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Laboratory Invesigation of Static and Dynamic Mechanical Response of Rocks to Cyclic Injection and Production

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Summary

The mechanical response of sedimentary rocks is known to be different during injection versus production, a property that has an important role in reservoir engnieering, geomechanics, and time-lapse seismic. In this study, comprehensive sets of laboratory tests were designed to invistigate the static and dynamic mechanical response of sandstone and carbonate rocks to consecutive cycles of injection and production. The results show that responses of the samples are significantly different for sandstone and carbonate rocks and in different cycles of injection and production.

Introduction

Most sedimentary rocks are expected to behave more deformable during loading than unloading especially in early stages of deformation (Fjær et al., 2008). In reservoir geomechanics, a similar difference is expected for the rock response to pore pressure increase (i.e., injection) and pore pressure decrease (i.e., production). This issue is more complex for the operations that consist of consecutive cycles of injection and production such as water flooding, CO_2-EOR and cyclic stream injection. Unfortunately, despite its great importance, this behaviour of sedimentary rocks is usually underestimated in reservoir geomechanics, reservoir engineering and time-lapse seismic. This study was conducted to acquire a better understanding of this behaviour by investigating the static and dynamic mechanical responses of sandstone and carbonate samples acquired from different geological formations in Alberta, Canada to cyclic injection/production. The methodology used for conducting these tests and the results of the tests are briefly discussed in the following.

Testing Methodology

After conducting common petrophysical tests to measure permeability and porosity of the samples, the samples were mounted in a triaxial apparatus and saturated with fluids with similar chemical composition to the brine at the locations of sampling. In the initialization stage, pore pressure and stresses were adjusted to a state representing the approximated in-situ field conditions. Then, pore pressure was gradually varied to simulate two cycles of injection and production. The tests were performed in a uniaxial deformation condition meaning that the samples were laterally confined and only vertical deformation was allowed, a condition which resembles deformation of laterally extensive reservoirs. To apply this condition, by monitoring and adjusting the confining pressure, the radial deformation was hold to be insignificant. In addition to measuring vertical deformation, shear and compressional ultrasonic wave velocities were also recorded during the entire testing time to study the effects of pressure change on dynamic properties of the rock samples.

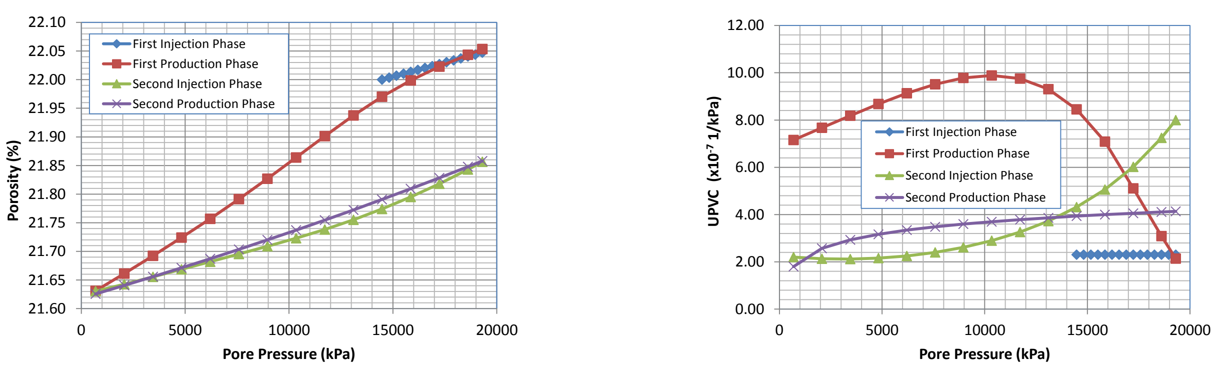
Results of Static Measurements

The results of triaxial tests show different patterns of deformation for sandstone and carbonate rocks. Figures 1a shows porosity change in different cycles of pore pressure change for a sandstone sample with a depth of 1268m. According to this figure, as expected, the first phase of injection leads to smaller changes in pore volume than the first phase of production. As a result, the sample's uniaxial pore volume compressibility (UPVC) is smaller during injection compared to production as shown in Figure 1b. Figure 1a also shows that, in the first phase of production, pore volume change is more than the second phase of production. Pore volume changes during injection and production in the second cycle are very close in value meaning the rock behaves almost elastically during this cycle. The results of measurement shown in these figures are very similar to the results of conventional consolidation tests for soils and rocks (e.g., Fjær et al., 2008).

Figures 2a and 2b, respectively, show porosity and uniaxial pore volume compressibility variation as functions of pore pressure for a carbonate sample with a depth of 1780m. According to these figures, during the first cycle of pressure change, similar to sandstones, the pore volume change during the injection phase is lower than that of production, but this trend reverses during the second cycle. In contrast to the sandstone samples, the porosity change with pressure variation in the carbonate samples in the second cycle is more significant than the first cycle. In addition, it can be observed from Figure 2b that the carbonate samples show much higher compressibility coefficients in comparison to the sandstone samples, probably because of their vuggy nature.

Results of Dynamic Measurements

Figures 3 and 4 show the values of different elastic properties (i.e., compressional wave velocity, shear wave velocity, dynamic Poisson's ratio and dynamic Young's modulus) based on the ultrasonic measurements for the same sandstone and carbonates samples shown in Figures 1 and 2, respectively. It is important to note that the vertical scales in these figures were chosen to show the very small variations in these parameters though these variations may not be significant relative to the absolute values of these parameters.



(a) (b)

Figure 1. Results of triaxial test for a sandstone sample shown variation of (a) porosity and (b) uniaxial pore volume compressibility (UPVC) versus pore pressure.

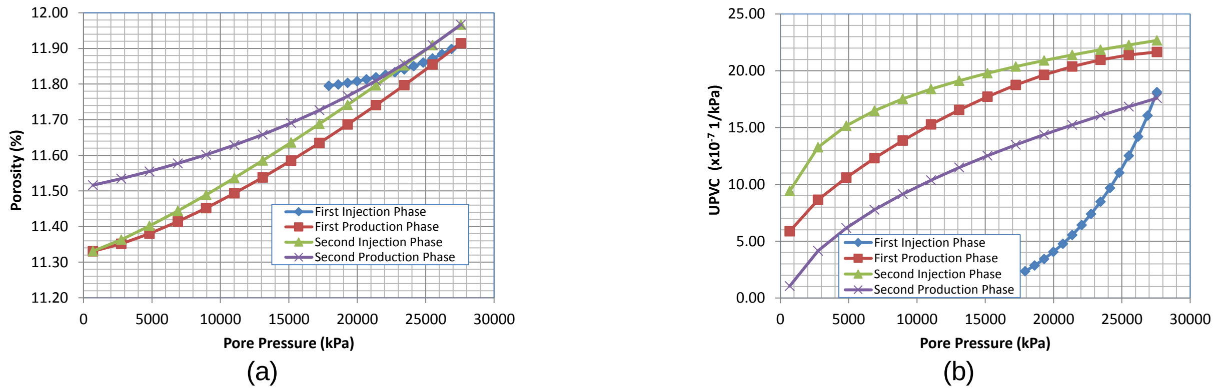


Figure 2. Results of triaxial test for a carbonate sample showing variation of (a) porosity and (b) uniaxial pore volume compressibility (UPVC) versus pore pressure.

According to Figures 3 and 4, except dynamic Poisson's ratio, all other elastic properties decrease in value during injection and increase in value during production. For the sandstone sample, dynamic elastic properties in the first injection phase seem to fall slightly apart from other curves probably due to the effects of sample initialization. It can also be observed from Figures 3 and 4 that the compressional wave velocity is more sensitive to pressure change in comparison to shear wave velocity.

Figure 5a and 5b show the variation of shear wave velocity versus compressional wave velocity for the same rock samples shown in Figures 1 and 2, respectively. According to these figures, the relation between shear and compressional wave velocities is quasi-linear, a property that can be used to estimate variation of shear velocity based on compressional velocity when it is not available.

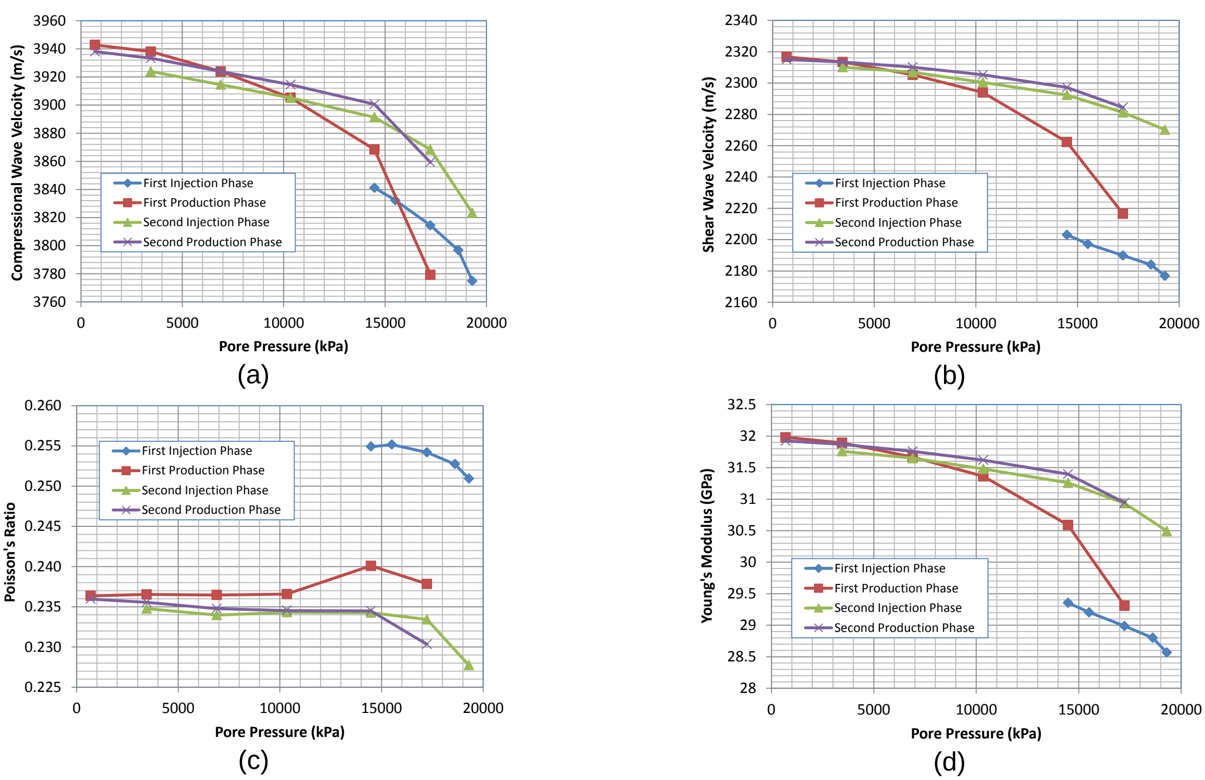


Figure 3. Results of ultrasonic measurements for the sandstone sample of Figure 1 showing variation of (a) compressional wave velocity, (b) shear wave velocity, (c) Poisson's ratio and (d) Young's modulus.

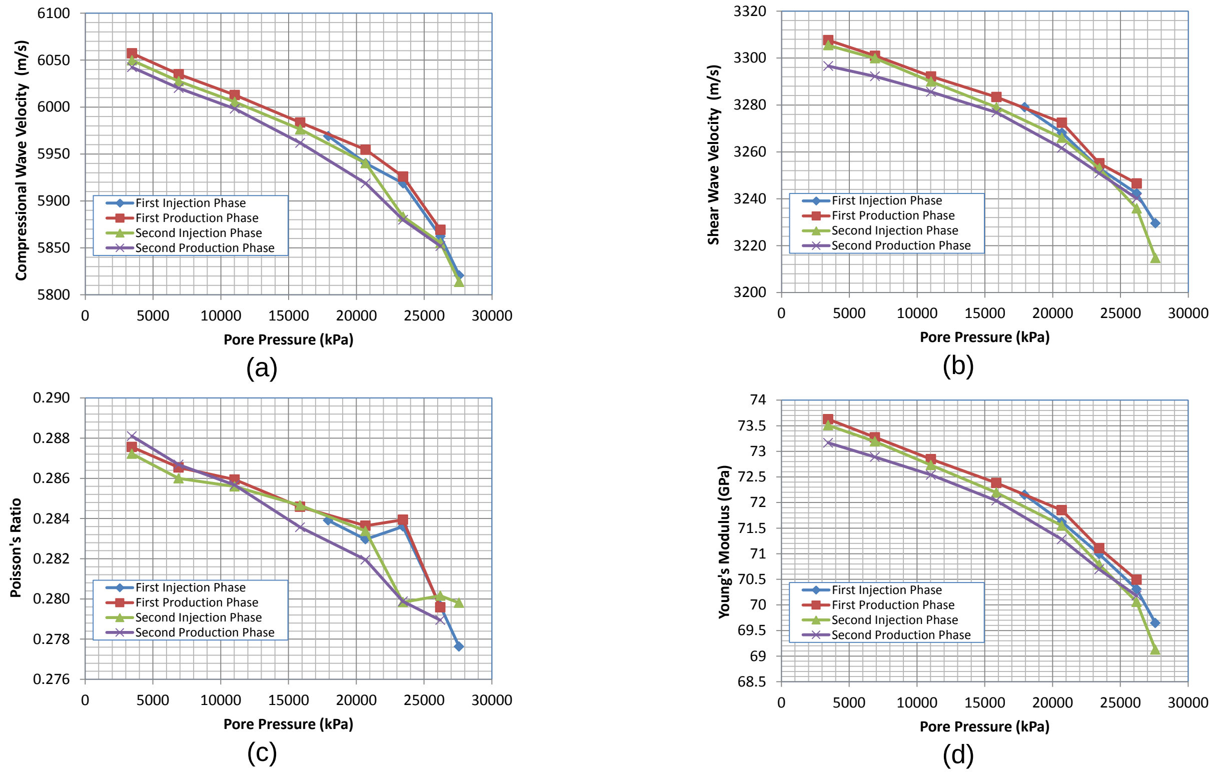


Figure 4. Results of ultrasonic measurements for the carbonate sample of Figure 2 showing variation of (a) compressional wave velocity, (b) shear wave velocity, (c) Poisson's ratio and (d) Young's modulus.

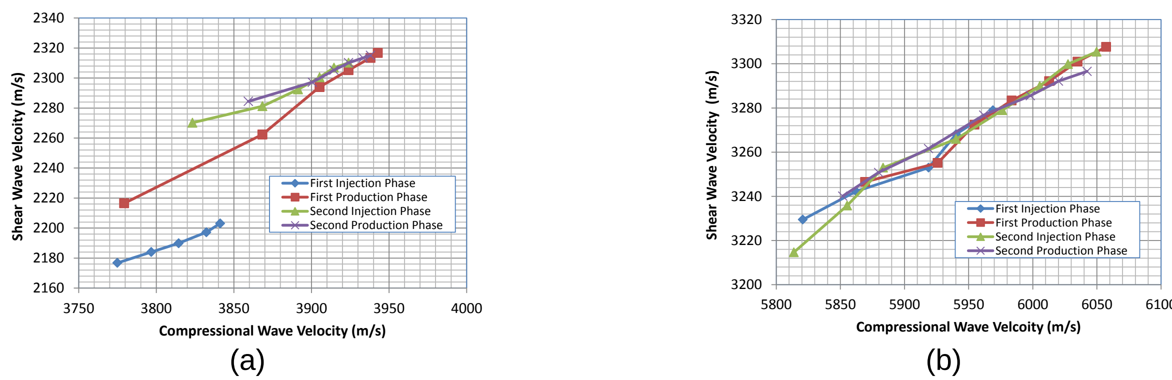


Figure 5. Variation of compressional wave velocity versus shear wave velocity during pore pressure change for (a) the sandstone sample of Figure 1 and (b) the carbonate sample of Figure 2.

Conclusions

The results of this study confirm that mechanical responses of sedimentary rocks to production and injection can be considerably different. These responses also was shown to be significantly affected by hysteresis. Additionally, these results show that the nature of this behaviour is dependent on the rock's lithology.

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References

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