Petroleum Research

Petroleum Research, 2019 (December-January), Vol. 28, No. 108, 18-21

DOI: 10.22078/pr.2019.3563.2627

Effect of Hydrostatic Stress Loading on Petrophysical, Geomechanical and Structural Properties of Carbonate Reservoir Rock

Yaser Salimidelshad[1], Ali Moradzadeh[1]*, Ezatallah Kazemzadeh[2], Peyman Pourafshary[3] and Abbas Majdi[1]

1 School of Mining Engineering, College of Engineering, University of Tehran, Iran

2. Division of Petroleum Engineering, Faculty of Upstream Petroleum Industry, Research Institute of Petroleum Industry (RIPI), Tehran, Iran

3. Department of Petroleum Engineering, School of Mining and Geosciences, Nazarbayev University, Astana, Kazakhstan

a_moradzadeh@ut.ac.ir

DOI: 10.22078/pr.2019.3563.2627

Received: December/09/2018 Accepted: July/16/2019

INTRODUCTION

Carbonate reservoir rock is one of the main structures in the porous media of a hydrocarbon reservoir. During production of the reservoir, the fluids will be removed from the porous media that disturb the balance of the system, and eventually, effective stress on rock increases and rock deforms under compression [1,2].

Pressure variations in a reservoir can affect the petrophysical properties of the reservoir rock such as porosity and permeability. Moreover, the strain induced can be restored if it does not exceed rock failure [3]. The porosity and structural changes in sandstone porous media under triaxial loading conditions to measure the relationship of porosity and permeability have been investigated by Karacan et al [4]. It has been concluded that in the ductile failure condition, the porosity has been reduced by applying pressure in all directions, and it has increased after approaching to ductile-plastic deformation condition. Also, there has been a gradual reduction in the permeability due to loading; in addition, with the onset of fracturing, an increase in permeability has been observed [4]. The lack of reliable data of petrophysical properties necessitates a comprehensive study of rock properties with a critical consideration of the hysteresis effect as a less well studied phenomenon. Furthermore, it is important to know how the cyclic loading/unloading tests affect petrophysical properties and cause damages in the core. In this study, the effect of hydrostatic loading on alteration of porosity and permeability of two carbonate core samples has been studied using CMS (Core Measurement System) apparatus. Furthermore, the petrophysical and geomechanical analyses of core samples have been accomplished by CT scan, SEM, AutoPore III, and Sonic Viewer SX.

EXPERIMENTAL PROCEDURE

In this research, two carbonate reservoir rock samples were selected to investigate petrophysical, geomechanical, and structural changes under various loading conditions. At first, the samples have been washed with toluene and methanol using a Soxhlet unit to remove all fluids and salts. Then the plug samples were placed in an oven at 60 °C for 24 hours. A helium porosimeter and air permeameter have been used to measure the porosity and permeability of the dried samples respectively. The results are shown in Table 1.

Table 1: Initial petrophysical properties of samples.

Sample name	A	B
Length (cm)	5.961	5.443
Diameter (cm)	3.768	3.753
Density (gr/cm^3)	2.71	2.71
Porosity (%)	22.17	21.87
Permeability (mD)	1.31	4.20

The effect of loading on porous media and rock structure is firstly processed by CT scan images which have been used to investigate the structure of the samples. Then, petrophysical properties including porosity and permeability have been measured with compressional and shear wave velocities. Moreover, to analyze the results, the scanning electron microscopy (SEM) and pore throat changes have been performed. The loading pattern is designed based on the following samples:

Sample A: 6000 psi and 8000 psi for 5 days,

Sample B: 2000 psi and 4000 psi for 5 days.

RESULTS AND DISCUSSION

CT SCAN ANALYSIS

Figure 1 shows the CT scan images of selected samples, and it shows that the plug samples have no fracture and heterogeneities.

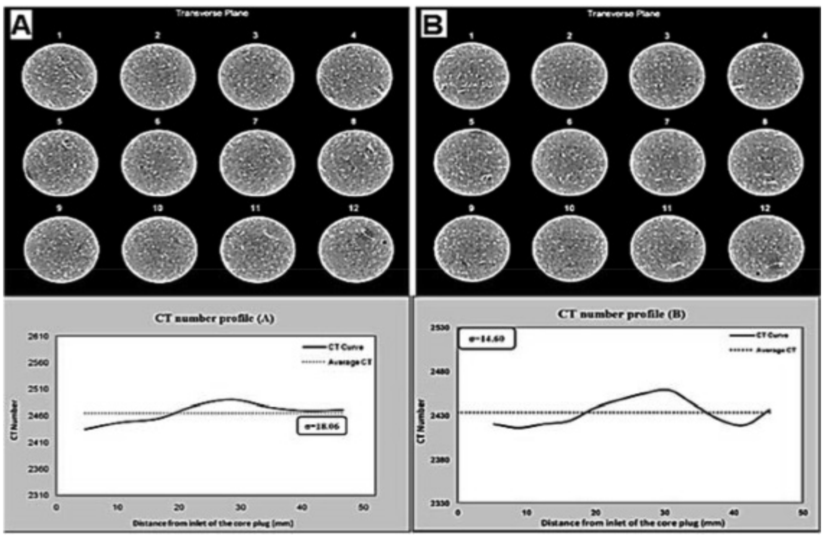

Figure 1: CT scan images of samples A and B.

PETROPHYSICAL PROPERTIES

According to Figure 2, the porosity and permeability of sample A after loading of 6000 psi and 8000 psi at 5 days have been reduced. This has also happened for sample B after loading under 2000 psi and 4000 psi for 5 days. As it can be seen, in first loading steps, the highest reduction has been observed. The critical note is the different changes of porosity and permeability. Moreover, the permeability versus pressure has changed five times higher than porosity of sample, as in 8000 psi, 36% permeability reduction has taken place. Also, the rock behavior changes with pressure with a different trend in porosity and permeability. In addition, it is expected that changes move toward zero by increasing loading.

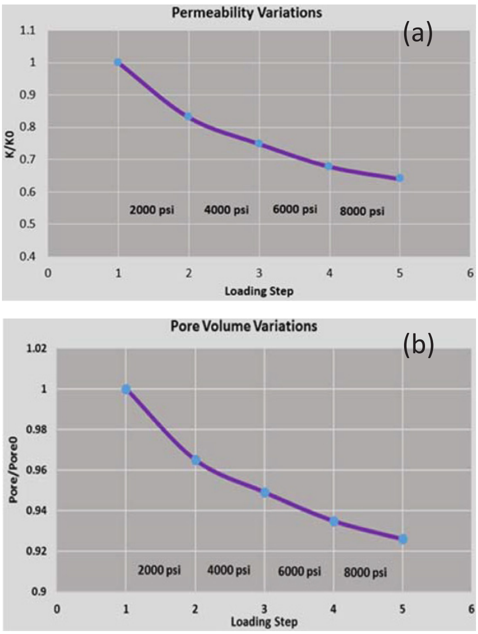

Figure 2: The trend of normalized permeability (a) and pore volume variations (b) under loading of sample.

SONIC WAVE VELOCITIES

The results of compressional (Vp) and shear (Vs) wave velocities have demonstrated that the velocities after loading of both samples have increased about 35%, and the dynamic modules have raised at least two times, which it has illustrated increased compressional strength against deformation. In addition, these results have confirmed the outcomes of CMS test and reduction in petrophysical properties of samples.

PORE SIZE DISTRIBUTION AND SEM

In this study, a mercury injection test has been performed to measure the pore size distribution. In this method, the saturated sample is placed inside the cell, and mercury is injected under different pressures. The pore size distribution is determined from the mercury volume penetrated. The mercury injection data have been measured by an Auto Pore III device.

Figure 3 shows the area of each section of pore size distribution graph. The surface area C has reduced, and the surface area A has increased, which it means the pores have been compressed. In addition, it is a reason for filling pores by crushed particles and changing in porous media, which can also be seen under SEM images in Figure 4.

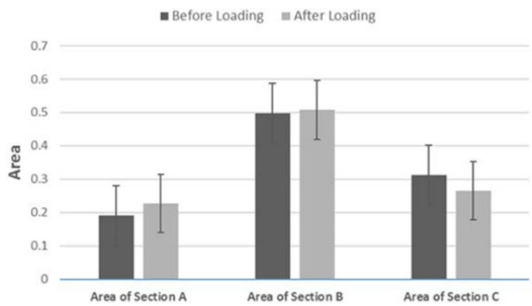

Figure 3: The area of three regions in pore size distribution diagram before and after loading.

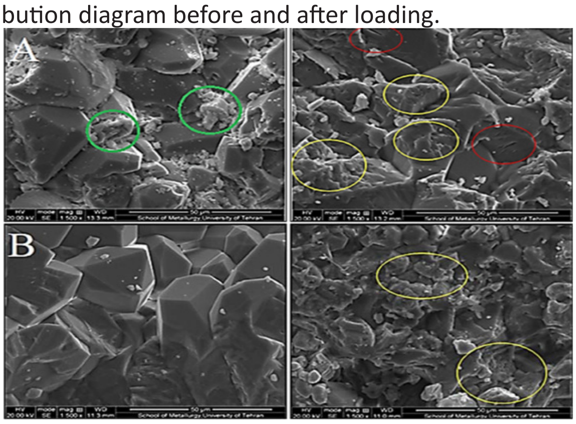

Figure 4: SEM images of samples before (left) and after (right) loading.

CONCLUSIONS

- The permeability and porosity of reservoir rock depend on effective stress and loading time. The results of this study can be summarized as below:
- The results of CMS test have shown that the rate of petrophysical properties alteration during loading has a reducing trend, and rock strength to compression increases by increasing effective stress.
- The microscopic images have shown that the natural texture of rock deforms under loading. In primary loading steps, the particles have crushed and decreased the permeability by blocking the pore throats.
- The mercury injection test has illustrated that the pores' size has changed from big and medium to small that is due to compression of pores.
- The changes in sonic wave velocities have shown that the particles have filled the pore spaces due to loading and have provided a new path for sonic wave velocities.

REFERENCES

[1]. Nagel N. B., *"Compaction and subsidence issues within the petroleum industry: From Wilmington to Ekofisk and beyond,"* Physics and Chemistry of the Earth, Part A: Solid Earth and Geodesy, Vol. 26, Issue 1-2, pp. 3-14, 2001.

[2]. Skinner J. T., Tovar F. D. and Schechter D. S., *"Computed tomography for petrophysical characterization of highly heterogeneous reservoir rock,"* In SPE Latin American and Caribbean Petroleum Engineering Conference, Society of Petroleum Engineers, 2015.

[3]. Abdelkarim A. and Abdullatif O., *"Combining petrophysical properties and ultrasonic velocity for improved prediction of tight carbonate reservoir,"* In Unconventional Resources Technology Conference, pp. 2201-2207, Society of Exploration Geophysicists, American Association of Petroleum Geologists, Society of Petroleum Engineers, Austin, Texas, 24-26, July 2017.

[4]. Karacan C. O., Grader A. S. and Halleck, P. M., *"4-D Mapping of porosity and investigation of permeability changes in deforming porous medium,"* In SPE Eastern Regional Meeting. Society of Petroleum Engineers, 2001.