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Analysis of Broken Zone in CBM Artificial Momentum Cavity Completion

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Abstract: *Cavity completion of coalbed methane as an emerging technology has gradually been widely used abroad; there are three zones after completion, cavity, broken zone and disturbed zone. This technology could improve the permeability of coalbed and then improved the productivity greatly. In this paper, the crack propagation of pressurization process and the shear fracture of relief process are under series of studies. In conclusion, the potential radius of extension fracture zone is presented; shear fracture always taking place along the minimum horizontal stress direction is proved theoretically, and anisotropic coalbed is suitable for artificial momentum cavity completion.*

Keywords *CBM; cavity completion; artificial momentum; crack propagation; shear fracture; anisotropy*

1. Introduction

CBM, as a kind of traditional unconventional energy has showed great potential. CBM artificial momentum cavity completion has been widely used abroad, the technology can make the coalbed and the wellbore connected to the greatest extent, thus the pollution of the near wellbore area will be removed, the effective radius of the wellbore will be increased, and the permeability and the productivity will be effectively improved. In general, the production increasing mechanism of CBM artificial momentum cavity completion Can be summarized as three points [1]: (1) Physical cavity. After completion, the diameter of cavity made by Borehole collapse was several times the diameter of the previous wellbore, thus expanding the seepage area of coalbed methane. (2) Broken zone. Fracture zone is divided into extensional fracture zone and the shear fracture zone. The flow conductivity and the permeability of coalbed are improved because of the expansion of cracks and crushing of coal. (3) Disturbed zone. The coalbed is disturbed by the release of the stress, and there is part of the intensive reservoir outside of the fracture zone. These cause an area where permeability rising.

In our country, Due to equipment and awareness reasons, the crack propagation mechanism of cavity completion is unclear, and the research on the crushing law of coal is not perfect. Therefore, perfecting the CBM cavity completion theory and technology, analyzing and discussing the fracture zone, these have a positive significance and will play a guiding role in site engineering.

2. Crack propagation of pressurization process

2.1 types of crack and criterion of fracture

The butt cleat and face cleat of coal and rock are developed well, the breakage of coal can be thought of as the crack extension and intersection in artificial momentum cavity completion. According to the force conditions, the mode of crack is classified into three types, opening mode (Mode I), sliding mode (Mode II) and tearing mode (Mode III).

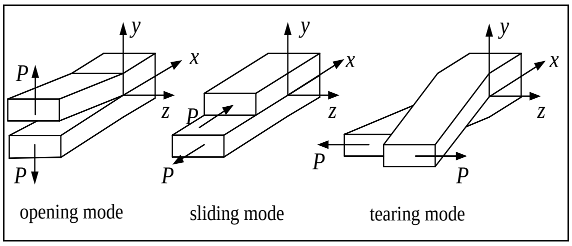

Figure 1. *Three basic modes of crack*

Because of the complexity and diversity of crack, generally crack was simplified as a two-dimensional crack for research [2]. The stress intensity factors of type I, type II and type III, crack were characterized by K_I, K_{II} and K_{III}, K_{IC} is fracture toughness. Cracks will extend when the stress intensity factor reaches the critical value, $K_I+K_{II}+K_{III} \geq K_{IC}$ was the judgment basis of crack extending [3].

2.2 Rupture angle of crack

A model of the crack near the wellbore is established, as shown in figure 2.

σ_H is the maximum horizontal stress and σ_h is the minimum horizontal stress in the crack zone; β is the angle between the axis of crack and the direction of maximum horizontal stress.

When the crack surface is closed completely, only slide and tear extension can take place under the

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effect of stress; In fact, the crack could not closed completely as a result of the filling of impurities, the existence of stratum water and point contact. The expansion of the crack is mainly by tensile stress in pressurization process after cavity completion. In order to simplify the analysis, we consider that the cracks only by tensile stress in the process of extending.

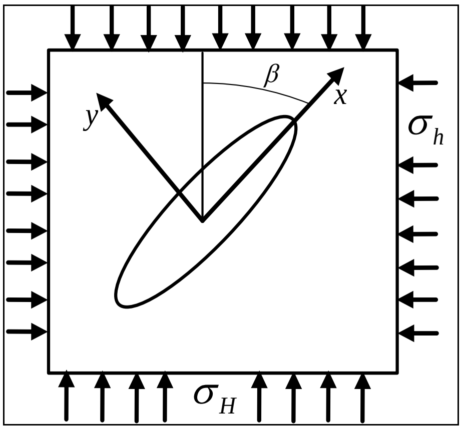

Figure 2. *A crack model near the borehole*

The figure 2 shows that the pressure and shear force on the crack surface respectively are [4]:

$$f(x)=\sigma_H \sin^2\beta+\sigma_h\cos^2\beta \qquad (1.2.1)$$

$$g(x)=(\sigma_H-\sigma_h)\sin\beta\cos\beta \qquad (1.2.2)$$

Within the zone of the near wellbore, suppose that the stress of down hole P_b is exerted on the surface of crack resulting stress P'_b. Among them, $P_b=MP_b$, M defined as conduction coefficient. M is a function of the distance '*r*' between crack and wellbore, $M=f(x)$. This moment, the crack surface is subjected to compressive stress $f(x)$, pore pressure P_i and P'_b.

The normal stress on the two surface of the crack is:

$$\sigma' = P_i + P_b' - f(x) \qquad (1.2.3)$$

The intensity factor at the crack tip is:

$$K_I=(f(x)-P_i-P_b')\sqrt{\pi a} \qquad (1.2.4)$$

In the formula, '*a*' is a half long of crack.

According to the fracture criterion of strain energy density factor, raised by Xue Changming [5] on the crack tip, the strain energy density '*W*' per unit volume can be expressed as

$$W=\frac{1}{R}(a_{11}K_I^2-2a_{12}K_IK_{II}+a_{22}K_{II}^2+a_{33}K_{III}^2) \qquad (1.2.5)$$

From the above equation, we know that *'W'* has the singularity of 1/R, introducing the strain energy density factor '*S*':

$$W=S/R \qquad (1.2.6)$$

Due to the crack is I, type crack, then K_{II}=0, K_{III}=0.

The formula (1.2.5) can be rewritten as:

$$S=a_{11}K_I^2 \qquad (1.2.7)$$

Among them

$$a_{11}=\frac{1}{\pi\mu}[(3-4\upsilon-\cos\theta)(1+\cos\theta)] \qquad (1.2.8)$$

υ is the Poisson's ratio; $\mu=\frac{E}{2(1+\upsilon)}$; E, is Elastic Modulus; *'θ'* is the rupture angle between the direction of potential crack extension and the axis of crack; *'R'* is the distance between unit and the crack tip.

There are two basic assumption tips in Strain energy density factor theory, first, the crack extend along the direction of the minimum strain energy density factor S_{min}, that rupture Angle should satisfy $\frac{\partial S}{\partial\theta}=0,\frac{\partial^2 S}{\partial\theta^2}>0$; Second, the crack begin to extend when S_{min} reaches a certain critical value.

According to, $\frac{\partial S}{\partial\theta}=0,\frac{\partial^2 S}{\partial\theta^2}>0$, we can solve the rupture angle $\theta=0°$. Obviously, the extension direction of I, type crack will progress along the axis direction.

1.3 The length of the crack extension

In the vast majority of coal bed, the trend of face cleat is the same as the direction of the maximum horizontal stress direction, the trend of butt cleat is the same as the direction of the minimum horizontal stress direction. According to the figure 2, for the horizontal crack, $\beta=0°$, extension of crack should overcome the minimum horizontal stress. The work is the least; we can think that when tensile cracks extend alone the direction of the maximum horizontal stress they reaches farthest, this is consistent with the understanding of the field engineering.

The intensity factor of the crack tip is:

$$K_I=(\sigma_h-P_i-P_b')\sqrt{\pi a} \qquad (1.3.1)$$

Due to the pressure lost of downhole in the process of conduction, P_i and P'_b were changed gradually with the increase distance between the borehole. When the cracks extend a certain length, we need to re-determine whether the stress intensity factor of the crack still satisfies the extension condition. Through constant iteration to determine the end region of crack extension, thereby determining the ultimate range of tensile rupture.

The propagation radius of tensile crack was determined eventually, namely the radius of extensional fracture zone:

$$l=\frac{2K_{IC}^2}{\pi(\sigma_h-P_b'-P_i)^2} \qquad (1.3.2)$$

2. The shear broken of coal in pressure relief process

2.1 The shear broken position

Establish a mechanical model about the stress of rock near the wellbore for analysis. On the infinite plane, a circular hole forces a uniform internal pressure, at the same time forces the maximum horizontal stress σ_H, the minimum horizontal stress σ_h and there is overburden pressure in the vertical direction (as shown in figure 3).

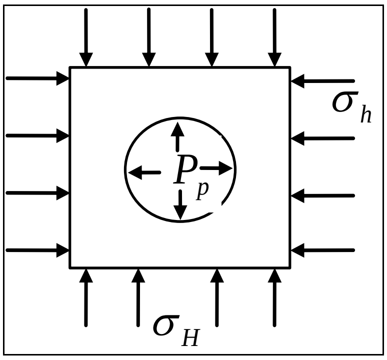

Figure 3. *The stress schematic diagram of rock around wellbore*

The stress state of rock around wellbore can be expressed by the radial stress σ_i, circumferential stress σ_θ, vertical stress σ_z and the shear stress $\tau_{r\theta}$. As the shear failure of Rock, there is usually, $\sigma_\theta > \sigma_z > \sigma_r$, σ_z is the intermediate stress [6].

In the process of drilling and completion, the main reason of wellbore collapse is the fluid column pressure too low in borehole. The shear failure will happen when the stress of the rock around wellbore exceeds the rock strength. For plastic formation, such as mudstone, the plastic deformation will happen in borehole, causing shrinkage. For brittle formations, such as coal seams, collapse will happen, causing borehole diameter expanding.

According to the Coulomb-Mohr criterion:

$$\tau \geq C + \mu\sigma \qquad (2.1.1)$$

In the formula, C is cohesive force, μ coefficient of internal friction of rock, $\mu=\tan(\Phi)$, 'Φ' is the internal friction angle of rock.

When there is pore pressure P_i, the Coulomb-Mohr criterion can be expressed by effective stress as:

$$(\sigma_1 - \alpha p_p) = (\sigma_3 - \alpha p_i)\cot^2(45^\circ - \frac{\Phi}{2}) + 2C\cot\left(45^\circ - \frac{\Phi}{2}\right) \qquad (2.1.2)$$

We know that Rock shear failure is mainly affected by the maximum and minimum principal stress from formula (2.12). When reaching the limit equilibrium, if increase the difference between σ_3 and σ_1, the balance equation will be broken, resulting the occurrence of the borehole instability. The maximum and minimum horizontal stress of rock is circumferential stress and radial stress respectively, so the lost stability and collapse will happen more easily when σ_θ-σ_r is larger.

Due to circumferential stress on the borehole changes with angle (θ), 'θ' is an angle between the radius vector of points in the well wall and the direction of maximum horizontal stress), σ_r is a constant on the anywhere of wall. As shown in figure 4 is σ_θ change curve with angle θ, when θ=90°, or θ=270°, corresponding M and N in figure 5, the maximum of $(\sigma_\theta - \sigma_r)$ is reached. When differential stress $(\sigma_\theta - \sigma_r)$, force on M and N, reaches or exceeds the rock's shear strength, the borehole will lost stability and cause borehole avalanche. The wellbore will change from circular to elliptical, and the direction of minimum horizontal stress is consistent with long axis of the ellipse [7].

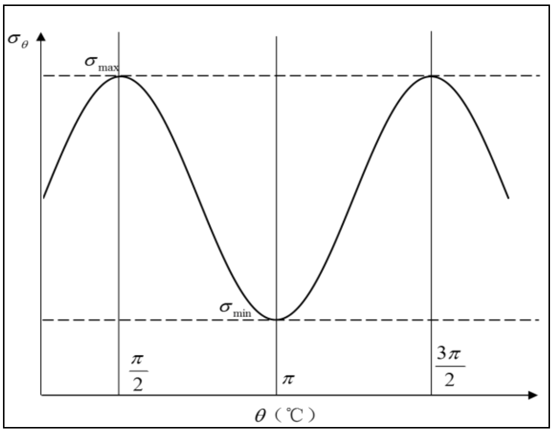

Figure 4. *Circumferential stress 'σ_θ' change curve with angle 'θ'*

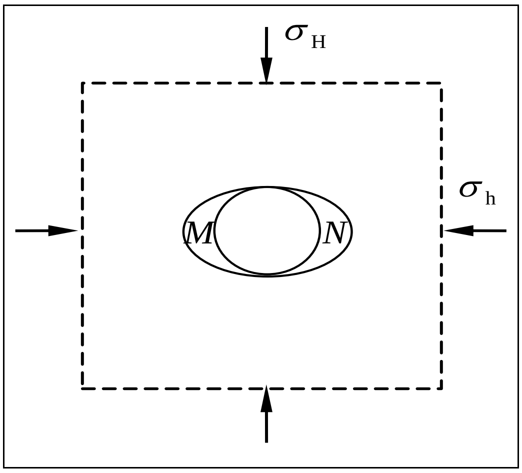

Figure 5. *Schematic diagram of borehole avalanche ellipse*

In the pressure relief process of CBM artificial momentum cavity completion, causing the low pressure or negative pressure in downhole, making (σ_θ-σ_r) larger due to the reduction of 'σ_r', equally the maximum of (σ_θ-σ_r) is reached. Therefore in the pressure relief process of cavity completion, the M and N two point alone with the minimum horizontal stress happen to shear break and then wellbore wall loss stability, this form a range of collapse zone, namely shear fracture zone of cavity completion

2.2 The influence of anisotropy

Take any one micro fission in the plane of coalbed, the stress state is expressed in the polar coordinates.

'ρ' is the radial coordinate and 'φ' is the ring coordinate. As shown in figure 6:

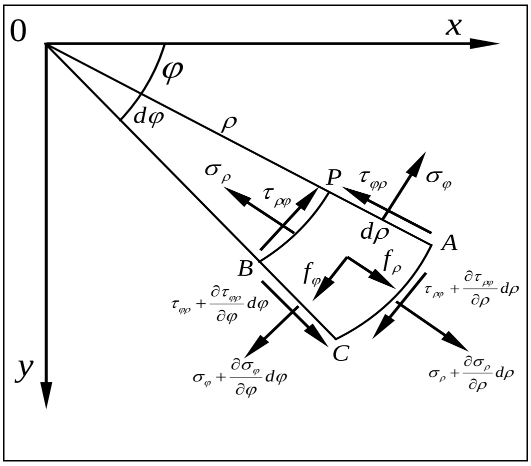

***Figure 6**. The stress state of micro fission*

Stress component, transformed from rectangular coordinates to polar coordinates, is:

$$\begin{cases} \sigma_\rho = \sigma_x \cos^2\varphi + \sigma_y \sin^2\varphi + \tau_{xy}\sin 2\varphi \\ \sigma_\varphi = \sigma_x \sin^2\varphi + \sigma_y \cos^2\varphi - \tau_{xy}\sin 2\varphi \\ \tau_{\rho\varphi} = (\sigma_y - \sigma_x)\cos\varphi\sin\varphi + \tau_{xy}\cos 2\varphi \end{cases} \quad (2.2.1)$$

Make $\frac{\partial \tau_{\rho\varphi}}{\partial \varphi} = 0$, we can get the minimum and maximum shear stress on cross section that determined by 'φ', solve the equation:

$$\tan 2\varphi = \frac{\sigma_x - \sigma_y}{2\tau_{xy}} \quad (2.2.2)$$

$$\begin{cases} \tau_{\max} = +\sqrt{(\frac{\sigma_x - \sigma_y}{2})^2 + \tau^2{}_{xy}} \\ \tau_{\min} = -\sqrt{(\frac{\sigma_x - \sigma_y}{2})^2 + \tau^2{}_{xy}} \end{cases} \quad (2.2.3)$$

Make $\Delta\sigma = \sigma_x - \sigma_y$, put in

$$\tau_{\max,\min} = \pm\sqrt{(\frac{\sigma_x - \sigma_y}{2})^2 + \tau^2{}_{xy}} = \pm\sqrt{(\frac{\Delta\sigma}{2})^2 + \tau^2{}_{xy}} \quad (2.2.4)$$

Take the derivative of the maximum shear stress with respect to $\Delta\sigma$ .we can get:

$$\frac{\partial \tau_{\max}}{\partial \Delta\sigma} = \frac{1}{\sqrt{1 + (\frac{2\tau_{xy}}{\Delta\sigma})^2}} \quad (2.2.5)$$

According to (2.2.4) and (2.2.5), the difference between two horizontal stresses and the shear stress suffered have important influence on the maximum shear stress. For isotropic coalbed formation, the maximum shear stress slants small when $\Delta\sigma$ tends to be zero, coal is not likely to happen shear failure; For anisotropy of coalbed formation, the greater the $\Delta\sigma$, the greater the maximum shear stress. The shear failure of coal and rock is more likely to occur when only shear occurs.

Therefore, we should try to choose the anisotropic coalbed to construct when choosing the formation of cavity completion. It is conducive to the formation of cavity and the effect of cavity completion is also more prefect.

3. Conclusion and understanding

1) Cracks of coal mainly extend alone the direction of the maximum horizontal stress in pressurization process, the potential stretching radius of fracture zone is $R = \frac{K_{IC}^2}{\pi(\sigma_h - P_b^{'} - P_i)^2}$.

2) The shear breakage of coal will be the first occur at two points along the minimum horizontal stress direction in pressure relief process. If using other ways to make cavity, such as mechanical or hydraulic way, we can first construct along the minimum horizontal stress direction. This is easy to make the cavity.

3) Choose the great anisotropic zone for artificial momentum cavity completion, the effect of cavity completion will more prefect.

4) The stress field distribution of coal can be changed in the pressurization process and the pressure relief process. Increasing constructing cycles appropriately is advantageous to the expansion of disturbed zone. Thus it can strengthen the reservoir and increase the permeability.

References

[1] A Study on Open Cavity Completion Technology for Coal Gas Well [D]. Beijing: China University of Petroleum, 2002.

[2] Study on mechanism of coal borehole stability and engineering application**:** [D]. Beijing: Research Institute of Petroleum Exploration and Development, 2002

[3] Li Qingfen, *Fracture Mechanics and its Engineering Application*, Harbin Engineering University Press, 1998

[4] Gentzis T, "Stability analysis of a horizontal coalbed methane well in the Rocky Mountain Front Ranges of southeast British Columbia", International Journal of Coal Geology, 77(3), Pp. 328-337, 2009

[5] Yin Xiangchu, *Solid Mechanics*, Seismological Publishing House, 2011.

[6] Deng Jingen and Zhang Hongsheng, *Mechanical mechanism of borehole instability in drilling engineering*, Petroleum Industry Press, 1998.

[7] Chen Mian, *Rock mechanics of petroleum engineering*, Science Press, 2008.

[8] David H -S Law, Van Der Meer, L G H and Gunter, W D "Numerical Simulator Comparison Study for Enhanced Coalbed Methane Recovery Processes", Part I: Pure Carbon Dioxide Injection[C]. presented at the SPE Gas Technology Symposium, 2002; SPE 75669, doi.org/10.2118/75669-MS

[9] Sundaram, M.S., Supdtg. Reliance CBM Exploration in India. Methane to Markets (M2M) Conference, February, 2007

[10] Bans Goktas and Turgay Ertekin, "Development of a Local Grid-Refinement Technique for Accurate Representation of Cavity-Completed Wells in Reservoir Simulators", *Society of Petrolum Engineers*, 4(3), Pp.187-195, 1999

[11] Goktas, B., and Ertekin, T., "A Comparative Analusis of the Production Characteristics of Cavity Completions and Hydraulic Fractures in Coalbed Methane Reservoirs", *Gas Well*, PP205-214., 1999.

[12] Muthukumarappan Ramurthy, Rudy E. Rogers and Dana Weida, "Analysis of the Success of Cavity Completions in the Fairway Zone of the San Juan Basin", *Acta Scientiarum Polonorum Agricultura*, 15(1), Pp. 57-64, 1999.

[13] Shi, J. Q., Durucan, S. and Sinka, I. C., "Key Parameters Controlling Coalbed Methane Cavity Well Performance", *International Journal of Coal Geology*, 49(1), Pp.19-31, 2002.