Rock Physics Laboratory Experiments on Bitumen Saturated Carbonates from the Grosmont Formation, Alberta

Arif Rabbani, Oliver Ong, Xiwei Chen, Douglas Schmitt, University of Alberta; Jason Nycz, Laricina Energy Ltd.; Ken Gray, Osum Oil Sands Corp.*

Summary

Time-lapse seismic monitoring is an effective tool of mapping out the temporal changes in reservoir properties during production. However, knowledge of how the subsurface changes with variations in temperature, pressure, and fluid saturation state is required. In this study, laboratory measurements of the P- and S-wave velocities are conducted on a single bitumen-hosted dolomite sample from the Grosmont formation of Alberta, Canada. Compressional and shear velocities are estimated using the Pulse-Transmission method while studying the effects of confining and pore pressure, temperature, and fluid saturation. For unaltered core samples, the wavespeeds decrease with temperature, suggesting a strong temperature dependence on the fluid. Measurement runs at a constant differential pressure shows the wavespeeds increasing with confining pressure. Furthermore, fluid saturation effects were studied after extracting the bitumen from the core and substituting it with water. Observations showed that there are significant differences in wavespeeds alluding to the influence of fluid saturation.

Introduction

In recent years, interest in unconventional reservoirs have increased, but due to the economic risks associated with producing from these types of reservoirs, they have largely been left untouched. Heavy oil reservoirs for example, need to reduce the in-situ viscosity of the hosted hydrocarbons in order to enhance its recovery factor, and as such, enhanced recovery techniques such as SAGD (Steam-assisted gravity drainage) or partial combustion are employed (Kendall 2009, Shabelansky, Malcolm and Fehler 2015). With the advent of better acquisition of time-lapse seismic data, it is possible to monitor the temporal changes in viscosity as a result of these recovery methods. However, it is imperative to have a solid understanding of the subsurface properties as the seismic response will depend on the variations in pore pressure, temperature, and fluid saturation state (Schmitt 2005) associated with these methods. A significant amount of studies has been completed on the physical rock properties of the oil sands reservoirs common in Alberta, Canada (Eastwood 1993, Hornby and Murphy III 1987, Nauroy, et al. 2012, Hickey, Eastwood and Spanos 1991, Wang and Nur 1988). However, studies on heavy oil hosted carbonates have been relatively sparse (Rabbani, et al. 2014). In this contribution, we study the temperature and pressure dependence of bitumen hosted carbonates from the Grosmont formation of Alberta, Canada, and provide some preliminary laboratory data.

Method

Due to the implications for time-lapse seismic monitoring, this study primarily focuses on the velocity response to variations in pressure and temperature. Here, we have adapted the use of the widely used Pulse-transmission method at ultrasonic frequencies.

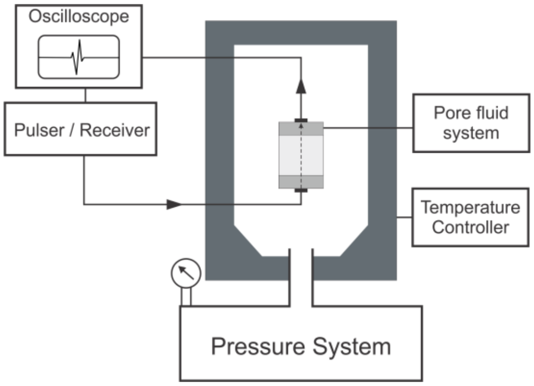

Figure 1: A simplified schematic of the experimental configuration

Samples are cored into 1.5 inch cylindrical samples with the ends ground parallel. PZT (lead zirconate titanate) piezoelectric elements with a resonance frequency of 1 MHz are adhered onto aluminum endcaps serving as a buffer between the pulsing ceramic and sample. These endcaps are then placed on opposing ends of the cylindrical sample and encased in Tygon™ tubing acting as a jacket. The experimental setup consists of a pulser / receiver system, digital oscilloscope, digitizer, and pressure vessel with a temperature controller (Figure 1). The pulser / receiver system produces a repeating excitation voltage to drive the pulsing element. The pulse propagates through the buffer and sample as an elastic wave and is transduced back into an electric signal by the receiving element. The signal is passed through a digitizer and stacked to remove random and electric noise before being recorded on the oscilloscope. Transit times are picked at the first extremum of the resulting waveform and shifted to the first arrival through calibration of the endcaps.

Preliminary Results and discussion

Samples were acquired from the Grosmont Formation, a dolomitized, shallow marine, carbonate complex within the West Athabasca oil sands region of Alberta. Preliminary ultrasonic velocity measurements are shown in this study for a bitumen-hosted dolomite sample from the Grosmont D unit cored at a depth of 315 m (Figure 2a). Mercury injection porosimetry provided estimates of the porosity and permeability showing values of 9% and 5.04 mD respectively. Measurements were first conducted on the sample with in-situ conditions preserved while adjusting factors such as confining pressure, pore pressure (using silicone oil pore fluid), and temperature. Afterwards, samples undergo bitumen extraction using a Soxhlet extractor and toluene solvent, leaving a relatively clean frame (Figure 2b). Subsequent runs are performed on the dry clean frame in addition to the frame saturated in various fluids of known properties.

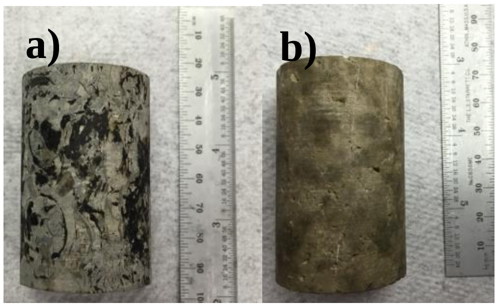

Figure 2: Picture of a) bitumen-saturated core as-is b) core after Soxhlet extraction of bitumen

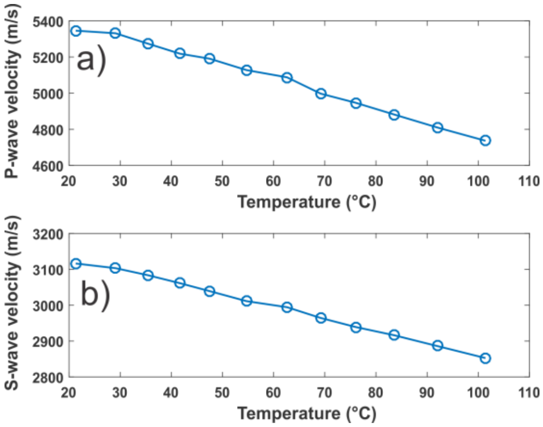

Figure 3: Plot of estimated wavespeeds as a function of temperature for a) P-wave velocity and b) S-wave velocity for a bitumen saturated sample. Constant 5 MPa differential pressure is applied.

The temperature dependence of the sample is first studied with Figure 3 plotting the estimated P- and S-wave velocities of an in-situ condition sample at a constant 5 MPa differential pressure. Velocities for both P- and S-waves are observed to significantly decrease with increasing temperature. This decrease in compressional and shear velocity is likely due to a number of factors, although it is postulated that the temperature dependence of the bitumen bulk modulus plays the greater role.

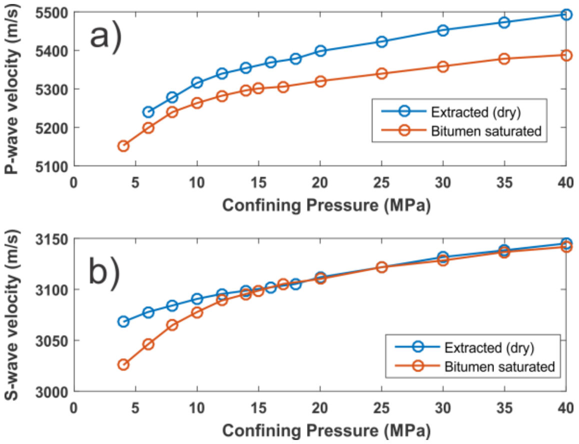

Figure 4: Comparison of estimated wavespeeds of extracted (dry) and bitumen saturated sample as a function of confining pressure. Wavespeeds plotted for a) P-wave and b) S-wave. Measurements performed under drained conditions (no pore pressure control)

Figure 4 plots the observed P- and S-wave velocities as a function of confining pressure at room temperature. These measurements were performed under drained conditions having the pore pressure vented to the atmosphere. Results show that both compressional and shear velocity increases with confining pressure for both dry (bitumen extracted/clean) and bitumen saturated samples. A noticeable discrepancy is observed for the compressional velocity as the dry and bitumen saturated values differ by a 100 m/s at the highest confining pressure. However, for the shear velocity, the initial deviation of the values decreases with the increase of confining pressure.

Lastly, to study the effects of the fluid on the sample, we compare the P- and S-wave velocities for the bitumen saturated sample with a water saturated sample (Figure 5). Silicone oil and water were used as pore fluids for the bitumen saturated and water saturated samples respectively. Pore pressure was increased incrementally to maintain a constant differential pressure of 15 MPa. Significant differences in the compressional velocity can likely be attributed to the higher bulk modulus of water in comparison to that of bitumen. Observations of the shear velocity exhibits the opposite trend with the bitumen saturated sample displaying higher velocity. Bitumen has been noted to have a non-zero shear modulus (Han, Liu and Batzle 2008) and thus would have an influence on the shear velocity in comparison to a water saturated sample.

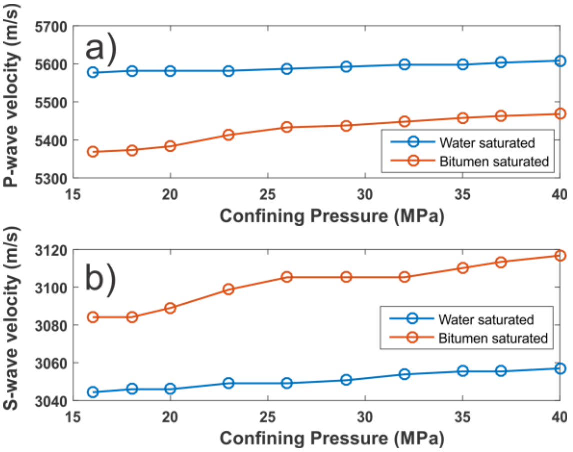

Figure 5: Comparison of estimated wavespeeds of bitumen saturated and water saturated sample as a function of confining pressure. Wavespeeds plotted for a) P-wave and b) S-wave. Measurements are run under a constant 15 MPa differential pressure at room temperature.

Implications for time-lapse (4D) seismic monitoring

Time-lapse seismic imaging is often used to observe and understand the temporal changes in the physical properties of the reservoir, particularly during production or enhanced oil recovery methods such as CO_2 injection or steam flooding. Figure 6 shows an acoustic impedance map illustrating the difference in AI during a steam injection of the Grosmont C reservoir between December 2012 and February 2011. The AI map was created using a joint PP/PS inversion of the reflectivity and shows an observable decrease in acoustic impedance up to 1.4 x 10^6 kg/m^{2}s along the two injection wells.

The acoustic impedance map is an effective method of estimating the movement of the steam front as seen by the stark contrast in AI in reference to the background levels. However, the change in AI can be attributed to a number of factors, and as such, a rock physics model is necessary to further invert the acoustic impedances to fluid saturation and pressure. Therefore, the laboratory measurements outlined in this study are crucial in creating the model that relates the acoustic impedance changes to variations in temperature, pressure, and fluid saturation states subjected to the reservoir during enhanced oil recovery.

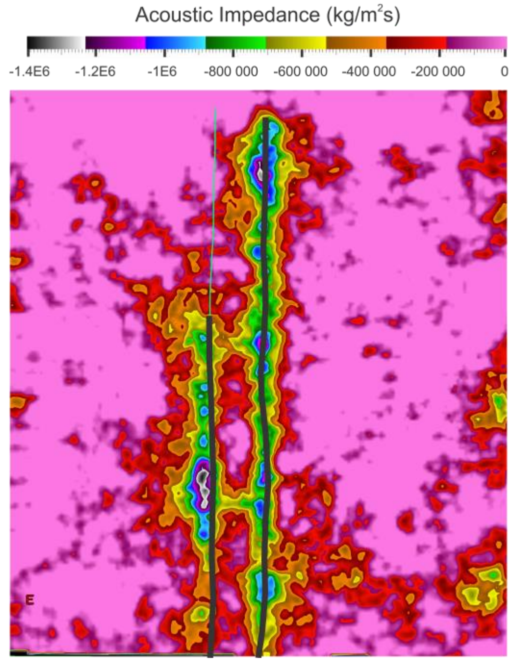

Figure 6: Acoustic impedance difference between February 2011 and December 2012 showing the effect of steam injection of the Grosmont D reservoir.

Conclusions

This study primarily focuses on the laboratory measurements of P- and S-wave velocities on bitumen hosted carbonates from the Grosmont formation of Alberta, Canada. The measurements were conducted using the Pulse-Transmission method at ultrasonic frequencies and a range of testing conditions. The observed compressional and shear wavespeeds appear to be strongly dependent on temperature, fluid saturation, and pressure. These are factors that can influence the reservoir properties during enhanced oil recovery methods such as steam flooding and thus may be used in building a rock physics model for the application of time-lapse seismic monitoring.

Acknowledgements

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EDITED REFERENCES

Note: This reference list is a copyedited version of the reference list submitted by the author. Reference lists for the 2016 SEG Technical Program Expanded Abstracts have been copyedited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

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