

The Effect of Pressure and Temperature on Bitumen Saturated Carbonate

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Summary

Bitumen carbonates generally have quite complicated properties, and these properties are temperature-dependent, since temperature has great influence on bitumen viscosity and moduli. Moreover, pressure also has non-negligible impact on the bitumen carbonates properties through changing the grain contact, pore shape and microcracks.

We proposed a new approach to estimate the porosity of rock samples, making use of porosimeter measurements, bulk density, and bitumen density. The new method can also provide estimation of bitumen saturation. In addition, the velocity variations with pressure of the two bitumen carbonate samples are measured, and the results are compared and analyzed. Moreover, the influence of temperature on bitumen carbonate properties is studied. The sensitivity of bitumen carbonates' velocities to temperature is investigated.

Introduction

As conventional oil and gas resources are depleting, more and more people pay attention to unconventional reservoirs, among which heavy oil reservoir is one significant class. The amount of heavy oil reservoirs even overtakes the amount of conventional reservoirs (Meyer and Attanasi, 2003). The heavy oil reservoirs are made up of oil sands and bitumen saturated carbonates (Hein et al., 2007). Although the industry historically focused on oil sands, the bitumen saturated carbonates are of huge potential, and about 400 billion barrels of Alberta's bitumen is in carbonate reservoirs (Lagasca, 2012).

The viscosity of bitumen is highly sensitive to temperature, and it drops rapidly with increasing temperature. And the bitumen moduli also show drastic drop with increasing temperature (Han et al., 2006). These complex properties of bitumen make the bitumen carbonates' velocities decrease with increasing temperature (Raabani et al., 2014).

Moreover, pressure can also affect the bitumen carbonates' properties. Higher pressure can increase grain contacts, change the pore shape, and close the microcracks in carbonates, which leads to larger moduli of the rocks (Gardner et al., 1974).

Because of the high viscosity of bitumen, much production of bitumen carbonate reservoirs involves injecting steam, and it is meaningful to study the pressure and temperature effects on bitumen carbonates, so as to provide guidance for production.

Porosity estimation

The measurements were carried out in Rock Physics Lab in University of Houston. The measured two bitumen carbonate samples are shown in Figure 1. As can be seen in Figure 1, the #1 sample appears to be darker than #2, indicating the higher level of bitumen saturation in #1.

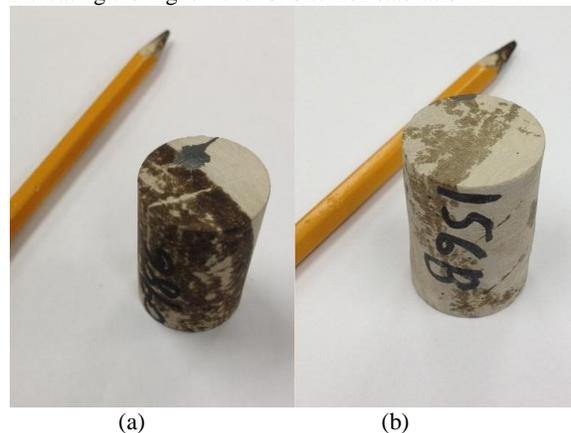


Figure 1. Picture of (a) sample #1; (b) sample #2.

Since porosity is a significant property and is essential for further analysis, the porosity estimation is implemented first. The porosities are measured through porosimeter. However, the porosimeter only measures the unfilled pore space, and the pore space that is saturated with bitumen is not included. Therefore, the measured porosities are the in situ porosities, not the true porosities. The results of the measurements are shown in Table 1.

Table 1. The measured porosity and frame density.

Sample No.	#1	#2
In situ Porosity	7.38%	10.23%
Frame density(g/cm ³)	2.74	2.74

In Table 1, the frame density is 2.74g/cm³, which is larger than the generally-assumed carbonate density 2.71g/cm³. Since the frame is not the pure carbonate, the bitumen is also incorporated into the frame in the measurement. Therefore, the pure carbonate should have a density over 2.74g/cm³, and the mineral should be aragonite with a density of 2.83g/cm³. And the relationships of densities and porosities are shown in Equation 1 and 2.

$$\rho_b = \rho_m(1 - \phi) + \rho_o\phi S_o \quad (1)$$

$$\phi_m = \phi(1 - S_o) \quad (2)$$

The Effect of Pressure and Temperature on Bitumen Saturated Carbonate

where ρ_b is the bulk density, ρ_m is the mineral density, ρ_o is the density of bitumen, S_o is the saturation level of bitumen, ϕ_m is the measured in situ porosity, and ϕ is the true porosity.

Since the bitumen has a API gravity of 6.5, its density can be calculated through the Equation 3.

$$API = \frac{141.5}{\rho} - 131.5 \quad (3)$$

And the density of the bitumen is calculated as 1.025g/cm³.

Combining the Equation 1 and 2, the measured bulk density, in situ porosity, mineral density, and bitumen density, the true porosity is calculated as 15.5% for #1, and 18.2% for sample #2; and the bitumen saturation is 52.4% for #1, and 43.8% for #2. These calculations are rough estimations, and may be subject to errors of the mineral compositions and the measured bulk density. Nevertheless, this method provides an effective approach to predict the porosity of bitumen carbonates, and the results are consistent with the previous observations that #1 has higher level of bitumen saturation and so appears darker.

Pressure effect

Pressure effect on bitumen carbonates' properties is mainly due to the microcracks' opening and closing caused by pressure variation. When differential pressure is high, the microcracks are closed, so the bitumen carbonates' moduli are large, and vice versa. We experimentally quantify the pressure-sensitive of the two carbonates' velocity, with a differential pressure range from 0 psi to 3000 psi. The measurements are displayed in Figure 2, 3, 4, and 5. Figure 2 and 3 show the Vp and Vs variation with pressure of sample #1, and Figure 4 and 5 show the Vp and Vs variation with pressure of sample #2. The blue diamonds are the measurements of wet samples, while red squares are the measurements of dry samples.

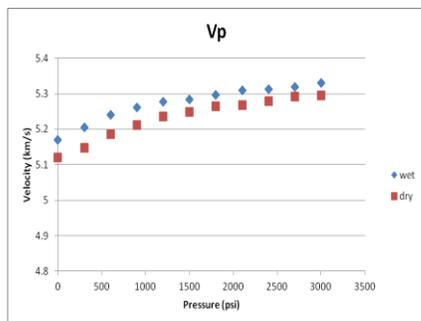


Figure 2. P-wave velocity variation with pressure of sample #1.

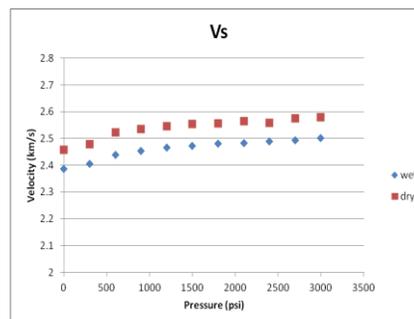


Figure 3. S-wave velocity variation with pressure of sample #1.

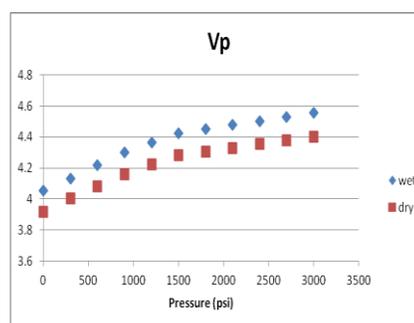


Figure 4. P-wave velocity variation with pressure of sample #2.

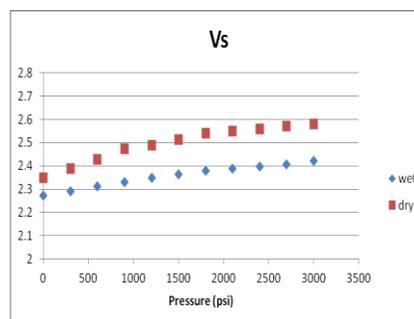


Figure 5. S-wave velocity variation with pressure of sample #2. Blue marks are the wet sample; red marks are the dry sample.

In Figure 2 and 4, it can be seen that for both #1 and #2, the P-wave velocities increase with increasing temperature. And the Vp increases fast at a smaller differential pressure below 1200 psi. When pressure is large, especially when pressure is above 1200 psi, the Vp increases with a smaller gradients. Besides, Vp of #1 is larger than Vp of #2. But the Vp of #1 only increases 0.17km/s, whereas the Vp increase of #2 is about 0.5km/s. The Vs curves show similar trends. Vs increases with increasing pressure, and it increases with higher gradients at low pressure and with lower gradients at high pressure. Besides, Vs of #1 is larger than Vs of #2. But #2 has more Vs increase. Vs of #1 increases 0.12km/s, while Vs of #2 increases more – about 0.16km/s. The main reason of these differences is the porosity and bitumen saturation. Since both #1 and #2 are from the same well, and they are buried at the

The Effect of Pressure and Temperature on Bitumen Saturated Carbonate

similar depth, the properties of carbonate rock frame should be similar. However, sample #1 has smaller porosity and higher bitumen saturation. Considering that bitumen is in solid state and has large bulk modulus and shear modulus under room conditions (bulk modulus is 3.01Gpa, and shear modulus is 0.13Gpa, as predicted by FLAG programs), it is reasonable to expect the sample with higher bitumen saturation to have larger bulk modulus and shear modulus than the other one. For better comparison, the statistical comparisons of Vp and Vs variations are shown in Figure 6.

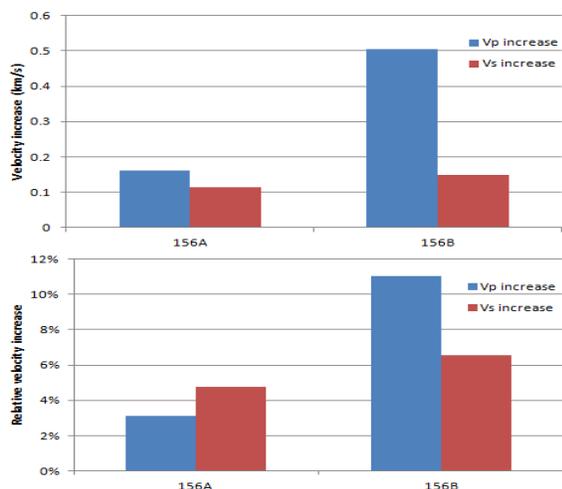


Figure 6. (Top) velocity increase from differential pressure of 0 psi to 3000 psi; (bottom) relative velocity increase.

As can be seen in Figure 6 that, #2 has a larger increase of velocity, both in Vp and Vs. And the relative velocity increase of #2 is also larger. These comparisons suggest that #2 is more sensitive to pressure than #1. This is because of the smaller porosity and higher bitumen saturation of #1. Although under room conditions, these bitumen will increase the bulk modulus and shear modulus of the carbonate rock, it will also impede the rocks' microcracks from closing, and thus will lessen the rock's sensitivity to pressure.

Temperature effect

Temperature can have significant influence on bitumen carbonates' properties, due to the temperature-dependent bitumen properties. Bitumen viscosity and moduli drop rapidly with increasing temperature. Figure 7 and 8 show the measured velocities (both Vp and Vs) variation with temperature of sample #1. In Figure 9 and 10, the Vp and Vs of sample #2 are shown. The blue diamonds are the velocities under a differential pressure of 1260 psi; the red squares are the dry sample velocities under 20°C and 1200 psi, and the green triangles are the water-saturated samples' velocities under same conditions.

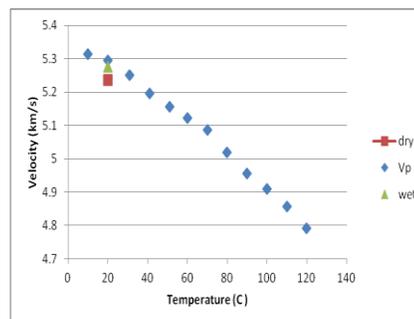


Figure 7. P-wave velocity variation with temperature of #1.

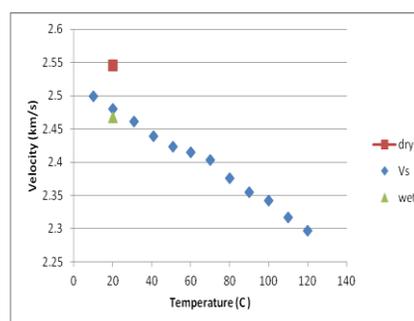


Figure 8. S-wave velocity variation with temperature of #1.

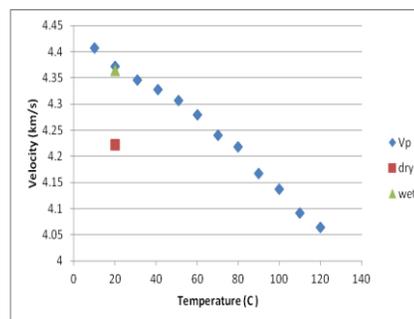


Figure 9. P-wave velocity variation with temperature of #2.

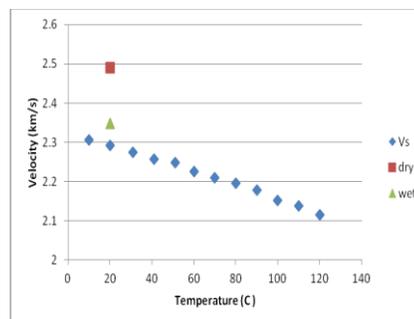


Figure 10. S-wave velocity variation with temperature of #2.

The Effect of Pressure and Temperature on Bitumen Saturated Carbonate

It can be seen in Figure 7 and 9 that both #1 and #2 show that V_p decreases with increasing temperature. #1 has a 9.8% V_p drop (from 5.32km/s to 4.79km/s), whereas #2 shows a 8% V_p drop (from 4.41km/s to 4.06km/s). Besides, dry samples' V_p is smaller than wet samples, which can be explained by Gassmann theory. The water saturation, although increases the sample's density, increases more of the rock's bulk modulus. Therefore, the wet samples have higher V_p than samples.

In Figure 8 and 10, the V_s of #1 and #2 also drop with increasing temperature. #1 has a V_s drop from 2.5km/s to 2.29km/s, almost 8% drop; and #2 has a V_s drop from 2.3km/s to 2.11km/s, near 8.2% drop. Moreover, the dry sample S-wave velocities are larger than wet sample S-wave velocities. This is because that the water saturation has no contribution to the rock's shear modulus, but it increases the rock's density. So the wet rocks' V_s are smaller. To show the comparison of temperature sensitivity of #1 and #2, Figure 11 displays the velocity drop and relative velocity drop during the heating process.

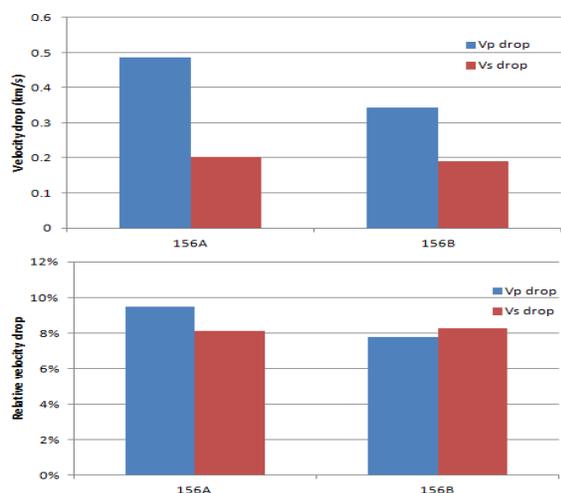


Figure 11. (Top) velocity drop from temperature of 10°C to 120°C; (bottom) relative velocity drop.

In Figure 11, #1 has more velocity drop than #2, both in V_p and V_s , and the relative V_p drop is also larger than that of #2 (relative V_s drop of #1 is close to that of #2). This can be explained by the fact that both #1 and #2 have similar sizes, but #1 contains more bitumen than #2 as shown in figure 1. Since bitumen bulk modulus and shear modulus drop drastically with increasing temperature, the high bitumen saturation will cause #1 velocities to drop more with increasing temperature than #2.

Moreover, in comparison of velocity variation with pressure, it seems that for #1, the velocities are more sensitive to temperature than pressure under the lab

measurement conditions. The V_p drops over 9% and V_s drops close to 8% with temperature increasing from 10°C to 120°C, whereas the V_p drops close to 3% and V_s drops below 5% with pressure decreasing from 3000 psi to 0psi. Nevertheless, the P-wave velocity of #2 seems to be more sensitive to pressure than temperature. The V_p drops below 8% within temperature range, while V_p drops close to 11% within pressure range. This is also due to the porosity and bitumen saturation. #2 has larger porosity with lower bitumen saturation, and it will certainly be affected more by pressure and less by temperature.

Conclusions

The porosity estimation method provides an alternative approach to estimate the rock porosities. Although the porosity measured by porosimeter is the in situ porosity, the true porosity can be calculated once the mineral density, bitumen density, and sample's bulk density are known. In addition, the bitumen saturation can be also estimated.

The velocity measurements under different pressure indicate that both the two carbonate samples' velocities increase with increasing pressure. And sample #2 shows more pressure-sensitive velocities than #1, due to its larger porosity and lower bitumen saturation.

Both #1 and #2 show temperature-dependent velocities, and the velocities decrease with increasing temperature, due to the temperature-sensitive viscosity of bitumen. Moreover, the comparison suggests that #1 is relatively more temperature-sensitive than #2. This is in accordance with the estimated porosity and bitumen saturation-#1 has higher level of bitumen saturation than #2.

Overall, #1 has higher V_p and V_s than #2 both under pressure measurement and under temperature measurement. This is also related to the porosity and bitumen saturation. The smaller porosity and higher bitumen saturation would reasonably enable the #1 to have higher velocities, given the high viscosity of bitumen which makes it like a solid.

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EDITED REFERENCES

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