Analysis of common reservoir damage problems in coalbed methane wells and study on acid plugging removal agent system

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Abstract. Reservoir damage is an important factor limiting the productivity of coalbed methane wells. In this paper, the coal seam in a coalbed methane producing area in the southeast edge of Ordos Basin is taken as the research object, and the types of reservoir damage in this block are analyzed through the composition test of coal samples and the comparison of production conditions, and the targeted solutions are given. The results show that the main types of reservoir damage in this block are solid plugging and water locking damage. The dissolution rate of acidic plugging removal working fluid with hydrochloric acid, hydrofluoric acid, acetic acid and hydrogen peroxide as main components for pulverized coal in this block reached 13.73%. After acidification, the permeability increased by 1.8~6.9 times, and the porosity increased by 0.35%~2.87%, indicating that the plugging removal working fluid system can effectively dredge the liquid seepage channel, reduce the seepage resistance and achieve the plugging removal effect.

Keywords: Coalbed methane; reservoir damage; acidic plugging remover; experimental evaluation.

1. Introduction

China is a big coal producer, and as an associated mineral of coal, the resources of coalbed methane are also very considerable[1]. According to statistics, China's coalbed methane resources with a buried depth of less than 2000m are about 3.7 billion cubic meters, equivalent to 35 billion tons of standard oil, which has great development potential. However, although the country attaches great importance to the development of coalbed methane industry and gives policy support, three consecutive five-year planning targets of coalbed methane industry have not been achieved, among which the surface coalbed methane output in 2020 is about 6 billion cubic meters, far below the 10 billion cubic meters required in the Thirteenth Five-Year Plan for the Development and Utilization of Coalbed Methane (Coal Mine Gas), and the target completion rate is only about 60%.

There are many reasons for this situation, among which reservoir damage is one of the important limiting factors that restrict the productivity of coalbed methane wells. Affected by geology and production, the fluid seepage velocity in coal reservoir is low, which leads to the reservoir damage problems such as water lock and solid phase blockage in the production process of coalbed methane wells, further limiting the production, resulting in low production or even shutdown of gas wells. Taking a block in the southeastern margin of Erduo Basin as an example, the average daily gas production of more than 50 coalbed methane wells in this block is less than 100 cubic meters due to reservoir damage. If the plugging can be successfully removed, the daily gas production can exceed 20,000 cubic meters, with remarkable benefits.

It is an important way to jointly tackle key problems in large areas and develop targeted technologies according to local conditions. In this paper, taking a coalbed methane block in the southeastern margin of Ordos Basin as an example, the causes of reservoir damage are analyzed, and a targeted plugging removal agent system is developed based on the coal samples in this block.

2. Cause Analysis of Reservoir Damage in Coalbed Methane Wells

2.1 Coal Sample Analysis

Taking the 5# coal seam in a coalbed methane block in the southeast edge of Ordos Basin as the research object, the coal samples were analyzed, which were taken from a coal producing area about 500 meters away from a coalbed methane production well (also from 5# coal seam). The mineral composition and characteristics of porosity and permeability system of the samples were analyzed, and the results were recorded as follows.

(1) Microscopic analysis

The test coal samples were crushed and made into optical sheets[2], and the vitrinite reflectance was measured by LV100PO polarized microscope. The test results are shown in Figure 1.

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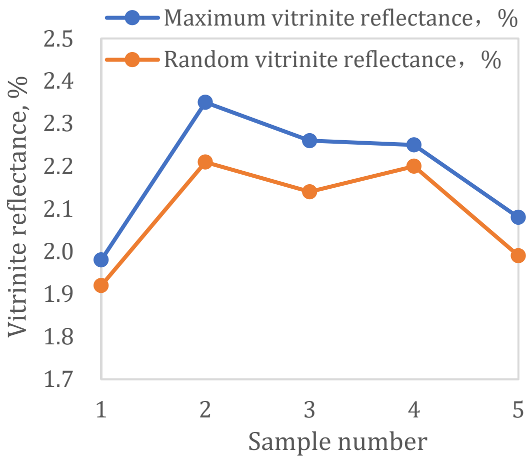

Figure 1: Test Results of Vitrinite Reflectance of Coal Samples

According to the experimental results, the maximum vitrinite reflectance of coal samples is between 1.98% and 2.35%. According to the relevant industry standards, all coal samples belong to middle-rank coal VII[3]. Generally speaking, low coalification will lead to low organic matter content, and it is difficult for methane enrichment to reach the level of industrial development; Excessive coalification will lead to poor pore connectivity, which is not conducive to methane gas seepage. The experimental coal sample belongs to middle-high rank coal with moderate coalification degree, which is a favorable condition for coalbed methane development.

(2) Mineral composition test

Based on X-ray diffraction whole rock analysis technology, the mineral composition of coal samples in this block was tested, and the test results obtained according to diffraction patterns are shown in Table 1.

Table 1: Test Results of Mineral Components.

Serial number	Mineral composition, %								
	clay mineral	barite	quartz	potassium feldspar	plagioclase	calcite	dolomite	siderite	pyrite
6	79.6	—	—	—	—	9.3	11.1	—	—
7	64.7	—	—	—	—	14.2	17.6	—	3.5
8	77.3	—	3.1	—	—	6.9	12.7	—	—

According to Table 1, the mineral components of coal samples in this block are mainly clay minerals, accounting for about 60%~80%, in addition to some carbonate minerals such as calcite and dolomite. According to the experience of acidizing operation, hydrofluoric acid and hydrochloric acid, which are commonly used in acidizing, can effectively dissolve the above minerals. Therefore, when the reservoir damage caused by mineral migration occurs in the coal reservoir, it is theoretically feasible to remove the plugging by acidification.

(3) Determination of characteristic parameters of porosity and permeability

The porosity and permeability characteristics of coal samples are closely related to the storage and seepage of coalbed methane, and directly related to the production of coalbed methane. Poor porosity and permeability parameters will increase the risk of reservoir damage. The coal sample is made into a cylinder with a diameter of 25.0mm and a height of 40.0~50.0mm, and the porosity and permeability parameters of the coal sample in the block are measured by using a gas porosity and permeability tester with nitrogen as the medium. The test results are shown in the following table.

Table 2: Measurement Results of Porosity and Permeability Parameters of Coal Samples

Serial number	length, mm	diameter, mm	porosity, %	permeability, mD
H1	50.0	25.0	4.58	0.023
H2	48.2	25.0	11.52	0.031
H3	47.9	25.0	7.38	0.095
H4	42.6	25.0	5.33	0.117
H5	50.0	25.0	4.91	0.143
H6	44.7	25.0	5.84	0.027
H7	48.9	25.0	6.63	0.058
H8	50.0	25.0	6.85	0.083

According to the test results, the porosity of coal samples in this block is between 4% and 12%, which varies greatly among different coal samples, but the porosity is mostly around 5%. The permeability mainly fluctuates between 0.02 and 0.15 mD, and the permeability of most coal samples is lower than 0.1 mD. On the whole, the coal samples in this block have typical characteristics of "low porosity and low permeability".

2.2 Cause Analysis of Reservoir Damage in Coalbed Methane Wells

According to the test results of coal samples, the reservoir in the study block is medium-high rank coal with moderate coalification degree, and the abundance of coalbed methane reserves meets the requirements of industrial development. However, the coal seam in this block has typical characteristics of "low porosity and low permeability" and clay minerals are developed, so the reasons for reservoir damage of coalbed methane wells in this block are summarized as follows:

(1) Water lock damage caused by polymer adsorption and retention, capillary force (resistance) and so on. A large number of polymer working fluids, such as guanidine gum and polyacrylamide, are used in fracturing coalbed methane wells. Due to the low formation pressure and insufficient gel breaking in coalbed methane wells, these polymers cannot be completely discharged back to the ground, resulting in retention and water lock damage. In addition, according to the capillary force formula, the smaller the pore throat radius and the more hydrophilic the coal petrography are, the greater the seepage resistance of liquid will be. In general, coal petrography are more hydrophilic, and the coal reservoir in the research block has the typical characteristics of "low porosity, low permeability and low pressure", which leads to the large seepage resistance of liquid in the production process, and the liquid is easy to block at the narrow throat, resulting in water lock damage.

(2) Water sensitivity damage caused by incompatibility between foreign fluids and reservoir rocks. During the drilling and reservoir reconstruction of coalbed methane wells, a large amount of working fluid will enter the reservoir. Generally speaking, clay stabilizer and iron ion stabilizer will be added to these working fluids to prevent reservoir damage. However, it is difficult for foreign fluids not to damage the reservoir completely, especially for layer with high clay mineral content, water-sensitive damage is almost inevitable. After water-sensitive damage, clay minerals absorb water, swell, disperse and migrate, which leads to narrowing or even blocking the throat and aggravates the damage of water lock.

(3) Solid plugging caused by solid particle migration. In the production process of coalbed methane wells, coal powder, clay minerals and sediments will migrate with liquid seepage due to the influence of hydraulic scouring and stress change. These solid particles are easy to gather in the narrow throat, and then block the migration channel. The produced water of coalbed methane wells in the research block is mostly black water or slightly black water, and solid particles such as coal powder can be seen after standing, so it can be judged that the reservoir damage caused by solid plugging is common in this block.

3. Feasibility Analysis of Acid Plugging Removal in Coal Reservoir

According to experimental research and production experience, water lock damage and solid plugging are important factors that limit the productivity of coalbed methane wells in the research block, and it is difficult to solve the above problems simultaneously by traditional physical plugging removal methods. The purpose of plugging removal is to dredge the fluid seepage channel and reduce the fluid seepage resistance. According to the capillary force formula, the ways to reduce seepage resistance mainly include reducing surface tension, increasing contact angle and increasing throat radius. Therefore, theoretically speaking, using acidic working fluid and selecting appropriate additives can realize the unblocking of coal seams in this block.

(1) The coal petrography minerals in the study area are mainly clay minerals and carbonate minerals, with a small amount of quartz and pyrite. According to scholars' research results and acidizing experience, these minerals can be dissolved by hydrochloric acid, acetic acid and hydrofluoric acid, and the carboxyl group (-COOH) in acetic acid can form a complex with iron ions through coordination to prevent secondary precipitation. The reaction equation between acidic working fluid and coal seam minerals is as follows(Where M is a metal ion) [5-6]:

$$\mathrm{MCO_3}(Carbonate\ minerals) + \mathrm{HCl} \rightarrow \mathrm{MCl} + \mathrm{H_2O} + \mathrm{CO_2} \uparrow \quad (1)$$

$$\mathrm{MCO_3} + \mathrm{HA_c} \rightarrow \mathrm{MA_c} + \mathrm{H_2O} + \mathrm{CO_2} \uparrow \quad (2)$$

$$\mathrm{Fe_2O_3} + \mathrm{HCl} \rightarrow \mathrm{FeCl_3} + \mathrm{H_2O} \quad (3)$$

$$\mathrm{Al_2Si_2O_5(OH)_4}(kaolinite) + \mathrm{HF} \rightarrow \mathrm{AlF_3} + \mathrm{H_2SiF_6} + \mathrm{H_2O} \quad (4)$$

$$\mathrm{AlO_3} \cdot 4\mathrm{SiO_2} \cdot \mathrm{H_2O}(montmorillonite) + \mathrm{HF} \rightarrow \mathrm{H_3AlF_6} + \mathrm{H_2SiF_6} + \mathrm{H_2O} \quad (5)$$

$$\mathrm{SiO_2} + \mathrm{HF} \rightarrow \mathrm{SiF_4} + \mathrm{H_2O} \quad (6)$$

$$\mathrm{SiF_4} + \mathrm{HF} \rightarrow \mathrm{H_2SiF_6} \quad (7)$$

(2) Oxidant can dissolve part of coal matrix through oxidation, and release heat, carbon dioxide and organic acid at the same time, so as to dredge seepage channels and improve reservoir porosity and permeability. Jing Zhenhua and others compared and analyzed the oxidation effects of hydrogen peroxide, potassium permanganate, sodium hypochlorite and potassium persulfate on coal powder when studying the mechanism of oxidation and infiltration enhancement of coal reservoir. The results showed that all four oxidants could react with coal powder, and potassium permanganate and sodium hypochlorite had the best dissolution effect on coal powder. However, the reaction product of potassium permanganate contains manganese dioxide which is insoluble in acid, and sodium hypochlorite will generate toxic chlorine gas in acidic solution, which are not suitable for adding into acidic plugging remover. The oxidation of hydrogen peroxide will be more intense under acidic conditions, and the reaction product is mainly water, which has high environmental protection value. At the same time, hydrogen peroxide can destroy the chemical bonds on the coal surface and promote the desorption of methane molecules, which is a good choice for oxidizing coal matrix.

(3) Fluorocarbon surfactants can effectively improve the interface parameters. Fluorocarbon surfactant is one of the

commonly used surfactants in oil and gas fields at present. Compared with conventional surfactants, it has better effect of reducing surface tension and improving wettability, and can effectively reduce liquid phase seepage resistance. In addition, fluorocarbon surfactants have good acid resistance and is a good choice for acidic working fluids when the cost allows.

4. Experimental Evaluation of Working Fluid for Acid Plugging Removal of Coal Petrography

With hydrochloric acid, hydrofluoric acid, acetic acid and hydrogen peroxide as the main components, a four-factor and three-level orthogonal experiment was designed for single-dose compounding. After the orthogonal experiment was completed, the effect was analyzed with the dissolution rate of pulverized coal as the main evaluation index, and the main formula of acid solution was obtained. Fluorocarbon surfactant A was selected as the working fluid additive, and finally the acidic plugging removal system JD1-1 was obtained. Taking the coal sample in the research block as the experimental object, the indoor evaluation experiment of acid plugging removal system JD1-1 was carried out, and the results are as follows.

(1) Pulverized coal dissolution experiment

The working fluid JD1-1 is mixed with dry pulverized coal in a plastic beaker according to the ratio of 30ml: 3g, and fully stirred with an inert plastic rod to make the acid liquid fully contact with pulverized coal. After 12 hours, the acid solution mixed with pulverized coal in the beaker was filtered with fine filter paper to obtain wet pulverized coal. Drying the wet pulverized coal to obtain the weight after acid solution dissolution and calculate the dissolution rate. After repeated experiments for three times, the dissolution rate of acidic plugging remover JD1-1 for pulverized coal in this block is 13.05%~14.30%, with an average of 13.73%, which shows that the dissolution effect is good.

Table 3: Test Results of Dissolution Rate

Serial number	Quality before treatment, g	Quality after treatment, g	Lost quality, g	Dissolution rate, %
1	30.00	26.09	3.92	13.05
2	30.00	25.85	4.15	13.84
3	30.00	25.71	4.29	14.30

(2) Evaluation experiment of porosity and permeability parameters before and after acidification

The core was soaked in acidic working fluid JD1-1 for 12 hours, dried at 60℃, and the porosity and permeability parameters after acidification were measured by gas porosity and permeability tester. The experimental results show that after acidification, the core porosity increases by 0.35%~2.87%, the permeability increases by 1.8~6.9 times, and the porosity and permeability parameters are significantly improved.

Table 4: Test Results of Dissolution Rate

Serial number	Length,mm	Diameter,mm	Porosity before acidification,%	Permeability before acidification, mD	Porosity after acidification,%	Permeability after acidification, mD
1	25	43.7	6.14	0.045	9.01	0.356
2	25	49.3	8.53	0.091	8.88	0.255
3	25	45.9	7.42	0.074	8.49	0.221

5. Conclusion and Recommendations

(1) The coal petrography minerals in the study area are mainly clay minerals and carbonate minerals, with a small amount of quartz and pyrite.Solid plugging and water lock damage are the main reasons for reservoir damage of coalbed methane wells in this block.

(2) The acid plugging removal system JD1-1 was developed according to the damage causes of the research block. The test results show that the working fluid can effectively dissolve pulverized coal and improve the porosity and permeability parameters of coal core.

(3) The plugging removal effect of acid plugging removal system JD1-1 is only aimed at the coal samples in the study block, and has not been verified by field tests. It is

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suggested to develop a more universal plugging removal system for more coal samples in the future, and to carry out field tests to verify the plugging removal effect.

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