

## Numerical Well Test for Well with Finite Conductivity Vertical Fracture in Coalbed

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**Abstract** A new model is developed for the hydraulic fractured well in coalbed, by considering the following aspects: methane desorption phenomena, finite conductivity vertical fracture, and asymmetry of the fracture about the well. A new parameter is introduced to describe the storage of the fracture, which is named combined fracture storage. Another new concept called fracture asymmetry coefficient is used to define the asymmetry of the fracture about the well. FEM is used to solve the new mathematic model. Both well test type curve and seepage field are got and analyzed. The effects of combined fracture storage, desorption factor, the fracture conductivity, fracture asymmetry coefficient, etc. on type curve are all discussed in detail in this paper.

**Key words:** coalbed, fractured well, numerical method, FEM, finite conductivity

### INTRODUCTION

Coalbed methane is one of the most important gas resources developed recently in China. To study well test method in coalbed, especially how to assess the fractured wells are a key step for reasonable producing process. Only a few numerical models are presented on the hydraulic fractured well in domestic and abroad. Gringarten et al. [1] developed a model of uniform flex and infinite conductivity for vertical fractured well in normal reservoir. Cinco-Lee et al. [2] introduced well test model for the fractured well with finite conductivity fracture firstly. He et al. [3] found a model to assess new finite conductivity fractured well by considering the deformation of media in CBM. In 2005, Y.W. Liu et al. [4] developed the numerical model for the multiwells in coalbed at first time. These research all used the Langmuir adsorption theory. In 2010, Ouyang et al. [5] developed a new model for fractured well with infinite conductivity fracture. On basis of above, a new numerical model for fractured well with finite conductivity vertical fracture is presented in this paper.

### MATHEMATICAL MODEL

Governing equation

$$\frac{\partial^2 p_D}{\partial x_D^2} + \frac{\partial^2 p_D}{\partial y_D^2} + \alpha_{1D} + \alpha_{2D} (p_D - p_{CD}) = \frac{1}{K_r C_{Df}} \frac{\partial p_D}{\partial T_D}, \quad x_D, y_D \in \Omega \quad (1)$$

$$\text{Initial condition : } p_D = 0 \quad (2)$$

$$\text{Inner boundary condition : } \sum L_{iD} \left( \frac{\partial p_{iD}}{\partial n} \right) \Big|_{r_{in}} = 2\pi \left( -1 + \frac{d p_{wD}}{d T_D} \right) \quad (3)$$

Outer boundary condition

$$\text{Infinite boundary : } p_D|_{x,y \rightarrow \infty} = 0 \quad (4)$$

$$\text{Constant pressure boundary : } p_D|_{r_{\text{out}}} = 0 \quad (5)$$

$$\text{Closed boundary : } \frac{\partial p_D}{\partial n}|_{r_{\text{out}}} = 0 \quad (6)$$

Where:  $p_D$  is the dimensionless pressure,  $T_D$  is the dimensionless time,  $x_D, y_D$  is the dimensionless position in the coalbed,  $p_{cD}$  is the dimensionless critical adsorption pressure,  $\alpha_{1D}$  is the dimensionless steady adsorption coefficient,  $\alpha_{2D}$  is the dimensionless unsteady adsorption coefficient,  $L_{fD}$  is the dimensionless length of fracture,  $\Gamma_{\text{in}}$  indicates the inner boundary,  $\Gamma_{\text{out}}$  indicates the outer boundary,  $\Omega$  indicates the research region,  $C_{fD}$  is the dimensionless combined fracture storage,  $K_r$  is the ratio of permeabilities between the fracture and the coalbed.

## CALCULATING METHOD

**1. FEM method** To solve the above mathematical model, Galerkin finite element method with weighted residual method and selected interpolation function  $N_i$  as weight function is used,  $N_i = a_i + b_i x + c_i y$ ,  $i = 1, 2, 3$ . Then

$$\iint_A N_i^e \left( \frac{\partial^2 p_D}{\partial x_D^2} + \frac{\partial^2 p_D}{\partial y_D^2} + \alpha_{1D} + \alpha_{2D} p_D - \frac{1}{C_{Df} K_r} \frac{\partial p_D}{\partial T_D} \right) dA = 0 \quad (7)$$

The weak solution formation

$$\iint_A \left( \frac{\partial N_i^e}{\partial x_D} \frac{\partial p_D}{\partial x_D} + \frac{\partial N_i^e}{\partial y_D} \frac{\partial p_D}{\partial y_D} - N_i^e (\alpha_{1D} + \alpha_{2D} p_D) + \frac{N_i^e}{C_{Df} K_r} \frac{\partial p_D}{\partial T_D} \right) dA = \int_{\Gamma} N_i^e \frac{\partial p_{wD}}{\partial n} dl \quad (8)$$

Finite element equations discretized

$$\begin{aligned} & K_r \left( b_i^2 + c_i^2 + \frac{1}{6C_{Df}\Delta T_D} - \frac{\alpha_{2D}}{6} \right) p_i^{e,n+1} + K_r \left( b_i b_j + c_i c_j + \frac{1}{12C_{Df}\Delta T_D} - \frac{\alpha_{2D}}{12} \right) p_j^{e,n+1} + \\ & K_r \left( b_i b_k + c_i c_k + \frac{1}{12C_{Df}\Delta T_D} - \frac{\alpha_{2D}}{12} \right) p_k^{e,n+1} - \frac{L}{3} \frac{\partial p_i^{e,n+1}}{\partial n} - \frac{L}{6} \frac{\partial p_{j/k}^{e,n+1}}{\partial n} = \\ & \frac{1}{6C_{Df}\Delta T_D} p_i^{e,n} + \frac{1}{12C_{Df}\Delta T_D} p_j^{e,n} + \frac{1}{12C_{Df}\Delta T_D} p_k^{e,n} + \frac{\alpha_{1D} K_r}{3} \end{aligned} \quad (9)$$

**2. Discrete of grid for finite elements** In order to calculate finite elements it is necessary to discrete the zone of object, using triangle grid under non-structural and with round out-boundary.

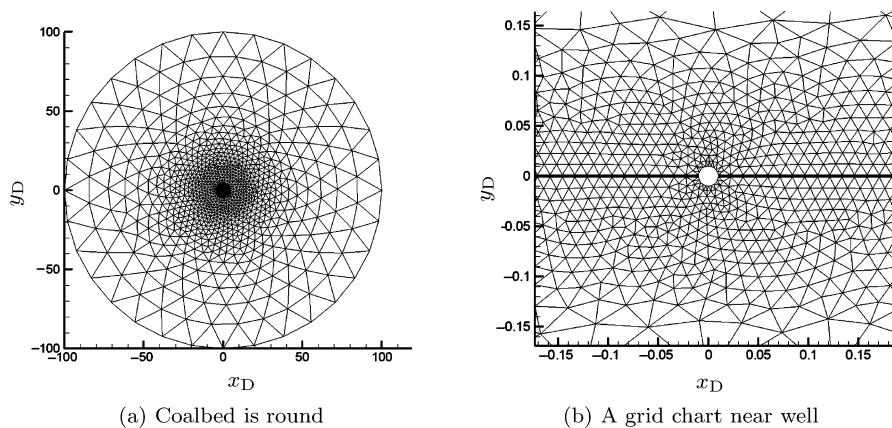


Figure 1: Grid chart of coalbed with non-structure

## RESULT AND ANALYSIS

**1. Well test type curve** The following parameters are taken: dimensionless fracture storage  $C_{Df} = 0.001$ , dimensionless fracture conductivity is 2, dimensionless fracture width is 0.002 and the radius of closed out boundary is 100. The

result of calculation is shown in Figure 2. It is generally divided 4 parts based on the characteristic curve of theory: the first part is wellboe control section line with slope 1, the second part indicated the finite conductivity fracture feature is the straight line with slope 0.25. The third part is a horizontal line of 0.5 with radial fluid flow around the wellbore. The forth one is straight line with slope 1 shown the effect of boundary.

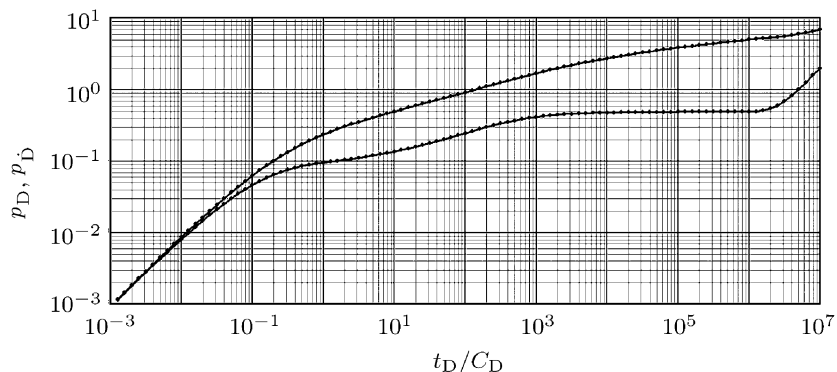


Figure 2: Log-Log type curve for fracture fractured well with finite conductivity fracture

**2. Effects of desorption on type curves** Considering the effect of stable desorption coefficient, i.e.  $\alpha_{1D}$  of coalbed, we take  $\alpha_{1D} = 0, -10^{-4}, -2.04 \times 10^{-4}$  respectively, and unstable desorption coefficient  $\alpha_{2D} = 0$ , combined fracture storage  $C_{Df} = 0.001$ , the radius of boundary  $R = 100$ . The results are shown in Figure 3.

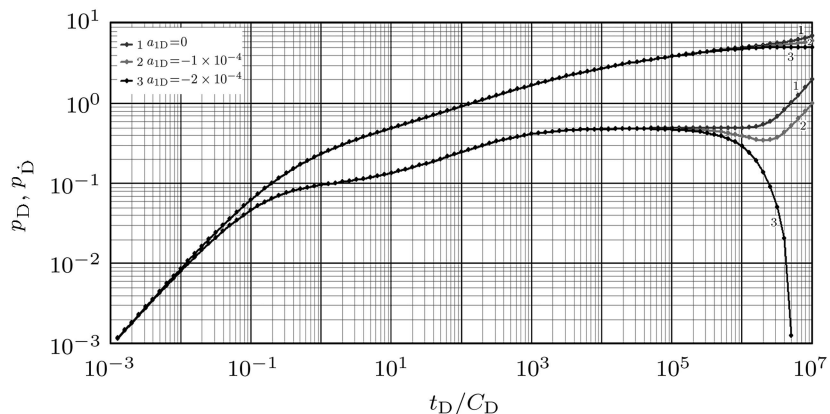


Figure 3: Log-Log type curves for fracture fractured well with different stable desorption coefficients

**3. Seepage field** The seepage fields for the fractured well with different fracture asymmetry coefficients are calculated. In order to see the pressure distribution near the fracture, the seepage fields near the fractured well are drawn as Figure 4. From Figure 4, it shows clearly that the fracture asymmetry coefficients have significant effects on the seepage fields.

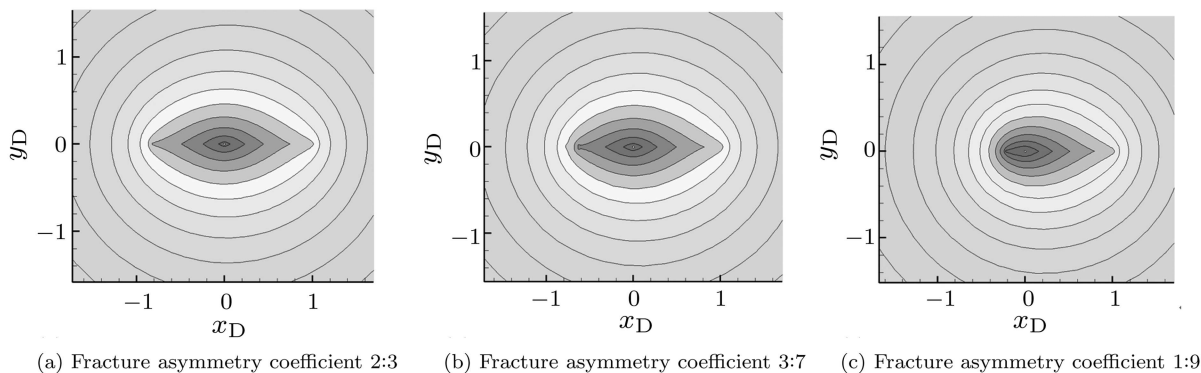


Figure 4: Seepage fields near the fractured well with different fracture asymmetry coefficients

## CONCLUSION

(1) A new model is developed for the hydraulic fractured well in coalbed. Two new conceptions are introduced as combined fracture storage and fracture asymmetry coefficient.

(2) The effects of methane desorption phenomena, finite conductivity vertical fracture, and asymmetry of the fracture about the well on well test type curves are discussed in detail.

(3) The results show that the desorption coefficient delays the pressure propagating in coalbed, the more higher the fracture conductivity, the more larger the drainage area. The fracture asymmetry about the well affects on the seepage field significantly.

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