E3S Web of Conferences **53**, 04002 (2018) https://doi.org/10.1051/e3sconf/20185304002
ICAEER 2018

Research progress and prospects of CO_2 enhanced shale gas recovery and geologic sequestration

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Abstract. CO_2 injection to strengthen shale gas development is a new technology to improve shale gas recovery and realize geologic sequestration. Many scholars have studied these aspects of this technology: mechanism of CO_2 displacement CH_4, CO_2 and CH_4 adsorption capacity, affecting factors of shale adsorption CO_2, CO_2 displacement numerical simulation, and supercritical CO_2 flooding CH_4 advantages. Research shows that CO_2 can exchange CH_4 in shale formations, improve shale gas recovery, on the other hand shale formations is suitable for CO_2 sequestration because shale gas reservoir is compact. The supercritical CO_2 has advantages such as large fluid diffusion coefficient, CO_2 dissolution in water to form carbonic acid that can effectively improve the formation pore permeability etc., so the displacement efficiency of supercritical CO_2 is high. But at present the technology study mainly focus on laboratory and numerical simulation, there is still a big gap to industrial application, need to study combined effect of influence factors, suitable CO_2 injection parameter in different shale gas reservoir, CO_2 injection risk and solutions etc.

1 Introduction

CO_2 capture and geologic sequestration is a kind of technology of CO_2 emission reduction, many countries have taken it seriously. Shale gas reservoir has the characteristics of low porosity, low penetration and extreme compactness, which results in very low gas recovery ratio of shale reservoirs. Conventional natural gas recovery ratio can reach to about 60%, while shale gas reservoirs recovery ratio is only about 4.7% to 10% without hydraulic fracturing [1]. While fracturing fluid is likely to cause pollution, need to study a new environmental friendly technology for shale gas development. CO_2 injection not only can enhance recovery ratio of shale gas reservoirs, but also can realize the permanent geologic sequestration of CO_2. It is a kind of new technology of CO_2 storage and use. Its application has great significance for shale gas development and environment protection.

2 CO_2 displacement CH_4 mechanism in shale gas reservoirs [2-4]

From the micro, because CO_2 molecular structure is linear, diameter less than the diameter of CH_4, CO_2 can access smaller micro-pore, which increase contact area and contact time of CO_2 with shale reservoirs, sequentially increase CH_4 displacement amount of CO_2 in shale gas reservoirs.

From the adsorption ability, the contrast laboratory experiments of shale adsorption performance of CO_2 and CH_4 showed that adsorption capacity, adsorption rate and adsorption equilibrium time of CO_2 is better than those parameters of CH_4 in the same experiments time. Numerical simulation model also showed a same result: CO_2 is easier to be adsorbed by shale than CH_4 for CO_2 has stronger adsorption ability.

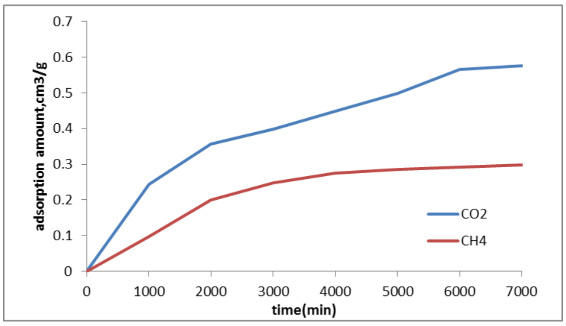

Fig. 1 Isothermal adsorption curves of CO_2 and CH_4 at 35°C with same sample

From the macro, CO_2 replacing CH_4 in shale reservoirs conform to the extension form of the Langmuir equation (equation 1). The injected CO_2 increased the total gas pressure and reduce the CH_4 partial pressure within the shale reservoirs, which will lead to CH_4 desorption from shale to achieve the new adsorption equilibrium.

$$V_i = V_{mi} \frac{\frac{P_{yi}}{P_{Li}}}{1+\mathrm{P}\sum_{j=1}^{nc}\frac{y_j}{P_{Lj}}} \quad (1)$$

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V_i: adsorption amount of gas component i,cm^3/g
V_{mi}: Langmuir adsorption constant of component i, cm^3/g
P: gas pressure in reservoir, MPa
y_i: Mole fraction of gas component i
P_{Lj}: pressure of gas component j when adsorption amount of the gas component j reaches to 50 % of the adsorption limitation ,MPa
nc: numbers of different gas component

3 Influencing factors of CO_2 adsorption in shale gas reservoirs [2-6]

Shale desorption analytical test with shale sample which was made to pieces in a certain size proved that the adsorption of CO_2 in shale is the physical adsorption, which is influenced by temperature, pressure and the mineral composition of shale, moisture content, shale gas composition and other factors:

1) Adsorption capacity decrease with temperature increasing;

2) Adsorption capacity increase with pressure increasing;

3) Temperature and pressure have a comprehensive effect on the adsorption and desorption of shale. Under the low temperature and pressure range, the influence of pressure on adsorption performance is greater than that of temperature. The influence of temperature on adsorption performance is greater than that of pressure in high temperature and pressure condition;

4) Adsorption capacity increase with the content of organic matter increase. Montmorillonite with more calcareous has the highest CO_2 adsorption capacity, while CO_2 adsorption capacity of kaolinite is the least;

5) Pore structure has an influence on the adsorption capacity;

6) When there are water in the shale gas reservoir, CO_2 will dissolve in water to form carbonic acid to erode the formation and increase CO_2 adsorption, which can effectively improve the permeability of the formation and increase shale gas production;

7) CO_2 will produce convection diffusion with shale gas with CO_2 injecting which will form a CO_2 - shale gas multivariate system. The shale gas content is bigger, the easier retrograde condensation occur, it will influence CO_2 adsorption and the way of shale gas production.

Above conclusion is almost same at shale desorption analytical test with shale samples which was preserved the original core structure, compared with the test that simulated shale reservoir environment.

4 CO_2 displacement laboratory test with shale core sample [2,7]

Studies showed that temperature and pressure of CO_2 injection have important effect on shale gas recovery. The recovery ratio increase with CO_2 injection temperature and pressure increasing.

Table1. CO_2 adsorption experiment data of shale sample1

35℃		45℃	
Balance pressure,Mpa	Adsorption amount,cm^3/g	Balance pressure,Mpa	Adsorption amount,cm^3/g
2.06	0.921	2.82	0.032
3.78	0.356	4.41	0.11
6.02	0.806	7.06	0.201
8.02	0.998	8.46	0.365

Table 2. CO_2 adsorption experiment data of shale sample2

35℃		45℃	
Balance pressure,Mpa	Adsorption amount,cm^3/g	Balance pressure,Mpa	Adsorption amount,cm^3/g
1.93	0.038	2.38	0.035
3.62	0.11	3.12	0.098
5.08	0.198	4.41	0.143
6.16	0.239	5.08	0.221

Gas recovery ratio is different at different producing start time under the condition of CO_2 injection. Injecting CO_2 10 hours later, the competitive adsorption of CO_2 and CH_4 is sufficient. The gas recovery ratio is higher than that gas production start at the same time of CO_2 injecting. The reason is that the concentration of CO_2 in the shale reservoirs or the CO_2 partial pressure is low when CO_2 inject for a short time, the displacement amount of CH_4 is very low. After enough competition adsorption, CO_2 will spread deep into the shale matrix and displace CH_4 more. At the same time, the shale volume will expand after a large amount of CO_2 adsorption, so that the pore adsorbed CH_4 will open again and CO_2 will displace the inner CH_4 of shale, which will increase the recovery ratio.

5 Numerical simulation of CO_2 displacement shale gas [3,6]

The numerical simulation simulated the influence on recovery ratio of CO_2 injection timing, CO_2 injection rate, and the influence of crack numbers. The results showed that CO_2 injection parameters exists an optimal value. Multi-stage horizontal fracture will increase the crack number, but it will not improve gas recovery ratio obviously.

The concept model of CO_2 displacement CH_4 of shale showed that displacement process can be divided into two situations: at low CO_2 injection pressure, shale samples with smaller micro-pore ratio surface area and smaller micro-pore volume ratio have higher CO_2 sequestration ability. While at higher CO_2 injection pressure, shale samples with larger micro-pore ratio surface area and smaller micro-pore volume ratio have higher CO_2 sequestration ability.

6 Supercritical CO_2 exploitation shale gas [8,9]

CO_2 critical temperature is 31.1℃, critical pressure is 7.38 MPa, critical density is 0.448 g/m^3 .When the temperature and pressure of the shale gas reservoir are greater than the critical temperature and pressure, the injected CO_2 reaches the supercritical state. Supercritical CO_2 has the excellent characteristics different from the conventional liquid, gas, which can improve reservoirs pore and fissure development level, can improve the reservoirs permeability significantly, etc. Supercritical CO_2 can improve the single well production and gas recovery ratio of shale gas reservoirs with these characteristics.

First, supercritical CO_2 viscosity is low, diffusion coefficient is larger than that of CH_4, and the most important is its surface tension is zero. Therefore, it is very easy to flow into the reservoirs pore, and able to enter into any space greater than CO_2 molecular. Under the effect of external force, the supercritical CO_2 can displace free CH_4 in the tiny pore and fracture effectively. Second, supercritical CO_2 fluid density has strong ability of solvating, it can dissolve pollutants near wellbore area, reduce the flow resistance, increase shale reservoir permeability, which is benefit to shale gas production. When temperature and pressure of environmental conditions is higher than CO_2 critical condition, the density of CO_2 is more close to the density of the fluid, then the property differences between supercritical CO_2 and shale gas increases, which lead to the convection diffusion effect abating. Supercritical CO_2 displacing shale gas likes a piston displacement process under high pressure and temperature. That will increase displacement efficiency. In addition, the viscosity of supercritical CO_2 is much higher than that of shale gas. In higher pressure, the displacement efficiency improves with the increasing of the viscosity difference.

7 Technical prospect and further research Suggestions

The technology compared with the traditional fracturing technology, has these advantages: water saving, environmental protection, simple process, has a broad development prospects, but at present the main research forces on laboratory test and numerical simulation. In order to realize its industrialized application as soon as possible, still need to strengthen following research:

1) The adsorption and desorption performance of shale gas are influenced by many factors. At present, most researches are studies on a certain factor independently. The effects of multiple factors are not studied or less. In the future, it is necessary to study the results of the combined effects of various factors under stratigraphic conditions.

2) Needs to study CO_2 injection pressure, CO_2 injection temperature and CO_2 injection timing of different characteristics shale gas reservoirs, to determine the reasonable CO_2 displacement parameters.

3) Select 1or 2 integrity shale gas reservoirs to carry out pilot test, verify the laboratory test and numerical simulation research, form series technology which adapt to shale gas reservoirs development with different depth, temperature, pressure ;

4) Needs to study whether is shale gas reservoirs still suitable for CO_2 geologic sequestration or not after the implementation of the fracturing measures;

5) Due to the corrosive effects of CO_2 and the risk of CO_2 leakage, it is necessary to strengthen the study of risk identification and risk countermeasures.

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