ROCK PROPERTY CHANGES FOR CARBONATE RESERVOIR DURING CO_2 INJECTION

M. Shimokawara, S. Takahashi, F. Kono, A. Kato, K. Tsushima
JOGMEC

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ABSTRACT

Carbonate minerals can be dissolved when carbon dioxide CO_2, in presence of aqueous solution, is injected into carbonate rocks. It is therefore known that porosity increases by dissolution as well as porosity decreases by compaction. Porosity changes by dissolution and compaction are one of the most important factors in order to understand fluid flow characteristics and monitor CO2 invasions. Especially, we need to consider that the change of rock properties is affected during CO2 injection into the carbonate reservoirs, when we evaluate seismic data. However it has not been clarified quantitatively.

In this study, we conducted core flooding tests with carbonate rock samples under the cyclic load test to clarify the effects of porosity changes. Carbonate rock samples were collected from a Middle East reservoir. In the core flooding test, CO_2 saturated water was injected into the rock samples for 200 Pore Volume Injected (PVI). Porosity, permeability, and elastic wave velocities were measured every 50 PVI. Porosity was measured using conventional Helium porosimetry and NMR methods. The amount of the dissolved carbonate minerals that is related to porosity increase was evaluated based on the amount of the dissolved cations in the CO_2 saturated water. In addition, the change of carbonate surfaces was also observed with SEM during CO_2 saturated water flooding.

Results show that carbonate dissolution occurred at the early stage of CO_2 saturated water flooding. Porosity decreased under compaction when rock frame was weakened by dissolution. The elastic wave velocities reduce with or without compaction effects when carbonate minerals are dissolved by CO_2 saturated water flooding.

INTRODUCTION

In the field operation of CO_2-EOR as well as carbon capture and storage (CCS), it is important to accurately understand the interaction between rock and fluids in addition to the behavior of the injected CO_2. In crosshole seismic data acquired in the field, cases of significantly decrease of seismic velocity in rocks has been reported after CO_2 was injected [4]. These velocity changes were substantially higher than those due to fluid substitution, as predicted by the Gassmann theory; consequently, it has been argued that these changes were caused by dissolution of carbonate rock minerals.

It is also known that carbonate minerals are dissolved due to CO_2. The effects of mineral dissolution on the rock properties have been investigated by laboratory measurements, and the results have been reported. Vanorio et al. [3] and Kono et al. [2] conducted experiments on carbonate rock samples that were injected with CO_2. Changes in physical properties such as acoustic velocity and porosity were assessed and changes in rock microstructures were observed with SEM images. The results showed that micritic carbonate minerals were dissolved with aqueous solutions of CO_2, leading to increased porosity and decreased acoustic velocity. Grombacher et al. [1] also conducted integrated laboratory measurements including NMR, SEM and CT-scan for carbonate rock samples injected with CO_2. They reported changes in acoustic velocity, permeability, and microstructures.

This paper presents the results of core flooding tests of carbonate rock samples under the cyclic load test to understand the changes of the rock properties and wave velocities during CO_2 injection.

PROCEDURE

1.5-inch-diameter plug samples were used for this study. Samples were carbonate rocks collected from a reservoir in a Middle Eastern oil field. Properties of each plug sample are shown in Table 1.

The laboratory measurement workflow is shown in Figure 1. CO_2 saturated water was prepared by bubbling CO_2 in water. The pH (potential hydrogen) of the distilled water decreased from 6.5 to 3.9. The rock samples were placed inside a pressure vessel to be arranged in series, and the CO_2 saturated water was allowed to be flooded through them. CO_2 saturated water was injected at the rate of 0.1 ml/min. For each 50 PVI flooded, the samples were removed from the pressure vessel. NMR analysis was conducted for the samples fully-saturated with CO_2 saturated water. After drying and basic measurements, elastic wave velocity measurement was conducted. Then, the samples were returned to the pressure vessel, and the experiment procedure was repeated up to 100 PVI. In addition to NMR and elastic wave velocity measurements, observations of carbonate mineral dissolution were performed with a scanning electron microscope (SEM: QUANTA600), and analyses of the amount of dissolved cations in the effluent were also conducted. The data results were used for evaluating effects of dissolution due to CO_2 saturated water on rock properties.

RESULTS

Figure 2 shows the change of the ratio of the pore volume to the initial pore volume (PV/PV0) during the CO_2 saturated water flooding. The porosity of Core_B without the compaction effects increased by 3.6% at the first 50 PVI, and the porosity increased by 6.0% from 50 to 100 PVIs. On the other hand, the porosity of Core_A with the compaction effects decreased by 4.3% at the first 50 PVI, and then the porosity was kept. At the end of 100 PVI, the difference of porosity between Core_A and Core_B was about 8%.

Figures 3 and 4 show the change of normalized elastic wave velocities when CO_2 saturated water was injected. The normalized P-wave velocities decreased by 10% compared to the initial values in the both samples at the first 50 PVI and were constant from 50 to 100 PVIs. The normalized S-wave velocities of Core_B also decreased by 10% as the same as the normalized P-wave velocities whereas the normalized S-wave velocities of Core_A decreased by 5% at 100 PVI of the CO_2 saturated water. Dissolution of carbonate minerals was measured by produced water analysis. The amount of dissolution was confirmed to be substantially equal to the change of porosity.

DISCUSSION

In the case of Core_B without the compaction effects, the change of porosity at the first 50 PVI was greater than after 50 PVI. So the dissolution of the carbonate minerals by CO_2 saturated water flooding occurred at the early stage of flooding. On the other hand, Core_A with the compaction effects showed decrease in porosity. This suggested that the decrease was caused by compaction load because rock frame was weakened by dissolution.

The elastic velocities of Core_B without the compaction effects decreased when the bulk density decreased with porosity increase. Core_A with the compaction effects also showed elastic velocities decrease. This indicates that the elastic wave velocities reduce with or without compaction effects when carbonate minerals were dissolved by CO_2 saturated water flooding.

CONCLUSION

We conducted CO_2 saturated water flooding test for carbonate and evaluated the change of rock properties. Results showed that carbonate dissolution occurred at the early stage of CO_2 saturated water flooding. It is suggested that the porosity decreased under compaction because rock frame was weakened by dissolution. In addition, results showed that the elastic wave velocities reduce with or without compaction effects when carbonate minerals are dissolved by CO_2 saturated water flooding.

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Table1 The properties of rock core samples.

Sample ID	Diameter	Length	Dry weight	Pore volume	Grain density	Porosity	Kair	With compaction
	cm	cm	g	ml	g/cm3	fraction	mD	
Core_A	3.804	4.076	89.92	12.56	2.66	0.271	20.9	*yes*
Core_B	3.790	6.154	147.20	15.34	2.72	0.221	28.4	*none*

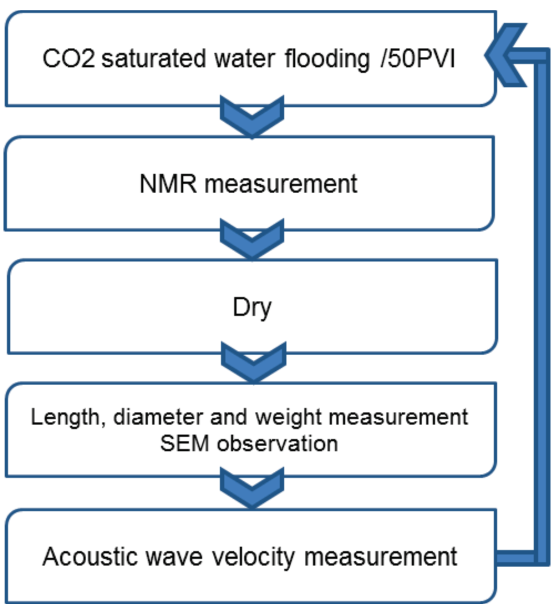

Figure.1 Laboratory measurement flow.

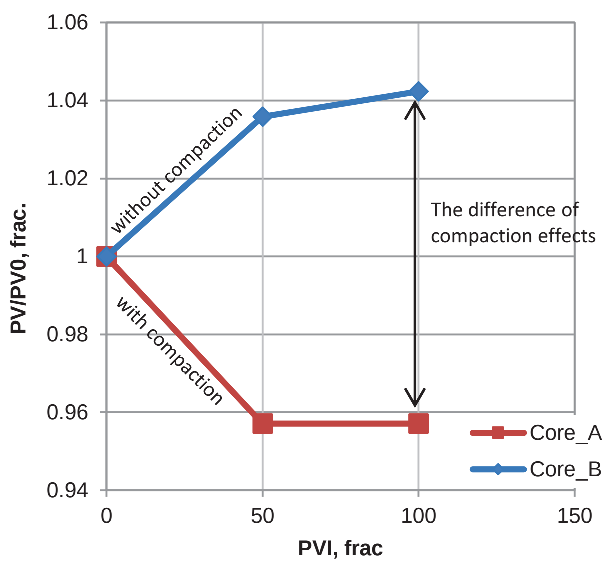

Figure.2 The comparison of PV/PV0 between with compaction effects.

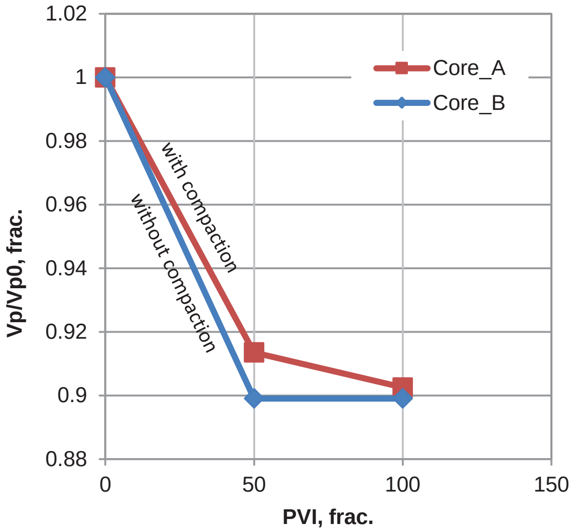

Figure.3 Normalized P-wave velocities.

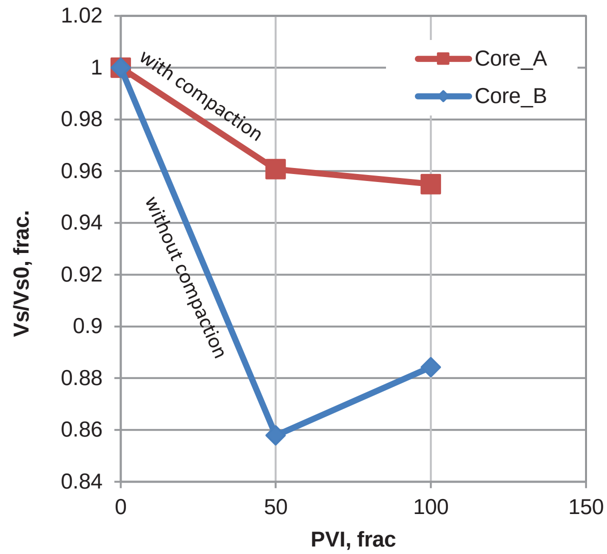

Figure.4 Normalized V-wave velocities.