The role of wettability on seismic wave attenuation

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Summary

Seismic wave attenuation in porous media is influenced by various factors, including wave-induced fluid flow effects at different scales, thermoelastic effects, and intergranular friction. Among these factors, wave-induced fluid flow effects at different scales are considered to be the primary cause of seismic wave attenuation. The attenuation of wave-induced flow primarily determined by the coupling between the solid and fluid phases. Recent experimental results in literature on uncemented glass beads suggest that the wettability of the rock matrix might be one of the nonnegligible factors affecting the fluid-solid coupling, thereby influencing the attenuation characteristics of waves. In this paper, we consider this problem further by making a well cemented artificial sandstone to conduct rock physics experiments within the ultrasonic frequency band. The effect of wettability on the attenuation characteristics of ultrasonic waves in porous media will be analyzed in detail. The content presented in this paper could be of great significance for seismic wave monitoring in unconventional EOR heavy oil recovery, CO2 flooding, and other processes involving the modification of pore wall wettability.

Workflow

Recently, there has been increased interests in the relation of wave properties and wettability of rock. For example, through a series of measurements with high-porosity synthetic epoxy-bonded carbonate saturated with different fluids, Wang et al. (2015) found that the wettability can alter the P and S wave speeds. Experiments on glass beads conducted by Li et al. (2022) have a significant impact on ultrasonic wave propagation in granular porous medium. However, to our knowledge, investigation into the wettability and seismic wave attenuation on a cemented rock sample has not yet been conducted. Therefore, we produced a cemented (not by using epoxy as done by Wang et al. (2015)) artificial sandstone rock sample with high porosity (26.34%) and high permeability (3917.33mD) (Figure 1).

First, we record the ultrasonic wave transmitted through a saturated rock sample with strong water wetting (prior to wettability alteration, Figure 2a). Then, the rock sample is dried, and a silane coupler liquid is used to alter the wettability. The same ultrasonic experiment is repeated on the same rock sample, but with weak brine wettability (Figure 2b). Denoising and window functions are applied to all recorded waveforms to extract the coherent waves (first coherent transmissions, Figure 3). Then, the frequency spectra is calculated and from which the attenuation factor $\Delta t^* = \frac{1}{2}\frac{f_S - f_R}{\sigma_S^2 + \sigma_R^2}$ is derived (Figure 4). Here f_S and f_R are, respectively, the centroid frequencies of ultrasonic waves from the standard aluminum and the rock sample. The counterpart variances are denoted by σ_S and σ_R.

Figure 1. High-porosity and high-permeability artificial sandstone

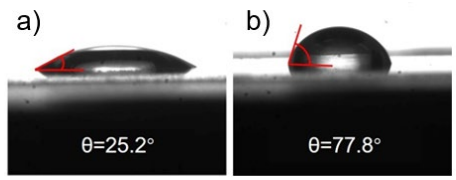

Figure 2. Brine contact angle a) before and b) after wettability alteration. Low contact angle indicates strong brine wettability and high contact angle means weak brine wettability.

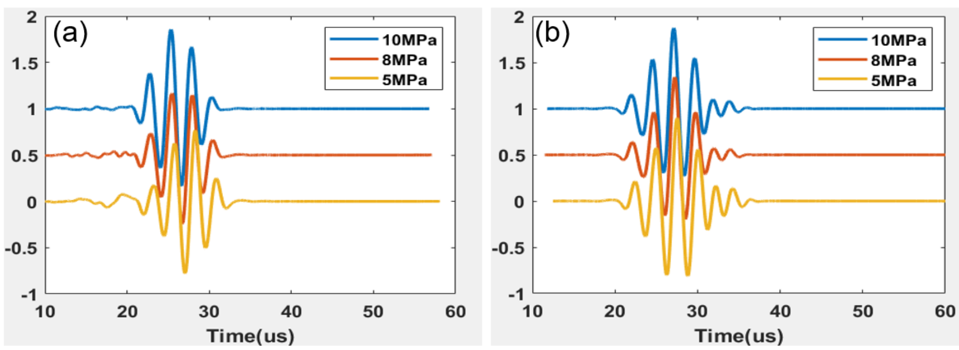

Figure 3. Recorded transmission ultrasonic waves a) before and b) after wettability alteration

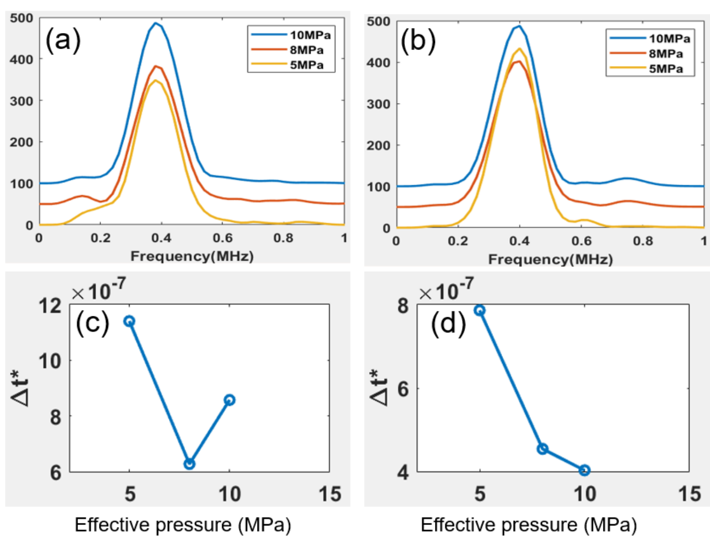

Figure 4. The frequency-amplitude spectra a) before and b) after wettability alteration. The results in c) and d) are the corresponding attenuation factors.

Observations and Conclusions

As depicted in Figure 4, the attenuation factor decreases with increasing effective pressure, attributed to the reduced porosity with increasing pressure. Although the peak frequency shift is very slight, as shown in the plots after the artificial sandstone becomes hydrophobic, the attenuation factors clearly indicate a reduction in the strength of wave attenuation. This reduced attenuation rate can be attributed to decreased liquid-solid coupling effects caused by the weakened brine-rock frame contact (Figure 2b).

The presented experiments and results are obtained within the ultrasonic frequency band, so some of the mesoscopic attenuation effects are unlikely to be observed. Thus, there is a high demand for similar rock physics experiments within the seismic frequency band.

Acknowledgements

This research is supported by the National Natural Science Foundation of China (grant No. 42274161)

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