurry will have good mobility; the surface area of the spherical particle is smaller than that of the particle with irregular shape, but enough for maintaining stable, and spherical weighting additive absorbs other additives regularly so that the slurry properties can be adjusted easily.

Spherical weighting agent MicroMAX is selected for ultra-heavy slurry, which is mainly made up of Mn_3O_4 and has average particle diameter of 0.5 μm, specific gravity of 4.8, and specific surface area from 2 m^2/g to 4 m^2/g. MicroMAX provides not only density increase but also lubrication among other particles, consequently, the slurry mobility can be greatly improved. Table 1 shows that the plastic viscosity of the slurry with density of 2.71 g/cm^3 reduces by 33.7 mPa·s after adding MicroMax and that of the slurry with density of 2.80 g/cm^3 reduces by 53.5 mPa·s.

1.2 Selection of weighting materials and design of cement particles

Any kind of materials can not meet the demand of ultra-heavy slurry when used singly, but two or more types of weighting materials which have high purity and density must be combined to get desirable slurry. Then, the slurry properties can be adjusted to get the desirable density at low dosage. Through lab selection, reduced iron powder, iron powder and MicroMAX were selected as weighting materials of the ultra-heavy slurry (Table 2).

Reasonable particle size distribution and close packing allows the porosity of cement to decline considerably. According to the theory of close packing based on particle size distribution (known as PSD), spaces filled by particles can be increased and van der Waals forces between particles can be risen by configuration of particles with different sizes [7–10]. In addition, small particles can play the role of ball bearings among large particles, so less water is needed for preparation of cement slurry, and low water content promotes fast bridging between particles, thus improving the cement slurry's comprehensive performance [10]. Particles of ultra-heavy cement are designed using Anderson continuous packing equation (Equation 1) [11] to achieve close packing. Particle size distribution of ultra-heavy slurry with density of 2.80 g/cm^3, in which the proportions of reduced iron powder, iron powder and MicroMAX are respectively 30%, 40% and 30%, is designed using Equation 1. Actual particle size distribution curve of the cement matches well with the theoretically optimal distribution curve (Fig. 1), and the distribution is near the ideal close packing.

$$Y = \left(D / D_L \right)^m \quad (1)$$

where, Y—cumulative probability below a certain particle size, %; D—size of any particle in the slurry, μm; D_L—size of the largest particle in the slurry, μm; m—packing factor, given as 0.3.

Table 1 Comparison of rheology data of slurry with and without MicroMAX

Slurry density/($g \cdot cm^{-3}$)	With/Without MicroMAX	Rheology data		
		Flow behavior index	Consistence coefficient/($Pa \cdot s^n$)	Plastic viscosity/(mPa·s)
2.71	Without MicroMAX	0.89	0.33	156.5
	With MicroMAX	0.86	0.34	122.8
2.80	Without MicroMAX	0.81	0.74	172.5
	With MicroMAX	0.90	0.26	119.0

Note: n—flow behavior index

Table 2 Physical properties of selected weighting materials

Name	Main component	Specific gravity	Average particle diameter/μm	Appearance
Reduced iron powder	Fe	7.2	41.0	Grey powder
Iron powder	Fe_2O_3	4.9	33.0	Brown powder
MicroMAX	Mn_3O_4	4.8	0.5	Brown powder

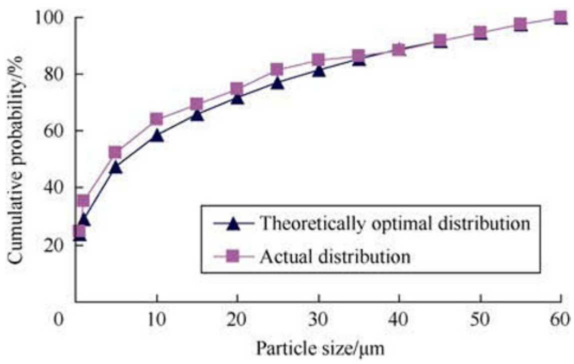

Fig. 1 Particle size distribution of the ultra-heavy slurry

1.3 Properties of ultra-heavy slurry

With optimized weighting materials and matching additives selected by lab experiments, ultra-heavy slurries with density

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