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Research Progress on Casing Deformation Mechanisms of Horizontal Wells in Coalbed Methane Reservoirs

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Abstract

With the advancement of coalbed methane exploration and development into deep formations and structurally complex areas, horizontal well technology has become a key means for the development of deep CBM. However, casing deformation problems occur frequently throughout its full life cycle, severely restricting the efficient development of horizontal wells. Based on existing literature, this paper systematically combs the core mechanisms of casing deformation in CBM horizontal wells from two major dimensions: geological factors and engineering factors. In terms of geological factors, the anisotropy of in-situ stress field and reservoir heterogeneity, the special mechanical properties of coal rocks with granulated and cataclastic structures, and the migration of overlying strata and mining-induced stress disturbance are the root causes. Among engineering factors, drilling and completion processes and well trajectory design, as well as defects in cementing quality and cement sheath performance, are important auxiliary causes. Meanwhile, this paper summarizes the controversial points in current research regarding core inducing factors and quantitative numerical simulation. Finally, it is pointed out that future research needs to deepen the study on the coupling mechanism of geological-engineering factors and promote the integration of mechanism research with engineering practice, so as to provide a theoretical basis for the optimization of casing deformation prevention and control technologies.

Keywords

Coalbed Methane; Casing; Geological Factors; Deformation Mechanism.

1. Introduction

With the extension of coalbed methane (CBM) exploration and development to deep formations and structurally complex areas, horizontal well technology has become a key technical means for the development of deep CBM due to its significant improvement in reservoir contact area and single-well production. [1] However, casing deformation problems occur frequently during the full life cycle of drilling, completion, fracturing and production, leading to damaged wellbore integrity, interrupted fracturing operations, reduced productivity and even wellbore abandonment, which has become a major bottleneck restricting the efficient development of horizontal wells. Based on existing literature research, this paper systematically combs the core mechanisms of casing deformation in CBM horizontal wells from two dimensions: geological factors and engineering factors, summarizes the current research status and controversial points, and provides a theoretical basis for the subsequent optimization of prevention and control technologies. [2-3]

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2. Influence of Geological Factors on Casing Deformation

In the development of deep coalbed methane, geological conditions have been identified as the root causes of casing deformation. Their influence runs through the entire life cycle of the wellbore, particularly in deep coal reservoirs. Such complex geological environments significantly disrupt the stress balance of the casing, thereby triggering multiple modes of structural failure.

2.1. Influence of In-situ Stress Field Characteristics and Reservoir Heterogeneity

Anisotropy of in-situ stress is prevalent in deep coalbed methane (CBM) reservoirs, and with the increase in depth, the in-situ stress value rises significantly and its distribution becomes extremely inhomogeneous. During the extension of horizontal wells, they are subjected to substantial differential stress between the horizontal and vertical directions.

Taking the high-steep coal measure in Midong, Xinjiang as an example [4], the high-steep structure in this area leads to the coupled distortion of natural fractures and the in-situ stress field, thereby generating stress concentration around the wellbore. Under the action of such inhomogeneous stress, the casing is highly prone to radial compression or non-axial bending deformation.

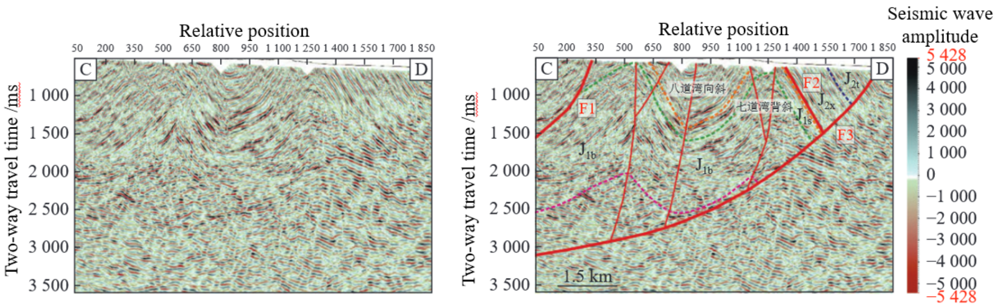

Figure 1. Seismic section of the Midong Block, Xinjiang

In addition, coalbed methane reservoirs themselves exhibit extremely strong mechanical heterogeneity. Coal seams have low strength and well-developed cleat and fracture systems, and the rock mechanical parameters show significant discreteness, especially in structurally fractured zones. The interaction between the casing and the formation is extremely complex, and local weak zones act as stress concentration points, thus significantly accelerating the casing deformation process.

(a) Nib damage (b) Crescent indentation of lead mold

Figure 2. Casing deformation phenomena

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2.2. Influence of Coal Rock Properties

Based on the comprehensive analysis of drilling core and logging data, the CBM reservoirs in wells with casing deformation mainly present granulated and cataclastic structures.

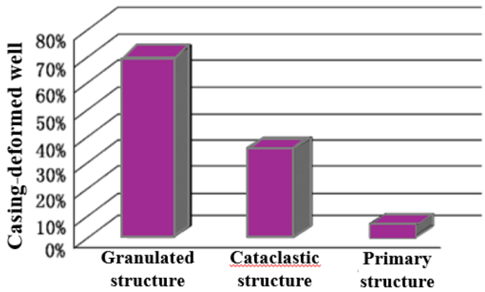

Figure 3. Proportion Diagram of the Relationship between Casing-Deformed Wells and Coal Structures

These two types of coal rocks have the following mechanical characteristics, which constitute the intrinsic driving force for casing deformation [5]. Granulated and cataclastic coal rocks are easily disturbed by the drill bit during drilling, leading to wellbore collapse, borehole enlargement and irregular borehole shape, which directly weakens the geometric constraint foundation of the casing. Such coal rocks have low elastic modulus, high Poisson's ratio, and their mechanical properties are highly heterogeneous and anisotropic. With the progress of drainage and production operations, the stress field of coal rocks changes drastically, making them prone to compressive deformation. Due to the influence of perforation operations, the compressive strength of the production casing decreases, and it is highly prone to deformation when subjected to the extrusion of the above-mentioned coal rocks.

3. Influence of Engineering Factors on Casing Deformation

The process selection, parameter design and construction quality during engineering operations indirectly induce or aggravate casing deformation by changing the mechanical properties, stress state and formation environment of the casing itself, and are important auxiliary inducing factors for casing deformation under the action of geological factors.

3.1. Influence of Drilling and Completion Processes and Well Trajectory

The design of drilling and completion processes for deep CBM horizontal wells has a decisive influence on the stress state of the casing. Due to the low strength of coal rock mass itself, open-hole completion is extremely prone to wellbore collapse; although screen pipe or casing completion can provide necessary wellbore support, during the running-in process of completion, the eccentricity of the pipe string and the uneven borehole enlargement will cause uneven stress on the casing, laying hidden dangers for subsequent deformation. In addition, the curvature change points between the build-up section and the horizontal section of horizontal wells are key parts where the casing is stressed. The casing here is prone to bending stress and fatigue deformation during long-term service. [6]

3.2. Defects in Cementing Quality and Cement Sheath Performance

Cementing quality is a key link to ensure the structural safety of the casing, and its influence is mainly realized through the mechanical properties of the cement sheath and the bonding quality of the interface.

Studies by Zhang Chaoqi et al. [7] point out that insufficient bonding quality of the cementing interface in deep CBM wells is the core inducing factor for casing deformation. If there are microcracks between the cement sheath, casing and formation, the transmission path of formation stress will be interrupted. In this case, the casing cannot obtain uniform support from the formation, the stress state becomes extremely unbalanced, and stress concentration is likely to form locally.

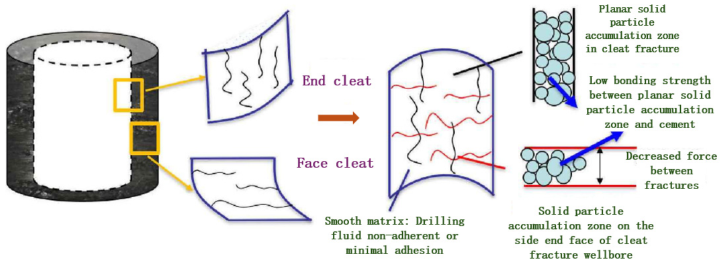

Figure 4. Schematic diagram of poor bonding quality caused by weak cementing interface

In addition, the brittle characteristics of the cement sheath itself are also an important factor for casing instability. The elastic modulus of the cement sheath does not match that of the casing and the formation. Due to formation deformation, the deformation capacity of the cement sheath is limited, and it is prone to cracks and fractures. This phenomenon of "loss of constraint" directly leads to the loss of external support for the casing, which in turn causes radial compression or dislocation deformation.

4. Conclusion and Prospects

Casing deformation in CBM horizontal wells is the result of the combined action of geological and engineering factors. The fundamental inducing factors include in-situ stress distortion, activation of natural fractures/faults, and migration of overlying rocks; while cementing defects, improper fracturing parameters and insufficient casing design are key contributing factors. These factors induce various failure modes such as tension, compression, shear and bending by changing the stress state of the casing and weakening its mechanical properties.

Future research directions:

(1) Deepen the research on the coupling mechanism of geological-engineering factors, and construct a coupled deformation model considering the dynamic stress evolution and fracture propagation of coal reservoirs by combining field monitoring and high-precision numerical simulation;

(2) Promote the integration of mechanism research and engineering practice, optimize casing design, cementing processes and fracturing parameters based on deformation mechanisms, and form a targeted deformation prevention and control technology system.

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