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Research article

Key technology for treating slack coal blockage in CBM recovery: A case study from multi-lateral horizontal wells in the Qinshui Basin

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Abstract

Due to the nature of coal bed, slack coal production is inevitable in gas recovery sby water drainage. When coalbed methane (CBM) wells are reentered after low energy exploitation and shut-in, the negative effect of slack coal production on productivity of CBM is irreversible. In this paper, the CBM occurrence characteristics and multi-lateral horizontal well trajectory in the Qinshui Basin, Shanxi Province, were analyzed. In the multi-lateral horizontal wells, the expected gas production rate could not be reached and the production rate after shut-in maintenance could not restore to the level before shut-in. The reason for these issues is that migration pathways in the reservoirs are blocked by slack coal deposits, while formation water and slack coal deposit accumulated at the troughs of horizontal sections enlarge the resistance for gas to flow into the bottom hole. Furthermore, three key technologies to deal with slack coal blockage were proposed. Firstly, CBM horizontal well trajectory should follow the principle of keeping the wellbores smooth and updip instead of being "wavy", on the premise of guaranteeing CBM drilling rate. Secondly, the cavities of production wells, as an important part of multi-lateral horizontal wells, are capable of settling sand, and can be used for gas–liquid–solid separation. And thirdly, a tree-like horizontal well with its main hole set on stable seam top or floor, provides a stable well flushing passage for coal powder. This research provides a useful attempt in solving the problem of slack coal production in gas recovery by water drainage.

Keywords: Coalbed methane (CBM); Recovery by water drainage; Slack coal; Multi-lateral horizontal well; Coal bed drilling rate; Tree-like horizontal well; Wellbore trajectory control; Cavern completion; Qinshui Basin

Coalbed methane (CBM) is a form of natural gas occurring in coal beds of a sedimentary basin mainly in an adsorption state and coexisting with formation water [1,2]. A CBM reservoir, as an unconventional gas reservoir, has its particular occurrence and accumulation features, making its recovery essentially different from a conventional gas reservoir.

1. Co-existence of water, gas and slack coal in CBM recovery

A CBM reservoir is different from a conventional gas reservoir in its composition. A conventional gas reservoir is mainly composed of mineral matters, while a CBM reservoir is mainly composed of carbon-rich matters formed by chemical alteration and thermal alteration of organic detritus, which decides the inevitable generation of slack coal. Moreover, the nature of coal reservoir itself decides the mechanical property and strength of coals, and the engineering disturbance becomes the inducement of slack coal generation. In the Qinshui Basin, high-order coal beds were severely transformed at late stage [3], and they are characterized by low compressive strength, small Young's modulus, small Poisson's ratio, frangible and apt to sloughing [4,5]. Accordingly, slack coals exist in coal beds in multiple states, such as free slack coal filled in coal cracks, framework grain slack coal fallen off the coal crack surface and plastic slack coal resulted from the destruction of coal bed textures [6].

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Some researchers conducted in-depth analysis on the production mechanism of slack coals [5−8]. Wei Yingchun et al. [8] discussed the characteristics of slack coals produced during the CBM recovery in Hancheng block, in terms of concentration, particle size and component, and indicated that production of slack coal was mainly controlled by well type, completion technology, recovery system, coal characteristics, coal texture and coal bed texture. Especially, coal texture (structural destruction) was the primary factor. Slack coal can be classified into inherent slack coal in coal bed and slack coal resulted from engineering disturbance [9,10]. The particle size of slack coal in the Qinshui Basin changes largely, from 80 to 300 meshes, or even finer, exhibiting suspended state in water.

During the CBM recovery, under the action of drawdown pressure, both inherent slack coal in coal bed and slack coal resulted from engineering disturbance migrate, together with CBM and formation water, in coal cracks to wellbore and finally to the surface. The practice in Fanzhuang block in southern Qinshui Basin shows that slack coal exhibits suspended state in grey or dark grey formation water, with slack coal grain almost invisible, but dark grey paste settlings are seen after being held for a long time. In other words, water, gas and slack coal co-exist in the recovery of CBM.

2. Impact of slack coal on the productivity of CBM horizontal wells

Slack coal is known by virtue of practical CBM exploitation. Its impact on the productivity of a CBM well was systematically analyzed [10−13]. This paper presents the impact in two aspects, through an analysis of the CBM recovery characteristics and multi-lateral horizontal well trajectory in the Qinshui Basin.

2.1. Slack coal deposit affects CBM reservoir permeability

Slack coal production has bidirectional impact on the physical properties of CBM reservoirs. When slack coal migrates together with CBM and formation water into wellbore, it improves the physical properties of a CBM reservoir. However, when a well is shut down due to certain reasons, slack coal will deposit in and block the cleats and minor cracks of the reservoir. Once the well is started up again, slack coal must overcome static friction, static shearing stress and other obstacles [14] to migrate, namely, higher threshold velocity is required. The recovery of CBM is conducted below desorption pressure, i.e., under low energy condition, such slack coals deposited in cleats and minor cracks where the pore throat shape and surface morphology are awfully irregular cannot migrate once more, and therefore block the migration pathway. This is a major reason for the problem that most multi-lateral horizontal wells in the Qinshui Basin could not reach the expected gas production rate before shut-in for maintenance.

2.2. Slack coal deposit may result in "filtered slack coal blockage" in horizontal section

Target coal beds in the Qinshui Basin are generally 3−8 m thick, with a burial depth of 500−1000 m. Affected by tectonic movement, the coal beds are not horizontal but highly fluctuant. For realizing a higher drilling rate, coal bed drilling is tracked, which usually results in a U-shaped wellbore. Especially, when the coal bed dip angle changes locally, the coal bed top or floor may be encountered. In case of top encountered, the hole angle should be dropped off in an attempt to enter the coal bed. In case of floor encountered, the hole angle should be built up to enter the coal bed. As a result, a "wavy" well trajectory occurs (Fig. 1).

During the CBM recovery, formation water and slack coal may be held up at the "trough" of the "wavy" wellbore, resulting in the reduction of net sectional area of horizontal hole. Especially, when the fluctuation height of drilled wellbore is larger than the wellbore diameter, formation water and slack coal would accumulate at the "trough" and form a "slug", which increases the resistance for the CBM to flow from the formation to the bottom hole (Fig. 2).

As CBM is recovered, slack coal would accumulate (dissolve, suspend or settle) in the slug at "trough" due to gravitational differentiation. The slug forms a filtering effect on the slack coal. The ceaseless accumulation of slack coal further increases the resistance for CBM to flow through the "slug", until the "filtered slack coal blockage" occurs ultimately. Moreover, when the CBM horizontal well is started up again after shut-in, there are several "slugs" in the horizontal section, which block the expulsion of CBM. When the CBM

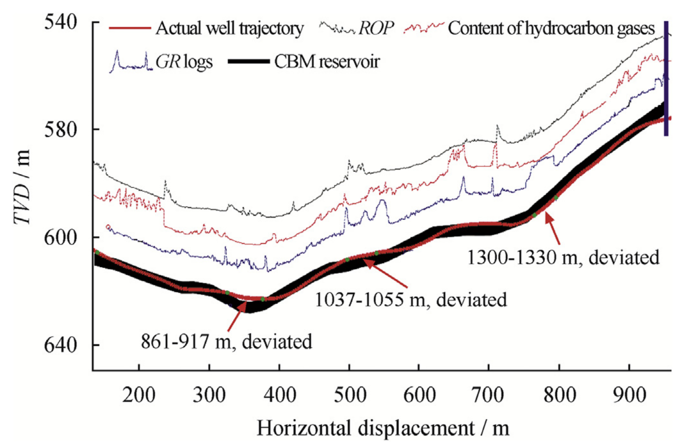

Fig. 1. Engineering trajectory of Well FSU1.

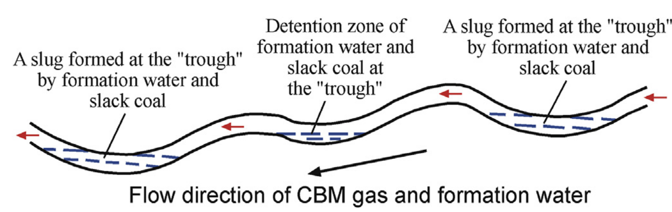

Fig. 2. "Slugs" formed in a "wavy" wellbore.