A Data Driven Solution to the Mystery of Seismic Velocities in Oil Sands

Ahmad Javanbakhti

Summary

I present a rock physics model which estimates P- and S-wave velocities of oil sands as a function of fluid and rock properties at different frequency values. The inputs to the model are available through common petrophysical analyses. Model parameters have been deterimend by utilizing the well log dataset of an Athabasca oil sands play and the validity of the model is verified with ultrasonic lab measurements, sonic data from the heated wells and multicomponent seismic data. The main advantage of the model is its ability to properly estimate the shear regidity of the rock at different temperature and frequency settings and hence enables us to characterize the reservoir using P- or multicomponent seismic data. I will demonstrate several applications of the model in;

1- Calculating the 2D map of steam chamber thickness which is consistent with the cummulative production data
2- Identifying the thief zones and the presence of barriers
3- Creating maps of the heated and cold zones for future development planning.

Theory

In order to calculate saturated velocities of the reservoir rock, effective elastic moduli and density of the rock need to be estimated properly. I use the empirical relationship derived in Javanbakhti (2018) to estimate saturated shear modulus (μ_{sat}):

$$\frac{1}{\mu_{dry}} - \frac{1}{\mu_{sat}} = A\mu_a^m S_o^n \phi^p \mu_{dry}^q \quad (1)$$

where μ_{dry}, μ_a, S_o and ϕ are dry shear modulus, bitumen's shear modulus, saturation of oil and porosity, respectively. Coefficient *A* and *m*, *n*, *p* and *p* exponents are defined in Table 1.

Table 1 Parameters in Equation 1 and their corresponding values.

Parameter	*A*	*m*	*n*	*p*	*q*
Value	0.10	0.27	0.14	-1.9	-1.76

Like any other empirical relationship, this model has some limitations, but it successfully covers Canadian oil sands. Figure 1 compares the calculated μ_{sat} using Gassmann (1951), Ciz and Shapiro (2007) and Javanbakhti (2018) with the observed values from ultrasonic measurements. As Figure 1 shows, Ciz and Shapiro (CS) model underestimates the shear property and hence results in lower P- and S-wave velocities. Bitumen's shear modulus as a function of temperature, API gravity and frequency can be estimated using either FLAG program or empirical relationships in Javanbakhti (2018). The variations of μ_a as a function of frequency, enables us to model the effect of modulus (velocity) dispersion in oil sands (Figure 2). The saturated bulk modulus (K_{sat}) is calculated using the Gassmann's equation. Like μ model, fluid bulk modulus is dependent on proper estimation of bitumen's bulk modulus. This can be calculated as described in Javanbakhti (2018) or from FLAG program. The application of the model on multi-component seismic data reveals that the effect of density reduction due to bitumen-steam substitution is more dominant than the effect of bitumen's shear rigidity at cold state.

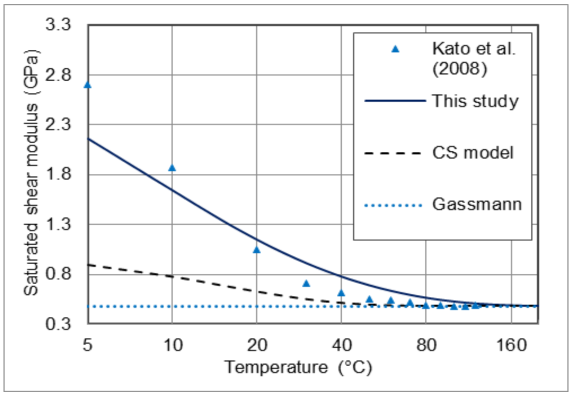

Figure 2. Shows the temperature effect on the saturated shear modulus of the heavy oil saturated sample #9 in Kato et al., (2008).

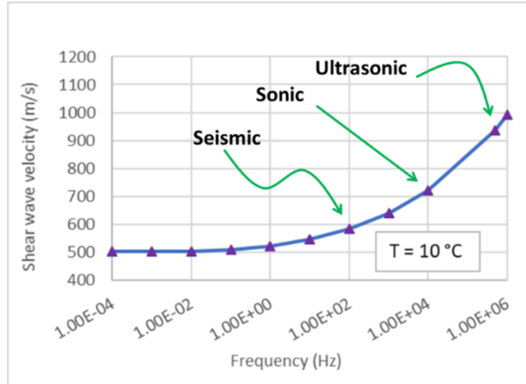

Figure 2. Modeling of P- and S-wave velocity dispersion for sample #9 in Kato et al. (2008) experiment at in-situ reservoir conditions.

The effect can be seen in Figure 3 where the ratio of V_S from monitor survey to V_S of the base shows a range from 0.94 to 1.05. A simple inversion technique can be applied to calculate the cumulative time thickness of cold, heated and steam-saturated zones as shown in Figure3b.

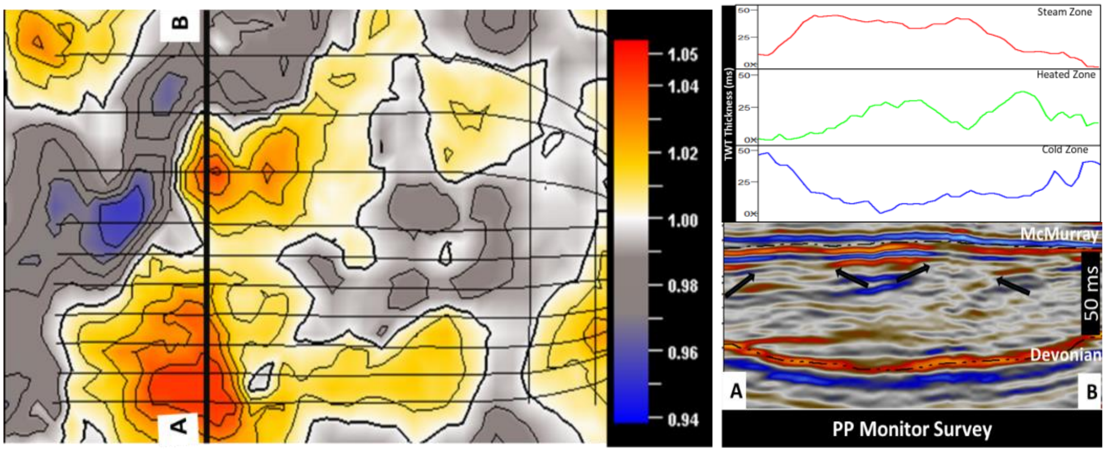

Figure 3 a) A 2D map of the ratio of the monitor V_S to the base velocity ($V_{S\text{-}mon}/V_{S\text{-}base}$). b) Time thickness of each zone along A-B.

Acknowledgements

I would also like to express my gratitude to Nexen Energy ULC. for providing the data and granting publication permission.

References

Ciz, Radim, and Serge A Shapiro. 2007. "Generalization of Gassmann Equations for Porous Media Saturated with a Solid Material." *Geophysics* 72 (6).

Gassmann, F., 1951, "*Elastic waves through a packing of spheres*", Geophysics, 16, 637-685

Javanbakhti, A. (2018). Empirical Modeling of the Saturated Shear Modulus in Heavy Oil Saturated Rocks, PhD thesis. University of Calgary, Calgary, AB.

Kato, A., Onozuka, S., & Nakayama, T. (2008). Elastic property changes in a bitumen reservoir during steam injection. The Leading Edge, 27(9), 1124‑1131.