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ScienceDirect

Natural Gas Industry B 2 (2015) 354—359

www.elsevier.com/locate/ngib

Research article

Contamination effects of drilling fluid additives on cement slurry

Zheng Youzhi [a,b], She Chaoyi [a,b], Yao Kunquan [c], Guo Xiaoyang [d], Zhang Huali [a,b], Yang Tao [a,b], Li Ming [d,*]

[a] *Gas Production Engineering Research Institute of Southwest Oil & Gas Field Company, PetroChina, Chengdu, Sichuan 610500, China*
[b] *Gas Production Engineering and Technology Research Institute, National Energy R&D Center of High-sulfur Gas Reservoir Exploitation, Guanghan, Sichuan 610083, China*
[c] *Engineering and Technology Supervision Department of Southwest Oil & Gas Field Company, PetroChina, Chengdu, Sichuan 610051, China*
[d] *School of Material Science and Engineering, Southwest Petroleum University, Chengdu, Sichuan 610050, China*

Received 6 January 2015; accepted 25 September 2015
Available online 29 November 2015

Abstract

During the cementation of deep wells, contamination at the contact surface between cement slurry and drilling fluid will present a technical challenge, which may threaten operation safety. To deal with the problem, lab tests and analysis were performed specifically on the compatibility of fluids during cementation in Sichuan and Chongqing gas fields. Impacts of commonly used additives for drilling fluids were determined on fluidity and thickening time of conventional cement slurry. Through the infrared spectrum analysis, SEM and XRD, infrared spectrum data of kalium polyacrylamide (KPAM) and bio-viscosifier were obtained, together with infrared spectrum, SEM and XRD data of cement slurry with additives. Contamination mechanisms of the cement slurry by conventional additives for drilling fluid were reviewed. Test results show that both KPAM and bio-viscosifier are such high-molecular materials that the long chains in these materials may easily absorb cement particles in the slurry to form mixed network structures; as a result, cement particles were prone to agglomeration and eventually lost their pumpability. Finally, assessment of and testing methods for the contamination effects of drilling fluid additives on cement slurry were further improved to form standards and codes that may help solve the said problems. This study will provide technological supports for the preparation of drilling fluids with desirable properties prior to cementation, the selection of optimal drilling fluids additives, and the development of innovative drilling fluids additives.

Keywords: Cement slurry; Drilling fluid; Interface contact contamination; Fluidity; Thickening time

Natural gas resources in the Sichuan—Chongqing region play an important role in guaranteeing national energy security. In recent years, more and more deep and ultra-deep wells have been drilled in this region as national energy demands increase continuously. For example, Well LG 63 in LG structure is 7050 m deep, and Well L 104 in JLS structure is 6320 m deep. As for deep wells, more requirements on cementing technologies should be satisfied. In the process of well cementation, cement injecting operation is the most important sector [1—3]. In order to solve more and more complex problems in oil and gas exploration and development in the Sichuan—Chongqing region, novel drilling fluid additives and composite cementing materials were frequently developed, but some drilling fluid additives are of poorly chemical compatibility with composite cementing materials, so cementing operation is delayed and drilling cost is increased. And to make it worse, safety accidents may be induced and even interlayer isolation formed by cement sheath is damaged [4,5]. In recent years, a series of countermeasures have been adopted, but complex cementing situations still

* Corresponding author.
E-mail address: swpulm@126.com (Li M.).
Peer review under responsibility of Sichuan Petroleum Administration.

http://dx.doi.org/10.1016/j.ngib.2015.09.009

occur in oil and gas fields in the Sichuan–Chongqing region. For example, the drilling fluids were not isolated completely by spacer fluids at the "oversized" interval when Well LG 001-3 was cemented with ø127 mm liners, so slurry contacted drilling fluids while it was running in the annulus, subsequently resulting in pipe stuck. In order to solve the interface contact contamination between cement slurry and drilling fluid, it is necessary to verify the effect rules and mechanisms of drilling fluid additives on the properties of cement slurry [6,7].

To deal with serious interface contact contamination between cement slurry and drilling fluid in some deep and ultra-deep wells in the Sichuan–Chongqing region, infrared spectrum analysis, SEM and XRD were adopted to investigate the contamination mechanisms of drilling fluid additives on cement slurry [6,8], so as to provide feasible suggestions on the optimization of drilling fluid additives for ultra-deep wells in this region and important reference for safe cementing operation, economical operation and good-quality cementation.

1. The effect of drilling fluid additives on the conventional properties of slurry

In this study, 14 types of commonly used drilling fluid additives were sampled on the site of gas well cementation in JLS block. Detailed investigation was performed on the effect rules of the 14 drilling fluid additives on fluidity and thickening time of conventional-density slurry by changing their dosages. The conventional-density slurry adopted in this test is the extended slurry which is used for the cementation of 177.8 mm casing in Well L002-4, i.e. Grade Jiajing G high-resistance oil well cement + 2.0% sweller + 1.4% fluid loss additive + 0.4% dispersant + 1.0% extender 1 + 0.12% extender 2 + 0.2% defoamer. Its water-cement ratio is 0.45, density 1.90 g/cm^3, normal-temperature fluidity 21 cm, high-temperature fluidity 22 cm (preset for 2 h at 90 °C in atmospheric thickening unit), and thickening time (105 °C × 60 MPa × 50 min) 300 min.

1.1. The effect rules of drilling fluid additives on the fluidity of conventional-density slurry

The test data are shown in Table 1.

Based on test results, the fluidity of conventional-density slurry is not or little affected by such drilling fluid additives as HSP, SHR, JN-A, MG-1, LS-2, KR102 and RCL-101, but seriously affected by SMP-1, KHM and YH-S whose dosages should be less than 1%, and to some extent, affected by SMT, SMC and bio-viscosifier whose dosages should be less than 1.2%, 2% and 0.5% respectively. The effect of KPAM on the fluidity of conventional-density slurry is uncontrollable.

1.2. The effect rules of drilling fluid additives on the thickening time of conventional-density slurry

After fluidity tests, HTHP contamination thickening test was conducted by adding 13 types of drilling fluid additives (excluding KPAM) with different dosages into conventional-density slurry (105 °C × 60 MPa × 50 min) (Table 2), so as to investigate the effect rules of drilling fluid additives on the thickening time of conventional-density slurry.

Based on test results, the thickening time of slurry can be prolonged by SMC, KHM, HPS, SHR, MG-1, LS-2, YH-S, RLC-101 and KR102 if their dosages are controlled in a certain range. The thickening time of slurry can be shortened by SMT, SMP-1 and JN-A, but their effects are controllable, so their dosages should be controlled below 0.5%, 0.3% and 0.3% respectively. Besides, it is sharply shortened by the bio-viscosifier, whose effect is uncontrollable.

To sum up, among the 14 types of drilling fluid additives that were commonly used in gas wells in JLS block, KPAM and bio-viscosifier have more contamination effect on the conventional-density slurry. In order to ascertain the contamination micro-mechanisms of these two additives on cement slurry and understand their physical and chemical properties, infrared spectrum analysis, SEM and XRD were conducted, so as to provide theoretical basis for settling down the contamination problems of cement slurry essentially [9–13].

2. Experimental analysis on the contamination effect of KPAM and bio-viscosifier on cement slurry

2.1. Infrared spectrum analysis

KPAM is the derivative of carboxylic potassium polyarylamide, with molecular weight of 2–3 million. As a kind of strong-inhibition shale dispersant, it can be used to control mud making in formations, reduce fluid loss, improve flow pattern, and increase lubricity. The major groups that are distinguished in KPAM by infrared spectrogram are shown in Table 3.

The bio-viscosifier is mainly composed of multiple fine industrial chemicals, with larger molecular weights. Its liquid phase viscosity is higher after it is dissolved in water. In the molecules of bio-viscosifiers, there are both adsorbing groups and hydrochemical groups. Networks are formed due to the inter-adsorption of adsorbing groups. Adsorbing groups are adsorbed at the surface of clay particles, so multiple clay particles are bonded on polymer chains and then bridges are built up. Besides, the viscosity of drilling fluids rises because the liquid phase viscosity of drilling fluids is increased by bio-viscosifiers. The major groups that are identified in the samples are shown in Table 4.

Fig. 1 shows the infrared spectrogram of samples of pure conventional-density slurry, conventional-density slurry + 0.3% KPAM and conventional-density slurry + 0.3% bio-viscosifier. It is shown that carbonate occurs around 1478.12 cm^{-1}, characteristic peak strength of C_3S around 454.84 cm^{-1} and liquid water around 3445.24 cm^{-1}. Around 3641.80 cm^{-1} is the vibration zone of hydroxyl of $Ca(OH)_2$, one of the hydrated products, which is the characteristic symbol of hydration. Compared with conventional density slurries, no obvious change occur in infrared spectrum after two types of additives are added to them.