Novel Responsive Controllable Solidification Plugging Agent to Overcome Lost Circulation Problems in Long Open Hole Intervals

Long Li¹, Da Yin² and Weiwei Hao¹

¹CNPC Engineering Technology R&D Company Limited, Beijing 102206, China
²PetroChina Tarim Oilfield Company, Korla 841000, China
E-mail: lilongdr@cnpc.com.cn

Abstract. A new type of responsive controllable solidification plugging agent (RCSP) for long open hole intervals was developed, and the sealing characteristics were evaluated. RCSP had the characteristics of rapid water loss, high filter-cake consistency and good residence capacity. The experimental results indicated that the maximum pressure-bearing capacities of plugged zones in 5 mm and 10 mm slotted templets are 16.6 MPa and 11 MPa, respectively. So RCSP is an effective plugging agent for strengthening wellbore stability. RCSP is appropriate for sealing wide range of fracture sizes. Using RCSP-based plugging mud to address lost circulation problems in troublesome thief zones is a very powerful and economical approach. In the future, RCSP might hold great promise to resolve lost circulation problems in multiple leakage zones in long open hole sections.

1. Introduction

Lost circulation can be defined as the loss of drilling fluids or cement slurries into the formation either partially or completely, and it is one of the most common and costly problems in drilling and well construction [1-3]. The partial or total losses of drilling fluids may lead to serious borehole instability problems. The uncontrolled flow of wellbore fluids into formation while drilling or primary cementing can lead to substantial non-productive time (NPT) [4-6]. Since it can increase borehole instability problems and differential sticking, many of drilling problems could be directly related to loss circulation.

Preventing loss circulation is very challenging. For the abnormal pressure zones and natural fractures, fluid loss could not be prevented by simply improving the rheological properties of drilling fluids. During the drilling operation of abnormal high pressure formation in long open hole intervals, due to the drilling-induced or natural fractures that allow the fluids to enter the formation, serious lost circulation problems may occur [7-9]. It is very difficult to locate the leakage zone of these induced leakages, so it will bring great challenge to plugging technology. In addition, there are usually multiple induced leakage points for the long barefoot intervals in the deep drilling of abnormal high pressure formations [10-13]. Lost circulation materials to prevent the losses of drilling fluids involve approaches to prevent the initiation of fractures and to inhibit the growth of any pre-existing or drilling-induced microfractures [14-17].

A new kind of responsive controllable solidification plugging agent (RCSP) is prepared, and it has the advantages of high filter-cake consistency, good residence capacity and high bearing pressure. In the process of plugging operation, due to rapid water loss and high water loss, RCSP could enter the thief zones and accumulate effectively, and the compact sealing layer could be obtained, so the leakage channel could be sealed efficiently.
RCSP are considered an efficient plugging material that can seal wide range of fracture sizes, and it is a novel consolidating plugging agent for strengthening wellbore stability. Using RCSP to control lost circulation is a very powerful and economical approach to resolve multiple leakage zones in long open hole well sections. In addition, the RCSP-based plugging mud might hold great promise to address instability problems in long horizontal intervals.

2. Preparation of RCSP

Given the nature of high water loss plugging agent, RCSP is composed by filtration material, fiber web-forming material, and gelling material. All things considered, RCSP should have the characteristics of rapid water loss, high water loss, high filter-cake consistency and good stability.

Taking into consideration of various components, the proportion of filtration material, fiber web-forming material, and gelling material is optimized, and a new kind of responsive controllable solidification plugging material is developed.

Formula of RCSP: (30-45%) filtration material + (30-45%) fiber web-forming material + (25-30%) gelling material.

After RCSP and fresh water are mixed and stirred fully, a kind of plugging mud with good suspension and strong fluidity is prepared. The filter cake formed under high-pressure conditions could be used to seal the formations with porous leakage or fractured leakage.

3. Results and Discussion

3.1. The Evaluation of Suspension Stability

Due to poor suspension stability, the preparation of plugging mud is difficult, and it's easy to be deposited in the drilling tools for the plugging mud under exceptional circumstances, resulting in the failure of plugging operation. When the plugging mud has been prepared, it is very important not to be deposited in a certain amount of time to meet the requirements of the preparation and pumping of plugging mud.

![Figure 1. The evaluation of water absorption rate of different concentrations of plugging mud containing RCSP](image)

A certain amount of plugging mud is poured into 100 mL glass cylinder, and the fresh water can be separated out from the plugging mud. The volume of separated fresh water at different times is water absorption rate. Generally, the water absorption rate should be less than 20%. The poor suspension stability of different concentrations of plugging mud containing RCSP is tested in Figure 1.
As shown Figure 1, the results indicate that the higher the concentration of plugging mud containing RCSP, the lower the water absorption rate. In addition, the water absorption rate can be raised with the increase of standing time. The water absorption rate of different concentrations of plugging mud containing RCSP in 1 min is less than 5%, and the water absorption rate of different concentrations of plugging mud 60 min is less than 20%, so the plugging mud containing RCSP have good suspension stability, and it could meet the requirements of safety plugging operation.

3.2. The Filtration Properties

The filtration performance of RCSP is the key performance indicators for plugging operation. Based on the sealing mechanism, the filtration properties are composed by total filtration time, filtration loss and filter-cake consistency. The total filtration time is the most important parameter that has important effect on the residence speed of obtained filter cake from plugging mud under differential pressure.

The evaluation of total filtration time and filtration loss. Based on API filter loss test method, the total filtration time and filtration loss of different concentrations of plugging mud containing RCSP at a pressure of 0.69 MPa are showed in Figure 2.

The experimental results indicate that the total filtration time of different concentrations of plugging mud containing RCSP is 10-15 s, and the filtration loss of different concentrations of plugging mud is 102-152 mL. The filtration rate and filtration loss can be raised with the increase of the concentration of plugging mud containing RCSP. As a result, the faster the residence speed of plugging mud in leakage zone, the higher the enrichment density of plugging materials in sealing layer, the higher the plugging success rate.

Figure 2. The evaluation of total filtration time and filtration loss of plugging mud containing RCSP

The thickness and compressive strength of filter cake. Figure 3 demonstrates the thickness and filter-cake compressive strength of filter cake from different concentrations of plugging mud containing RCSP. As the concentration of plugging mud containing RCSP increases, the thickness and compressive strength of filter cake can be increased gradually. The thickness of filter cake is 21-24 mm, and the compressive strength of filter cake is 3.4-9.5 MPa. All these can be explained by: the higher the concentration of plugging mud containing RCSP, the higher the solid content of plugging mud, the thicker the filter cake after total filtration, the higher the compressive strength of filter cake. Therefore, based on different leakage features, such as leak-off velocity and fracture width, the appropriate concentration of RCSP could be designed scientifically, and different concentrations of bridging materials could be introduced.
3.3. The Evaluation of Plugging Ability

**The residence capacity.** The effective residence of plugging agent in the leakage channel is very important for the formation of sealing plug. In the sealing analog device with different sizes of slotted templets, the residence capacity of plugging mud with 50% concentration of RCSP is evaluated under the natural gravity, as shown in table 1.

**Table 1.** The evaluation results of residence capacity of plugging mud containing 50% concentration of RCSP in different slotted templets

| Number | Formulas for plugging mud | Fracture width/mm | Evaluation results |
|--------|---------------------------|-------------------|--------------------|
| 1      | fresh water +50% RCSP     | 1                 | Rapid residence, no leakage |
| 2      |                           | 3                 | Rapid residence, the percentage of leak mud is 5% |
| 3      |                           | 5                 | Unable to reside effectively, all the plugging mud is missing |
| 4      |                           | 10                | Unable to reside effectively, all the plugging mud is missing |
| 5      | fresh water +50% RCSP+3.5% 1-3 mm bridging particles | 5 | Effective residence, the percentage of leak mud is 15% |
| 6      | fresh water +50% RCSP+3.5% 1-3 mm bridging particles+2.5% 3-5 mm bridging particles | 10 | Effective residence, all the plugging mud is missing |
| 7      | fresh water +50% RCSP+3.5% 1-3 mm bridging particles+2.5% 3-5 mm bridging particles | 5 | Effective residence, the percentage of leak mud is 10% |
| 8      | 5 mm bridging particles    | 10                | Effective residence, the percentage of leak mud is 18% |

The experimental results indicate that the plugging mud containing RCSP could reside effectively in the slotted templets with size of 1 mm and 3 mm. There are not large-grained bridging plugging materials in plugging mud, but the size grading of solid phase particles in plugging agent and fiber material could play an important role in bridging and residing.

The residence of plugging mud containing RCSP becomes more and more difficult with the increase of fracture width. The plugging mud containing RCSP can not reside in 5 mm and 10 mm slotted templets, and all the plugging mud is missing rapidly, but the plugging mud containing RCSP could
reside effectively when a certain amount of composited material is added to plugging mud. With the increase of fracture width, the concentration and particle size of composited bridging particles in plugging mud should be increased. For instance, 3.5% concentration of 1-3 mm bridging particles should be added to plugging mud to meet the requirement of effective residence of plugging mud in 5 mm fracture, but 2.5% concentration of 3-5 mm bridging particles should be added to plugging mud for effective residence in 10 mm fracture.

As a result, a certain size of bridging particles could improve the residence time of plugging mud in leakage zones. Based the lost circulation feature and fracture width, a given concentration of composited bridging particles with suitable particle size should be added to improve the residence capacity of plugging mud in plugging operation.

**The test of sealing characteristics.** The plugging mud containing RCSP is prepared, and the plugging performance of RCSP is evaluated by HTHP sealing analog device. Using 5 mm and 10 mm slotted templets to simulate the leakage zone, the sealing strength of plugged zone produced from plugging mud containing RCSP is shown in Figure 4.

The results indicate that the plugging mud could reside and pile up in the simulated leakage zone. When the squeezing amount is less than 200 mL, the squeeze pressure is low, and rapid water loss is encountered. When the squeezing amount is more than 250 mL, the complete filtration of plugging mud is encountered. The squeeze pressure rises gradually with the increase of squeezing amount. The plugging mud containing RCSP is compacted gradually in the leakage zone, and the highest pressure-bearing capacities are 16.6 MPa and 11 MPa, respectively.

![Figure 4](image-url)

**Figure 4.** The evaluation of sealing ability of plugging mud containing RCSP in 5 mm and 10 mm slotted templets

4. Conclusions
(1) A new kind of lost circulation agent for plugging material in long open hole intervals is prepared. RCSP has the advantages of rapid water loss, big water loss and high filter-cake consistency.

(2) RCSP has good residence capacity. The plugging mud containing RCSP could the requirement of different sizes of fractures if a given concentration of composited bridging particles with suitable particle size are added.

(3) The highest pressure-bearing capacities of plugged zones obtained from plugging mud containing RCSP in 5 mm and 10 mm slotted templets are 16.6 MPa and 11 MPa, respectively. So RCSP could resolve lost circulation problems in long open hole intervals, and thus improve wellbore strength greatly.

RCSP are considered an efficient plugging material that can seal wide range of fracture sizes, strengthen the wellbore and provide solution for lost circulations under extreme drilling conditions.
conditions. RCSP could play an essential role in sealing the leakage intervals in long open hole section, improving wellbore stability, and avoiding severe drilling problems. In the future, RCSP might hold great promise to resolve lost circulation problems in long horizontal intervals.

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