Laboratory construction of a novel elastic self-sealing cement slurry

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Abstract. The elastic self-sealing cement slurry is a novel slurry system, which is capable of facilitating self-repairs of cement sheath in the extreme wellbore conditions, but it involves seldom approached. In this work, a novel elastic self-sealing cement slurry is designed and preliminarily established, by means of screening the functional additives. The main compositions of elastic self-sealing cement slurry are determined, which will provide important information for the development of high performance self-sealing cement slurry systems.

1. Introduction

The main objective of oilwell cement is to offer zonal isolation and well integrity, and to protect the casing and tubing. In most cases, conventional cement systems can meet these requirements; however, conventional cement is not always the effective way for more challenging reservoirs. For example, during the productive phase of the wellbore, set cement behind casing are subjected to stressed due to pressure and temperature changes in the wellbore. Not surprising, the cement sheath may develop cracks internally or debond at the casing or the wellbore creating flow pathways for unwanted fluid migration. Therefore, extreme conditions demand the development of specific cementing technologies.

Elastic self-sealing cement slurry is one of novel slurry systems, which introduces a self-repairing cementitious materials into compositions, allowing the cement to set, wherein upon a loss of structural integrity the set cement self-seals. As a result, the potential pathways of fluid migration in cement stones can be obstructed. Cavanagh et al [1] showed that for a self-sealing cement slurry, self-repair materials are fundamental to contribute to the self-sealing property. On the basis of such design, Dry et al [2] has successfully prepared an oil & gas activated self-sealing cement sheath, wherein a key swellable material is added to perform seal-repair by cold flow.

Previous studies disclosed that the elastomeric materials are one of crucial compositions to establish elastic self-sealing cement slurry system. The elastomeric material may be semi-crystalline, amorphous, partially amorphous, or the combinations described above [3-5]. In spite of various investigation on elastic self-sealing cement slurry system, the previous achievements appear to be limited in constructing such novel cement slurry. It is thus necessary to understand the design process of elastic self-sealing cement slurry, which will provide key information on development of high performance cement slurry suitable for different formations. As an ongoing study on high performance cement slurry, in the present
work, a latex cement slurry with elastic self-sealing property has been specially constructed, and the main compositions have been explored and analyzed in combination to the property requirements of cement slurry.

2. Laboratory tests
To determine the appropriate compositions of elastic self-sealing cement slurry system, the main additives linked with applied performance have been selected by means of laboratory tests. Previous studied showed that together with the elastomer, filtration reducer, retarder, dispersant, and toughener are indispensible to construct the elastic self-sealing cement slurry. So the basic formula of the elastic self-sealing cement slurry is: G class cement + 60wt.% fresh water + 30wt.% NaCl + 5wt.% filtration reducer + (0.3~1)wt.% dispersant + 0.5wt.% retarder + toughening agent + elastic material. The detailed type of additives will be investigated and defined.

Typical applied performance of cement slurry such as rheology, sedimental stability, filtrate loss, compressive strength, and thickening property have been systematically tested to design the elastic self-sealing cement slurry. Rheological data of the designed cement slurry were examined at 300, 200, 100, 6, and 3rpm using a Fann 35 viscometer. Filtration tests were performed at 60 \( ^\circ \text{C} \) and 7MPa by a filter tester, wherein the testing temperature was defined in terms of the wellbore environments. The thickening data of cement slurry were measured under the designed conditions with a thickening apparatus.

3. Results and discussion
3.1. Selection of filtration reducer
Filtration reducer is an important composition for the elastic self-sealing cement slurry system, which has a positive effect in controlling the solution loss. In order to determined effective type of filtration reducer, a set of additives involving CG88L, CG82L, CG81L, SY626L, and SY616L have been examined and the results are given in Table 1.

| Filtration reducer | Filtrate loss (ml) | \( \Phi \)300 | \( \Delta \rho \) (g/cm\(^3\)) |
|--------------------|-------------------|-------------|-----------------|
| CG88L              | 26                | 233         | 0.010           |
| CG82L              | 28                | 236         | 0.035           |
| SY626L             | 76                | /           | 0.010           |
| CG81L              | 46                | 243         | 0.030           |
| SY616L             | 80                | /           | 0.015           |

Table 1 tabulates the filtration loss, \( \Phi \)300 dial readings, \( \Delta \rho \) of the elastic self-sealing cement slurry with the considered filtration reducers. It can be easily observed from Table 1 that, the values of filtrate loss are in the range of 26~80ml, and CG88L has the minimum value, indicating the best effect of filtration loss control. Meanwhile, in the considered series, SY626L and SY616L, no testing value are obtained, suggesting much bad rheological property for the slurry systems. While for CG81L, CG81L, and CG88L, these specimen exhibit comparable rheology control capability, and \( \Phi \)300 readings vary from 233 to 243. A further comparison of \( \Delta \rho \) discloses that CG88L and SY626L has the strongest sedimental stability, whose \( \Delta \rho \) is as low as 0.01 g/cm\(^3\). Therefore, CG88L are recommended as the filtration reducer on the basis of the comparison of performance data.

3.2. Selection of retarder
Thickening performance of cement slurry is of importance to ensure the pumping capacity upon cementing, and such performance is generally controlled by the retarder. Herein, several types of
retarders such as lignosulfonates, cellulose, polycarboxylic acid, and polymers have been selected by evaluating their role played in thickening behaviors.

| Retarder | Dosage (%) | Thickening time (min) | Description                        |
|----------|------------|-----------------------|------------------------------------|
| Blank    | 0.0        | 180                   | /                                  |
| H21L-M   | 0.5        | 265                   | Thickening curve with right-angle-set set |
| CTR      | 0.5        | 267                   | Thickening curve with obtuse-angle-set set |
| PBT      | 0.5        | 192                   | Thickening curve with right-angle-set set |
| HPAA     | 0.5        | >300                  | Thickening curve with vibration     |
| DPSC     | 0.5        | 152                   | Thickening curve with vibration     |
| MPAA     | 0.5        | >300                  | Thickening curve with vibration     |

The obtained thickening data and the related description are summarized in Table 2. According to the data in Table 2, one can find that in the considered dosages, all of the thickening times are increased with exception of DPSC. In the referred systems, H21L-M, CTR, HPAA, and MPAA exhibit better thickening capability, and the thickening times exceed 260 min. Moreover, analysis on thickening curve shows that the cement slurry with retarder H21L-M has a right-angle-set, meaning a short liquid-solid conversion time, which is able to meet the application requirements. Hence H21L-M is selected as the retarder for the designed cement slurry.

### 3.3. Selection of dispersant

Dispersant is also fundamental to the cement slurry, which can adjust the rheological property by weakening the chemical association of cement particles. Herein 6 dispersants have been evaluated by examining the rheological data, filtration loss, and gel strength.

| Dispersant | Dosage (%) | Φ300 | Filtrate loss (ml) | Initial consistency (BC) | Gel strength (Pa) 10s | Gel strength (Pa) 10min |
|------------|------------|------|--------------------|--------------------------|------------------------|------------------------|
| CF44L      | 1          | 262  | 22                 | 18                       | 7/                     | 25                     |
| CF42L      | 1          | 293  | 62                 | 32                       | 9/                     | 47                     |
| CF46L      | 1          | 260  | 48                 | 18                       | 10/                    | 49                     |
| CF49L      | 1          | 270  | 32                 | 16                       | 9/                     | 28                     |
| UNF        | 0.3        | 247  | 49                 | 27                       | 17/                    | 32                     |
| FRC        | 0.3        | /    | 29                 | 39                       | 23/                    | 66                     |

The characteristic parameters of Φ300 readings, filtration loss, gel strength values of the investigated systems are collected in Table 3. In the investigated specimen, CF series present suitable Φ300 readings, wherein CF44L has the strongest filtration loss property than others. In addition, its initial consistency is equal to 18 BC, which means the proper rheological property for the designed cement slurry. A further comparison of gel strength tested shows that for the cement slurry with CF44L, the gel strength values are tested to be 7 Pa and 25 Pa at 10s and 10min, respectively, which are less than those tested in other systems, suggesting excellent pumping property. In combination of rheology and filtration loss, CF44L are finally recommended as the dispersant for the studied cement slurry.

### 3.4. Evaluation on toughening agent

Toughening agent is paramount to the comprehensive property of the cement slurry, which is, to some degree, able to determine, together with toughening capability, the rheological and filtration loss property. Previous studies showed that latex can perform well as toughener and, thus, latex is selected as toughener for the construction of elastic self-sealing cement slurry system [6, 7].
As the unique liquid toughener, latex functions are summarized as follows:
- Reducing the permeability of cement sheath;
- Improving the densify conversion performance of cement slurry;
- Reducing the elastic modulus of cementing bond;
- Improving the cementing quality between cement and pipe column, cement and formation interface, and preventing oil, gas and water channeling;
- Reducing the filtration of cement slurry.

3.5. Evaluation on elastometric agents

Elastometric agent is the most key composition in the elastic self-sealing cement slurry, which contributes mainly to the self-sealing behavior. In view of the early results, an elastometric material, RES, has been selected as the elastometric agent to construct the cement slurry system.

**Figure 1.** Deformation recovery tests of RES material: a. initial sample; b. 50% of compression; C. deformation recovery

The selected RES possesses the two main characters: (1) high elastic properties similar to rubber, and (2) modulus of elasticity in the range of 4.9~5.2 MPa. Figure 1 presents the recovery experiments of RES under a certain compression. It can be readily found that within the condition of strong compression and deformation, RES can recover the initial shape without cracks and damage, verifying its strong elasticity, which can be helpful for curing the potential damage of cement sheath.

**Figure 2.** Microstructure of RES upon recovery tests: (a) initial surface before the recovery test, (b) surface after the recovery test

Figure 2 further shows the RES microstructures before and after recovery tests. As can be seen in Figure 2, the surface of RES before recovery test appears to be very rough, and fine gel particles can be observed in the surface. After the recovery test, however, the RES surface becomes more compact and smooth than that before tests. Apparently, the compression load can has a large impact on the internal structure of RES material, which can facilitate the redistribution of gel particles in the material. It can
be concluded that an introduction of RES should effectively reinforce the self-sealing property of cement sheath.

4. Conclusions
In the present work, a novel elastic self-sealing cement slurry has been preliminarily established by a suite of laboratory tests. The main functional additives such as elastomer, filtration reducer, retarder, dispersant, and toughener have been determined by examining the rheological, filtration loss, and microstructure. These conclusions should be instructive to further design and develop high performance cement slurry.

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