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# Fluid loss control mechanism of using polymer gel pill based on multi-crosslinking during overbalanced well workover and completion

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ABSTRACT

Recently, polymer gel used as fluid loss pill for well workover and completion is reported more, while it mainly focuses on using single crosslinking mechanism. To the best of our knowledge, polymer gel based on multi-crosslinking is commonly used in the aspect of water shutoff. The theory of multi-crosslinking for preparing polymer gel has rarely been used in overbalanced well workover and completion. In this paper, we conduct experimental study to reveal the physical process and fluid loss control mechanism of the polymer gel pill based on multi-crosslinking during overbalanced well workover and completion. We propose the design philosophy of the multi-crosslinking based on two or three crosslinking reactions under different conditions. In this paper, the first gelation reaction of the target polymer gel is between a kind of high-temperature resistance acrylamide based polymer (abbreviated as "SPAM") and fresh chromium acetate as metallic-ion crosslinker to quickly form a pre-crosslinking gel with strength of around Code C at surface temperature of 30 °C. It aims at guaranteeing pumping performance and restricting free water for lowering the risk of fluid loss in inner tube wall and or the separation of polymer and crosslinker during pumping process. Subsequently, with the increasing of wellbore temperature during the pumping process, the pre-crosslinking gel will gradually become mature (when gel reaches at the final gel strength) to form high strength gel by the use of either polyethyleneimine (PEI) or hexamethylenetetramine (HMTA) or both as organic crosslinker(s) through covalent bonding. The mature polymer gel can realize the complete crosslinking structure to guarantee gel thermal stability. The mature polymer gel pill based on multi-crosslinking formulated with a combination of SPAM, fresh Chromium acetate, PEI and HMTA indicates an obvious viscoelasticity characteristic at high temperature of 150 °C, while exhibiting a notable elastic performance for the formula without crosslinker HMTA. The fluid loss evaluation experiment result shows that the mature polymer gel based on multi-crosslinking can really act as fluid loss pill to withstand high positive pressure during overbalanced well workover and completion. Whilst there is some degree of permeability damage for the treated core, but not too high. Besides, the scanning electron microscope (SEM) is further employed to reveal the fluid loss control mechanism of the mature polymer gel at the micro level. This study provides an avenue to implement polymer gel pill based on multi-crosslinking for fluid loss control during overbalanced well workover and completion.

## 1. Introduction

Mature oil and gas fields around the world have been developed into production decline stage. The formation pressure coefficient is greatly decreased due to long-term development. Therefore, using conventional brine as working fluid for well workover and completion can provide high positive pressure in depleted reservoir. Hence, the depleted reservoir will face serious fluid loss during overbalanced well workover and completion. Working fluid is required to have the function to control fluid loss and bear high positive pressure.

Numerous well workover and completion fluids are developed in the past decades. For instance, solid-free working fluids commonly use polymer as the filtrate reducer to control fluid loss [1–3]. But the solid-free working fluid often cannot bear high positive pressure work condition in low pressure reservoir, which can induce serious fluid loss. A variety of foam workover fluids are developed to reduce the working positive pressure for a better temporary plugging performance in the low pressure reservoir [4,5]. However, foam system has complex formulations composed of many additives such as foaming agent, thickening agent, stabilizing agent etc, which can bring out the complexity of

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**Table 1**
Gel Strength Code.

| Gel strength code | Gel description |
|---|---|
| A | No detectable gel formed: The gel appears to have the same viscosity as the original polymer solution. |
| B | Highly flowing gel: The gel appears to be only slightly more viscous than the initial polymer solution. |
| C | Flowing gel: Most of the gel flows to the bottle cap by gravity upon inversion. |
| D | Moderately flowing gel: Only a small portion (5–10%) of the gel does not readily flow to the bottle cap by gravity upon inversion (usually characterized as a tonguing gel). |
| E | Barely flowing gel: The gel can barely flow to the bottle cap and/or a significant portion (> 15%) of the gel does not flow by gravity upon inversion. |
| F | Highly deformable nonflowing gel: The gel does not flow to the bottle cap by gravity upon inversion. |
| G | Moderately deformable non flowing gel: The gel deforms about half way down the bottle by gravity upon inversion. |
| H | Slightly deformable nonflowing gel: only the gel surface slightly deforms by gravity upon inversion. |
| I | Rigid gel: There is no gel surface deformation by gravity upon inversion. |

**Table 2**
Composition of test gel formulas.

| Sample | SPAM weight concn,% | Chromium acetate weight concn, % | PEI weight concn, % | HMTA weight concn, % |
|---|---|---|---|---|
| **A** | 2 | 0.1 | 0.5 | 0 |
| **B** | 2 | 0.1 | 1 | 0 |
| **C** | 2 | 0.1 | 1.5 | 0 |
| **D** | 2 | 0.1 | 0.5 | 0.2 |
| **E** | 2 | 0.1 | 1 | 0.4 |
| **F** | 2 | 0.1 | 1.5 | 0.6 |

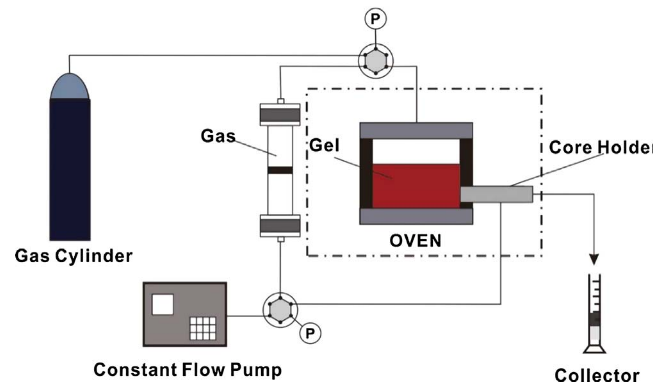


**Fig. 1.** Set-up diagram for fluid loss evaluation experiment.

**Table 3**
Physical parameters of core.

| Sample | Length,cm | Diameter,cm | Porosity, % | Gas permeability,mD |
|---|---|---|---|---|
| **1** | 5.02 | 2.51 | 14.40 | 11.13 |
| **2** | 5.01 | 2.50 | 16.00 | 29.06 |
| **3** | 5.03 | 2.50 | 13.60 | 30.52 |
| **4** | 4.98 | 2.50 | 16.50 | 76.09 |

**Table 4**
Gelation performance of various gel formulas.

| Sample | Strength code of gel at different time | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 30 °C | | | 150 °C | | | | | | | |
| | 1 h | 2 h | 3 h | 1 d | 2 d | 3 d | 5 d | 7 d | 10 d | 12 d | 15 d |
| A | A | B | C | H | H | H | H | H | H | H | H |
| B | A | B | C | H | H | H | H | H | H | H | H |
| C | A | B | C | H | H | H | H | H | H | H | H |
| D | A | B | C | H | H | H | H | H | H | H | H |
| E | A | B | C | H | H | H | H | H | H | H | H |
| F | A | B | C | H | H | H | H | H | H | H | H |

fluid preparation as well as high operation cost. In addition, the long-term foam stability is also a big question. The solidified water working fluid has been successfully applied in well workover and completion jobs [6]. But this fluid cannot withstand the high positive pressure during overbalanced operation. Today, polymer gel has been widely used as water shutoff or conformance control agent in the enhanced oil recovery aspect [7,8]. The mature $Cr^{3+}$/HPAM gel used for water shutoff can represent favorable sealability to reduce filtration in the fractured reservoir [9,10]. The PEI/HPAM gel also indicates favourable sealability to resist water flow in the fractured reservoir [11]. Hence, it is deduced that using polymer gel as workover fluid has the potential to perform temporary plugging ability in high permeability zone during overbalanced well workover and completion. To the best of our knowledge, the polymer with complex macromolecule chain is difficult to penetrate the pore throat. Additionally, the crosslinked polymer has the potential to form three-dimensional structures with strong structure strength to improve the temporary plugging performance. Recently, polymer gel used as workover fluid for fluid loss control is aroused some attention. For instance, a crosslinked polymer used for fluid loss control was prepared by hydroxyethylcellulose (HEC) crosslinking with metal ions [12–14]. The organically crosslinked polymer sealant for near-wellbore applications is developed by the use of copolymer of acrylamide and t-butyl acrylate (PAtBA) crosslinking with PEI to form a mature gel system [15]. Gamage et al. [16] prepared polymer gel as fluid loss control pill for overbalanced well workover in high-temperature reservoirs. This gel is prepared by a synthetic water-soluble polymer crosslinking with a metal crosslinker. Sun et al. [17] reported a nanocomposite hydrogel used as well killing fluid, which is formulated with a combination of HPAM, added Chromium acetate and Nano silica. However, the aforementioned polymer gels used for workover and completion mainly focus on single crosslinking. As is well-known, the multi-crosslinked polymer gel is often used in the aspect of water shutoff [18–22], and the multi-crosslinking gel system is rarely reported in overbalanced well workover and completion. Whether the mature polymer gel based on multi-crosslinking has the potential to control fluid loss during overbalanced well completion and workover is worth to investigate. In this paper, we propose the design philosophy of the multi-crosslinking including two or three crosslinking reactions under different conditions. In this study, the first gelation reaction of the target polymer gel is between SPAM and fresh Chromium acetate as metallic-ion crosslinker to quickly form a pre-crosslinking gel with strength of around Code C at surface temperature. We choose the surface temperature of 30 °C as a representative to study the pre-crosslinking behavior of the target gel. The pre-crosslinking strategy aims at guarantying pumping performance. Besides, the pre-crosslinking gel can restrict all components of polymer gel system to reduce the adsorption in the pipeline and prevent the separation of polymer and crosslinker during pumping process, which can guarantee the subsequent gelation performance in the well bottom. Subsequently, with the increasing of wellbore temperature during the pumping process, the pre-crosslinking gel will gradually become mature by the use of either PEI or HMTA or both as organic crosslinker(s) through covalent