Temperature Dependence of Acoustic Velocities in Gas-Saturated Sandstones

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Monitoring of steam conformance

Temperature dependence of seismic velocities enables inversion of time-lapse (cross-well) seismic data for temperature changes in thermal EOR

- What is the temperature dependence of fluid and gas saturated rocks?
- Is the Gassmann model applicable?
- What is the effect of velocity dispersion?
Temperature dependence of ultrasonic velocities

Velocities: \[ V_p = \sqrt{\frac{K_{sat} + \frac{4}{3} \mu_{sat}}{\rho(T)}} \quad ; \quad V_s = \sqrt{\frac{\mu_{sat}}{\rho(T)}} \]

Gassmann theory: \[ K_{sat} = K_{dry} + \frac{\phi}{K_{fl}(T)} + \frac{(1-\phi) - K_{dry}}{K_{gr}} \]

\[ \mu_{sat} = \mu_{dry} \]

Measured temperature dependences of \( V_p \) and \( V_s \) are stronger than expected from Gassmann theory if we assume that the dry-rock stiffness is temperature independent:

- \( V_s \) should be nearly temperature-independent (except for some density effects)
- For (partially) gas-saturated rock, \( K_{fl} \) is small and little temperature dependence would be expected.
Dry-rock temperature dependence of $V_p$ and $V_s$

What is “dry”?

Presence of very small amount of water (e.g. condensation during cool down) results in sizable temperature dependence of $V_p$ and $V_s$.

In the absence of any water (heated under vacuum), $V_p$ and $V_s$ are nearly temperature independent ($\Delta V_p/V_p < 10^{-4} \text{ K}^{-1} \cdot \Delta T$).

Experiments have to be carried out under well-defined conditions to yield reproducible results.
Is the Gassmann model applicable if we define “dry rock” as the rock matrix in contact with a small amount of pore fluid (wetting of grain surfaces and grain contacts)?

Approach:

- Measure temperature dependence of “dry” rock stiffness (with well-defined fluid saturation)
- Apply Gassmann model to predict $V_p$ and $V_s$ of fully saturated rock
Temperature dependence of $V_p$ and $V_s$ of Castlegate sandstone – Temperature dependence

Test done by Gesteinslabor Dr. Jahns, Germany (www.gesteinslabor.de)

Temperature dependence of $V_p$ and $V_s$ can be described by the Gassmann model by taking the temperature dependence of the “dry”-rock stiffness into account.
$V_p$ and $V_s$ of Castlegate sandstone – Temperature dependence

“Dry”-rock stiffness depends on pore fluid:
Higher stiffness and enhanced temperature dependence for glycerin as pore fluid

- Compressibility of glycerin is smaller than that of water at RT
- Glycerin has high viscosity at RT
- Viscosity is strongly temperature dependent

Test done by Gesteinslabor Dr. Jahns, Germany
Is the temperature dependence of Vp and Vs at seismic frequencies as high as at seismic frequencies?

Previous studies have shown that the “dry”-rock stiffness is frequency dependent due to time-dependent relaxation processes.

Relaxation times are temperature dependent $\Rightarrow$ temperature dependence of “dry”-rock stiffness

Origin of velocity dispersion:

(A) Local flow (micro cracks, etc.)

(B) rock-surface energy
Velocity dispersion in heavy oil sands

- Decrease of dispersion with temperature
- Little dispersion at seismic frequencies ⇒ Gassmann model applicable at seismic frequencies
Conclusions

• Gassmann model is applicable for describing the temperature dependence of $V_p$ and $V_s$ of fluid-saturated sandstones if temperature dependence of “dry”-rock stiffness is taken into account.

• As “dry”-rock stiffness we define the stiffness of the rock with a small but finite fluid saturation ⇒ “dry”-rock stiffness depends on pore fluid.

• Temperature dependence of $V_p$ and $V_s$ might be significantly smaller at seismic frequencies than at ultrasonic frequencies due to velocity dispersion effects ⇒ more studies are needed for better understanding.
Q & A