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 by 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 settled in grey or dark grey formation water.

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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

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**Fig. 1.** Engineering trajectory of Well FSU1.

**Fig. 2.** “Slugs” formed in a “wavy” wellbore.
reservoir energy is insufficient to overcome the resistance of the “slugs”, the CBM desorption would stop. This is a critical reason for failure to reach the expected flow rate of multi-lateral horizontal wells in the Qinshui Basin, and also another important reason for multi-lateral horizontal wells to hardly restore production rate before shut-in for maintenance.

3. Key technology for treating “slack coal blockage”

The CBM recovery is a process of draining water, gas and slack coal. The impact of slack coal production on the productivity of a CBM well has been paid high attention to by scholars and field technicians in China. As a consistent viewpoint, slack coal production can be properly controlled by the optimization of recovery system and the techniques like sand control pump [10,15–18]. These solutions play an active role in maintaining the productivity of multi-lateral horizontal wells, but have not radically address the impact of slack coal on productivity. Therefore, the slack coal treatment has become one of the core issues in CBM horizontal well development. The impact of slack coal deposit on CBM reservoir permeability and the “filtered slack coal blockage” occurred in the horizontal section due to slack coal deposit tend to be irreversible under the circumstance of low energy exploitation of CBM reservoirs. Therefore, slack coal should be “removed” rather than “controlled”. The “slack coal removal” can be achieved by CBM horizontal well design techniques.

3.1. Updip trajectory design can bring the gravitational potential energy of formation water into full play, which is favorable for “slack coal removal”

The fluid production of most wells is less (generally 3–10 m³/d) in the CBM recovery in the Qinshui Basin, which cannot meet the expulsion condition of slack coal that entered the wellbore. The “wavy” wellbore is especially unfavorable for the expulsion of slack coal. Therefore, the location of CBM horizontal well should be rationally selected [19], and the updip trajectory design of horizontal section is preferred. In actual CBM drilling, we should abandoned the old trajectory control method of “dropping off once the bed top encountered, or building up once the bed floor encountered” adopted in the past for pursuing a higher ratio of drilling and hitting productive strata. Instead, for the purpose of smoothness and generally updip of a wellbore, we would rather lower down such a drilling-encounter ratio to avoid any “wavy” wellbore in actual well trajectory control.

3.2. The cavity of a recovery well has “settling” function, and is an indispensable part of a multi-lateral horizontal well

The “cavity” of a recovery well of multi-lateral horizontal wells is designed for connecting treatment wells [20]. With the development of connecting technology, connection without cavity has been realized up to now. With the Fluent discrete facies module in CFD software, The CFD–DEM coupling method is used to calculate the transference of mass, momentum and energy between fluid and particles at the junction of a horizontal well and its “cavity”, and then, numerical simulation is conducted on the migration and settling process of particles with different sizes. Based on the description of mechanical parameters of gas, liquid and solid fluids, the change in flow field and amount of slack coals at the junction of the horizontal well and its “cavity” is studied, showing that the lithic particles carried out of wellbore by drilling fluid account for 16.5%, whereas the particles settled in the pocket account for 83.5%. Therefore, the “cavity” of a recovery well is convenient for the connection of a treatment well and a recovery well, and also has a separation chamber function of gas, liquid and solid at the time of recovery (Fig. 3). It is an indispensable part of a multi-lateral horizontal well.

According to the long-term field practices, for bringing the liquid and solid separation chamber function of the “cavity” of a recovery well into full play, the following design principles should be followed.

1) For the purpose of ensuring the cavity to be stable for a long time, the cavity should be constructed in a stable formation, e.g., the top or floor of a coal bed.

2) The “cavity” of a recovery well should be located at the lower part of a horizontal well trajectory, so it is convenient for the main and branch holes to drain water down the “potential” and for gas, liquid and solid separation. Simultaneously, when there are slough matters in the horizontal hole, the water can transport them to the cavity, and thus ensure the wellbore to be unblocked.

3.3. Stable main hole is the basis to realize the flushing of multi-lateral horizontal wells

The nature of a coal bed leads to inevitable “slack coal production” in the CBM recovery. Therefore, flushing becomes an effective means for ensuring the CBM horizontal well to be in
normal production. However, under the existing technical conditions, the main and branch holes of CBM multi-lateral horizontal wells are all within the coal bed; since the leakage pressure of the coal bed is low, and the wellbore of the main hole is easily sloughed and blocked, there is no flushing channel in conventional multi-lateral horizontal wells, flushing cannot be conducted effectively, and the slack coals settled in the coal bed or wellbore cannot be effectively treated. Through continuous research and practice, PetroChina Huabei Oilfield Company presents for the first time such CBM horizontal well construction concept as “unclogging main hole, enlarging branch hole area, and increasing production by subbranch hole”, and innovatively presents a tree-like horizontal well type [21], i.e., the main hole is constructed on stable seam top or seam floor, the branch holes enter the coal bed by sidetracking from the main hole, and then, several subbranch holes are sidetracked from the branch holes. This well type uses the main hole built on the stable top or floor of the coal bed to provide a reliable channel for flushing the well and removing slack coal.

4. Field application

To solve the problem of “slack coal blockage”, the PetroChina Huabei Oilfield Company designed and drilled a tree-like horizontal well — ZS1P-5H in the Qinshui Basin of Shanxi Province, China. This well is composed of one treatment well (ZS1P-5H), one recovery well (ZS1P-5V1) and one monitoring well (ZS1P-5V2) (Fig. 4). The main hole of the treatment well was built in the mudstone of the coal bed top, about 0.5—3.0 m away from the top of the coal bed, with hole angle larger than 90°. Cavities were created at the top of the coal bed in both the recovery well and monitoring well, with the bottom of cavities being about 1 m away from the coal bed, the diameter of 0.6 m and height of 6 m. The design of this well meets 3 conditions: (1) main hole updips; (2) the cavity of the recovery well is located in stable mudstone at the top of the coal bed; and (3) there is a stable flushing channel. This well was flushed successfully and put into production in May 2013. Currently, its daily gas flow rate is higher than 1 × 10⁴ m³, 14.3 times the peak gas production of vertical wells in the block. The monitoring results by the monitoring well show that the main hole of this well has all along been in a stable drainage and production state, without any “slack coal blockage”.

5. Conclusions and proposals

1) The traditional trajectory control method of “dropping off once coal bed top encountered, and building up once coal bed floor encountered” usually results in “wavy” well trajectory, and subsequently “filtered slack coal blockage” often occurs during the recovery of CBM. It is proposed that, for the purpose of smoothness and overall updip of a wellbore, a drilling-encounter ratio can be dropped to such a certain degree that a “wavy” wellbore can be prevented.

2) The cavity of the recovery well has a “settling” function, and is an indispensable part of a CBM multi-lateral horizontal well. For bringing such a “settling” function into play, the cavity should be created at the lower part of the horizontal well trajectory in a stable bed, i.e., at its roof top or floor bottom.

3) The tree-like horizontal well with its main hole created on the stable top or the floor of a coal bed represents a beneficial attempt for solving the problem of slack coal. With the optimized design (for example, main hole updips, and the main hole and the cavity of the recovery well are left in stable mudstone at the top of the coal bed), Well ZS1P-5H has realized long-term stability, without any “slack coal blockage” ever occurring.

References


