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The Effect of Coal Seam Gas saturation on CBM Well Productivity-A Case Study of Central Region of Hedong Area

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Abstract

Coal seam gas saturation is an important index of CBM evaluation, and it impacts CBM well productivity. The central region of Hedong area is one of the major CBM development block in Ordos basin. The coal seam gas saturation changes seriously in the target area. In this study, coal seam 8+9 was chosen as the study seam. And this study conducted simulation to investigate gas saturation effects on CBM well productivity. The sensitivity simulation results between different saturated coal seam and well productivity show that the higher gas saturation of the coal seam, the higher peak gas rate and the recovery factor. Coal seam permeability is the key parameter that affects CBM well gas productivity, in this study, a relationship between permeability and gas saturation was established to interpret the gas saturation affects on well productivity. Accoriding to the simulation results which show the reletionship betweent different saturated coal seam and peameability change intensity, the fundamental influence principle of gas saturation to CBM well productivity was that during the depleting, the higher the gas saturation was, the bigger the rate of the permeability increased, and ultimately the better the well productivity appeared.

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Keywords: Central Region of Hedong Area; Coal Seam Gas Saturation; CBM Well Productivity; Permeability Ratio

1. Introduction

Recently, CBM development in China is in the boom period. Although some blocks of China have entered the CBM commercial demonstration phase, the production of coalbed methane well remains low.

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Coal seam gas saturation is the important index of CBM evaluation [1]. The gas saturation in China where the gas content is above 4m^3/t varies from 20% to 91%, while the average gas saturation is 45% [2], which shows the low level of whole country, and this restricts the production of CBM well in China.

Many researchers have studied factors that impact productivity of CBM well. Concluded that these factors can be divided into two categories: geological factors and engineering factors. And the key factors of the former are gas content and permeability [3-9]. The latter mainly includes reservoir damage or aggravation during the drilling, completion and stimulation operation [10-11].

Many former researchers have confined to statistics, the geological coupling analysis or simulation methods to study the relationship between coal seam gas saturation and well productivity [12-14]. Almost all of the reserch results show that the high gas saturation will inevitably lead to high productivity, but there is no in-depth analysis of its reasons. The purpose of this study is to find the main reason why coal seam gas saturation and production is positively correlated, and it will help provide scientific criteria to CBM exploration and the reasonable gas drainage.

The central region of Hedong area is one of the major CBM development block in Ordos basin. The coal seam gas saturation change seriously in the target area and little research about coal seam gas saturation and CBM well productivity have been conducted. In this study, coal seam 8+9 in central region of Hedong area was selected as the target seam, and a simulator was employed to investigate the gas saturation of target seam effect on well productivity.

2. Geology Setting

The Hedong area is located on the eastern margin of the Ordos basin (Figure 1). A structure map shows that the strata in the Hedong area dip gently westward at 3 to 8 degrees into the basin (Figure 1). The stratum in this block as well as its circumjacent areas includes Ordovician, Carboniferous, Permian, Triassic, Cenozoic and Quaternary. The coal seams are contained within the Upper Carboniferous Taiyuan and Lower Permian Shanxi Formations. There are totally 14 coal seams in this block. Seam 3+4, seam 5 of Shanxi formation in Permian and seam 8+9 of Taiyuan formation in Carboniferous are three major CBM exploitation coal seams. In this paper, we select coal seam 8+9 as the target seam.

Seam 8+9 extends stably in this area and the burial depth range from 400m to 1400m, average in 729.54m. The coal seam thickness varies from 3.3m to 10m, averagely 5.84m. Vitrinite reflectance (R_o) ranges from 1.47% to 1.83%, meanly 1.64%. Volatile combustible content changes from 13.71% to 26.92%, averagely 16.73%, which indicates the coal belongs to low and moderate volatile bituminous coal. Gas content varies from 2.86 to 13.67 m^3/t, and the permeability changes from 5 to 30 mD.

3. Methodology

Peak gas rate and recovery factor of CBM well are the two significant indexes to well diliverbility .This study used numerical simulation method to analyze the relationship between gas saturation and CBM well productivity.

In this research, simulation software of SimedwinⅡ was employed to determine the effect of the variation in saturation of coal seam 8+9 on peak gas rate and recovery factor by sensitivity analysis. And then the mechanical cause for variation in saturation of coal seam on gas rate was found by examining the variation in permeability in different gas saturation coal seam during production.

The main purpose of this study is to simulate single-well analysis of gas productivity's sensitivity to gas saturation. According to the 21%-91% range of CBM gas saturation in China, the range of this research was set from 100% to 20%, and simulation was conducted when gas saturation changed by 10%. The test lasted 6000 days.

The input data files for well were generated before simulation. In this study, the drainage area of the simulated well was assumed as 360m×360m (Figure 2).

The details simulation input data were summarized in table 1.

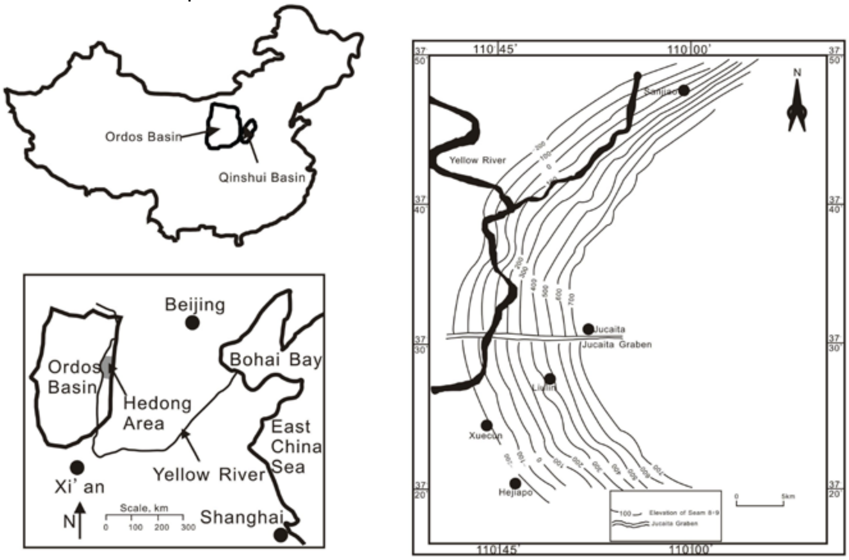

Fig.1: Location of Hedong area

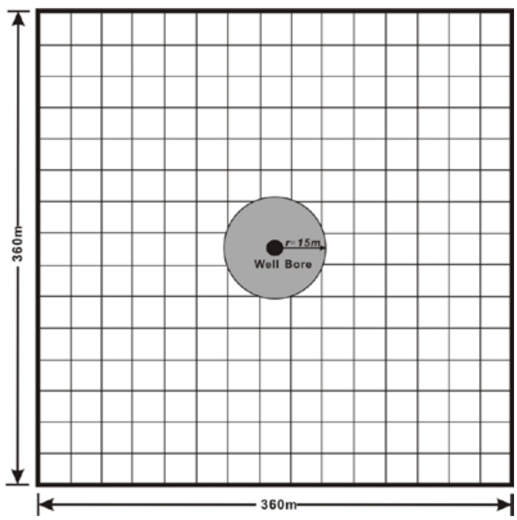

Fig.2 Cartesian grid for the simulation model

Table 1: Input data for simulation

Parameters	Values									Data Source
Burial Depth，m	729.54									Well Log
Initial Pressure，Kpa	7150									Well Test
Coal Thickness，m	5.84									Well Log
Permeability，mD	7.8									Well Test
Porosity，%	1%									Core Test
Coal Density，kg/m^3	1350									Core Test
Fluid components	Water and Methane									
Water saturation，%	100%									Assumed
Temperature，°C	30									Well Log
Langmuir Pressure，Kpa	2050									Core Test
Langmuir Volume，m^3/t	23.3									Core Test
Gas Saturation，%	20%	30%	40%	50%	60%	70%	80%	90%	100%	Calculate
Gas Content，m^3/t	3.71	5.57	7.42	9.28	11.13	12.99	14.84	16.7	16.88	
Desorption Pressure，Kpa	350	582	865	1224	1690	2324	3232	4650	7150	Calculate
Sorption Times，d	5									Core Test
Fracture Half Length，m	100									Fracture Test

4. Simulation Results and discussions

4.1 Simulation Results

Peak gas rate and recovery factor of CBM well are two significant indexes to well deliverbility. The curve of relationship between gas saturation and gas rate shows (Figure 3) the peak gas rate of saturated CBM well can be achieved after 157 days at a rate of 9822.76m^3/d, while it take 220 days and 430 days for 90% and 80%-saturated wells to build-up to a peak gas rate of 6128.44m^3/d and 4000m^3/d respectively. But the peak gas rate of 50%-and 40%-saturated wells are only 980m^3/d and 540m3/d, while it takes separately 1400 days and 2000 days to achieve peak gas rate.

During the 6000 days simulation time, as the abandonment pressure was 0.5Mpa, the final recovery factor of saturated gas reservoir can be up to 70%, while that of 20% saturated CBM well is only 4%, and that increases together with gas saturation, which is showed in Figure 4

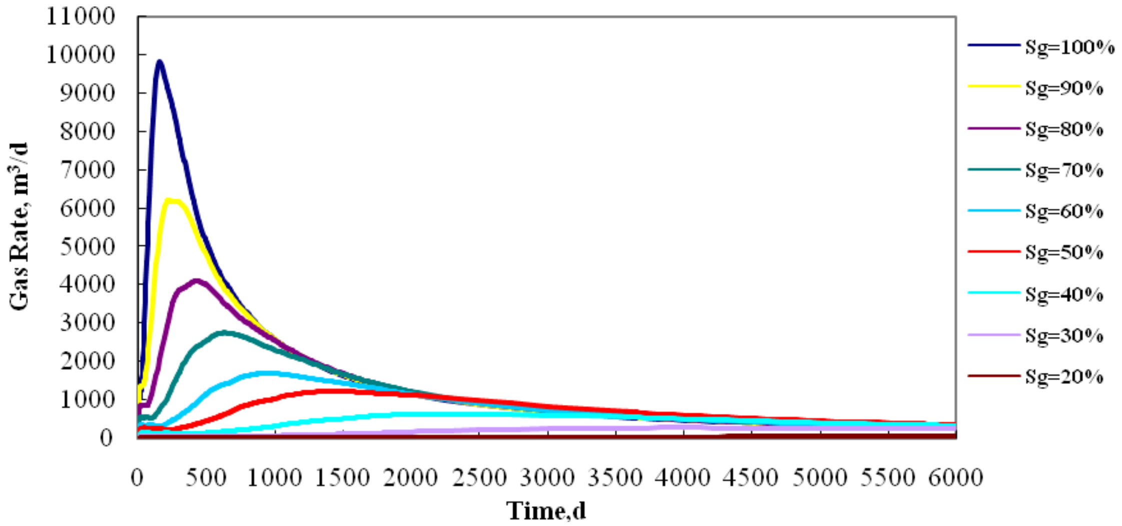

Fig.3: Daily productivity of differently saturated coal seams tested with the 6000 days simulation time

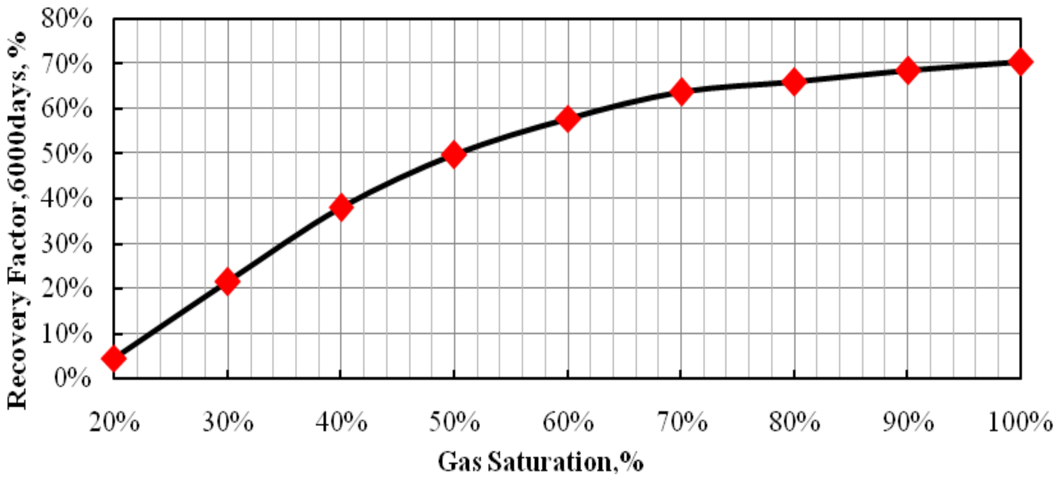

Fig.4: Final recovery factor changes with drainage process of differently saturated coal seams

4.2 Discussions

The reservoir pressure drawdown seriously near the well bore, and this would inevitably leads to noncoincident permeability changes of reservoir during the drainage process. For the purpose of this study, a cell 15m from the well bore were chosen as the study point (Figure 2).

Coal seam permeability is the key parameter that affects CBM well gas productivity, in this study, a relationship between permeability and gas saturation would be established to interprete the gas saturation affects well productivity.

Figures5 is the relation of Seam 8+9 between pressure and permeability under different gas saturations. As is shown in these figure, during the drainage process, the permeability of 100%-saturated coal seam increases all the time; while permeability of 90%-, 80%-, 70%-, 60%- and 50%-saturated coal seams decreases at first and then increases, with the adsorption pressure being the transition point. And permeability of 40%-saturated seam decreases with the drainage process.

In order to explain permeability changes of coal seams with different saturation levels, a new terms named permeability ratio (μ) was introduced. And it can be decrypted by equation 1.

$$\mu=(ki-ke)/(pi-pe) \quad (1)$$

Where:

μ, permeability ratio, KPa/mD;

k_i, the initial reservoir permeability, mD;

k_e, the final permeability, mD;

p_i, the initial reservoir pressure, KPa;

p_e, the final reservoir pressure, KPa.

Equation 1 represents that permeability decreases while the μ value is plus and permeability increases while the μ value is minus. And the absolute value of μ reflects the change speed of permeability when reservoir pressure decreases.

Figure 6 is the relation between gas saturation and permeability ratio in 6000 days. As the figure illustrates, the rate of 100%- and 90%-saturated seams is minus, indicating the permeability of over 80%-saturated seam increases during the drainage process.

The absolute permeability change ratio of 100% saturated coal seam is 0.00374, while that of 90%- and 80%-saturated coal seams is separately 0.73 and 0.94 times lower. That is, during the drainage, the permeability change ratio is positive with the gas saturation. The permeability of seam, where the gas saturation is between 80% and 20%, decreases with the drainage process, for the relation plot shows that its change ratio is positive. Lower gas saturated coal seam of this kind would have a bigger decrease than higher gas saturated seam.

Figure 7 is the permeability decrease comparison of under saturated coal seam. As the figure demonstrates, the initial permeability of both 90%- and 40%-saturated seams is 7.8mD, while during the drainage, the permeability to the adsorption pressure is individually 4.67mD and 2.25mD, indicating that the permeability decrease is separately 3.13mD and 5.55mD. The comparison reveals that coal seam with lower gas saturation has a bigger decrease in permeability during the drainage process, and this kind seam has a lower permeability.

The desorption pressure of lower gas saturated coal seam is lower than that of higher gas saturated seam. During the drainage process, the effective stress over lower gas saturated coal seam outweighs that of higher gas saturated, for it consumes more time for the lower saturated seam pressure to go down to the desorption pressure, with the negligible matrix shrink. So there is a bigger decrease in permeability of low saturated coal seam than the high saturated coal seam. The decrease in permeability indicates that it would cost long time to reach the peak gas rate, as a result of the fracture and cleat closure and the conductivity reduction. However, higher gas saturated coal seam can reach to desorption pressure in a shorter time than the lower gas saturated seam. During the drainage process, the permeability is mainly affected by the effective stress before the pressure down to the desorption pressure. Thus, there is a short time decrease in permeability. While reservoir pressure is lower than desorption pressure, the permeability starts increasing, for coal matrix begins to shrink and this effect exceeds that of the effective stress. There comes the wide gas pathway and a good productivity. Therefore, the higher gas saturated coal seam has greater peak value in production and need less time to reach the peak gas rate during the drainage process.

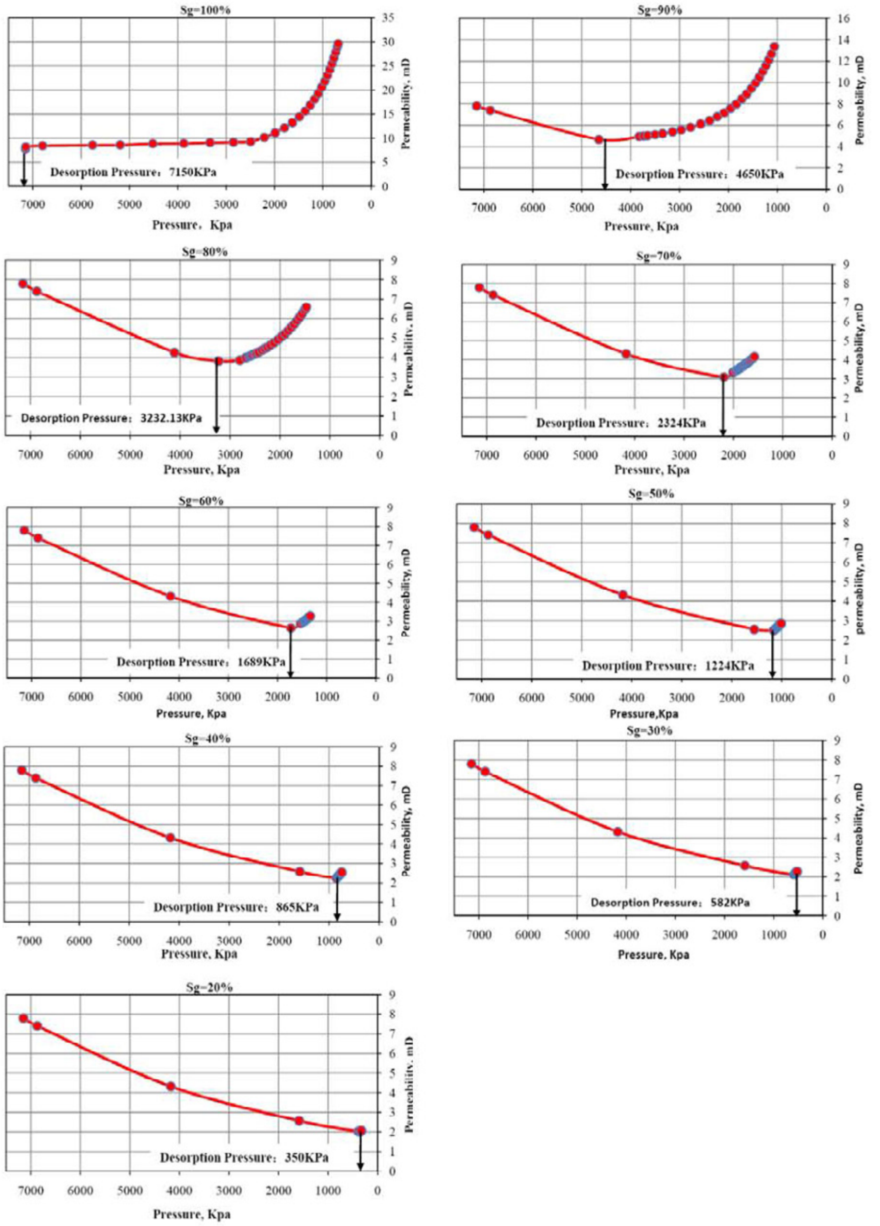

Figure 5: Permeability change in differently saturated coal seams tested in the 6000 days simulation time

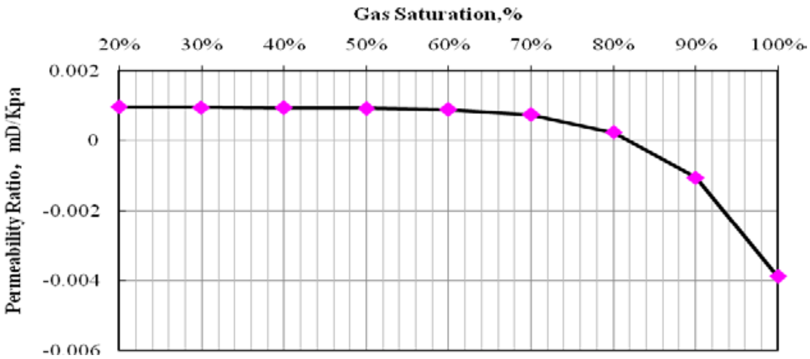

Figure 6: Permeability ratio in differently saturated coal seams tested in the 6000 days simulation time

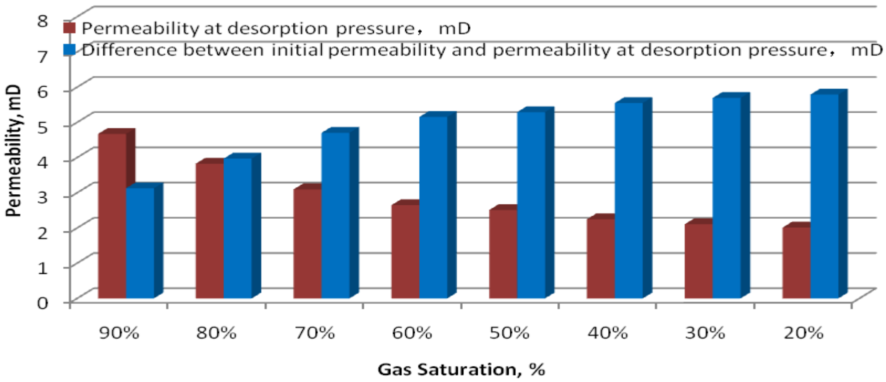

Figure 7: Difference between initial permeability and permeability at desorption pressure

5. Conclusions

- The analysis results of gas saturation sensitivity to CBM well productivity indicated that the higher the gas saturation, the bigger the peak gas rate and the shorter the time that production rose to the peak.
- The simulation results demonstrated that permeability of the saturated coal seams continuously increased with pressure depletion, while that of under-saturated seams decreased before the reservoir pressure dropped to desorption pressure and then increased after the desorption pressure.
- The fundamental influence principle of gas saturation to CBM well productivity was that during the drainage process, the higher the gas saturation was, the bigger the intensity of the permeability increased, and ultimately the better the well productivity appeared.

Acknowledgements

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