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Experimental study of a heavy oil carbonate under thermal recovery conditions: A case from the Grosmont Formation

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Summary

Monitoring sub-surface changes in heavy-oil reservoirs can be performed with time-lapse surface seismic methods. However, seismic characterization is limited without a thorough understanding of how the reservoir behaves in response to variations in pressure, temperature, and fluid saturation state. In this contribution, an ultrasonic velocity study is carried out on a bitumen-hosted carbonate sample from the Grosmont formation of Alberta, Canada. Preliminary results show a large temperature dependence of the velocity and elastic moduli, likely attributed to fluid changes in the unaltered rock. Removal of the bitumen from the rock and resaturation with water provided experimental results for comparison against Gassmann fluid substitution models. This model, using experimental and literature values produced bulk modulus values close to experimental values for the rock under full water saturation, but greatly underpredicts saturation with a heavy oil.

Introduction

In heavy oil reservoirs, thermal recovery methods such as SAGD (Steam-assisted gravity drainage) are employed to reduce the in-situ viscosity for the hosted hydrocarbons necessary for production [*Eastwood et al.*, 1994; *Schmitt*, 1999; *Mohebati et al.*, 2014; *Shabelansky et al.*, 2015]. During this process, the reservoir experiences substantial changes in it's properties due to variations in temperature, pressure, and fluid saturation states [*Schmitt*, 2005]. These changes elicit a change in seismic response and thus, are readily observed in 4D time-lapse seismic surveys, however a rock-physics model is needed to link these surface observations to the changes in reservoir properties. In this contribution, we experimentally study the temperature and pressure dependence of physical properties in bitumen-hosted carbonate rocks from the Grosmont formation of Alberta, Canada.

Method

This study focuses on the variations in ultrasonic velocity at differing conditions of pressure, temperature, and fluid saturation. The experimental apparatus, depicted in Figure 1, consists of a pulser / receiver system, digital-to-analog converter (DAC), digital oscilloscope, and a temperature controlled pressure vessel with pore pressure support.

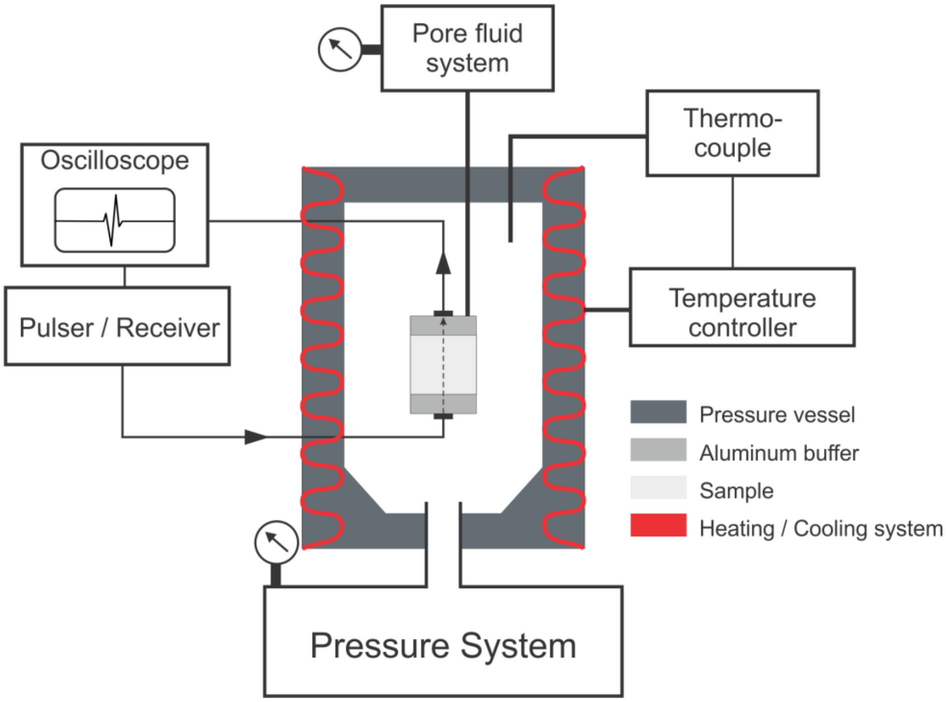

Figure 1. A simplified schematic of the experimental configuration. Modified from Rabbani et al. (2016)

The samples are 1.5 inch diameter cylindrical plugs bored out of the original 3.5 inch diameter core. Both ends of each plug are ground flat and parallel to provide uniform thickness and good coupling between the aluminum buffers and the sample. PZT (Lead zirconate titanate) piezoelectric elements with 1 MHz central frequencies are bonded onto aluminium buffers which are then placed at each of the cylindrical sample. The entire sample along with aluminum buffers are jacketed with Kuri-Tec ® Klearon™ 73 clear pvc tubing and sealed with hose clamps. The sample is placed into the pressure vessel, connected to the pore pressure system, and then connected to the data acquisition system. Pulse-tranmission waveforms are stacked to remove electrical noise and transit times are picked from the first extremum as opposed to first breaks to reduce the uncertainity in picking. Transit times are then calibrated to the first arrival through calibration of the aluminum buffers.

The experimental workflow consists of measuring velocity of the preserved core under various states of differential pressure ($P_{Confining}$ – P_{Pore}) and temperature ranges. After the intial set of measurements, the sample is cleaned of bitumen and other saturating fluids using a Soxhlet extraction method with a toluene solvent. The measurements are then repeated with the dry core to obtain the frame moduli used in our fluid substitution models. Afterwards, the frame is then fully saturated with water to obtain experimental data for comparison of modeled responses.

Preliminary results

Samples for this study were acquired from the Grosmont formation, an Upper Devonian carbonate platform present within the Western Canadian Sedimentary Basin located in North-East Alberta, Canada. Preliminary results will be presented for one dolomite sample taken from the Grosmont Unit C reservoir at a depth of 384 meters. From helium pycnometry, bitumen-saturated and dry bulk densities were determined to be 2456 kg/m^3 and 2257 kg/m^3, respectively. Porosity was determined to be approximately 16%.

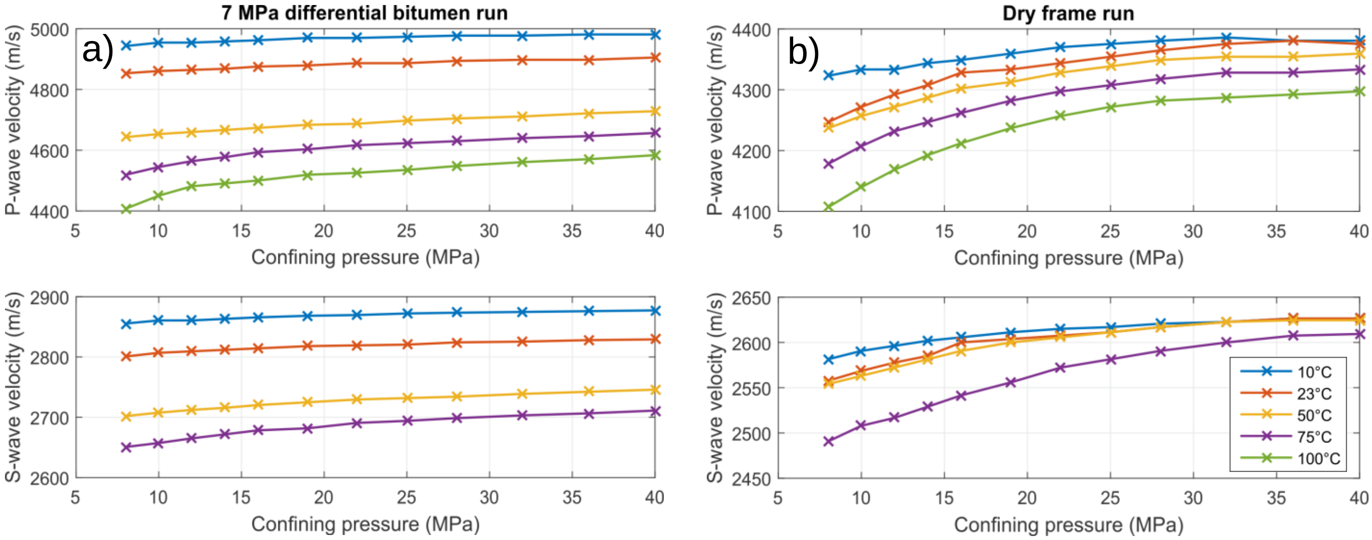

Figure 2. Measured P- and S-wave velocity data as a function of confining pressure for a) bitumen-saturated sample held at constant 7 MPa differential pressure and b) drained dry frame of sample

Figure 2 shows the raw velocity measurements for the preserved core as well as for the dry frame after removal of the bitumen and devoid of all saturating fluids. The initial run is conducted at a constant differential pressure of 7 MPa (approximately the in-situ effective pressure) and provides some early insight into the fluid influence on the rock with temperature. Properties of the rock frame are dependent on the differential pressure, therefore by increasing confining and pore pressure by the same amount, the fluid effect is more readily observed. Results show that the P- and S-wave velocities of the rock increase linearly with increasing pore pressure, most likely attributed to the increase in bulk and shear modulus of the fluid. In addition, both velocities decrease with increasing temperature, also speculated to be attributed to the change in properites of the bitumen. Similarly, the velocities of the dry frame are also observed to be temperature dependent to a lesser degree.

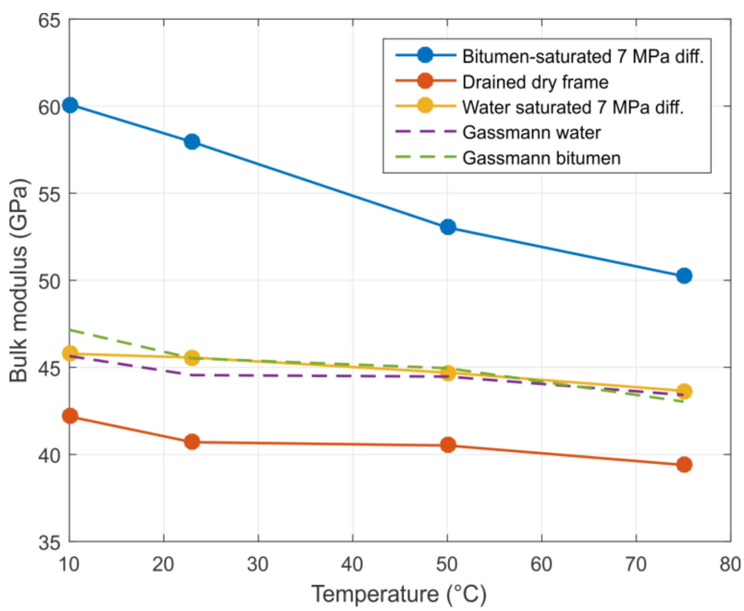

Figure 3. Bulk modulus as a function of temperature for sample. Solid markers indicate experimental data and dashed line indicates modeled response

Following the dry frame run, the experiment is repeated after resaturaturating the sample with water. Figure 3 shows the bulk modulus calculated from the velocities and densities of the sample and plotted as a function of temperature at 7 MPa differential pressure. In addition to the experimental points, expected values are calculated using Gassmann's fluid substitution model. The model uses experimental data for the dry frame and a combination of literature and experimental data for fluid moduli values. Modeled response for the water-saturated moduli are in agreement with experimental results, however, the modeled response significantly under-predicts the bulk modulus for the bitumen-saturated sample.

It is important to note that these results differ somewhat from our earliest observation on a lower porosity Grosmont dolomite (*Rabbani et al*., 2017) in which the dry frame modulus actually exceeded that for the bitumen saturated materia. We do not yet understand these results although they may depend on the very small pore throats (<80 nm) in that sample. Full characterization of the sample described here is still in progress.

Conclusions

The properites of heavy oils and rocks containing heavy oils are largely dependent on temperature, and to a lesser degree, pore pressure. This dependence is studied in a laboratory setting through ultrasonic velocity measurements of a bitumen-hosted carbonate sample from the Grosmont formation of Alberta, Canada. Preliminary results confirm the strong temperature dependence of the sample with large variations in velocity and bulk modulus largely attributed to fluid effects. Modeled responses using experimental and literature data shows the Gassmann fluid substitution model can adequately predict the water saturated bulk modulus, but greatly underpredicts the response of the same sample saturated with bitumen.

Acknowledgements

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