Finite Element Simulation of Fracture Initiation Pressure of Coal Seam Gas Well Perforation Completion

Tong Du [a], Jize Zuo [b]

School of Petroleum Engineering, Northeast Petroleum University, Daqing 163318, China.

[a]568866349@qq.com, [b]875854534@qq.com

Abstract

The lithologic character of coal is soft, breakable, low elastic modulus and high Poisson's ratio, it has stronger anisotropy in mechanics. Compared with the conventional sandstone reservoir, the complicated stress distribution around the hole of hydraulic fracturing coal seam completed by perforation leads to a big difference of mechanism of fracture initiation. In this paper, FEM simulation calculation model of hydraulic fracturing initiation pressure of CBM well perforation completion has been established by putting forward the finite element numerical simulation method. Based on the tensile failure theory of fracture mechanics, the calculation of fracture initiation pressure of coal seam perforation completion is simulated. Calculation shows that the fracture initiation pressure increases with the increasing of the perforation azimuth, perforating along the maximum horizontal principal stress direction, the fracture initiation pressure reach the minimum, while perforating along the minimum horizontal principal stress direction, the fracture initiation pressure reach the maximum, which is least likely to form fracturing fractures; With the increase of diameter of perforation eyehole, fracture initiation pressure increases, but the influence of perforation diameter on fracture initiation pressure is not obvious; while with the perforating depth increasing, the pressure has no obvious changes, and the increase of perforation depth has little influence on fracture initiation pressure.

Keywords

coal bed methane, perforation completion, hydraulic fracturing, fracture initiation pressure, numerical simulation.

1. Introduction

Hydraulic fracturing is an important technology to ensure effective development of coal bed methane, and accurate calculation and forecasting of the initiation pressure is an important prerequisite for the implementation of hydraulic fracturing, which has become a hot and difficult problem of hydraulic fracturing of coal bed methane(CMB) research. The present study of initiation pressure of hydraulic fracturing of sandstone is mainly on the basis of elastic mechanics of tensile failure criteria, on the premise of homogeneous formation hypothesis and corresponding calculating model is established [1-5]. For fractured reservoir, Jin Yan [6,7] considered the influence of reservoir fracture on the fracture pressure of open hole, and set up the corresponding calculation model, and Zhao Jinzhou [8-10] established the fracture pressure calculation model under the condition of fractured reservoir perforation completion, which analyzed the influence of different fracture initiation modes on fracturing pressure in fractured reservoirs. The initiation pressure calculation of coal seam perforation completion is mainly on the basis of the initiation pressure calculation model of the sandstone reservoir, and there is no more perfect theoretical method or other methods used to analyze the change of the initiation pressure of coal seam. In this paper, coal and rock will be assumed to be orthogonal

anisotropic medium under which condition the coal seam perforation completion of hole wall stress distribution is complex, and it is more difficult to solve by theory, therefore, the application of finite element simulation method is proposed, and respectively simulates and discusses the change of the initiation pressure of coal seam perforation completion under the condition of different perforation methods, It is expected that this paper will provide a new method for calculating the fracturing pressure of hydraulic fracturing in coal seam.

2. The Establishment of the Finite Element Model

In order to simulate the fracture initiation pressure of hydraulic fracturing under the condition of perforated completion of CBM wells, we assume the following conditions.

(1) It is assumed that the material of coal and rock is an orthotropic or transversely anisotropic linear elastic material, the mechanical behavior of loading and unloading is in line with the theory of linear elasticity.

(2) The coal rock bed extends infinitely in a horizontal direction.

(3) The shape of borehole and perforation are regular and both of them are cylindrical.

(4) The wall of coal bed and perforation are free boundary, when the completion pattern of coal-bed gas well is perforation completion.

(5) The initiation fracture of coal rock depends on its maximum tensile strength.

The model size has a certain influence on simulation results, but it can be neglected according to previous research when the size of model is twenty times larger than the borehole. Therefore, all the researches of simulation in this paper guarantee that the size of model is twenty times larger than the borehole. As for the mesh of the model, according to the different situations, the reasonable mesh encryption to the local area which needs to be encrypted is carried on to ensure the accuracy of the calculation.

The parameters of the model are as follows: the model size is 10m×10m×2m, open hole radius is 0.1m, perforation radius is 0.01m and the depth is 0.5m along the X axis direction. The model is divided into tetrahedral mesh and do mesh refinement for casing and perforation. The maximum horizontal principal stress of the X axis is 19.78MPa, the minimum horizontal principal stress is 16.21MPa, the vertical stress of the overburden is 18.60Mpa. The elastic modulus of each main direction are as follows: Ex=2906.34MPa, Ey=2156.64MPa, Ez=2689.34MPa. Poisson's ratio of different planes are μxy=0.345, μyz=0.301, μzx=0.329. And the shear modulus are Gxy=1080.42MPa, Gyz=828.84MPa, Gzx=1011.79MPa.

According to the calculation method of reference [11,12], in order to calculate the fracture initiation pressure of perforation completion, we should finger out the relationship between maximum tension stress and the stress of fracturing fluid through simulating, and then calculate the fracture pressure according to the maximum tension stress.

3. Literature References

First, simulate and calculate the change of circumferential stress under different internal pressure in the perforation hole wall, and then calculate maximum tensile stress of perforation hole wall under the different fracturing fluid pressure.

According to the results of the finite element simulation, the relationship between the maximum tensile stress of coal seam perforation completion and the internal pressure can be regressed. According to tensile strength criterion which shows that destruction will happen when tensile stress reaches the coal rock tensile strength 0.48MPa, combining with the regression equation:

$$0.48 = 3.2049\ p_f - 61.186 \tag{1}$$

Therefore, the fracturing pressure of the fractured borehole completion model with the maximum principal stress direction is 19.24MPa.

It can be seen that the fracture pressure can be calculated by the finite element model, and the influence of the perforation depth, azimuth and perforation diameter on the fracture initiation pressure is analyzed.

4. Analysis of Influencing Factors on the Initiation Fracturing Pressure of Perforated Completion in Coal Seam

In this paper, we study and discuss the effect of perforation completion parameters on fracturing initiation of hydraulic fractures in orthogonal anisotropic coal seam, and only study the change of initiation pressure of single hole without considering the porous and hole distribution caused by stress interference.

(1) The influence of perforation orientation on fracture initiation pressure

Changing the perforation azimuth from 0 °(along the maximum horizontal principal stress direction) to 90 °(along the minimum horizontal principal stress direction), simulating the fracture initiation pressure in different perforation azimuth, the calculated results of the simulation is shown in Fig.1 and Fig.2. The fracture initiation pressure of perforation completion increases with the increasing of perforation azimuth, it can be roughly divided into three stages: with the perforation azimuth ranging from 0 °to 15 °, fracture initiation pressure increases from 19.24MPa to 19.44MPa; with the perforation azimuth ranging from 15 ° to 75 °, the increasing of fracture initiation pressure becomes larger; with the perforation azimuth ranging from 75 °to 90 °, the increasing of fracture initiation pressure gets smaller, which ranges from 26.58MPa to 27.48MPa. The results show that: along the direction of the maximum horizontal principal stress of perforating, fracturing pressure reaches the minimum, which is easy to crack, and along the horizontal direction of minimum principal stress of perforating, fracturing pressure is the biggest, which is the most difficult to crack.

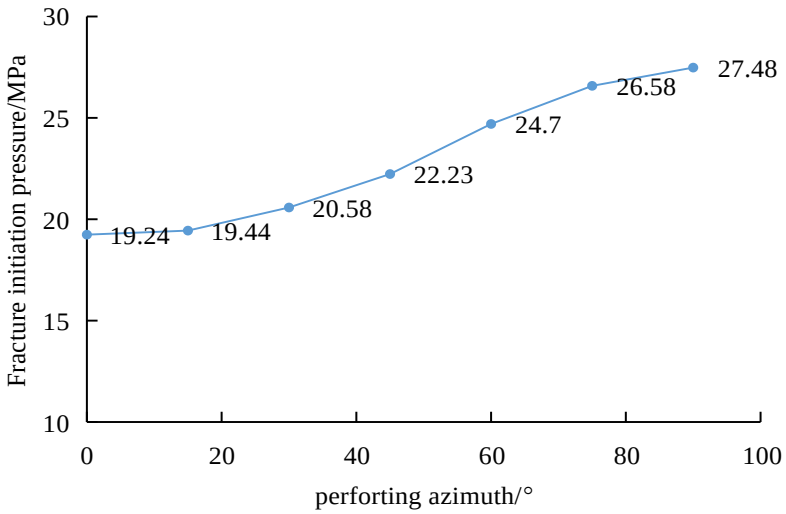
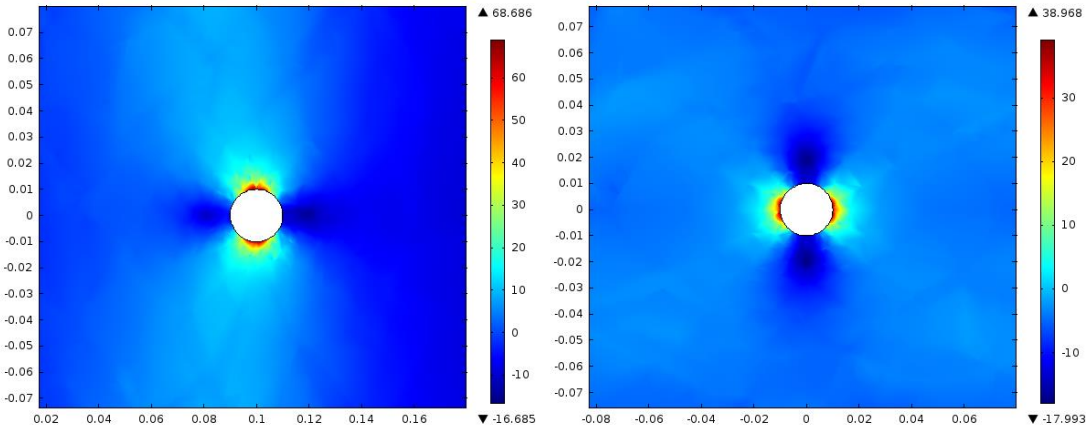


Fig.1 The relation between initiation fracturing pressure and perforated azimuth angle



Perforated azimuth angle of 45 ° Perforated azimuth angle of 90 °

Fig.2 The circumferential stress distribution of perforated hole on the condition of different perforated azimuth angle and borehole internal pressure 40MPa

(2)The influence of perforation diameter on fracture initiation pressure

When the influence of perforation diameter on the initiation pressure is analyzed, the direction of perforation is along the horizontal maximum principal stress. The increase of perforation radius from 0.01 to 0.05m respectively, simulation of changes in pore pressure, and the results are shown in Fig.3 and Fig.4.

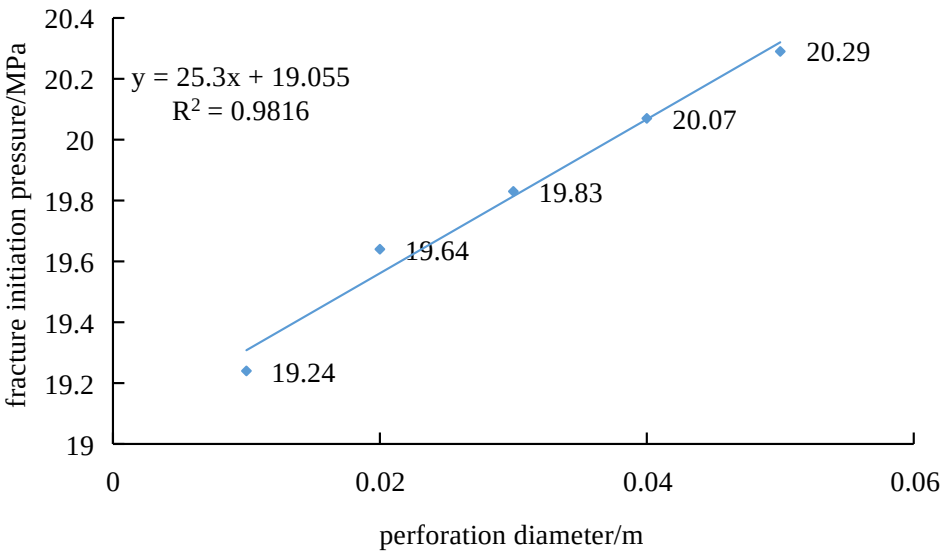
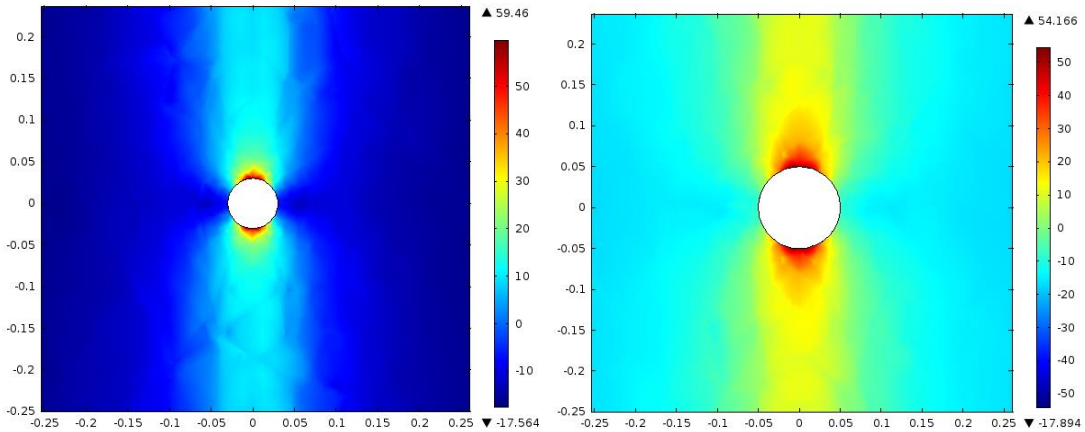


Fig.3 The relation between initiation pressure and perforation diameter



Perforation diameter of 0.06m Perforation diameter of 0.1m

Fig.4 The circumferential stress distribution of perforated hole on the condition of different perforation diameter and borehole internal pressure 40MPa

According to the results of simulation, the fracture initiation pressure increases with the increasing of perforation diameter, and it can be seen from the regression curve of perforation diameter and initiation pressure that the two have a better linear relation, but it is worth noticing that the numerical value of fracture initiation pressure is not large. Perforation diameter increases from 0.02m to 0.1m, and the corresponding fracture initiation pressure of coal seam increases from the original 19.24 MPa to 20.29 MPa, only changes 1.05 MPa. The results show that the perforation diameter has little effect on the fracture initiation pressure.

(3) The influence of perforating depth on fracture initiation pressure

The stress distribution of perforation wall is directly affected by perforating depth. The variation of the circumferential stress of the borehole wall is calculated when the depth of the perforation changes from 0.3 m to 1.1 m. According to the simulation results (Fig.5 and Fig.6), the influence of perforation depth on the initiation pressure is analyzed.

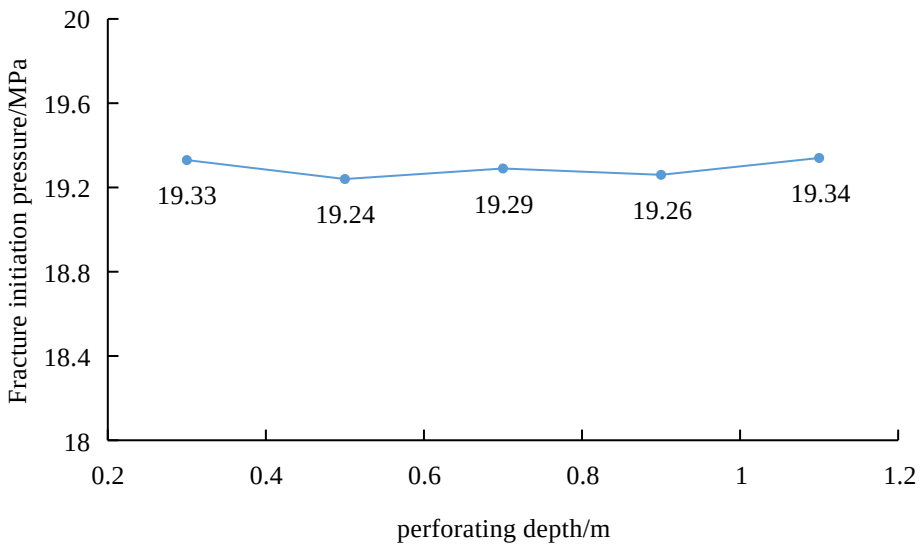
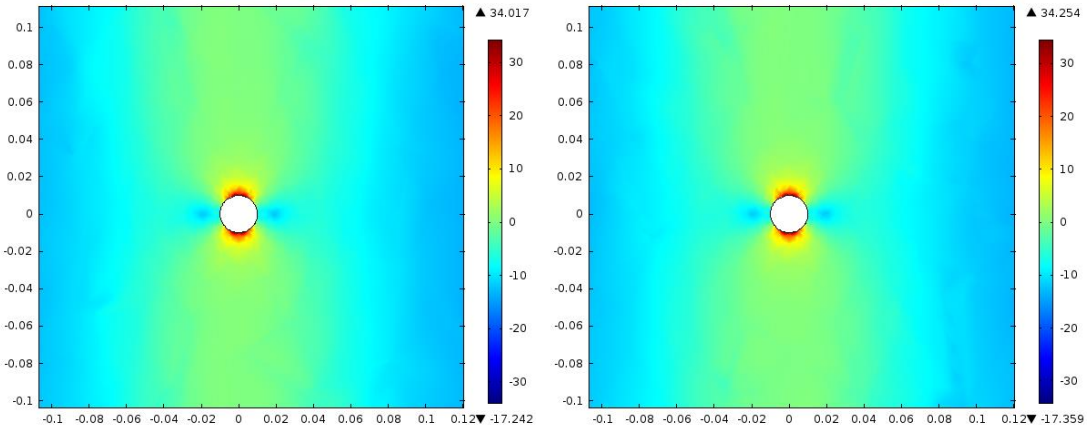


Fig.5 The relation between initiation pressure and perforating depth



Perforating depth of 0.3m Perforating depth of 0.7m

Fig.6 The circumferential stress distribution of perforated hole on the condition of different perforating depth and borehole internal pressure 30MPa

It can be concluded that the depth of perforation increases, and the initiation pressure of coal seam fractures decreases slightly and then increases slightly. There is no obvious increase or decrease trend, and the initiation pressure value fluctuates around 19.30MPa. A result shows that the increase in perforation depth has little effect on the crack initiation pressure.

5. Conclusion

(1) Although the coal rock has its unique mechanical properties, and the stress distribution around the perforation is very complex, the hydraulic fracturing initiation pressure can be calculated accurately through the finite element simulation method.

(2) The initiation pressure of the perforation completion of the coal seam increases with the increase of the perforation azimuth angle, and the perforation pressure is the smallest in the direction of the maximum horizontal principal stress. Along the direction of the minimum horizontal principal stress, the fracture pressure is the biggest and the most difficult to crack.

(3) With the increase of perforation diameter, the fracture initiation pressure of coal seam perforation fracture increases, the two have a good linear relationship, but the influence of perforation diameter on fracture pressure is not obvious; And with the increase of perforation depth, there is no obvious increase or decrease trend of fracture pressure, and the range of fracture initiation pressure is limited.

Acknowledgements

The support of the College Students Innovation and Entrepreneurship Training Schematic Project of Heilongjiang Province entitled "Study on Calculation Model of Fracture Initiation Pressure in CBM Wells" is gratefully acknowledged.

References

[1] Haimson B, Fairhurst C. Initiation and extension of hydraulic fractures in rocks[J]. Society of Petroleum Engineers Journal, 1967, 7(03): 310-318.

[2] Yew C H, Li Y. Fracturing of a deviated well[J]. SPE Production Engineering, 1988, 3(04): 429-437.

[3] Hossain M M, Rahman M K, Rahman S S. Hydraulic fracture initiation and propagation: roles of wellbore trajectory, perforation and stress regimes[J]. Journal of Petroleum Science and Engineering, 2000, 27(3): 129-149.

[4] Tianyu L U O, Jianchun G U O, Jinzhou Z, et al. Study on fracture initiation pressure and fracture starting point in deviated wellbore with perforations[J]. Acta Petrolei Sinica, 2007, 28(1): 139.

[5] Fallahzadeh S A H, Shadizadeh R S, Pourafshary P. Dealing with the challenges of hydraulic fracture initiation in deviated-cased perforated boreholes[C]//Trinidad and Tobago energy resources conference. Society of Petroleum Engineers, 2010.
[6] Jin Y, Zhang X D, Chen M. Initiation pressure models for hydraulic fracturing of vertical wells in naturally fractured formation[J]. Acta Petrolei Sinica, 2005, 26(6): 113-118.
[7] Yan J, Mian C, Xudong Z. Hydraulic fracturing initiation pressure models for directional wells in naturally fractured formation[J]. Acta Petrolei Sinica, 2006, 27(5): 124.
[8] Zhao J, Ren L, Hu Y, et al. A calculation model of breakdown pressure for perforated wells in fractured formations[J]. Acta Petrol. Sin, 2012, 33(5): 841-845.
[9] Zhao J, Ren L, Hu Y, et al. Hydraulic fracture tensile initiation pressure analysis for fractured formations[J]. Chin. J. Rock Mech. Eng., 2013, 32: 2855-2862.
[10] Lan R, Jinzhou Z, Yongquan H. Tensile initiation characteristics analysis of hydraulic fracture in perforated well of fractured formations[J]. Journal of Central South University: Science and Technology, 2013, 44(2): 707-713.
[11] Li C, Pan Y. Numerical simulation on coal hydraulic fracturing initiation pressure and crack propagation under different ground stresses[J]. Innovation and Practice on Prevention and Control of Coal Mine Bumps, High-end BBS, 2013.
[12] Gensheng L, Li L, Zhongwei H, et al. Study of effect of hydraulic perforating on formation fracturing pressure[J]. Journal of China University of Petroleum, 2006, 30(5): 42-45.