Research Article

Numerical Simulation Research on Hydraulic Fracturing Promoting Coalbed Methane Extraction

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Although hydraulic fracturing technology has been comprehensively investigated, few scholars have studied the influence of hydraulic fracturing on the effect of coalbed methane (CBM) extraction, and few considered the interaction between water and CBM in the research process, which is not conducive to guiding the engineering design of hydraulic fracturing wells. In this work, a hydraulic-mechanical-thermal coupled model for CBM extraction in hydraulic fracturing well is established; it combines gas-liquid two-phase infiltration, where nonisothermal adsorption is also considered. The COMSOL Multiphysics software is used to carry out the numerical simulation study of the CBM extraction process in hydraulic fracturing well and analyze the influence of coalbed permeability, initial methane pressure, and fracture length on CBM extraction in hydraulic fracturing well, and the results show that the hydraulic-mechanical-thermal coupled model for CBM extraction can be used for CBM extraction research in hydraulic fracturing well. The initial coalbed permeability, initial gas pressure, and fracture length all affect the migration speed of CBM to surface well in different ways and have a greater impact on the CBM production rate of hydraulic fracturing well. The greater the initial coalbed permeability and methane pressure are, the longer the fracture length is and the greater the CBM production rate of hydraulic fracturing well is. The change trend of coalbed permeability during the extraction process of surface fracturing well is directly related to the state of the reservoir. The factors of stress, temperature, and CBM desorption jointly determine the increase or decrease of coal seam permeability.

1. Introduction

CBM is an associated gas of coal. Its calorific value is 1~4 times that of general-purpose coal. With the rapid economic development and strong energy demand today, CBM development has become a hot issue [1]. China has the world's third largest CBM resources, but 75% of the CBM is in low-permeability, soft, and deep-buried coal seams, which greatly increases the difficulty of CBM resource development [2]. In order to increase the production of CBM and promote the utilization of CBM resources, hydraulic fracturing technology is widely used in surface well CBM extraction projects [3, 4].

The principle of coalbed hydraulic fracturing technology is to inject high-pressure liquid into the original coalbed to

promote the development of fractures and increase coalbed migration channels [5]. In 1947, the world's first fracturing well was completed in Hugoton Gas Field, Kansas, USA. With the rise of CBM development projects, it has been widely used in the field of CBM mining. In recent years, hydraulic fracturing wells have achieved widespread success in soft coalbed with low permeability. As of 2019, the CBM extraction volume of surface wells has reached 5.9 billion m³, most of which have adopted hydraulic fracturing technology.

Many scholars have done a lot of research on hydraulic fracturing technology: the authors of [6] analyzed the influencing factors of hydraulic fracturing on oil and gas production and proposed strategies to use the latest findings to enhance primary recovery and alleviate some

FIGURE 1: Schematic diagram of CBM exploitation process.

common problems in secondary recovery; the authors of [7] analyzed the influence of crustal stress field, confining pressure, and natural fractures on fractures in hydraulic fracturing wells by using similar laboratory tests; Zhang et al. [8] used a combination of hydraulic fracturing laboratory tests and three-dimensional scanning to analyze the influence of fracturing fluid injection pressure and velocity on the fracturing effect during the fracturing process; and Lei et al. [9] used true triaxial hydraulic fracturing physical simulation experimental equipment to analyze the influence of perforation on the direction of hydraulic pressure.

In terms of numerical simulation research of hydraulic fracturing, the author of [10] established a fully coupled elastic-plastic hydraulic fracturing model based on related theories of rock mechanics and fluid mechanics; the authors of [11] used numerical simulation method to study the characteristics of coal fracture development and propagation; the authors of [12] studied the influence of hydraulic fracturing on faults by numerical simulation; the authors of [5] analyzed the connection between macroscopic mechanical parameters and mesoscopic mechanical parameters based on two-dimensional particle flow code (PFC2D); the authors of [13] proposed a method to determine the maximum and minimum stresses and coal parameters of coalbed based on the pressure test values during hydraulic fracturing; and the authors of [14] established a thermohydromechanical coupled model to analyze the effects of coalbed permeability, gas pressure, temperature, and fracture radius on single-slit well gas drainage.

In this work, a hydraulic-mechanical-thermal coupled model for CBM extraction in hydraulic fracturing well is established; it combines gas-liquid two-phase infiltration, where nonisothermal adsorption is also considered. The COMSOL Multiphysics software is used to carry out the numerical simulation study of the CBM extraction process in hydraulic fracturing well and analyze the influence of coalbed permeability, initial pressure, and fracture length on CBM extraction in hydraulic fracturing well.

2. The Hydraulic-Mechanical-Thermal Coupled Model for CBM Extraction in Hydraulic Fracturing Well

CBM extraction will cause a series of changes in the coalbed. For example, CBM desorbs from the coal skeleton and migrates in the fissures, water seeps into the wellhead under the action of the pressure gradient, the coal body deforms, and the temperature exchanges (Figure 1). In order to establish a mathematical model describing the above process, the following hypotheses are proposed [1, 13, 15–17]:

- (1) The coalbed is a homogeneous isotropic body
- (2) Water and CBM filled the cracks in the coal
- (3) Extraction desorption and adsorption are all completed in an instant
- (4) The gas in coalbed is the ideal gas and does not consider the influence of temperature change on gas dynamic viscosity

2.1. Fluid Seepage Control Equation. The coalbed is full of methane and water. Under the pressure gradient, the methane and water continue to flow to the surface well. The process can be described by the fluid continuity equation [18]:

$$\frac{\partial m}{\partial t} + \nabla \cdot \left(\frac{\rho k}{\mu} \Delta p \right) = Q, \quad (1)$$

where Q is the quality source, $\text{kg}/(\text{m}^3 \cdot \text{s})$; m is the mass of fluid per unit volume of coal, kg/m^3 ; ρ is the fluid density in the coalbed, kg/m^3 ; $\vec{q}_g = -(k/\mu)\Delta p$ is the fluid seepage velocity in the coalbed, m/s ; k is the coalbed permeability, m^2 ; μ is the dynamic viscosity of gas, $\text{Pa} \cdot \text{s}$; p is coalbed pressure, Pa .

The methane mass per unit volume of coal can be expressed as [19]

$$m_g = \rho_g \varphi s_g + (1 - \varphi) \rho_{ga} \rho_s V_{cg}, \quad (2)$$

FIGURE 2: Establishment of numerical simulation model.

where φ is the porosity; ρ_{ga} is the gas density under standard conditions, kg/m^3 ; ρ_s is the density of coal skeleton, kg/m^3 ; $\rho_g = M_g P / RT$ is the methane density in the coal seam,

kg/m^3 ; T is the coal seam temperature, K, m^3/kg ; M_g is the gas molar mass, kg/mol ; R the gas molar constant, $\text{J}/(\text{mol}\cdot\text{K})$; V_{cg} is the gas adsorbed per unit mass of coal volume [15].

TABLE 1: Numerical simulation parameters.

Variable	Parameter	Value	Unit	Acquisition approach	Remark
E	Young's modulus of coal	2710	MPa	Experiments	
ν	Poisson's ratio	0.3		Experiments	
E_s	Young's modulus of coal skeleton	9520	MPa	Experiments	
α_s	Adsorption strain factor	0.06	kg/m ³	Experiments	
ρ_s	Density of coal skeleton	1380	kg/m ³	Experiments	
ϕ_0	Initial coalbed porosity	0.037		Experiments	
P_0	Initial pressure of coalbed	3.53	MPa	Field data	
k_0	Initial coalbed permeability	5.14×10^{-16}	m ²	Field data	
μ_g	Dynamic viscosity coefficient of methane	1.84×10^{-5}	Pa·s	References	[18]
μ_w	Dynamic viscosity coefficient of water	1.01	mPa·s	References	[18]
α_T	Thermal expansion coefficient	2.4×10^{-5}	1/K	References	[28]
V_L	Langmuir volume constant	0.02	m ³ /kg	Experiments	
P_L	Langmuir pressure constant	0.96	MPa	Experiments	
d_1	Langmuir pressure correction factor	0.07	MPa ⁻¹	References	[28]
d_2	Langmuir temperature correction factor	0.02	K ⁻¹	References	[28]
T_t	Laboratory reference temperature	300	K	References	[28]
C_s	Specific heat capacity of the coal skeleton	1300	J/(kg·K)	References	[28]
C_g	Specific heat capacity of gas	2550	J/(kg·K)	References	[28]
C_w	Specific heat capacity of water	4200	J/(kg·K)	References	
λ_s	Heat conductivity of coal skeleton	0.193	W/(m·K)	References	[28]
λ_g	Heat conductivity of gas	0.031	W/(m·K)	References	[28]
λ_w	Heat conductivity of water	0.598	W/(m·K)	References	[18]
q_{st}	Isosteric heat of adsorption	33.4	J/mol	References	[28]
s_{wr}	Irreducible water saturation	0.05		References	[18]
s_{gr}	Irreducible gas saturation	0.05		References	[18]

$$V_{cg} = \frac{V_L P_m}{P_L + P_m} \exp \left[-\frac{d_2}{1 + d_1 P_m} (T - T_t) \right], \quad (3)$$

where d_1 is the pressure coefficient, Pa⁻¹; d_2 is the temperature coefficient, K⁻¹; V_L is the Langmuir volume constant, m³/kg; P_L is the Langmuir pressure constant, Pa; T_t is the laboratory reference temperature, K.

The mass of water per unit volume of coal can be expressed as

$$m_w = \rho_w \phi s_w, \quad (4)$$

where s_w is the water saturation in the coalbed; ρ_w is the density of water, kg/m³.

The fluid seepage velocity in the coalbed can be expressed as

$$\begin{cases} k_g = k k_{rg}, \\ k_w = k k_{rw}. \end{cases} \quad (5)$$

According to the relative permeability model of porous media [20–23],

$$\begin{cases} k_{rw} = \left(\frac{s_w - s_{wr}}{1 - s_{wr}} \right)^4, \\ k_{rg} = \left[1 - \left(\frac{s_w - s_{wr}}{1 - s_{wr} - s_{gr}} \right) \right]^2 \left[1 - \left(\frac{s_w - s_{wr}}{1 - s_{wr}} \right)^2 \right], \end{cases} \quad (6)$$

where s_{wr} is the irreducible water saturation; s_{gr} is the irreducible gas saturation.

Simultaneous formulas (1)–(5) are the seepage control equation of methane and water in the coalbed which can be expressed as

$$\begin{aligned} \frac{\partial(\rho_w \phi s_w)}{\partial t} + \nabla \cdot \left(-\frac{\rho_w k k_{rw}}{\mu_w} \Delta p_w \right) &= Q_w, \\ \frac{\partial(\rho_g \phi s_g + (1 - \phi) \rho_{ga} P_s V_{cg})}{\partial t} + \nabla \cdot \left(-\frac{\rho_g k k_{rg}}{\mu_g} \Delta p_g \right) &= Q_g, \end{aligned} \quad (7)$$

where μ_w and μ_g are dynamic viscosity coefficients of water and methane, respectively.

2.2. Control Equation of Coalbed Stress Field. The Navier equation of coal space balance is [24–26]

$$\sigma_{ij,j} + F_i = 0, \quad (8)$$

where σ_{ij} is the total stress in the coal, N; F_i is the volume force component, N.

The Cauchy equation satisfied by the strain component and displacement component of the coal body is

$$\varepsilon_{ij} = \frac{1}{2} (u_{i,j} + u_{j,i}), \quad (9)$$

where ε_{ij} is the component of strain tensor, m; u is the displacement component, m.

Under the action of surface well, the amount of methane adsorption and temperature and stress on coal are constantly changing. The constitutive equation of coal

TABLE 2: Simulation strategy.

Program	Model
Case 1: influence of initial permeability on methane extraction effect of hydraulic fracturing well	Model 1: $k_0 = 5 \times 10^{-17} \text{ m}^2$
	Model 2: $k_0 = 9 \times 10^{-17} \text{ m}^2$
	Model 3: $k_0 = 13 \times 10^{-17} \text{ m}^2$
	Model 4: $k_0 = 17 \times 10^{-17} \text{ m}^2$
Case 2: influence of initial coalbed pressure on methane extraction effect of hydraulic fracturing well	Model 1: $P_0 = 2.53 \text{ MPa}$;
	Model 2: $P_0 = 3.53 \text{ MPa}$
	Model 3: $P_0 = 4.53 \text{ MPa}$
	Model 4: $P_0 = 5.53 \text{ MPa}$
Case 3: influence of fracture length on methane extraction effect of hydraulic fracturing well	Model 1: $L = 10 \text{ m}$
	Model 2: $L = 15 \text{ m}$
	Model 3: $L = 20 \text{ m}$
	Model 4: $L = 25 \text{ m}$

FIGURE 3: Comparison of numeric solution of methane production rate and field data of methane production rate.

FIGURE 4: Variation of methane production rate with different initial coalbed permeability.

FIGURE 5: Variation of coalbed methane pressure with different initial coalbed permeability. (a) $k_0 = 5 \times 10^{-17} \text{ m}^2$. (b) $k_0 = 9 \times 10^{-17} \text{ m}^2$. (c) $k_0 = 13 \times 10^{-17} \text{ m}^2$. (d) $k_0 = 17 \times 10^{-17} \text{ m}^2$.

hydraulic-mechanical-thermal coupling based on the theory of porous media can be expressed as [27, 28]

$$\begin{aligned} \varepsilon_{ij} = & \frac{1}{2G}\sigma_{ij} - \left(\frac{1}{6G} - \frac{1}{9K}\right)\sigma_{kk}\delta_{ij} + \frac{\alpha}{3K}p_g\delta_{ij} \\ & + \frac{\alpha_T}{3}(T - T_0)\delta_{ij} + \frac{\varepsilon_a}{3}\delta_{ij}, \end{aligned} \quad (10)$$

where G is the Lamé coefficient, $G = E/(2 + 2\nu)$, Pa; E is Young's modulus of the coal, Pa; K is the bulk modulus of the coal, Pa; $\alpha = 1 - K/K_s$ is Biot coefficient of coal; K_s is the bulk modulus of coal matrix, Pa; α_T is the volume thermal expansion coefficient, $1/K$; $\varepsilon_a = \alpha_a \Delta V_{cg}$ is the adsorption strain; α_a is the adsorption strain coefficient, kg/m^3 ; δ_{ij} is the Kronecker symbol; ν is the coal body's Poisson's ratio.

FIGURE 6: Variation of methane production rate with different initial coalbed pressure.

Combining (8)–(10) can obtain the control equation of coalbed stress field:

$$Gu_{i,jj} + \frac{G}{1-2\nu}u_{j,jj} - \alpha p_{g,i} - K\varepsilon_{s,i} - K\alpha_T T_i + F_i = 0. \quad (11)$$

$$\frac{\partial((\rho C_p)_c T)}{\partial t} + \eta \nabla T - \nabla \cdot (\lambda \nabla T) + K\alpha_T T \frac{\partial \varepsilon_a}{\partial t} + q_{st} \frac{\rho_c \rho_{ga}}{M_g} \frac{\partial V_{cg}}{\partial t} = 0, \quad (12)$$

$$(\rho C_p)_c = (1-\varphi)\rho_s C_s + \varphi s_g \rho_g C_g + \varphi s_w \rho_w C_w, \quad (13)$$

$$\eta = -\frac{k k_{rg}}{\mu_g} \nabla p_g \rho_g C_g - \frac{k k_{rw}}{\mu_w} \nabla p_w \rho_w C_w, \quad (14)$$

$$\lambda = (1-\varphi)\lambda_s + s_g \varphi \lambda_g + s_w \varphi \lambda_w,$$

where C_g is the specific heat capacity of methane, J/(m³·K); λ_g is the thermal conductivity of methane, W/(m·K); C_s is the specific heat capacity of the coal skeleton, J/(m³·K); λ_s is the thermal conductivity of the coal skeleton, W/(m·K); q_{st} is the equivalent heat of adsorption, J/mol; $(\rho C_p)_c$ is the effective specific heat capacity of coal and coal bed gas, J/(m³·K); η is the convection coefficient, J/(m²·s); λ_c is the thermal conductivity of coal skeleton and coal bed gas, W/(m·K).

FIGURE 7: Variation of coalbed permeability with different initial coalbed pressure at the reference point B.

2.3. Control Equation of Coalbed Temperature Field. Under the action of surface well, there is temperature exchange between methane, water, and coal skeleton in the coalbed. According to the first law of thermodynamics, the coalbed temperature field control equation can be expressed as

2.4. Cross Coupling. During the process of CBM extraction in surface wells, the continuous change of coalbed porosity under the influence of stress, temperature, and methane desorption can be expressed as [29]

$$\varphi = 1 - \frac{(1-\varphi_0)}{1+e} \left(1 - \frac{\alpha}{K} \Delta p + \alpha_T \Delta T + \alpha_a (V_{cg} - V_{cg0}) \right), \quad (15)$$

where φ_0 is the initial coalbed porosity.

Considering coal body damage, the coalbed permeability during methane extraction can be expressed as [30]

$$k = k_0 \left(\frac{1}{\varphi_0} - \frac{(1-\varphi_0)}{\varphi_0(1+e)} \left(1 - \frac{\alpha}{K} \Delta p + \alpha_T \Delta T + \alpha_a (V_{cg} - V_{cg0}) \right) \right)^3, \quad (16)$$

where k_0 is the initial coalbed permeability, m².

FIGURE 8: Variation of coalbed methane pressure with different initial coalbed pressure. (a) $P_0 = 2.53$ MPa. (b) $P_0 = 3.53$ MPa. (c) $P_0 = 4.53$ MPa. (d) $P_0 = 5.53$ MPa.

3. Model Validation

Yuwu Coal Mine is located in the east wing of Qinshui Basin in China, with a minefield area of 160.24 km^2 . The main coalbed is 3#, with an average coalbed thickness of 6 m and a methane reserve of $16,568.519 \text{ Mm}^3$. Due to the large methane content in the minefield, the low coalbed permeability, and the difficulty of methane extraction, Yuwu Coal Mine has constructed 170

surface wells since 2008, of which 124 are hydraulic fracturing wells. The overall structure of the coal mine is gently dipping and monoclinic. On this basis, the development direction is relatively single and wide and gentle folds (the dip angle of the two wings is generally less than 10°); along the dip and strike, there are a small number of faults with a fault distance greater than 20 m and a certain number of faults less than 20 m fault and collapse column.

In order to analyze the impact of coalbed hydraulic fracturing on methane extraction, the LA-019 surface fracturing well of Yuwu Coal Mine is taken as the simulation object. The model size is $300\text{ m} \times 300\text{ m}$. The fracture development length and shape are obtained from underground observations. The two main fractures are distributed on both sides of the fracturing well, with a one-way length of about 15 m and an azimuth angle of 50° (Figure 2). The external boundary of this model is restrained from boundary-normal displacements and insulated for gas and thermal transport.

In order to facilitate the observation of the simulation effect, reference point B and reference line AC are set, and the coordinates of points A, B, and C are (0, 150), (200, 150), and (300, 150), respectively. Numerical simulation parameters come from the field, tests, or references (Table 1). In order to study the influence of initial coalbed pressure, initial permeability, and fracture length on the methane extraction effect of hydraulic fracturing well, the three sets of data were simulated by the controlled variable method (Table 2).

In order to verify the accuracy of the model, the methane production rate data of LA-019 surface fracturing well in Yuwu Coal Mine was compared with the numerical simulation data (the calculation of gas production is in standard state). As illustrated in Figure 3, although the field data fluctuates, there is a clear trend of change. The simulation results are highly matched with the field data, indicating that the built model can be used for methane extraction research in hydraulic fracturing wells.

4. Numerical Simulation of Methane Extraction in Hydraulic Fracturing Well

4.1. Influence of Initial Permeability on Methane Extraction Effect of Hydraulic Fracturing Well. Figure 4 shows the variation of methane production rate with different initial coalbed permeability. As illustrated in Figure 4, the methane production rate of hydraulic fracturing wells gradually increases first and then gradually decreases. When the initial coalbed permeability $k_0 = 5 \times 10^{-17}\text{ m}^2$, $9 \times 10^{-17}\text{ m}^2$, $13 \times 10^{-17}\text{ m}^2$, $17 \times 10^{-17}\text{ m}^2$, the peak methane production rate is $254.29\text{ m}^3/\text{day}$, $361.99\text{ m}^3/\text{day}$, $490.21\text{ m}^3/\text{day}$, and $647.80\text{ m}^3/\text{day}$, respectively. Making the initial coalbed permeability $k_0 = 5 \times 10^{-17}\text{ m}^2$ as a reference, the peak methane production rate of $k_0 = 9 \times 10^{-17}\text{ m}^2$, $13 \times 10^{-17}\text{ m}^2$, $17 \times 10^{-17}\text{ m}^2$ is increased by 42.35%, 92.78%, and 154.75%, respectively.

Figure 5 shows the variation of coalbed methane pressure with different initial coalbed permeability. As illustrated in Figure 5, the greater the initial coalbed permeability, the better the methane extraction effect of hydraulic fracturing well. When the initial coalbed permeability $k_0 = 5 \times 10^{-17}\text{ m}^2$, $9 \times 10^{-17}\text{ m}^2$, $13 \times 10^{-17}\text{ m}^2$, $17 \times 10^{-17}\text{ m}^2$, after 3650 d of extraction, the average methane pressure of the coalbed is 2.79 MPa, 2.52 MPa, 2.32 MPa, and 2.17 MPa, respectively. Making the initial coalbed permeability $k_0 = 5 \times 10^{-17}\text{ m}^2$ as a reference, the average methane pressure of $k_0 = 9 \times 10^{-17}\text{ m}^2$, $13 \times 10^{-17}\text{ m}^2$, $17 \times 10^{-17}\text{ m}^2$ is decreased by 9.38%, 16.84%, and 22.22%, respectively.

FIGURE 9: Variation of methane production rate with different fracture length.

FIGURE 10: Variation of coalbed permeability with different fracture length at the reference point B.

4.2. Influence of Initial Coalbed Pressure on Methane Extraction Effect of Hydraulic Fracturing Well. Figure 6 shows the variation of methane production rate with different initial coalbed pressure. As illustrated in Figure 6, because the coalbed methane seepage velocity is greatly affected by the methane pressure gradient, increasing the initial reservoir pressure increases the pressure gradient between the coalbed and the extraction well, and the methane production of hydraulic fracturing well increases. When the initial coalbed pressure is $P_0 = 2.53\text{ MPa}$, 3.53 MPa , 4.53 MPa , and 5.53 MPa , the peak methane production rate is $284.21\text{ m}^3/\text{day}$, $312.87\text{ m}^3/\text{day}$, $413.16\text{ m}^3/\text{day}$, and $509.21\text{ m}^3/\text{day}$, respectively.

Figure 7 shows the variation of coalbed permeability with different initial coalbed pressure at the reference point B. As illustrated in Figure 7, during the process of methane

FIGURE 11: Variation of coalbed methane pressure with different fracture length. (a) $L = 10$ m. (b) $L = 15$ m. (c) $L = 20$ m. (d) $L = 25$ m.

extraction, coalbeds with different initial pressure have different trend in permeability. This is because the changes in coalbed permeability are the result of competition between two factors: the coal matrix shrinkage caused by temperature reduction and methane desorption and the coal matrix expansion caused by methane pressure decrease. When the methane pressure is high, the matrix expansion caused by methane pressure decrease dominates and the permeability decreases.

Figure 8 shows the variation of coalbed methane pressure with different initial coalbed pressure. As illustrated in Figure 8, although the permeability of the high initial

pressure coalbed is lower than the low initial pressure coalbed in the process of methane extraction, the higher the initial pressure under the influence of the pressure gradient, the greater the average methane pressure drop of the coal seam bed in the same time of extraction.

4.3. Influence of Fracture Length on Methane Extraction Effect of Hydraulic Fracturing Well. Figure 9 shows the variation of methane production rate with different fracture length. As illustrated in Figure 9, fractures increase the methane migration channel of the coalbed. The longer the fracture

length is, the greater the methane production rate is. When the fracture length $L = 10$ m, 15 m, 20 m, and 25 m, the peak methane production rate is $294.03 \text{ m}^3/\text{day}$, $361.99 \text{ m}^3/\text{day}$, $402.42 \text{ m}^3/\text{day}$, and $451.45 \text{ m}^3/\text{day}$, respectively.

Figure 10 shows the variation of coalbed permeability with different fracture length at the reference point B. As illustrated in Figure 10, affected by the efficiency of methane extraction, the permeability of the coalbed increases with the length of the fracture in the same extraction time. When the fracture length $L = 10$ m, 15 m, 20 m, and 25 m, after 3650 days of extraction, the permeability at the reference point B is $9.32e^{-17} \text{ m}^2$, $9.38e^{-17} \text{ m}^2$, $9.46e^{-17} \text{ m}^2$, and $9.55e^{-17} \text{ m}^2$, respectively.

Figure 11 shows the variation of coalbed methane pressure with different fracture length. As illustrated in Figure 11, the longer the fracturing fracture is, the higher the extraction efficiency is. When the fracture length $L = 10$ m, 15 m, 20 m, and 25 m, the average methane pressure of the coalbed is 2.79 MPa, 2.52 MPa, 2.32 MPa, and 2.17 MPa after 3650 days of extraction. Making the fracture length $L = 10$ m as a reference, the average coalbed methane pressure of $L = 15$ m, 20 m, and 25 m is decreased by 9.38%, 16.84%, and 22.22%, respectively.

5. Conclusions

In this work, a hydraulic-mechanical-thermal coupled model for CBM extraction in hydraulic fracturing well is established, and it combines gas-liquid two-phase infiltration, where nonisothermal adsorption is also considered. The COMSOL Multiphysics software is used to carry out the numerical simulation study of the CBM extraction process in hydraulic fracturing well and analyze the influence of coalbed permeability, initial pressure, and fracture length on CBM extraction in hydraulic fracturing well. The following conclusions can be drawn:

- (1) The hydraulic-mechanical-thermal coupled model for CBM extraction in hydraulic fracturing well established includes methane desorption, coal deformation, temperature exchange, and gas-water seepage. The numerical simulation effect of the model can be highly consistent with the field data, and it can be used for CBM extraction research in hydraulic fracturing well.
- (2) The initial coalbed permeability, initial methane pressure, and fracture length all affect the migration speed of CBM to the hydraulic fracturing well in different ways. The greater the initial coalbed permeability and methane pressure is, the longer the fracture length is and the greater the CMB production rate of hydraulic fracturing well is.
- (3) The change trend of coalbed permeability during the extraction process of surface fracturing well is directly related to the state of the reservoir. The factors of stress, temperature, and CBM desorption jointly determine the increase or decrease of coal seam permeability.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

The numerical simulation model was established by Yongpeng fan, Longyong Shu, and Zhonggang Huo. The field data were tracked and investigated by Jinwei Hao and Yang Li. All authors participated in data analysis and manuscript writing.

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