Effect of modified polyvinyl alcohol on fluidity of cement slurry

Jian Zhang¹,²,*, Zhihong Li¹,², Kai Tang¹,², Ya Shi³, Weichao Du³

¹ Drilling and Production Engineering Technology Research Institute of CNPC Chuanqing Drilling Engineering Co., Ltd, 710018, Xi’an, China
² National Engineering Laboratory for Exploration and Development of Low Permeability Oil and Gas Fields, 70018, Xi’an, China
³ Shaanxi Province Key Laboratory of Environmental Pollution Control and Reservoir Protection Technology of Oilfields, Xi’an Shiyou University, 710065, Xi’an, China

*Corresponding author Email: zhangjian_gcy@cnpc.com.cn

Abstract: Select appropriate amount of dispersant to modify polyvinyl alcohol, and explore the influence of modified polyvinyl alcohol on the rheology of cement slurry by investigating the thickening time, initial consistency, free liquid and density, fluidity index and viscosity coefficient of cement slurry. The results show that the thickening time of cement slurry is the shortest when the dispersant parameter is 1.5%, and the rheology of cement slurry becomes better and better when the dosage of polyvinyl alcohol increases. When 1.5% polyvinyl alcohol is added, the rheology of cement slurry is good and the viscosity is low.

Keywords: Modified polyvinyl alcohol Cement slurry Rheology.

1. Introduction
Cementing is one of the important links in the process of oil exploration and development, and it is also a relatively independent link in drilling engineering[1]. Oil well cement fluid loss additive can obtain proper w/C cement slurry by controlling the formation filtration of liquid phase permeability in cement slurry[2,3]. Fluid loss additive can reduce the permeability of mud cake and improve the viscosity of mud by adsorbing on the surface of cement particles, so as to control water loss[4]. China began to study filtrate reducer after 1980, but it developed rapidly, and many varieties soon reached the same level as foreign countries. But on the whole, there is still a big gap with foreign countries[5]. Since the 1990s, a variety of oil well cement fluid loss additives have been developed at home and abroad. These fluid loss additives are generally divided into water-soluble polymer materials and particulate materials[6]. Natural polymer materials have low cost and wide source. It can be divided into cellulose, lignin, humic acid, etc. they have strong retarding effect and can greatly prolong the thickening time. Moreover, the cement slurry with water-soluble polymer materials has high consistency and needs to add an appropriate amount of dispersant[7]. Bentonite, asphalt and talc powder are generally used as particulate materials, among which bentonite was first used as fluid loss additive[8,9]. The fluid loss additive in China is best to reduce the water loss rate to the formation, improve the rheological properties of cement slurry, prolong the thickening time, and achieve the advantages of dispersion and retarding[10,11]. At the same
time, efforts should be made to develop low-cost and effective fluid loss reducing agents, develop appropriate fluid loss reducing products for different formation conditions, and improve the functionality of fluid loss reducing agents\textsuperscript{12}. Under the current situation of petroleum industry and the severe environment of oil and gas reserves, it is an inevitable trend for fluid loss reducer to develop towards multi-function\textsuperscript{13}. Fluid loss reducer not only has the characteristics of reducing filtration, but also has the advantages of dispersing cement slurry and increasing thickening time. The longer the thickening time, the better the dispersion effect of fluid loss additive, which greatly improves the pumpable time and prevents the occurrence of cementing accidents.

2. Materials and methods

2.1. Materials

The cement is G-class oil well cement, purchased from Jiahua special cement plant, defoamer and dispersant from Chuanqing drilling and production Institute, and polyvinyl alcohol from Shandong Yousuo Chemical Technology Co., Ltd.

2.2. Experimental method

2.2.1. Preparation of cement slurry. 600g of grade G oil well cement required for the test and the admixture to be used shall be weighed on the weighing table, and the reagent to be used shall be stirred evenly after weighing; In this experiment, the water cement ratio of cement slurry is kept at 0.44, 264ml tap water is weighed, and the water is poured into the slurry cup; Place the mixing cup on the base of the constant speed mixer and start the mixer. First, mix at a low speed at 4000 ± 200 rpm, and then pour the mixed solid cement and admixture into the mixing cup at a uniform speed and quickly; After filling, cover with cup lid. Stir at high speed. Rotate speed is 12000 ± 500rpm. After stirring about 40s, turn off the machine. If froth is added, add defoamer to defoaming, then prepare the cement paste and prepare for subsequent test.

2.2.2. Cement slurry thickening test. Keep the inside of the pulp cup dry and clean, put the mixing paddle into the pulp cup, and ensure that the mixing paddle can keep rotating inside the pulp cup; Pour the cement slurry into the slurry cup without passing through the blade, and knock the outside of the slurry cup to remove bubbles to eliminate the influence; Cover the potentiometer of the pulp cup to ensure correct assembly and no gap at each seal. Put it into the thickener and ensure normal operation; Turn on the thickener motor, the thickener starts to heat up to 45 °C, the mixing paddle starts to rotate, keep the paddle rotating smoothly, and then start the experiment and record the data.

2.2.3. Cement slurry density measurement. Pour the prepared cement slurry into the drilling fluid densitometer and use the drilling fluid densitometer according to GB / T 19139-2012 standard. In order to prevent bubbles in the mixed cement slurry from affecting the experimental results, remove bubbles by fully stirring the slurry. If there are many bubbles, a few drops of defoamer can also be added; Cover the cup cover, wash and dry the shell, because the water droplets on the surface of the shell will affect the measurement results; Place the pressure densitometer on the support part, adjust the traveling code on the beam, and achieve balance when the steel ball in the beam is stable at the center between the scale lines; Finally, observe that the traveling code is at the position of the value, which is the measured cement slurry density.

2.2.4. Cement slurry free liquid test. Pour the prepared slurry into the curing cylinder of atmospheric thickener for 20min; After curing the cement slurry, transfer it to a 250ml glass measuring cylinder, reach the 250ml scale, and then seal the cylinder mouth with fresh-keeping film to prevent water volatilization; Place the measuring cylinder on the horizontal table and stand for 2 hours. After that, use
a syringe to measure the supernatant and measure the volume of the supernatant. Its volume value is the amount of free liquid.

2.2.5. Fluidity measurement of cement slurry. When the regulating instrument reaches 45 ℃, it shall be cured for 20min; After curing, quickly pour the cement slurry into the slurry cup of the rotary viscometer, and stop dumping after reaching the scale mark. Assemble the instrument, place the slurry cup at the correct position of the rotary viscometer, and then adjust the rotation speed step by step according to the rotation speed, starting from 600 revolutions and ending at 3 revolutions. After each adjustment, the corresponding reading shall be taken, and then the n value and K value shall be calculated according to the formula.

N and K values are obtained by two-point method:

\[ n = 2.096 \times \lg \left( \frac{\theta_{300}}{\theta_{100}} \right) \]  
\[ K(\text{Pa} \cdot \text{Sn}) = 0.4788F \cdot \frac{\theta_{300}}{511^n} \]

\( \theta_{300} \)—Viscosity at 300 rpm \\
\( \theta_{100} \)—Viscosity at 100 rpm

Among them, n value reflects the strength of non flowing fluid properties of cement slurry, and K value reflects the viscosity of cement slurry.

3. Results and discussion

3.1. Influence of dispersant content on cement slurry performance

3.1.1. Consistency and thickening time of cement slurry. Table 1 and figure 1 show the initial consistency of dispersants with different proportions at room temperature and the time when the consistency of cement slurry reaches 100BC. The formula is: 600g Jiahua grade G oil well cement + (0.5%, 1.0%, 1.5%, 2.0%, 2.5%) dispersant + 264ml tap water. It can be seen from the table that the initial consistency decreases with the increase of dispersant content, and the thickening time is the shortest when the dispersant content is 1.5%.

| Dispersant content | Initial consistency / BC | Thickening time / min |
|-------------------|--------------------------|-----------------------|
| 0%                | 5                        | 336                   |
| 0.5%              | 5                        | 709                   |
| 1.0%              | 5                        | 502                   |
| 1.5%              | 4                        | 336                   |
| 2.0%              | 4                        | 590                   |
| 2.5%              | 4                        | >780                  |
3.1.2. **Cement slurry density and free liquid.** It can be seen from table 2 that the dosage of dispersant is increasing, the density is decreasing, and the volume of supernatant is decreasing. The more the dispersant is added, the less the free fluid is, indicating that the better the cement quality, because excessive free fluid is unfavorable to the cementing quality. When 2.5% dispersant is added, the density of cement slurry is the smallest and the free liquid is the least.

**Table 2.** Effect of dispersant on density and free liquid of cement slurry

| Dispersant content% | density /g⋅cm⁻¹ | Free liquid volume /mL |
|---------------------|------------------|------------------------|
| 0                   | 1.81             | 4.3                    |
| 0.5                 | 1.86             | 3.0                    |
| 1.0                 | 1.85             | 3.0                    |
| 1.5                 | 1.84             | 2.0                    |
| 2.0                 | 1.838            | 2.0                    |
| 2.5                 | 1.81             | 1.0                    |

3.1.3. **Fluidity index and rheological coefficient of cement slurry.** The formula is: 600g oil well cement + 264ml tap water + (0%, 0.5%, 1.0%, 1.5%, 2.0%, 2.5%) dispersant. Measure the viscosity of water slurry at different speeds, and calculate the fluidity index n and viscosity coefficient K. It can be seen from the results in Table 3 that when the dispersant is added, the fluidity index of the cement slurry increases and the rheology obviously improves. When 1.5% dispersant is added, the fluidity index of cement slurry is 0.99666 and the viscosity coefficient is 0.02573 Pa ⋅ Sn. The cement slurry has good fluidity and low viscosity. When 1.0% dispersant is added, the viscosity coefficient of cement slurry is the smallest, which is 0.01371 Pa ⋅ Sn.

![Figure 1. Initial consistency and thickening time curve of cement slurry](image-url)
Table 3. Rheological properties of slurry with dispersant dosage

| Dispersant content % | n   | K (Pa·S°) |
|----------------------|-----|-----------|
| 0                    | 0.40439 | 3.53731 |
| 0.5                  | 0.90413 | 0.09199 |
| 1.0                  | 0.96130 | 0.01371 |
| 1.5                  | 0.99666 | 0.02573 |
| 2.0                  | 0.89283 | 0.03656 |
| 2.5                  | 0.99157 | 0.03169 |

3.2. Effect of polyvinyl alcohol on properties of cement slurry

3.2.1. Consistency and thickening time of cement slurry. Table 4 and Figure 2 show the initial consistency and thickening time of cement slurry reaching 100BC at room temperature with 1.5% dispersant and polyvinyl alcohol in different proportions. The formula is: 600g Jiahua grade G oil well cement + 1.5% dispersant + (0.5%, 1.0%, 1.5%, 2.0%, 2.5%) polyvinyl alcohol + 264ml tap water. The thickening time of cement slurry is higher than that of other polyvinyl alcohol, and the thickening time of cement slurry of other polyvinyl alcohol is similar. If the time is too long, the cement slurry will not set for a long time, which will affect the follow-up work. The thickening time with polyvinyl alcohol is higher than that without polyvinyl alcohol, indicating that polyvinyl alcohol has dispersibility to cement slurry. When 1.5% polyvinyl alcohol is added, the dispersion of cement slurry is the best.

Table 4. Initial consistency and thickening time of cement slurry

| Dispersant content % | Initial consistency / Be | Thickening time / min |
|----------------------|--------------------------|-----------------------|
| 0                    | 5                        | 336                   |
| 0.5                  | 9                        | 522                   |
| 1.0                  | 10                       | 528                   |
| 1.5                  | 25                       | 572                   |
| 2.0                  | 27                       | 525                   |
| 2.5                  | 29                       | 529                   |
3.2.2. **Cement slurry density and free liquid.** It can be seen from table 5 that the dosage of polyvinyl alcohol is increasing, the density is decreasing, and the volume of supernatant is decreasing. The more polyvinyl alcohol is added, the less free liquid is, and the better the quality of cement is. When the dosage of polyvinyl alcohol was 2.5%, the density was 1.62 g cm⁻¹ and the volume of supernatant was 0.2 ml. At this time, the density of cement slurry is the smallest and the free liquid is the least.

### Table 5. Effect of polyvinyl alcohol on density and free liquid of cement slurry

| Polyvinyl alcohol content% | density /g·cm⁻¹ | Free liquid volume /mL |
|---------------------------|----------------|-----------------------|
| 0                         | 1.83           | 2.0                   |
| 0.5                       | 1.80           | 2.0                   |
| 1.0                       | 1.80           | 0.7                   |
| 1.5                       | 1.78           | 0.5                   |
| 2.0                       | 1.62           | 0.2                   |

3.2.3. **Fluidity index and rheological coefficient of cement slurry.** Table 6 shows the fluidity index n and viscosity coefficient K of water slurry with different content of polyvinyl alcohol. It can be seen that the rheology of cement slurry is getting better and better with the increase of polyvinyl alcohol. When 1.5% polyvinyl alcohol is added, the fluidity index of cement slurry is 0.99852 and the viscosity coefficient is 0.05664. The fluidity of cement slurry is good and the viscosity is low. Comply with SY/t5504.3-2008. In addition, due to the viscosity of 2.0% and 2.5% polyvinyl alcohol, it is beyond the range of the viscometer.

### Table 6 Rheological properties of water slurry with different content of polyvinyl alcohol

| Polyvinyl alcohol content% | n         | K(Pa·S⁰) |
|----------------------------|-----------|----------|
| 0.5                        | 0.98202   | 0.03144  |
| 1.0                        | 0.99852   | 0.05664  |
| 1.5                        | 0.94610   | 0.31144  |
4. Conclusion
After adding dispersant into cement slurry, fluidity index increases and rheology improves obviously. When the dosage of dispersant is 1.5%, the fluidity index is the highest, the fluidity of cement slurry is the best and the viscosity is low. On the premise of adding 1.5% dispersant to the cement slurry with water cement ratio of 0.44, the consistency of cement slurry increases with the increase of polyvinyl alcohol content, and the rheological index is between 0 and 1, which is in line with SY/t5504.3-2008.

Acknowledgements
The work was supported financially by Shaanxi Provincial Key Research and Development Program (2019GY-136) and Youth Innovation Team of Shaanxi University. And we thank the work of Modern Analysis and Testing Center of Xi’an Shiyou University.

References
[1] Wang Zhiwei. Research on progress of cementing technology of PetroChina [J]. Western exploration engineering, 2021, 33(6): 34-35.
[2] Liu Xuepeng, Liu still Guang. Study on the action mechanism of oil well cement fluid loss additive [J]. Chemical research and application, 2017, 29(12): 1928-1932.
[3] Liu Xuepeng, Zhang Mingchang, Fang chunfie. Synthesis and properties of high temperature resistant oil well cement fluid loss additive [J]. Drilling fluid and completion fluid, 2015,32(6): 61-64.
[4] Wang Qingshun. Current situation and development trend of synthetic polymer fluid loss additive for oil well cement [J]. Drilling fluid and completion fluid, 2007, 2: 67-69.
[5] Guo Zihan, Li Ming, Yang Yan, Lu Ya, Guo Xiaoyang. Overview of research status of oil well cement fluid loss additive in recent years [J]. Modern chemical industry, 2015, 35(10): 49-53.
[6] Zhang Hongyin. Research and application of a new solid fluid loss additive [D]. Northeast Petroleum University, 2017.
[7] Xu Yonghui. Study on hydration mechanism of deep well cement [D]. Daqing Petroleum Institute. 2007.
[8] Zheng Chengsheng, Wang Huaiping, sun Zaichun. Research and application of water loss reduction materials for oil well cement at home and abroad [J]. Shandong science, 2004 (03): 49-54.
[9] Yuan Chunhua, Wu Fengying, Liu Yingfeng, et al. Harm of water loss of cement slurry and development status of oil well fluid loss additive, Inner Mongolia petrochemical industry, 2003, 29:201 202.
[10] Yang Xiaohua, Wang Zhonghua. Research and application progress of oil well cement admixture in China in recent 15 years [J]. Oilfield chemistry, 2004 (03): 290-296.
[11] Zhu Lei, Geng Yanan, Xu mingbiao, Wang Xiaoliang, Jin Yong. Laboratory study on ductile cement slurry system suitable for slim hole cementing [J]. Journal of petroleum and natural gas, 2014,36 (09): 106-108.
[12] Zhao Jun, Mei Wenbo, Xia Zhongyue, Xie Jiancheng, Jiang Lei. Study on flexible cement slurry system for slim hole cementing [J]. Chemical engineer, 2021, 35(1): 40-43.
[13] Guo Zihan, Li Ming, Yang Yan, Lu Ya, Guo Xiaoyang. Overview of research status of oil well cement fluid loss additive in recent years [J]. Modern chemical industry, 2015, 35(10): 49-53.
[14] Xue Yan. Research and application of fluid loss additive for oil well cement [J]. Utilization of rubber and plastic resources, 2008,1: 33-37.