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# Ultrasonic wave propagation and reflection in ultra-heavy oil

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## Introduction

There are numerous mechanisms that attenuate a sound wave passing through any real viscous fluid that depend on shear and bulk viscosity, thermal conduction, molecular relaxation, and (in colloidal suspensions) scattering (McClements, 1991). However, the contribution of these mechanisms to the attenuation of seismic waves through saturated formations is rarely explicitly considered. One reason for this is that in many ways we only poorly understand the dynamic rheological properties of the fluids themselves, particularly for the extra-heavy oils, the behaviour of which is further complicated by strong temperature dependence. Bitumen is an ultra-heavy oil for its API (American Petroleum Institute) value of less than 10°, density larger than 1 g/cm$^3$, and viscosity as high as ~10$^7$ cP at in situ condition. This viscosity must be reduced in order for it to be produced economically. As such time-lapse seismic monitoring has a role to play in the production of such oils, but more complete analysis of seismic observations requires a good understanding of the temperature and pressure dependent fluid properties. Here we discuss some recent issues with regards to our efforts using ultrasonic methods to better characterize bitumen produced from the carbonate Grosmont Formation, Alberta.

## Methods

We are adapting ultrasonic acoustical methods intended to provide measures of sound speed, density, and shear viscosity. Sound speeds are determined in a double direct pulse transmission with two independent receivers (piezoelectric transducers of 1 MHz) placed at unequal distances from a central transmitting PZT. There is some potential, too, that comparison of the observed waveforms can provide additional information on attenuation. Density and viscosity can also be measured at the same time using ultrasonic reflections in an experimental device consisting of two buffer pieces hosting a P-mode and and S-mode PZT. In principal, the density is determined from the complex reflection coefficient for the P or the S reflection from the buffer face in intimate contact with the fluid

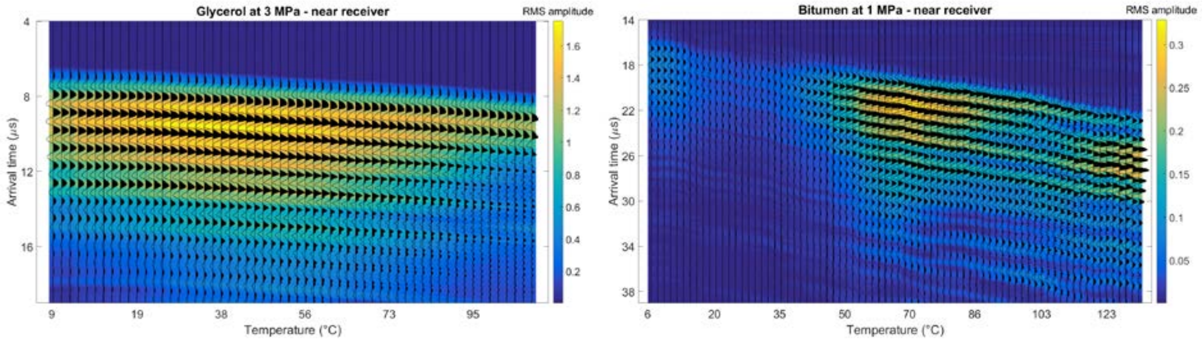
$$R^* = \frac{Z_s - Z_l}{Z_s + Z_l} = Re^{-i\omega\theta}$$

with $R = \frac{A_m}{A_r}$ and $\theta = \frac{1}{2}\cos^{-1}\left(1 - \frac{\left(1-R^2\right)^2}{\left(2R^2\right)}\right)$ where, $A_m$ and $A_r$ are the amplitudes of the reflected waves and the Z’s are the acoustic impedances. Thus the density ($\rho_l$) and shear viscosity ($\eta_s$) may be found through

$$\rho_l = \frac{Z_s}{V_p}\left(\frac{1-R}{1+R}\right) \quad \text{and} \quad \eta = \frac{Z_s}{\rho_l}\left(\frac{4\left(\left(1-R^2\right)R\sin\theta\right)}{\left(1+R^2+2R\cos\theta\right)^2}\right)\frac{\left(1+\omega^2\tau^2\right)}{\omega},$$ where $\tau$ is the relaxation time.

## Results and Discussion

The double receiver strategy allows the sound speed to be determined in water and glycerol to better than 0.5% for earlier standard measurements in the literature supporting the validity of the approach. Ensembles of ultrasonic traces obtained at constant fluid pressure but with increasing temperature (Fig. 1) show, however, some interesting differences in the behaviour of glycerol and the target bitumen. The sound speeds in both decrease with temperature as expected. However, the waveforms for the bitumen display further complications relative to the otherwise uniform character seen in the glycerol. This includes differences in signal strength (indicative of attenuation) and unexpected delayed variations in amplitude particularly at the highest temperatures in bitumen. The former likely relates to the *a*-transition from Newtonian fluid to viscoelastic solid in the bitumen (e.g., Lesueur, 2009). We do not know what causes the latter behaviour but speculate that it may result from acoustic scattering within the hydrocarbon-water emulsion that complicates the structure of this bitumen.



(a) (b)

*Figure 1: Variations of P-waveforms in (a) glycerol and (b) bitumen with temperature at constant P.*

The reflectometry techniques return acceptable measures of density and shear viscosity for water and glycerol. The values of shear viscosity found for bitumen appear reasonable. However, these examples of the P-wave reflection from the calibration in $N_2$ versus that in bitumen (Fig. 2) show substantial variation in the character of the reflected waveform (and hence the spectral content) that does not provide a good measure of density. Again, the reason for this is not known but it likely results from incorrect assumptions employed in the development of the formula above that may not take into account properly the complex rheology of the bitumen.

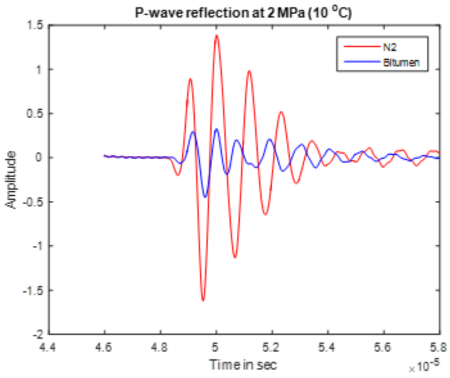


*Figure 2: P-wave reflections from nitrogen (reference) and bitumen.*

## Conclusions

Our main objective is to study physical properties of raw bitumen- and saturated rocks over a wide range of pressure, temperature, and frequency. Then, we will employ these data to quantify the effects that are due to the changes from fluid itself and not from fluid-rock interactions. These observations would assist interpreting 4D seismic surveys of a bitumen saturated reservoir.

### Acknowledgements

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### References

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