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Original article

The influence of water-based drilling fluid on mechanical property of shale and the wellbore stability

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ABSTRACT

Because of high cost and pollution of oil-based drilling fluid, the water-based drilling fluid is increasingly used now. However, bedding planes and micro-cracks are rich in shale formation. When water-based drilling fluid contacts formation rock, it causes the propagation of crack and invasion of drilling fluid, which decrease shale strength and cause wellbore instability. In this paper, we analyzed influence of water-based drilling fluid on shale strength and failure mode by mechanics experiment. Based on those experimental results, considering the effect of bedding plane and drilling time, we established modeling of wellbore stability for shale formation. The result from this model indicates that in certain azimuth of horizontal well, collapsing pressure increases dramatically due to shale failure along with bedding plane. In drilling operation, those azimuths are supposed to be avoided. This model is applicable for predication of collapsing pressure in shale formation and offers reference for choosing suitable mud weight.

1. Introduction

As a kind of unconventional energy sources, currently shale gas plays an important role in industrialization exploration of the natural gas [1]. In the shale gas exploration and development, the United States is leader in the world. Though China has abundant shale reserves as America, the development of shale gas is on elementary stage and faces so many challenges. Especially in drilling operation, borehole collapse has been a common problem [2], which increases drilling period and cost.

In view of the instability problem, normally oil-base drilling fluid is the first choice because of its relatively strong plugging and inhibitive property. But the defect of oil-base drilling fluid is too expensive and harmful to environment [3]. On the contrary, water-based drilling fluid has comparatively low prize and pollution. Therefore, many scholars are trying to develop an efficient water-based drilling fluid for shale formation. However, shale formation has strong anisotropy and sensitive for water fluid, leading to serious instability problems in drilling process.

In this paper, composition and structure of shale have been investigated by means of X-ray diffraction (XRD) and Scanning electron microscope. Meanwhile, triaxial compression test and shear test have been applied to observe its mechanics property. By those experiments, the effect of water-based drilling fluid on structure and mechanics can be analyzed. Those analyses indicate that crack propagation and bedding plane are two key factors of causing borehole collapse in shale formation. According to the result, we establish a wellbore stability model for shale formation. This model is practical for analyzing wellbore stability in shale formation.

2. Structure and composition of shale

2.1. Structure of shale

Rock samples were taken from Southern China Longmaxi formation of black shale. Bedding plane is clearly observed from

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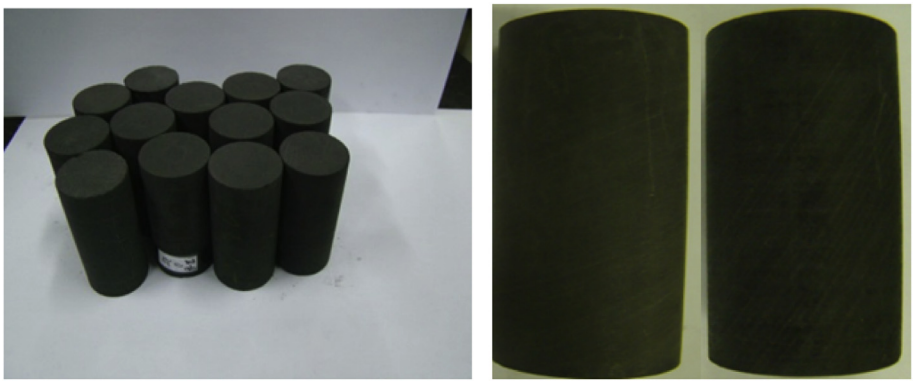

Fig. 1. Shale core samples.

standard shale cores (Fig. 1). Moreover, Scanning electron microscope was applied to observe substructure morphology of shale. The result in Fig. 2 shows micro-cracks and micro-pores are rich inside shale. By measurement, width of micro-cracks ranges from 0.4 μm to 3 μm.

2.2. Mineral composition and content analysis

XRD analysis results are presented in Table 1 and Table 2. In those samples, brittle mineral (quartz, plagioclase and calcite) is predominated and its average content is 80.77%, whereas clay mineral only averages 12.92% and ranges between 11.12% and 14.10%. In clay mineral, illite is the main content and averages 85.80%. Montmorillonite is extremely little and only averages 0.01%.

It is noted that content of brittle mineral is very high and clay mineral is not the abundant one in the component. In addition, Montmorillonite and illite smectite, which have strong hydration and swelling property, are in low content. According to that, the shale from Southern China Longmaxi formation is typical brittle shale and has weak hydration. So hydration swelling is not the key factor for borehole collapse.

3. Effect of water-based drilling fluid on mechanics of shale

Bedding plane has huge impact on strength of shale [4,5]. To analyze this type of mechanics structure, we assume that shale rock is composed by 2 parts—rock matrix and bedding plane. We use 2 methods to get shale strength by shear test (Fig. 3) so that obtain the strength of rock matrix and bedding plane respectively. In this experiment, we can get strength of rock matrix by shearing core in the direction perpendicular to bedding plane (Fig. 3a) and strength of bedding plane by shearing core in the direction parallel to the bedding plane (Fig. 3b).

According to above methods, shear test was used to obtain the strength of matrix and bedding plane after shale was soaked with water-based drilling fluid in different time. The results are presented in Fig. 4 and 5.

From results of Figs. 4 and 5, internal friction angle and cohesion of rock matrix are higher than bedding plane, which indicates bedding plane is relatively weak plane. After soaking water-based drilling fluid, the strength of bedding plane declines more quickly, which means that bedding plane is affected more by drilling fluid. The reason for that is the bedding plane has relatively high permeability, compared to rock matrix [6]. Therefore, it is easier for drilling fluid to penetrate inside. Consequently, bedding plane is more sensitive to water-based drilling fluid. Compared with decline trend of rock matrix and bedding plane, it is similar. Both of they drop dramatically firstly and then become stable in the late stage, which means the influence of drilling fluid is more obvious in initial stage.

To analyze the failure mode of shale, triaxial test was conducted along with the parallel and perpendicular direction of bedding plane, as shown in Fig. 6. Broken shale cores after triaxial test are illustrated in Figs. 7 and 8. Based on the results, different compressing direction has little influence on failure mode, which is still mainly single shear failure mode. In addition, there are several cracks around shear plane. With increase of

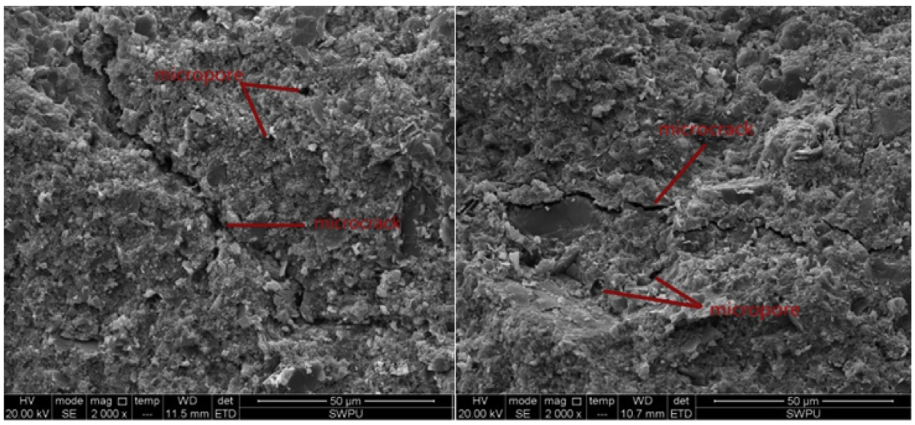

Fig. 2. Substructure morphology shale specimens.