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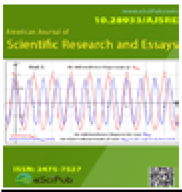

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Force and Control Measures of Pulverized Coal Migration in Coalbe-d Methane Horizontal Wells

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ABSTRACT

Pulverized coal production is a common problem in the process of coalbed methane drainage and production, which is one of the key factors restricting the continuous stability drainage and production of coalbed methane. The reasons and characteristics of pulverized coal output are summarized. Through a detailed analysis of the migration and stress of pulverized coal in the borehole, the migration of pulverized coal is controlled by the stress conditions of pulverized coal, which causes the migration position of pulverized coal to change. Under the action of total pressure difference ΔF, pulverized coal particles can be divided into three situations: downward inclination, upward inclination and near horizontal migration. Finally, a solution to the control of pulverized coal is put forward from two aspects: the control of drainage and mining system and the selection of drainage and mining equipment. The research shows that continuous stability drainage and mining is the key of drainage and mining system, and controlling the hydrodynamic difference ΔF is the means to control the migration of pulverized coal. Choosing a pump with strong adaptability to pulverized coal is beneficial to coalbed methane drainage and production and increase productivity. Two horizontal wells in Shizhuang South Area 2 were replaced by membrane pumps, and the diaphragm pump system guide cover scheme was adopted. The coalbed methane production increased by about 1000m3/d, and the number of well repair was significantly reduced.

Keywords: Pulverized coal; Migration; Stress; Control

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Coal reservoir is a carbon-rich material formed by chemical alteration and thermal alteration of organic residue. this property of coal reservoir determines that the generation of pulverized coal is an inevitable phenomenon. In China, coalbed methane is mainly medium-high rank coal reservoir, which is easy to produce pulverized coal in the process of drilling and completion, fracturing and coalbed methane drainage. The causes of pulverized coal production can be summarized as follows: (1) the transformation of primary reservoir by tectonic movement to produce fissures and pulverized coal; (2) during drilling, whether overpressure or underpressure drilling, the pressure on the reservoir changes and pulverized coal is produced; (3) the transformation of coal reservoir produces pulverized coal; (4) pulverized coal is produced in the process of drainage and gas production; (5) the migration of groundwater produces pulverized coal. (6) the chemical substances of groundwater (or fracturing fluid) interact with the reservoir to produce pulverized coal.

Pulverized coal is an unfavorable factor in coalbed methane production, which seriously affects the productivity of coalbed methane, but the output and concentration of pulverized coal in horizontal wells are much higher than those in vertical wells. During the migration of pulverized coal in the reservoir, with the decline of water production, the pulverized coal will remain in the reservoir pores and fractures or in the migration channel, reducing fracture conductivity and coal seam permeability, thus significantly reducing the productivity of gas wells. The migration of pulverized coal into the well or into the drainage and production system will lead to buried pumps and stuck pumps, resulting in frequent pump inspection and workover operations, which will seriously affect the drainage and production potential of coalbed gas wells and reduce the development efficiency. The problem of pulverized coal pump plugging is encountered in the process of horizontal well drainage and production in Shizhuang and Panhe mining areas, resulting in frequent workover rate of some wells, increasing production cost and time, and reducing production efficiency. To solve this problem is the most important problem to ensure normal production. This paper will put forward the solutions and countermeasures through the analysis of the characteristics of pulverized coal, the movement and force of pulverized coal, and the influence of coal seam accumulation to pulverized coal on production.

1. Pulverized coal characteristics

The pulverized coal encountered in coalbed methane drainage and production refers to the solid particles that exist, remain or migrate in the reservoir, channel and drainage equipment system in the process of coalbed methane development, which is also called "slime". The particle size of pulverized coal is different from that of industrial pulverized coal. The pulverized coal of industrial index is defined as the coal whose particle size is less than 0.5 mm, while the coal debris whose particle size is less than 10mm is called pulverized coal. The proportion of pulverized coal particle size larger than 2mm is about 50%, the particle size between 1mm and 2mm is about 8%, and less than 1mm is about 42%. The pulverized coal production of coalbed gas wells is accompanied by the whole process of gas well production. According to the on-site sampling test of coalbed methane horizontal wells, the particle size of pulverized coal produced is characterized by stage changes. The particle size and concentration of pulverized coal in coalbed methane drainage and production are different in different stages. See Table 1 for details.

Table 1 Particle size and concentration of pulverized coal in coalbed methane drainage

Stage	Particle size （mm）	Concentration（%）	Pulverized coal description
1. Drainage stage stage	5-10	＜1	There are mainly coarse and medium particles, and the bottom hole pressure is higher than the critical desorption pressure.
2. Primary stage	1-3	8	There are mainly medium and fine particles, and the bottom hole pressure fluctuates near the critical desorption pressure.
3. Stable production	＜2	＜0.5	Mainly fine particles, and the bottom hole pressure is close to zero.
4. Later stage1	＜1		Mainly fine particles, and the bottom hole pressure is zero

2. Pulverized coal migration and force analysis

2.1 Pulverized coal migration analysis

The migration of pulverized coal is controlled by its migration channel, and the migration channel is different when the geometric space of the migration channel is different; the migration of pulverized coal is controlled by the force condition of pulverized coal, which leads to the change of its migration speed and speed, which leads to the change of pulverized coal migration position and position, which is the judgment of pulverized coal accumulation position and accumulation position, which is the last reference for the selection of downhole equipment.

The migration of pulverized coal to the bottom hole can be divided into wellbore residue, wellbore residue and fracture residue in the reservoir, and it is found that the trouble caused by coalbed methane drainage and production is mainly caused by the friction caused by drilling tools to the coal seam during drilling and the friction caused by large discharge sand-carrying mixed fluid in the process of fracturing and the change of drilling fluid pressure during drilling.

2.2 Force analysis of pulverized coal particles

First of all, the analysis is set as follows: the upper and lower pressure of the wellbore is equal, the migration direction of pulverized coal is positive, the total pressure difference is ΔF(N), the volume is V（cm^3）, the density is d(g/cm^3), the mass is M(g), and the viscosity of the liquid is μ（Pa·s）(due to the complexity of liquid viscosity, this mechanical analysis will not be considered for the time being. In addition, when the body moves, it will produce a friction resistance, which is related to the viscosity and is not within the analysis range of the force), the gravity acceleration is g（m/s^2）, the particle migration direction is along the wellbore direction, the angle between the wellbore and the horizontal plane is α, and the wellbore diameter is 114.3 mm.

The moving speed of pulverized coal is as follows:

$$v = at^2 = \frac{\Delta F}{M}t^2 \qquad (1)$$

In formula (1)：

a is the acceleration，t is the migration time.。

The force of pulverized coal in the vertical direction is as follows:

$$\Delta f = mg - f_f = d_s V g - d_l V g = (d_s - d_l)Vg \qquad (2)$$

mg is the gravity of pulverized coal，*f* 浮 is buoyancy，*Δf* is coal particle force in vertical direction，and direction is downward. Under the action of △*f*，coal particles sink in the course of migration. Let the sinking height of coal particles be 114.3mm.

According to the free fall formula, there are:

$$h = \frac{1}{2}at^2 \text{..} \quad (A)$$

$$\Delta f = at \text{...} \quad (B)$$

According to expressions (A) and (B):

$$t = \frac{2h}{\Delta f} \text{...} \quad (3)$$

When h=114.3mm (11.43cm), it can be obtained from equations (2) and (3):

$$t = \frac{22.86}{(d_s - d_l)} \frac{1}{Vg} \text{ ....} \quad (4)$$

$$k = \frac{22.86}{(d_s - d_l)}$$

Formula (4) shows that the falling time of pulverized coal in the vertical direction is inversely proportional to the pulverized coal volume and gravity acceleration. the larger the volume is, the shorter the falling time is.

2.2.1 Force analysis of pulverized coal in wellbore direction

Under the action of ΔF, pulverized coal particles can be divided into three cases: downward dip (figure 1), updip (figure 2) and near-horizontal migration (slight downdip). When tilting upwards or downwards, the horizontal direction is ΔF1 and the vertical direction is ΔF2.

$$\Delta F_2 = \Delta F \mathrm{Sin}\alpha; \quad \Delta F_1 = \Delta F Cos\alpha$$

Conclusion:

$$\Delta F_1 = (d_s - d_l)VgCos\alpha$$

$$\Delta F_2 = (d_s - d_l)Vg\mathrm{Sin}\alpha$$

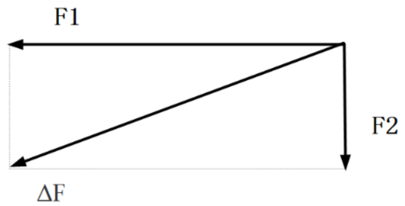

Fig. 1 schematic diagram of downtilting force decomposition

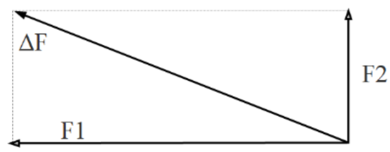

Fig. 2 schematic diagram of uptilting force decomposition

2.2.2 Analysis of pulverized coal migration

During the downward migration, the movement and fall of pulverized coal is relatively fast, and the amount of accumulated pulverized coal increases due to the increase of falling effect at points An and B (B2) in figures 5 and 6.

The downward force of the particles is (figure 3):

$$W=(d_s - d_l)Vg(1+\sin\alpha)$$

The force of horizontal migration of particles is: $\Delta F_1 = (d_s - d_l)Vg\cos\alpha$

Fig. 3 downdip force analysis diagram

When tilting, the fall of pulverized coal is relatively slow, and when moving from point B (B2) to point C, because the falling force is relatively less, the migration time is relatively longer in the process of migration, if the highest point of point C cannot fall to the bottom of the borehole, pulverized coal can continue to move forward due to water transport.

The downward force of the particles is (figure 4):

$$W=(d_s - d_l)Vg(1-\sin\alpha)$$

The force of horizontal migration of particles is: $\Delta F_1 = (d_s - d_l)Vg\cos\alpha$

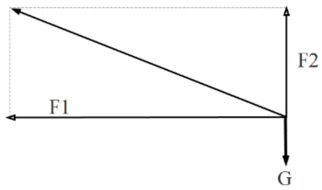

Fig. 4 Analysis of upward force

In the case of horizontal migration, when the weight of pulverized coal is constant, the larger the ΔF is, the longer the distance of pulverized coal migration is. Control ΔF, that is, to control the speed of water flow, the speed of water flow is related to the displacement of the pump, the displacement is large, the speed is also large. When moving horizontally, the direction of the flow changes, the flow is positive, the pulverized coal accumulates more, and the opposite direction is little or little or no.

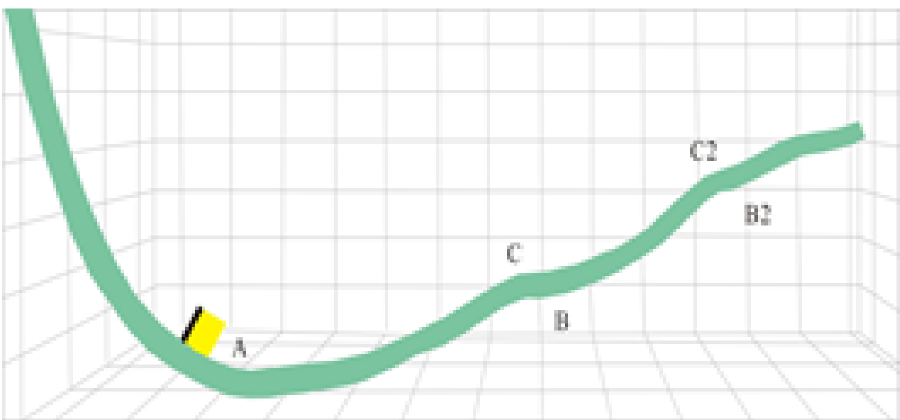

Fig.5 Schematic diagram of pulverized coal stress and migration in the wellbore

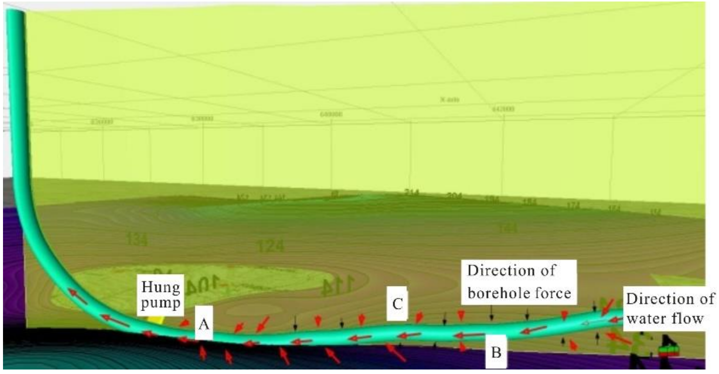

Fig. 6 Schematic diagram of the wellbore trajectory in the vertical direction 3 times

3. Control measures of pulverized coal

In order to effectively control pulverized coal, we should first be familiar with the migration and stress state of underground pulverized coal (reservoir, wellbore), and on this basis, study and put forward reasonable prevention and control measures. At present, there are many measures to prevent pulverized coal, including geological prevention, reservoir transformation, equipment optimization, drainage control and process control, etc. This paper mainly introduces the control of pulverized coal from the aspects of drainage and mining system and equipment optimization.

3.1 Control of drainage and mining system

According to the pulverized coal force, production law and pulverized coal characteristics, combined with drainage gas production and reservoir pressure, the corresponding drainage and production control measures are formulated for coalbed methane wells with different drainage gas production and pulverized coal production conditions in different drainage and production stages. to achieve the purpose of moderate powder production, sparse but not blocking, stable drainage and production.

In the mechanical analysis of pulverized coal migration, the discharge speed is the best control method. Try to make the distance of pulverized coal migration short, or distribute the pulverized coal more evenly in the hole, reduce the flow of pulverized coal into the vicinity of the pump, so as to reduce the workover frequency.

3.2 Selection of drainage and mining equipment

In coalbed methane drainage and gas production, pump is the main equipment, and the selection of pump is a method of controlling and treating pulverized coal in horizontal well, which can improve production efficiency. At present, there are jet pump, non-rod pump , rod pump , screw pump, electric submersible pump, diaphragm pump and so on.

There are many kinds of coalbed methane drainage pumps, and the technical parameters are not the same, each has its own advantages. Because the borehole shape of horizontal well is different from that of vertical well, deviated well, directional well, L-shaped well, U-shaped well, close butt well, etc., the requirements are as follows: (1) adapt to a large range of wellbore inclination; (2) small volume; (3) low energy consumption; (4) select the type of pump according to water production; (5) the pump with high running rate can reduce the workover cycle. (6) according to the different stages of drainage and mining, select the pore diameter of the screen; (7) the position of the dog leg is as small as possible; (8) the well deviation is not greater than 850, but not limited to this; (9) leave some pockets (pulverized coal deposition section or space) to avoid burying the pump.

4. Case analysis

Two horizontal wells (TS-018H and TS-314H) in Shizhuangnan area are taken as examples to illustrate the selection of drainage and production pumps for coalbed methane horizontal wells.

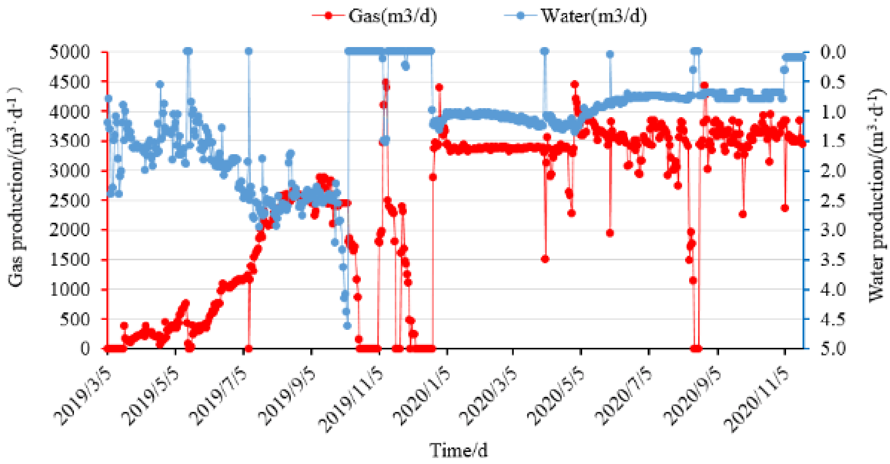

Fig. 7 Actual drainage and production curve of TS-018H well

TS-018H well description: operation of drainage equipment on April 7, 2019, pump inspection on May 15, 2019, pump inspection completed on May 18, pump shutdown on October 17 and completion on October 30, pump stop on November 20, pump replacement on November 24 (replacement of diaphragm pump by original screw pump), adopt diaphragm pump system guide cover scheme. It was put into production on December 22nd, 2019. At present, the well has intermittent production, stable operation for 226days and 20Hz operation. Intermittent production of the well starts and stops about 18 times a day, and the current daily gas production is about 4000m^3. The maximum dog leg degree of the well is 8.62°/30m, the pump hanging is 880m (vertical depth 757m), and the maximum well deviation is 83.4°. Figure 7 shows that after replacing the diaphragm pump, the gas output is above 3000m^3/d, while the previous production is below 3000m^3/d, and the output difference is above and below 1000m^3/d. The number of workover operations is less.

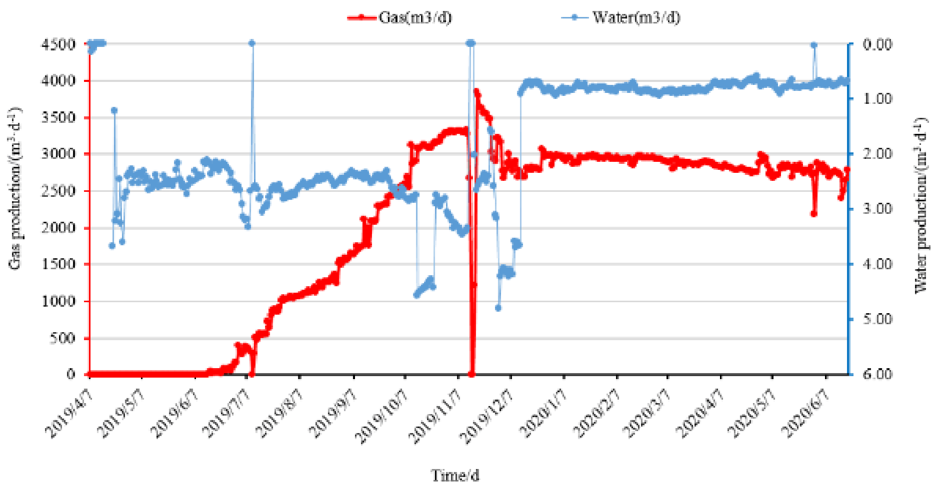

Fig. 8 Actual drainage and production curve of TS-314H well

TS-314H well description: equipment operation on April 7, 2019, pump stuck on April 9, operation completed on April 20, pump replacement on November 16 (diaphragm pump, same as TS-018H well). At present, the well intermittent production, 25Hz operation, intermittent production, start and stop about 12 times a day, the current daily gas production of about 3000m3/d. The maximum dog leg degree of the well is 13.87°/30m, the pump hanging depth is 960m (vertical depth 790m), and the maximum well deviation is 83.5°. Figure 8 shows that since November 16, 2019, gas production has been above or below 3000m^3/d, while before, gas production has been around 2000m^3/d.

5. Conclusion

The main results are as follows:

(1) the pulverized coal migration is controlled by the pulverized coal force condition, which leads to the change of the pulverized coal migration position, and the pulverized coal particles can be divided into three cases: downward dip, updip and near horizontal migration under the action of the total pressure difference ΔF.

(2) continuous and stable drainage and mining is the key to the establishment of drainage and mining system, and small drainage flow (controlling hydrodynamic difference ΔF) is a means to control pulverized coal migration.

(3) The selection of pumps with strong pulverized coal capacity is beneficial to the drainage and production of coalbed methane and increase production capacity. Two horizontal wells (TS-018H and TS-314H) in South Shizhuang area were replaced by membrane pump by original screw pump, and the diversion cover scheme of diaphragm pump system was adopted, the coalbed methane production was increased by about 1000m3/d, and the workover times were obviously reduced

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