

Properties of Oil Sands and Bitumen in Athabasca

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Abstract

SAGD (Steam Assisted Gravity Drainage) is one of the most effective methods to produce bitumen (Fig.1). For seismic monitoring of the steam front and its effect on the formation, it is important to know correctly the properties of oil sands and bitumen. We measured the P- and S-wave velocities of oil sands and bitumen from Athabasca, Alberta, by ultrasonic measurement system, and valuated the seismic velocities dependence on temperature and effective pressure. Velocity variation measured from ultrasonic measurements is encouraging for the seismic steam monitoring and they provide clues for quantitative evaluation of steam development during SAGD operation.

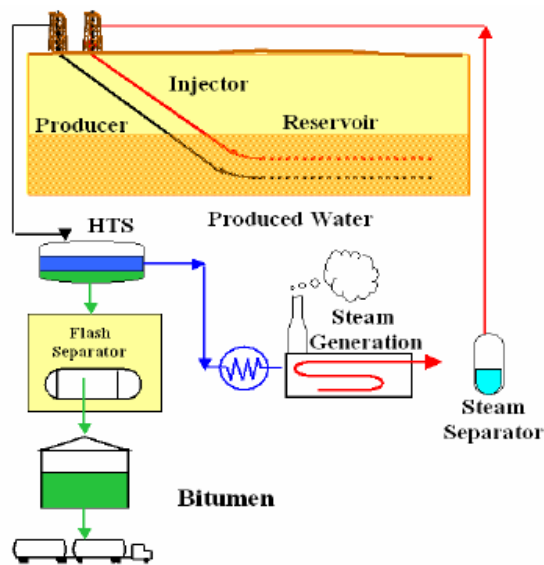


Figure 1. The concept of SAGD.

Introduction

SAGD is the methods to produce bitumen by reducing oil viscosity so they flow themselves. To monitor the location of the steam front is very important to operate SAGD. In time-lapse seismic analysis, amplitude change caused by decrease in velocity and density is widely used to

estimate the location of the steam front. The decrease depends on temperature and differential pressure (i.e., the difference between confining and pore pressures). The effects of steam flooding on the reservoir temperature and pressure conditions are shown schematically in Fig.2. Following five different cases in reservoir conditions are characterized by temperature, differential pressure and saturation.

The current study covers the effect up to Case 3:

Case 1. Cold oil at 10°C, 600psi, Sw20%.

Case 2. Cold oil at 10°C, 200psi, Sw20%.

Case 3. Hot oil at 100°C, 200psi, Sw20%.

Case 4. Hot water at 100°C, 200psi, Sw100%.

Case 5. Hot steam at 200°C, 200psi, Sw100%.

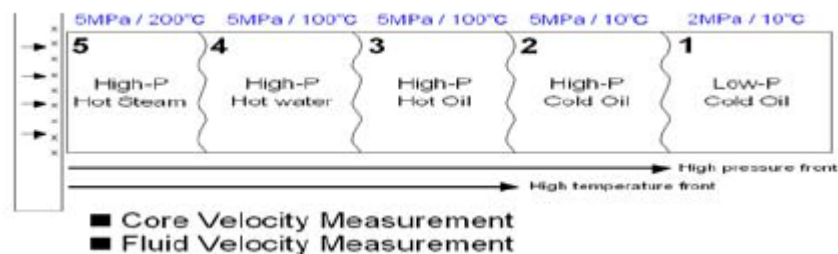


Figure 2. Five cases of reservoir conditions.

Oil Sands Properties

The samples are loose sands held together by bitumen from shallow depth around 300m. According to log data, it is estimated that average porosity of oil sands is 35.6 % and density is 2.1 g/cc. In grain size analysis, the sample is well sorted with a diameter of about 0.25mm. Water wet sands maintain a rim of water around grains. Since there is no direct contact between oil and minerals, it would be relatively easy to release oil. During specimen preparation, the sample was kept frozen (Fig. 3). A trimmed sample has a diameter of 3.8cm and a length of about 4.5cm. Though it looks uniform at a glance, the x-ray CT images show that the oil sands have many weak planes probably caused by pore volume expansion (Fig. 4). We managed to measure P- and S-wave velocities by ultrasonic system (1MHz).

It can be seen from Fig. 5 and Fig. 6 that velocities depend strongly on temperature and weakly on differential pressure. The velocity decreases linearly and sensitively to temperature from 0°C to 20°C. However, it can be seen the significant nonlinear decrease in P- and S-velocities from 20°C to 50°C. Over 50°C, velocities decrease linearly and gently with increasing temperature. It means there is a transition zone for bitumen properties to change from quasi-solid to fluid between 20°C and 50°C. Figure 6 suggests that at any constant temperature, P-wave velocity will

decrease by 10% during steam flooding when differential pressure varies from 600psi to 200psi. It should be noted that the S-wave velocity does not change much for the same differential pressure variation.



Figure 3. Oil sands sample plug; (a) Trimming and (b) Oil Sand Plug.

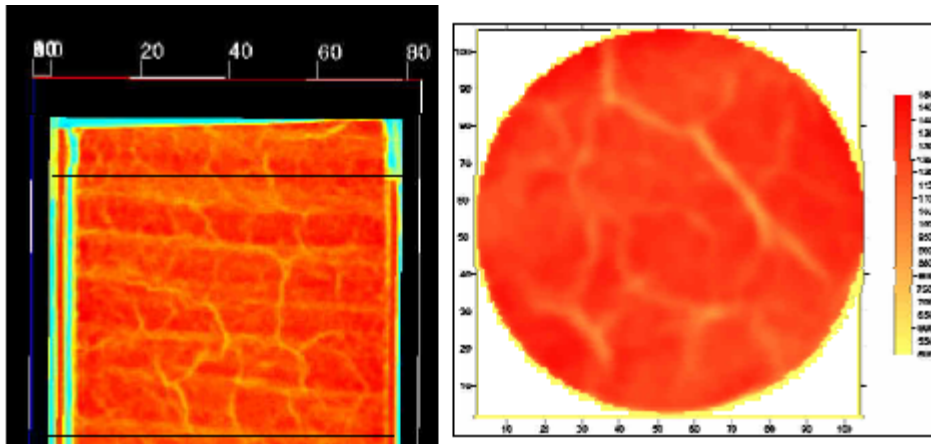


Figure 4. X-ray CT images of oil sands; (a) vertical image and (b) horizontal image.

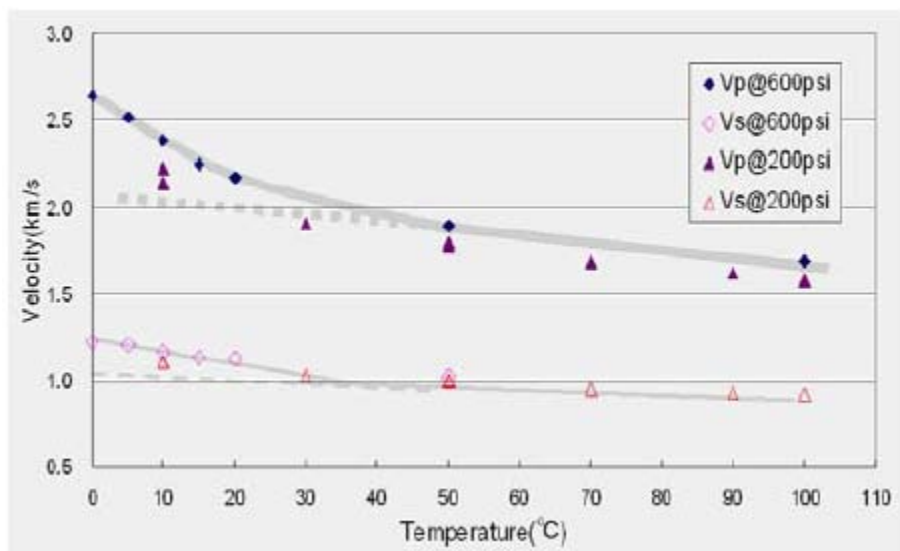


Figure 5. Temperature dependence of oil sands velocity.

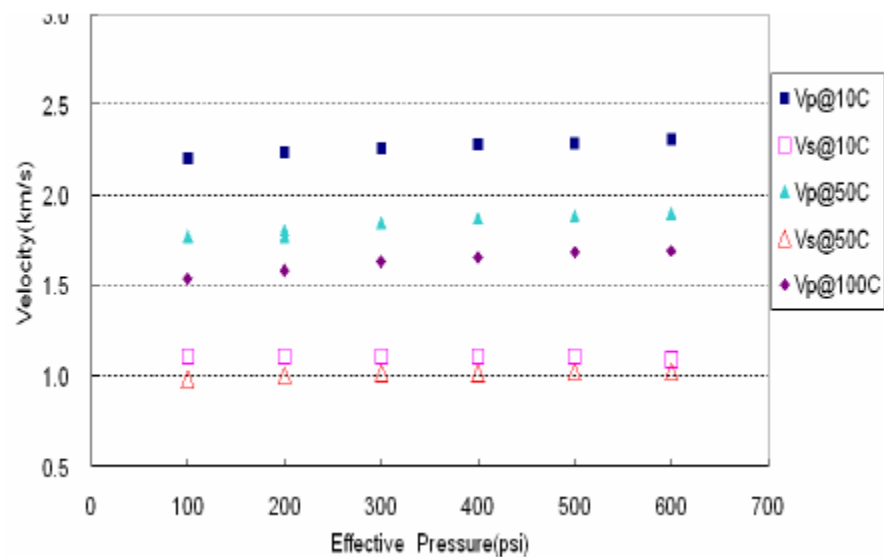


Figure 6. Pressure dependence of oil sands velocities.

Bitumen Properties

The bitumen sample from Athabasca has API gravity of around 8.5. Fig. 7 and Fig. 8 show dependency of bitumen density and viscosity on temperature respectively. It is inferred that the bitumen has less mobility at low temperature in original reservoir condition. Fig. 9 shows the P- and S- wave velocities measurements by reflected and transmitted waves. When bitumen is a solid below 0°C or a fluid over 40°C, P-velocities of bitumen linearly decrease in the same way as oil sands. In the transition zone from quasi-solid to fluid, heavy oil in fact has shear rigidity (Han and Lui, 2005). The limit of the current measurement system makes it difficult to read off S-wave travel times of bitumen accurately over 0°C. Judging from the trend clearly shown in P-wave response to temperature, S-wave velocity may be measured up to around 40°C.

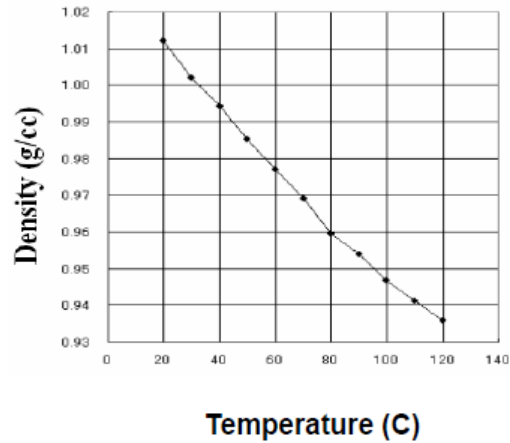


Figure 7. Temperature dependence of bitumen density.

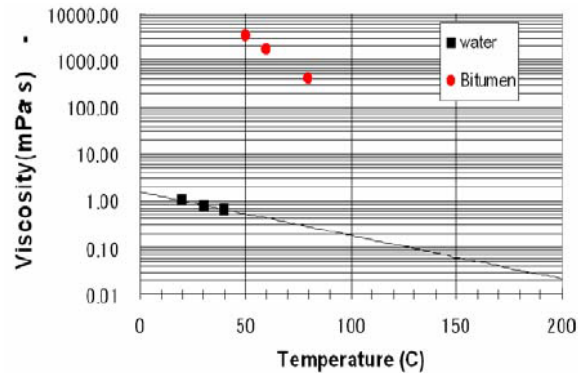


Figure 8. Temperature dependence of bitumen viscosity.

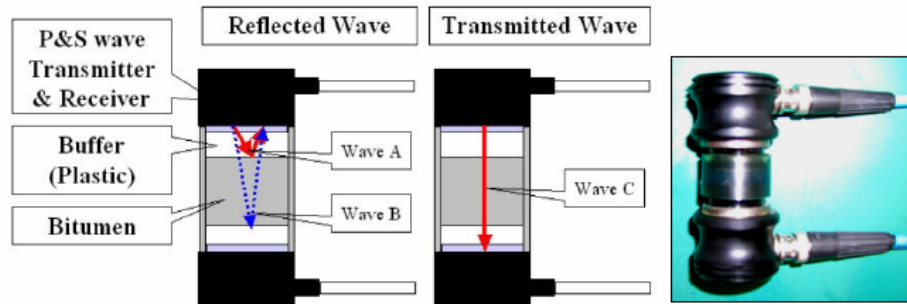


Figure 9. Bitumen velocity measurement system.



Figure 10. Bitumen samples.

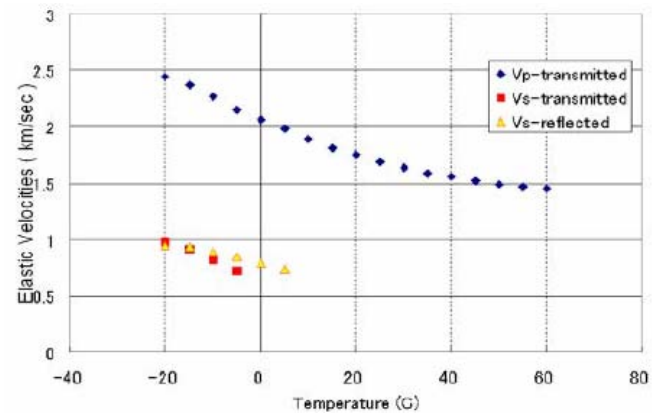


Figure 11. Measured velocities of bitumen.

Rock Physics Modeling

We calculated oil sands velocity using Gassmann's equation, which is applicable to measurements at low frequency. We assumed that oil sands consist of quartz minerals, brine and bitumen acts as pore fluids. In the reservoir condition at 10°C, it is expected that bitumen behaves as a quasi-solid and its velocity is higher than that calculated for a liquid (Fig. 12).

As a continuous film of water prevents the rock from direct contact between the bitumen and mineral surfaces, the difference between a quasi-solid and a fluid bitumen effects on grain would be small. Here, we applied measured bitumen velocity to calculate oil sands velocity. Dry rock moduli are calculated based on the contact model (Walton, 1987) and the cemented sand model (Dvorkin and Nur, 1996). Pore fluid properties at 10°C are estimated from the measured bitumen bulk modulus and brine properties by FLAG program developed in Fluids/DHI consortium.

Figure 13 shows, compared with calculated data that measured data agree with the calculation with the Walton contact model in case 1 and 2. The measured velocity in case 3 at 100°C is, however, below the estimation with the model. One of the possible reasons for this difference is the frame deformation. At high temperatures when water transforms into gas, it is likely for oil sands frame to change, too. Therefore, another frame models that describe this reservoir condition after steam flooding may have to be considered. On the other hand, the cemented model does not give consistent results with the measured velocities. It suggests that not many grains are in contact with bitumen.

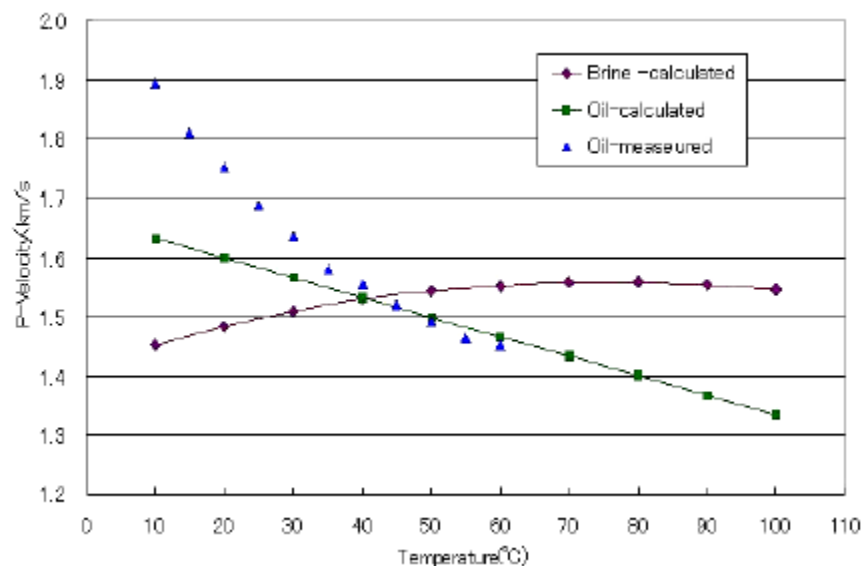


Figure 12. Measured and calculated P-velocities of bitumen.

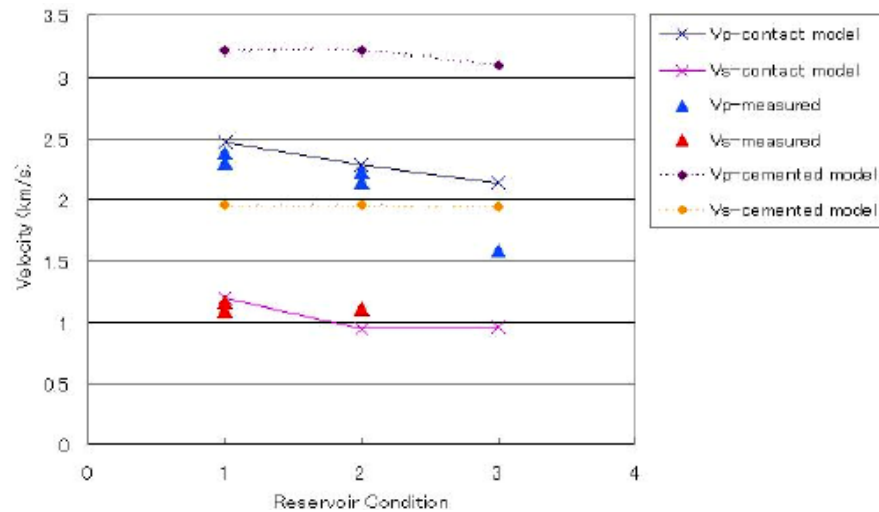


Figure 13. Measured and calculated P- and S-velocities of oil sands.

Further Application to the Seismic Monitoring

Logging data also matched the measured oil sands core velocities in case1. As seen in Fig.14, value of acoustic impedance (AI) decreases along a yellow arrow from case1 to case3. The decrease in AI is larger than the variation in facies. It suggests that AI is an effective method to estimate the location of the steam front in time-lapse seismic monitoring. Figure 15 shows that the measured data both Vp/Vs ratio and AI decrease but there is little difference in Vp/Vs ratio between case1 and case 2. Since bitumen acts as quasi-solid at low temperature in case 1 and 2, it has higher Swave velocity and lower Vp/Vs ratio than expected as in the case with more viscous fluids. In contrast to Vp/Vs, AI tells the effect of differential pressure. For application to seismic monitoring, AI should be describes as a function of frequency. If AI has significant variation at seismic frequency during SAGD operation, velocity measurements clarify the location of steam front in reservoir.

Conclusion

From the P- and S-wave velocity measurements, we confirmed that oil sands and bitumen properties are strongly dependent on temperature but weakly on differential pressure. AI is particularly an effective parameter to figure out the change in reservoir conditions affected by steam flooding. In order to apply the measurement for seismic analysis, we should consider velocity dispersion (frequency characteristics). In the FLAG program, the Maxwell model is used to estimate P-and S-wave velocity as a function of frequency. We will pursue the possibility of core velocity measurement into application for seismic monitoring. It is also important to know the effect of water saturation on cases 4 and 5. We will study the effects of saturation on the physical parameters as the next step.

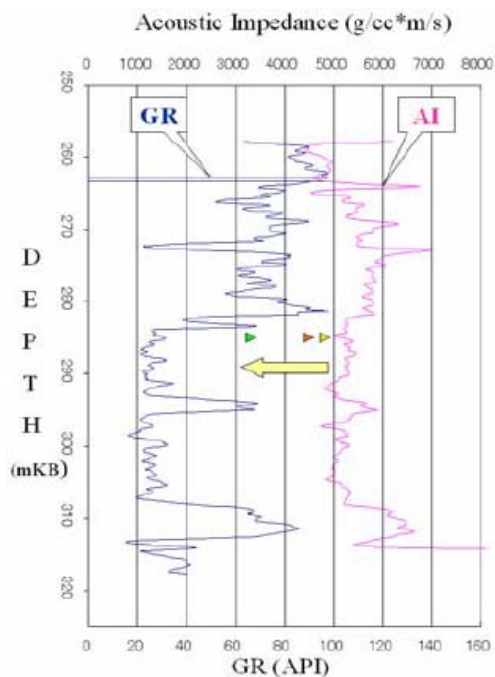


Figure 14. Acoustic impedance of core and log data.

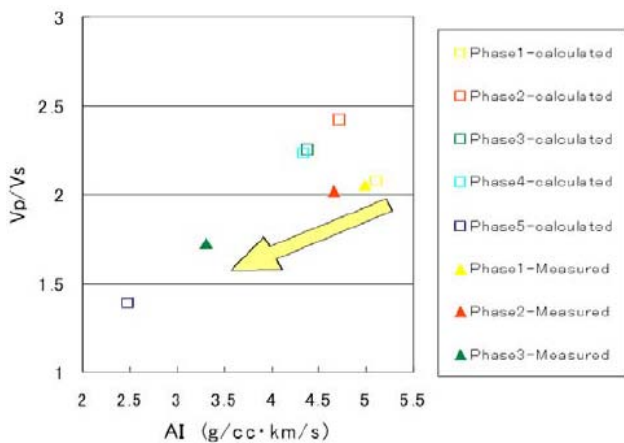


Figure 15. Vp/Vs ratio versus acoustic impedance of core data.

Acknowledgements

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