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Research article

An optimal design for millimeter-wide facture plugging zone

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Abstract

Lost circulation control in millimeter-wide fractures has been a challenge in well drilling all the time. Low pressure-bearing capacity of a plugging zone will result in excessive consumption of lost circulation materials (LCMs) and extra down time. In this study, laboratory experiments were conducted on the plugging of millimeter-wide fractures to evaluate the plugging effects of different types of LCM including rigid granules, elastic particles and fiber. Maximum plugging pressure, total loss volume before sealing and plugging time were taken as the evaluation index of the LCM plugging effect. According to the experimental results, the synergistic plugging mechanisms of different LCM combinations were also analyzed. Experimental results showed that the total loss volume of the plugging zone formed by rigid and elastic particle combination was generally greater than 400 mL, and the maximum plugging pressure of the plugging zone formed by elastic particle and fiber combination was generally less than 6 MPa. In contrast, the plugging zone formed by the combination of the three types of LCMs has the maximum plugging pressure of up to 13 MPa and total loss volume before sealing of 75 mL. In the synergistic plugging process, rigid granules form a frame with high pressure-bearing capacity in the narrower parts of the fractures; elastic particles generate elastic force through elastic deformation to increase the friction between a fracture and a plugging zone to make the plugging zone more stable; fibers filling in the pore space between the particles increase the tightness and integrity of the plugging zone. The experimental results can provide guidance for the optimal design of LCMs used in the field.

Keywords: Millimeter wide; Fracture plugging zone; Optimal design; Pressure bearing capacity; Rigid granule; Elastic particle; Fiber; Material synergy

Naturally fractured formation is one kind of the most commonly encountered formations. Lost circulation, which often causes a series of downhole problems, happens frequently during the drilling of this kind of formations [1]. Drilling fluid loss will lead to the increase of down time and have a negative impact on some important geological work. Researchers and engineers have made a lot of research on the lost circulation prevention and plugging during drilling [2—5]. The bridging method, as a most commonly used method, has always been the focus of attention [6—8]. As the EMW increases along with drilling depth, the plugging zone needs to meet the required pressure-bearing capacity after formed in the fracture, so Xu Chengyuan came up with a sealing strategy to enhance the pressure-capacity of plugging zones [9]. A dual fiber method proposed by Andrade in which the tough fiber formes a bridge and the soft fiber fills the gap, was successfully used in plugging the circulation loss in the fields in southern Mexico [10]. Li Jiaxue proposed a method to form a bridge at the fracture mouth with rigid particles, and calculated the particle size distribution based on the fracture width [11]. Kefi introduced a sealing method with the synergy effects of fibers forming a bridge and particles filling the gaps; he also presented a method to calculate the stiffness of fiber based on fracture width and differential pressure [12]. Jia Lili, Friedheim, Whitfill and Mao Hongjiang summarized the mostly used lost circulation materials (LCM) and predicted LCM development direction in the future [13—17]. Yan Fengming proposed the thought of temporary sealing, which involves forming a tight plugging zone at the fracture mouth with acid soluble materials [18], so the plugging zone could be easily

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removed with acids before production. It can be seen that methods for controlling loss circulation caused by micro fractures have been fairly mature.

Fracture width commonly ranges from several microns to several hundred microns under in situ formation stress [19], but often increases to millimeters as the stress state around the wellbore changes during drilling process, which results in a sharp increase in the rate and the amount of drilling fluid loss. In addition, the dynamic changes of fracture width with the stress state makes the plugging operation difficult. There are several difficulties in plugging fractures of millimeter width: ① LCM can hardly form a seal at the fracture mouth because of the large fracture width and high lost rate, and LCM flows into deep formations easily along with drilling fluid; ② the plugging zone formed by large size LCM is not tight and stable enough; ③ fracture width changes dynamically with pressure variation, so conventional LCM can't adapt to the change, making previously formed plugging zones prone to failure. In order to deal with millimeter fracture lost circulation more efficiently, laboratory experiments were conducted to select plugging materials and optimize the LCM formula.

1. Plugging mechanisms of different kinds of LCM

1) Fibers. Fiber is a common kind of LCM. When added in drilling fluid, fiber longer than the fracture can form a bridge and subsequently capture other fiber, forming a network structure which will enhance the total stability of fracture-plugging zone. Different kinds of fibers play different roles in the process of plugging. Hard fibers can be used to bridge, while soft fibers with low rigidity can intertwine and make the network more dense. But since fibers are low in rigidity on the whole, the maximum plugging pressure formed by fibers only cannot withstand large differentiate pressure. Soft fibers(DTR [20], QP-1) and hard fibers with different stiffness (plastic fibers, animal hair) were used in the experiments in this study (Fig. 1).

2) Rigid granules. Rigid particles, with high stiffness and compressive strength, act as frames in a plugging zone [21]. In field operations, quartz, walnut shells, $CaCO_3$ and broken cuttings are often used as rigid granules. In the process of plugging, rigid granules can bridge in the narrower part of the fracture and subsequent particles will be stopped and accumulate in the fracture. To form a fracture-plugging zone with rigid granules alone, the rigid granules should have different sizes so that the smaller sized granules can fill into the pore space between the larger granules. But the tightness of the fracture-plugging zone formed with rigid granules of different sizes is still not high enough because of the limit of granule shapes and sizes, so fiber and elastic particles are needed to further improve the tightness of the plugging zone. Walnut shells were selected as rigid granules in this paper. According to the granule size selection method, the bridging particle size should be smaller than the fracture width and larger than 0.6 times that of fracture width. Therefore, walnut shells of (8−12) mesh were chosen as the bridging particles in this paper.

3) Elastic particles. The addition of elastic particles will increase the friction between the plugging zone and the fracture surface because of their elastic deformation, thus improving the stability of the plugging zone. However, the plugging zone formed with elastic particles alone has lower maximum plugging pressure and tightness compared with the plugging zone formed with rigid granules alone and fibers alone because of its relatively lower stiffness and flexibility compared with rigid granules and fibers. According to the analysis above, different types of LCM have their advantages and disadvantages. In this study, rigid granules, fibers and elastic particles were used together to fully exploit their advantages and make up their disadvantages on the plugging effect.

2. Laboratory evaluation of plugging effect with LCM combinations

2.1. Experiment design and evaluation method

The objective of the laboratory experiments conducted in this study is to determine the optimal LCM combination and concentration for plugging millimeter-wide fractures and investigate the synergistic plugging mechanisms of different LCM combinations. Core samples with the fracture width of 2 mm were used for experimental evaluation (Fig. 2). To make sure the permeability is comparable the specimen has the same fracture before and after the fracture-plugging process. The experimental temperature was indoor temperature. The formula and the property of the basic fluid are shown in Tables 1 and 2.

Three key indexes were adopted to evaluate the plugging effect of LCM in this study: maximum plugging pressure, plugging time and total loss volume before sealing. Maximum plugging pressure refers to pressure a fracture-plugging zone

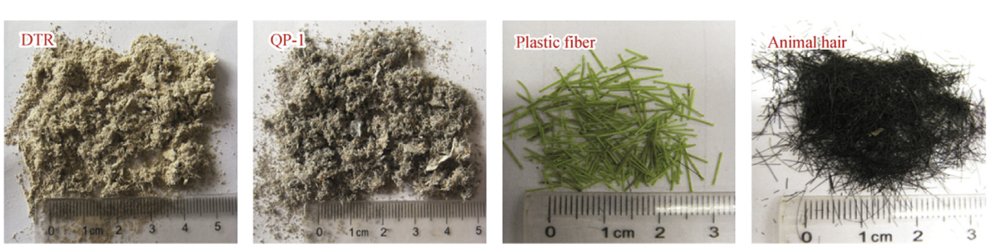

Fig. 1. Fibers and hair used for laboratory evaluation.