A new type of low density cement slurry suitable for sandstone formation

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Abstract. Unconsolidated sandstone reservoir is an important unconventional oil and gas resource with the characteristics of porosity, low permeability, strong heterogeneity and many interlayer. The main challenge of unconsolidated sandstone formation is sand production of oil wells, and the more serious situation is high-pressure oil and gas escaping, blowout accidents, environmental pollution and the safety of operators. In order to solve the sensitivity problem of loose sandstone, a low density admixture was developed: 10.5% artificial floating bead + 4.5% power plant floating bead + 35% micro silicon + 30% fly ash + 20% slag. The particle size distribution of single lightweight material is narrow, and the effect of reducing density is not significant. The developed low-density mixing material has wide and uniform particle size distribution, and can reduce the density of cement slurry to the maximum within the minimum dosage. The new low density admixture cement slurry with adjustable density in the range of 1.4 ~ 1.7 g / cm³ has good rheological property, short thickening time, water loss less than 50 ml, 24 h compressive strength more than 12 MPa, which can meet the needs of site construction. The temperature and pressure test results show that the system has a wide range of temperature and pressure applications and stable performance. Compared with the similar low density cement slurry, it is about 40% lower than the market price and suitable for commercial application.

1. Introduction
Shallow unconsolidated sandstone is an important unconventional oil and gas resource in China, which is characterized by low porosity, strong heterogeneity and many interlayers. It is mainly distributed in Xinglongtai block of Liaohe Oilfield, Xuqian block of Xuzhuang oilfield, Qikou block of Dagang Oilfield, high shallow north area of Jidong Oilfield, northern Songliao Basin and Western Sichuan basin [1]-[3]. The main challenge of shallow unconsolidated sandstone formation is sand production from oil wells. According to the combination mode of formation sand, formation sand is divided into filling sand and skeleton sand [4]. The filling sand is located in the pores of the reservoir. When the velocity of formation pore fluid passes through the sand filling area, the velocity and pressure difference will push the filling sand back out of the well. This stage of sand production is inevitable, and this stage of sand production helps to reduce the flow resistance of pore fluid, improve the formation permeability and increase the oil and gas production. However, when the velocity through the pore exceeds the critical velocity, the pore structure of the weak and loose sandstone is easy to collapse and collapse, causing permanent damage to the reservoir [5]-[7]. The more serious situation is the high pressure oil and gas escaping, blowout accident, pollution of the environment and harm to the safety of operators. Therefore, it is necessary to use cementing slurry to effectively seal the shallow unconsolidated sandstone formation to maintain the long-term stable production of oil.
wells. In the field of petroleum engineering, low density cement slurry is often used to seal loose sandstone formation [8]-[11]. It is considered that low-density cement slurry has the advantages of short setting time and good stability, which can greatly improve the construction safety and cementing quality of shallow wells prone to lost circulation.

2. Experimental equipment and methods

2.1. Experimental equipment

During the preparation of cement slurry, OWC-9360 constant speed agitator was used to mix cement slurry, TG-1220C atmospheric pressure thickener was used to maintain cement slurry at normal temperature, DFC-0712B double cylinder pressurized thickener was used to test the thickening time of cement slurry, HH420 electric constant temperature water bath was used to heat the cement slurry, 2NN-D6 six speed rotary viscometer was used to test the rheological reading of cement slurry, and Y-200 universal universal mechanical testing machine was used to test the slurry thickening time. The compressive strength of cement paste was tested, and the HTHP water loss of cement slurry was tested by TG-71 high temperature and high pressure water loss instrument.

2.2. Experimental methods

The preparation and experiment of cement slurry in this study are conducted according to SY/T5504.1-2005《Evaluation Method of Oil Well Cement Additives》, SY/T6544-2003《Performance Requirements of Oil Well Water Slurry》 and API specification Spec-10A. Because the cement slurry contains floating bead lightening agent, which is easy to be damaged under the mixing rate of 12000 r/min, which affects the performance of cement slurry; while the mixing rate of equipment for mixing cement slurry on site is only equivalent to that of indoor 2000 r/min, the indoor mixing rate should be controlled by compromise method, combining API standard and field operation conditions. The indoor configuration method is as follows: at the speed of 4000 r/min, pour the mixed ash into the slurry cup within 15s, and then continue to stir for 45s.

3. Design of cement slurry system

3.1. Design principle of cement slurry

There are many problems in the application of grade g Portland cement in unconsolidated sandstone formation. The most fatal problem is that low density cement stone needs longer curing time under low temperature. In order to overcome the above problems, the most important thing is to improve the hydration rate of cement at low temperature, so that the cement slurry can obtain enough strength in a short time to meet the requirements of subsequent drilling. In order to obtain a better low temperature cement slurry system, we need to start from the following three aspects: 1) using efficient early strength agent to make the cement slurry effectively set in a short time [12]. In order to make Portland cement have strength at low temperature, it is necessary to ensure that the cement slurry can effectively set in a relatively short period of time at low temperature, so as to shorten the hydration induction stage of cement as far as possible [13]. For the deep water low temperature and low density cement slurry system, the high efficient low temperature early strength agent is used to improve the hydration rate of cement slurry and accelerate the development of cement strength; 2) light materials are used to reduce the water cement ratio of cement slurry and improve the initial strength of cement paste; 3) Active filler and inert filler are used to fill the voids between cement particles through physical and chemical action to reduce the permeability of cement slurry [14]-[17].

3.2. Design of cement slurry system

After comprehensive consideration of the density, compressive strength, settlement stability, rheology, thickening time and cost of cement slurry, the low-density mixed material composed of floating beads, micro silica, fly ash and slag is considered to achieve high performance under the condition of low cost. Through a lot of basic research, the main components of low density admixture (DA) are determined as follows: 10.5% artificial floating beads + 4.5% power plant floating beads + 35% micro silica +
30% fly ash + 20% slag.

The main additive materials of cement slurry are early strength agent ACL, dispersant CF42L, fluid loss additive CG81L, retarder RE-L, enhancer ESC-S and defoamer CX60L are used in the preparation of cement slurry. The cement slurry systems with different densities constructed with the above additives are as follows:

0#: 100%Cement+3%ACL+139%Water+1.5%RE-L+4%CF42L+6%CG81L+2%ESC-S+1%CX60L

*Figure. 1 Particle size of different types of lightweight materials*
1#: 0#+91%DA (1.4g/cm³)
2#: 0#+72%DA (1.5g/cm³)
3#: 0#+58%DA (1.6g/cm³)
4#: 0#+32%DA (1.7g/cm³)

4. Results and discussion

4.1. Particle size analysis of low density mixed timber
The compressive strength, density, permeability and water loss performance of low-density cement slurry are mainly based on the particle grading technology. Through the three-level grading principle of solid particles, the primary pores of cement paste are filled and the space network structure of cement paste is improved. Therefore, the particle size distribution of low density mixed materials is very important. The particle size distribution of different types of lightweight materials is shown in Figure 1.

Through the particle size test of single lightweight material and mixed lightweight material, it can be seen that the particle size distribution of different lightweight materials is very different. The results show that the particle size distribution of the mixed low-density materials is enlarged, and the solid particles are evenly distributed in the range of 1-150 μm. This particle size distribution is helpful to improve the spatial structure of cement slurry colloid and enhance the mechanical properties of cement paste.

4.2. Performance evaluation of different density cement slurry system
For the cement slurry system used for cementing, its conventional properties usually include rheological property, stability, thickening time, water loss and compressive strength. These properties are generally concerned by laboratory tests and field cement slurry tests, which are directly related to the construction safety and cementing quality of cement slurry. According to the cement slurry system with different densities, the laboratory evaluated various properties of cement slurry at 50 °C. The experimental results are shown in Table 1.

| Number | Φ300 | Free water (mL) | Loss water (mL) | Thickening time (min) | Compressive strength (MPa) |
|--------|------|----------------|----------------|----------------------|---------------------------|
| 1#     | 173  | 0              | 52             | 309                  | 13.3                      |
| 2#     | 156  | 0              | 41             | 273                  | 14.2                      |
| 3#     | 149  | 0              | 48             | 280                  | 15.8                      |
| 4#     | 142  | 0              | 56             | 284                  | 15.2                      |

It can be seen from the experimental results that: 1) for different density cement slurry formula, its rheological property can meet the cementing requirements, and the cement slurry formula with different density does not have free fluid, and the cement slurry has good stability. 2) The water loss of cement slurry with different density is about 50ml. In order to further control the water loss of cement slurry, more fluid loss additive should be added. 3) The thickening time of cement slurry with different density is between 3 and 7 hours, which can meet the requirements of cementing. 4) Through the evaluation of the compressive strength of different density cement slurry system, it is found that the compressive strength of different density cement slurry system at 50 °C is greater than 12MPa, and the compressive strength of cement slurry system can meet the requirements of cementing in offshore unconsolidated sandstone formation.

4.3. Effect of temperature on the performance of cement slurry
The performance of cement slurry in shallow unconsolidated sandstone formation is investigated in laboratory, and the performance variation of cement slurry in the temperature range of 30 ~ 50 °C is considered. In order to understand the variation law of cement slurry performance with temperature, the rheological property, thickening property, water loss performance and compressive strength of cement slurry with 1.5g/cm³ density at 30 °C, 40 °C and 50 °C were tested in the laboratory. The test results are shown in Figure 2:

The test results show that temperature can significantly affect the basic properties of low density cement slurry, but has little effect on the water loss of low density cement slurry. The performance of cement slurry with density of 1.5g/cm³ at different temperatures can meet the needs of the industry. With the increase of temperature, the cement slurry becomes thinner obviously. The increase of temperature is helpful to promote the flow of cement slurry, so as to improve the dynamic stability of cement slurry [18]-[21]. Low temperature has a negative effect on the hydration reaction of cement slurry, prolonging the thickening time of cement slurry and reducing the initial compressive strength of cement paste.

4.4. Influence of pressure on performance of cement slurry

In order to study the influence of pressure change on the performance of cement slurry, the performance of cement slurry under different pressures of 50 °C was evaluated in laboratory. The experimental results are shown in Table 2.

| Test pressure (MPa) | Thickening time (min) | Compressive strength (MPa) |
|--------------------|-----------------------|---------------------------|
| 0                  | 312                   | 14.2                      |
| 10                 | 301                   | 13.8                      |
| 20                 | 283                   | 14.7                      |
| 30                 | 268                   | 15.5                      |

The experimental results show that the thickening time of cement slurry and the compressive strength after curing change regularly with the change of test pressure. The compressive strength of cement slurry increases with the time of thickening. It can be seen that the pressure has a great influence on the properties of cement slurry. The reasons for this phenomenon are as follows: (1) some lightening agents are broken, causing changes in the performance of cement slurry; (2) pressure changes the distribution of solids in the slurry. Because the influence of pressure on cement slurry is regular, it is recommended to accurately measure the bottom hole formation pressure in field application. Only by accurately mastering the real pressure data of cement slurry sealing section can we master the variation law of cement slurry according to the experiment and provide better and more direct guidance for field operation.
4.5. Cost comparison of cement slurry

At present, low density cement slurry mostly adopts single lightening material to reduce the density of cement slurry, neglecting the single particle size distribution of lightening material, which is difficult to reduce the density of cement slurry to the maximum extent. Moreover, some lightening materials are easy to cause the cement slurry to separate and disintegrate after curing, such as floating beads. On the other hand, the oil and gas industry is increasingly depressed, and major enterprises are pursuing "reducing cost and increasing efficiency" and seeking better development prospects. The same is true for cementing slurry. Previous researchers have neglected that a single lightening agent is easy to cause high cost of low-density cement slurry. Therefore, this paper has taken this into account at the beginning of the system construction, and on the basis of ensuring the performance of cement slurry, we seek the lowest cost low-density cement slurry. The average price of self-made low-density cement slurry is 2103 yuan / m³, while the average price of floating bead low-density cement slurry of the same series is 4285 yuan / m³, which is about 40% lower than the market price.

5. Conclusion

The average particle size distribution range of single low density lightening material is narrow, so it is difficult to fill the micropore and reduce the density of cement paste as much as possible. The particle size distribution of low-density composite material is extremely wide and uniform, which can reduce the density of cement slurry in the minimum dosage. The density of the self-developed low-density mixed cement slurry is adjustable, and the density has little effect on the basic performance of the cement slurry, which is more conducive to the field construction. Low density mixed cement slurry is made of inorganic inert materials. Under low temperature and low pressure, the performance of cement slurry is hardly affected by temperature and pressure. Different from deep-water low-temperature low-density cement slurry, the thickening time of low-density cement slurry mixed with loose sandstone can be shortened to 300 min, and the 24 hour compressive strength can exceed 12 MPa, and the average price is about 40% lower than that of deep-water low-density cement slurry.

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