Research on the Level of Stable Production in the Development of Coalbed Methane Well

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catalog

Introduction

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◆In the process of the development of coalbed methane, with the decline of the coalbed pressure, the effective pressure is increasing, so the porosity and permeability will decrease with the increase of the effective pressure.

◆Because the porosity and permeability is very low, the traditional stress sensitivity experiment is too difficult to be finished. So a new method to deal with this problem is necessary.

◆A simple model which can calculate the level of stable production of coalbed methane well through material balance equation and deliverability equation is found. Stress sensitivity is considered in this model. The model can be used to predict the years of stable production, the pressure of the coalbed, cumulative production and other targets in production.

Model for the change of porosity and permeability with the effective stress

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The simplification of the pore configuration

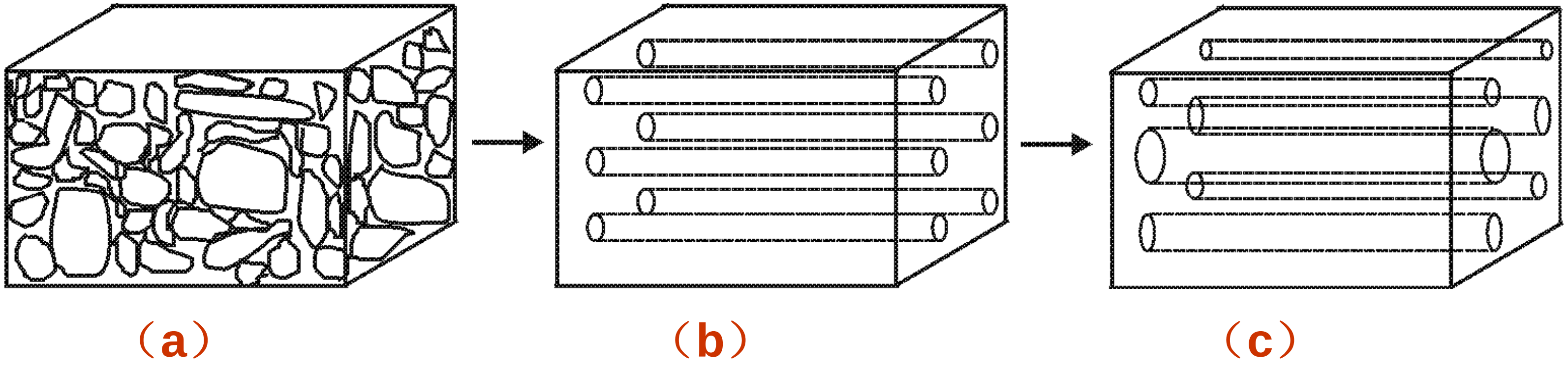


Fig. 1 Capillary tube models a. real pore configuration; b. equal diameter capillary tube model; c. unequal diameter capillary tube model

Model for the change of porosity and permeability with the effective stress

The relationship between porosity, permeability and surface area to volume ratio

$$\phi_0 = \frac{pore \quad volume}{rock \quad volume} = \frac{A \cdot n\pi r^2 L\tau}{A \cdot L} = n\pi r^2 \tau \qquad (1)$$

$$S_0 = \frac{pore \quad surface \quad area}{rock \quad volume} = \frac{A \cdot n2\pi rL\tau}{A \cdot L} = 2\pi rn\tau \qquad (2)$$

$$S_0 = \frac{2\phi_0}{\sqrt{\phi_0/(n\pi\tau)}} \qquad (3)$$

$$K = \frac{\phi_0^3}{2\tau^2 S_0^2} \qquad (4)$$

φ_0 — The porosity when the effective pressure is zero. %;
τ — amount of inclination of per capillary (bending capillary length/straight capillary length);
A — the area of the rock transaction, m^2;
L — Length of the coal rock, m;
S_0 — surface area to volume ratio, cm^2/cm^3;
K — permeability, md;
n — areic capillary tube number, $/m^2$.

Model for the change of porosity and permeability with the effective stress

The relationship between porosity, permeability of coal rock and the volumetric strain

$$\frac{\phi'}{\phi_0} = \frac{1-\varepsilon_v/\phi_0}{1-\varepsilon_v} \qquad (5)$$

$$\frac{k'}{k_0} = \left(\frac{\phi'}{\phi_0}\right)^3 = \left(\frac{1-\varepsilon_v/\phi_0}{1-\varepsilon_v}\right)^3 \qquad (6)$$

$$\varepsilon_v = 1-(1+\varepsilon_1)^2 * (1-\varepsilon_2) \qquad (7)$$

φ’—The porosity variation following the effective stress,%；
k’—The permeability caused by the volumetric strain, md；
ε_v—the volumetric strain, dimensionless;—the area of the rock transaction,m^2；
ε_1 —strain in radial direction, dimensionless;
ε_2 —strain in axis direction, dimensionless.

Model for the change of porosity and permeability with the effective stress

Experimental study of triaxial stress sensitivity

Table 1 The data of the samples deformation in different stress conditions

Axis Pressure (MPa)	Radial pressure (MPa)	Effective Stress (MPa)	Deformation in axis direction $h/10^{-6}$	Deformation in radial direction $d/10^{-6}$
10	10	0.0000	0	0
13.36	10	1.1200	119	-28
15.03	10	1.6767	485	-108
18.11	10	2.7033	1042	-294
20.35	10	3.4500	1636	-593
21.47	10	3.8233	1800	-668
23.7	10	4.5667	2161	-819
25.1	10	5.0333	2368	-916
27.06	10	5.6867	2643	-1031
28.46	10	6.1533	2866	-1133
30.42	10	6.8067	3141	-1252
32.65	10	7.5500	3375	-1367
34.33	10	8.1100	3647	-1497
35.45	10	8.4833	3885	-1628

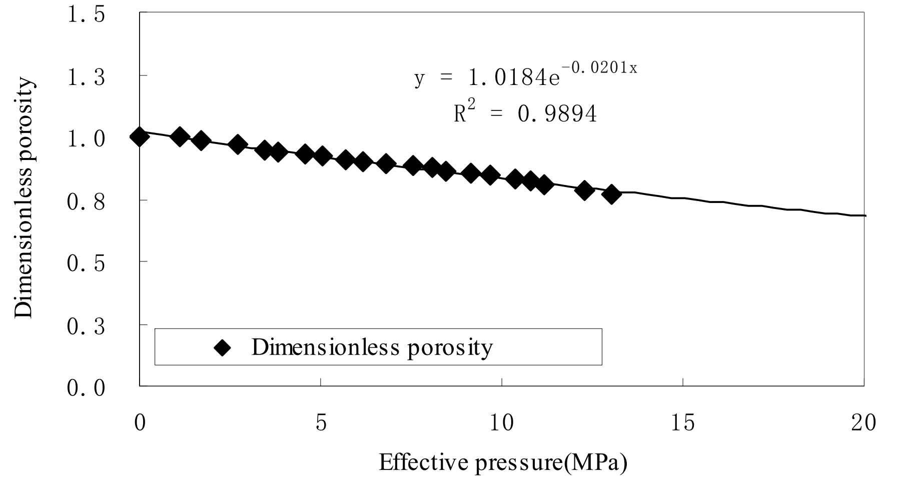
Model for the change of porosity and permeability with the effective stress

Table 2 The variation of SC1 porosity and permeability in different stress conditions

Effective stress (MPa)	Porosity	Permeability (md)	Dimensionless porosity	Dimensionless permeability
0.0000	5.00%	0.5000	1.0000	1.0000
1.1200	4.98%	0.4967	0.9967	0.9934
1.6767	4.93%	0.4868	0.9867	0.9735
2.7033	4.84%	0.4695	0.9690	0.9389
3.4500	4.73%	0.4477	0.9463	0.8954
3.8233	4.70%	0.4421	0.9403	0.8841
4.5667	4.64%	0.4302	0.9276	0.8605
5.0333	4.60%	0.4232	0.9200	0.8463
5.6867	4.55%	0.4143	0.9103	0.8287
6.1533	4.51%	0.4069	0.9021	0.8139
6.8067	4.46%	0.3981	0.8923	0.7962
7.5500	4.42%	0.3902	0.8834	0.7804
8.1100	4.37%	0.3813	0.8732	0.7625
8.4833	4.32%	0.3729	0.8636	0.7459
9.1367	4.26%	0.3633	0.8524	0.7266
9.6967	4.21%	0.3548	0.8423	0.7095
10.3467	4.16%	0.3458	0.8316	0.6916
10.8133	4.11%	0.3377	0.8218	0.6754
11.1867	4.05%	0.3282	0.8102	0.6564
12.3067	3.92%	0.3078	0.7846	0.6156

Model for the change of porosity and permeability with the effective stress

Fig.2 and Fig.3 based on the data from table 2.



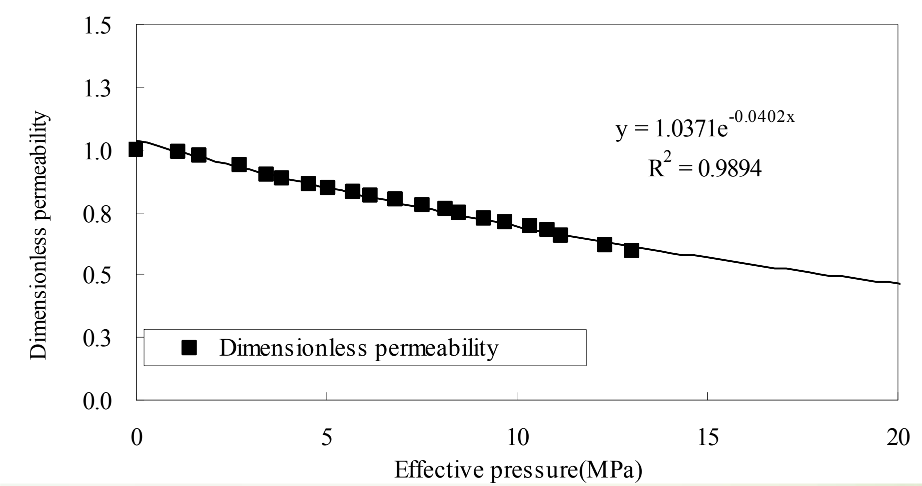


Fig.2 Illustration of the relationship between dimensionless porosity and effective stress of SC1

It shows that the porosity of SC1 decreases by the increasing of effective stress and there is an exponential equation about the porosity and effective stress, when the effective stress increases to 13.42MPa, the damage ratio of the porosity reaches to 28.57%, the dimensionless porosity is 0.7143.

Fig.3 The illustration of the relationship between dimensionless permeability and effective stress

It shows that the SC1 permeability decreases following the effective stress increasing; there is an exponential equation about permeability and effective stress. When the effective stress increases to 13.42MPa, the damage ratio of the permeability reaches to 48.98%, the dimensionless permeability is 0.5102.

The effect on the deliverability equation caused by the stress sensitivity

$$Pe^2 - P_{wf}^2 = AQ + BQ^2 \quad (8)$$

$$A = \frac{84.84\times10^{-4}\,\overline{\mu}_g \overline{Z} T_w P_{sc}}{khT_{sc}}(\lg\frac{r_e}{r_w} + 0.434S) \quad (9)$$

$$B = \frac{1.966\times10^{-16}\,\beta\gamma_g Z T_w P^2{}_{sc}}{h^2 T_{sc}}(\frac{1}{r_w} - \frac{1}{r_e}) \quad (10)$$

According to formula (8) to (10), the binomial factor A of the deliverability equation will increase with the decreasing of reservoir permeability, and the relevant open flow capacity will decrease.

k— permeability, md；
h— thickness of the coalbed, m；
r_e—well control radius, m；
r_w—well radius, m；
u_g—average of viscosity of the gas,；
γ_g—relative density；
z—Z-factor； z—average of Z-factor；
β—coefficient of turbulence；
S—skin factor；
Tw—well temperature, k；
Tsc, Psc —STP；

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Theoretical basement

Given P_{wfmin}

Calculate The reservoir pressure (material balance equation)

$$\frac{P}{Z} = \frac{Pi}{Z_i}(1 - \frac{qT}{ANg}) \quad (11)$$

Fix q, calculate P_{wf}

$$Pe^2 - P_{wf}^2 = AQ + BQ^2 \quad (12)$$

Compare with P_{wfmin} ,Define the period of stable production.

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The example of application

Table 3 Parameters of the well

Reserve controlled by one well （104m3)	Well Depth (m)	Coalbed Pressure (MPa)	Temperature of the coalbed (℃)	Relative density	A	B
1050	1450	10.14	40	0.57	47	124

Take one coalbed methane well for example, the level of stable production of this well could be predicted in use of the mentioned model which takes stress sensitivity into account. The parameters of the well are following as table 3:

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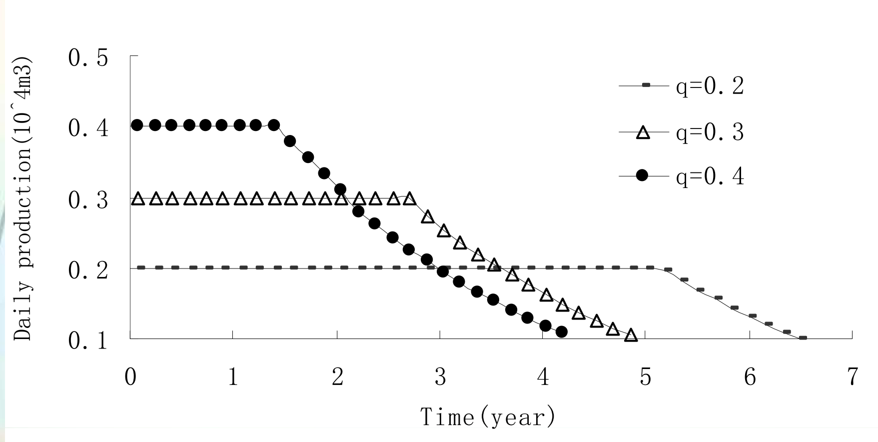
Don’t take stress sensitivity into account



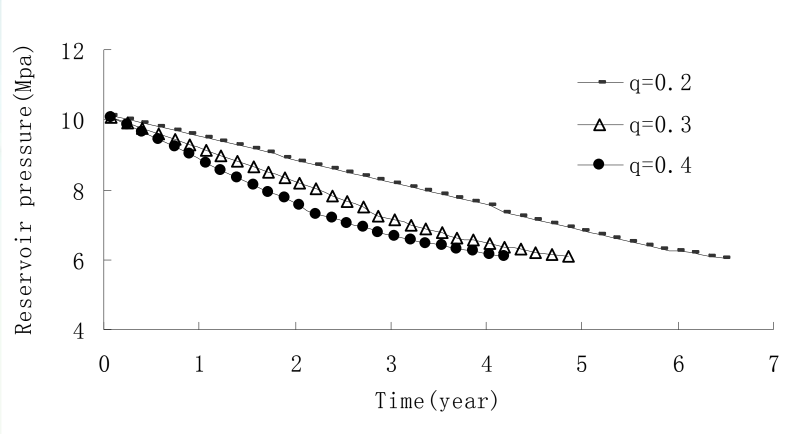


Fig.4 Variant daily production curves with time pressure.

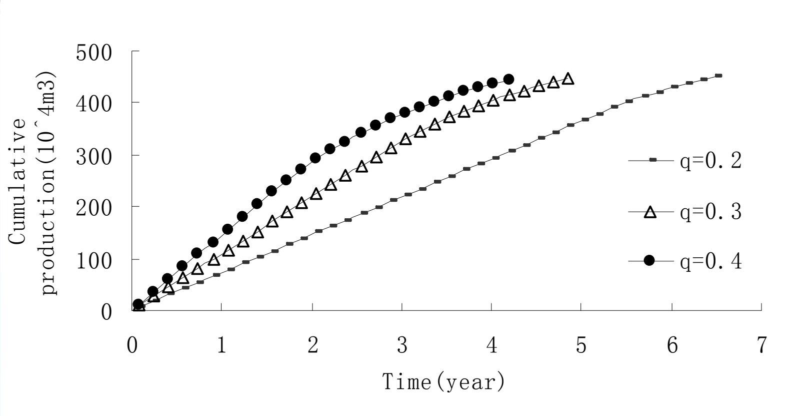
It shows the different gas production curves with production time. Fig.4 shows that the years of stable production will decrease with the increasing of daily production of gas. If the daily production is 0.2, the years of stable production is 5.1 years; if the daily production is 0.3, the years of stable production is 2.7 years; if the daily production is 0.4, the years of stable production is 1.4 years.

Fig.5 Reservoir pressure curves with time

it shows that the coalbed pressure with different daily production can be predicted, which decreases faster with larger production.

Research on the level of stable production

Don't take stress sensitivity into account



The targets of the well in different daily production are following as table 4:

Fig.6 Variant cumulative production curves with time.
it shows that cumulative production of gas with time can be predicted. If the daily production is 0.2, the recovery ratio in the years of stable production is 35.43%; if the daily production is 0.4, the recovery ratio in the years of stable production is 19.43%.

Table 4 The statistical list of the targets of stable production

Daily production （$10^4 m^3/d$)	Years of stable production (year)	Cumulative production of gas($10^4 m^3$)	Recovery ratio in the years of stable production
0.2	5.1	372	35.43%
0.3	2.7	297	28.29%
0.4	1.4	204	19.43%

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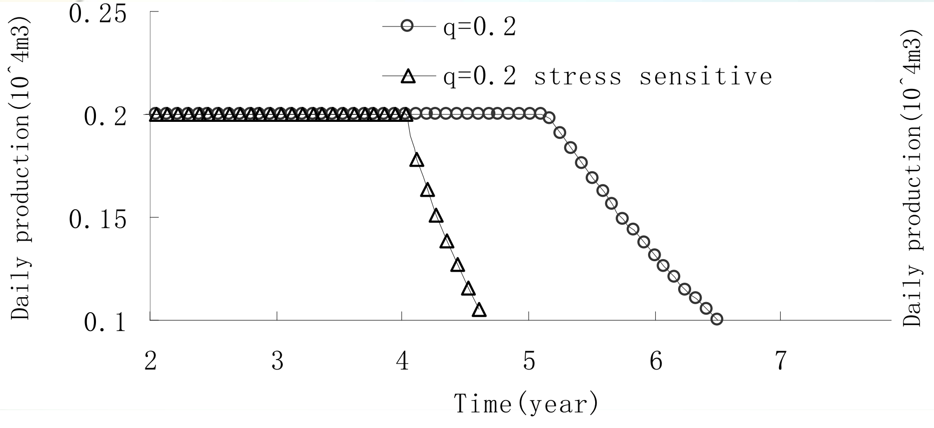
Take stress sensitivity into account



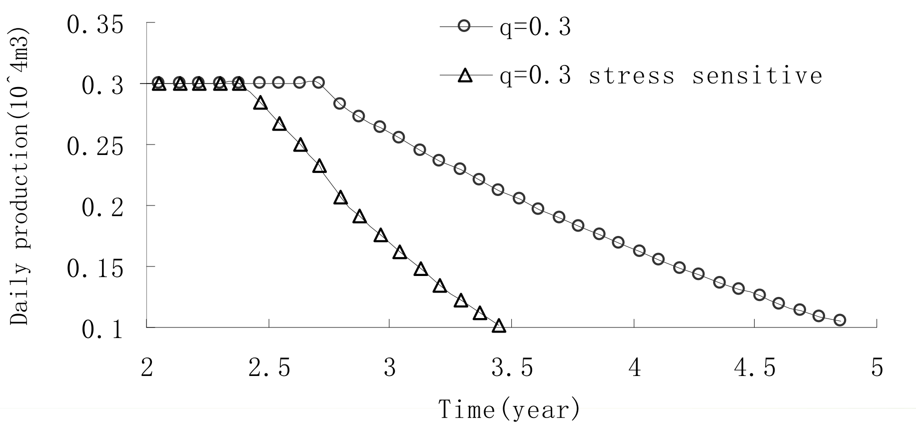


Fig.7 Comparing daily production of stress sensitivity and without stress sensibility

Assuming that the porosity and permeability would change with the decrease of the coalbed pressure; observe the stable production level when the daily production is different.

it shows that, considering the stress sensitivity, when the daily production is 0.2, years of stable production will decrease from 5.1 to 4.0, recovery of stable production decrease from 35.4% to 28.0%.

Fig.8 shows that when the daily production is 0.3, years of stable production will decrease from 2.7 to 2.38, recovery of stable production decrease from 28.29% to 24.86%.
The sensibility of coal rock causes the decrease of the years and recovery of stable production. The data are following as table 5 and table 6.

Research on the level of stable production

Take stress sensitivity into account

Table 5 Daily production is 0.2, data of different conditions

Model	Daily production（$10^4m^3/d$)	Years of stable production (year)	Cumulative production (10^4m^3)	Recovery of stable production
No stress sensitivity	0.2	5.1	372	35.43%
Stress sensitivity	0.2	4.0	294	28.00%

Table 6 Daily production is 0.3, data of different conditions

Model	Daily production（104m3/d)	Years of stable production (year)	Cumulative production (104m3)	Recovery of stable production
No stress sensibility	0.3	2.7	297	28.29%
Stress sensitivity	0.3	2.38	261	24.86%

conclusions

conclusions

- With the decrease of the coalbed pressure, there is a exponential relationship between effective stress and the porosity, permeability of the coal rock.

- After the production of the coalbed methane well is stable, the years of stable production, daily production, the coalbed pressure, cumulative production and recovery can be predicted by the new model.

- With the process of the production, the porosity and permeability of the coal rock will decrease. This kind of stress sensitivity causes the decrease of the years of stable production and recovery, the effect is obvious.

Thank you!

Acknowledgements

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