A comparison of Alaska and Alberta heavy oil sands

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Summary

As an important unconventional reservoir, heavy oil sands have their peculiar characteristics. Compared with conventional reservoir, heavy oil sands are usually buried at shallow depth, and the porosities are very high. Due to the temperature-sensitive viscosity of heavy oil, the velocities are highly temperature-dependent. Moreover, owing to the difference in porosity, compaction, and heavy oil viscosity, oil sands in distinct fields display difference between them.

In this paper, we compared the heavy oil sands from Alaska and Alberta, and analyzed the geological factors that can affect the rock properties. Based on our samples, the depth and porosity are compared. Moreover, the variations of velocity under different temperature, and the corresponding Vp/Vs ratios are investigated. In the end, the different velocity trends of Alaska oil sands and Alberta oil sands are inspected and explicated.

Introduction

Heavy oil has enormous amount of reservoir all over the world. According to USGS, the recoverable heavy oil resources are 434 billion barrels of oil (BBO), and recoverable bitumen resources are 651 BBO, whereas the conventional oil reservoirs are 952 BBO (Meyer and Attanasi, 2003). Figure 1 (a) and (b) respectively display the worldwide heavy oil resource percentage and distribution. In Figure 1(a), it can be seen that recoverable heavy oil, plus bitumen, has an amount over the conventional oil reservoir. Figure 1(b) shows that North America and South America take a large percentage of the heavy oil reservoir. Actually, for North America, it is mainly Canada (Alberta and Saskatchewan) and America (California, Texas, and Alaska); for South America, it is mainly Venezuela (Orinoco belt and Maracaibo).

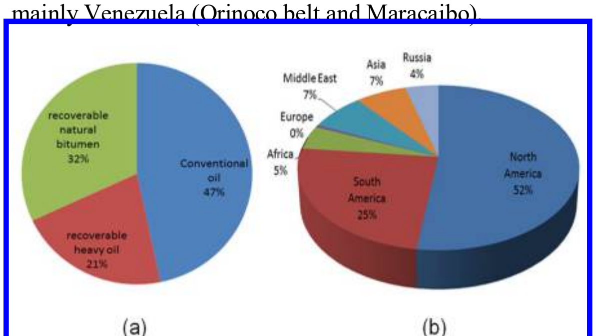

Figure 1. (a) Percentage of recoverable heavy oil and bitumen in world's reservoir resources; (b) Distribution of the heavy oil and bitumen. (Data from USGS)

Heavy oil sands are generally buried at shallow depth, which is related to the formation of heavy oil (Behura et al., 2007). Heavy oil is formed through biodegradation, a process that bacteria consume the light components in oil, and leave the heavy components, forming the 'heavy' oil. Since the bacteria are only active in the environment where there is much groundwater that can promote their metabolism (Chopra et al., 2010), hence the depth is usually very shallow. As can be seen in Figure 2, both the Alberta and Alaska oil sands are buried shallower than conventional oil reservoirs, which are generally buried several thousand meters deep. For Alberta oil sands, the depth is 400 m, and for Alaska oil sands, the depth is 1200 m. The shallower depth ensures more groundwater for Alberta oil, and therefore, the bacteria are more active, leading to heavier oil than Alaska. Actually, the API value of Alberta oil is 8, whereas the API of Alaska oil is 12, suggesting the higher density of Alaska oil.

Heavy oil sands generally have very large porosities. As can be seen in Figure 3, all the samples have porosities larger than 30%, and some samples even have porosities over 43%. On average, Alberta oil sands and Alaska oil sands have similar porosities. These large porosities are related to the depth. At shallow depth, the overburden pressure is small, therefore, the sand grains cannot be well-compacted, and thus the porosities are higher than the deep-depth sandstones.

The large porosities, plus the special properties of heavy oil, will equip the oil sands with distinct properties from conventional sandstone reservoir rocks, especially under different pressure and temperature conditions (Han et al., 2006; Yuan et al., 2013; 2016).

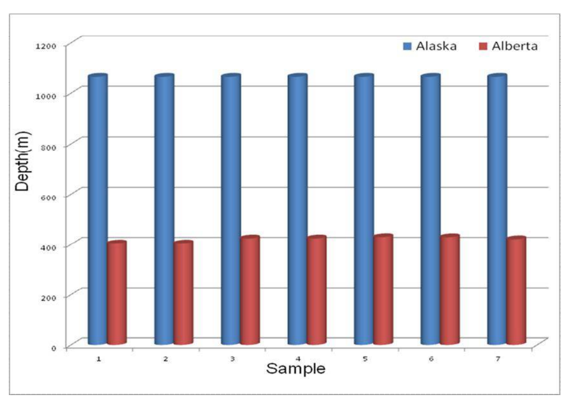

Figure 2. Statistics of heavy oil sands depth.

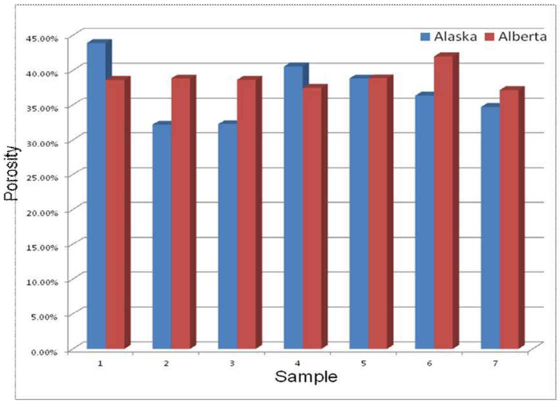

Figure 3. Statistics of heavy oil sands porosities.

Velocities vs. porosity

As mentioned above, oil sands samples of Alaska and Alberta have similar porosities, whereas Alaska oil sands are buried deeper than Alberta oil sands. Moreover, Alberta oil has smaller API value than Alaska oil, indicating its larger density and higher viscosity. These characteristics will inevitably affect the rock's properties.

Figure 4 and 5 show the Alaska and Alberta oil sands P-wave velocity and S-wave velocity comparison. It can be seen that for Alberta oil sands, the Vp ranges from 2.05-2.7 km/s, and Vs ranges from 0.8-1.3 km/s; while for Alaska oil sands, Vp ranges from 2.15-2.55 km/s, and Vs ranges from 0.88-1.17 km/s, suggesting that the velocities of Alaska oil sands more more fucused, which may be related to the depth. In addition, for both Alaska and Alberta oil sands, the velocities are not uniquely dependent on porosities. Even large-porosity samples can have high velocities, and low-porosity samples may also have low velocities. This may be caused by the heavy oil's high viscosity. The high porosities of the samples suggest that the sand grains are suspended in oil. At low temperature, the heavy oil viscosity is quite high, and the moduli are also very high. Consequently, even with more heavy oil in pore space, the rocks may not display small velocities. On the contrary, the oil saturation can increase the velocity. In Figure 6, the relationship between P-impedance (Ip) and S-impedance (Is) is shown. It seems that Alaska and Alberta oil samples have similar impedance trends. Both the ranges of Ip and Is overwrite each other, which suggests that impedance may not be an effective indicator to distinguish each other.

Velocities vs. temperature

To better investigate the differences of Alaska and Alberta oil sands, the velcotiy and Vp/Vs ratio variations with temperature are studied and compared, as displayed in Figure 7, 8, 9 and 10.

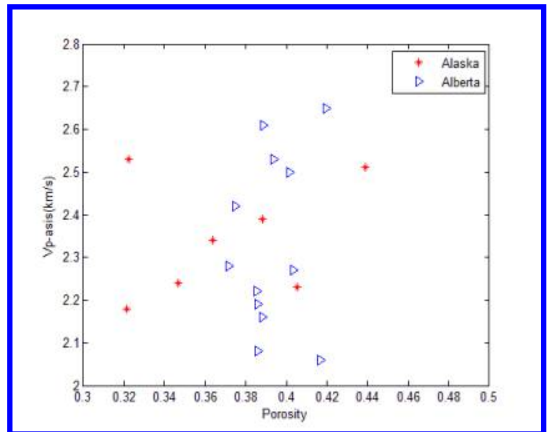

Figure 4. Alaska and Alberta oil sands P-wave comparison.

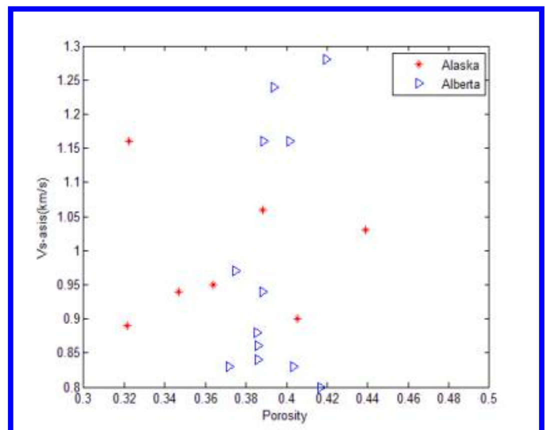

Figure 5. Alaska and Alberta oil sands S-wave comparison.

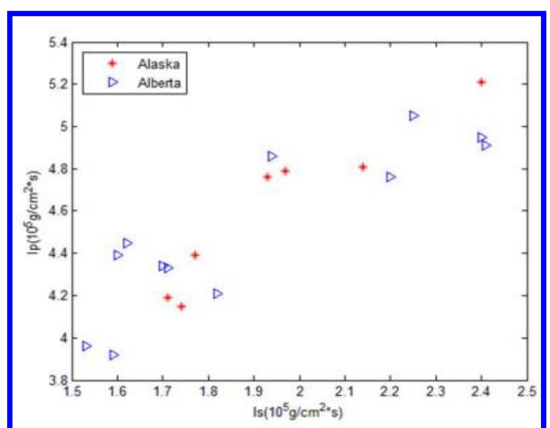

Figure 6. Alaska and Alberta oil sands Impedance comparison.

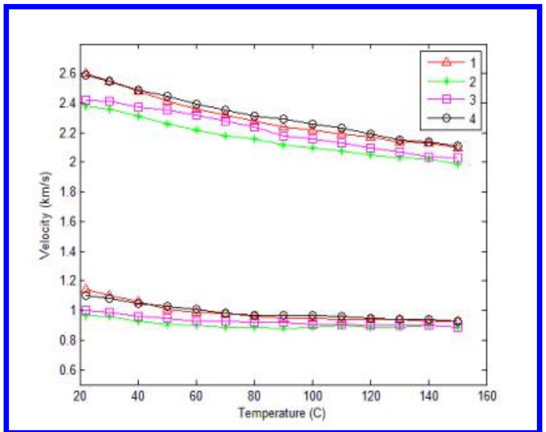

Figure 7. Alaska heavy oil sands velocities change with different temperature.

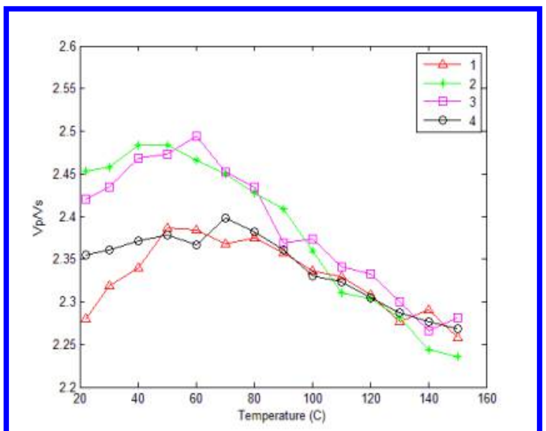

Figure 8. Alaska heavy oil sands Vp/Vs ratio change with different temperature.

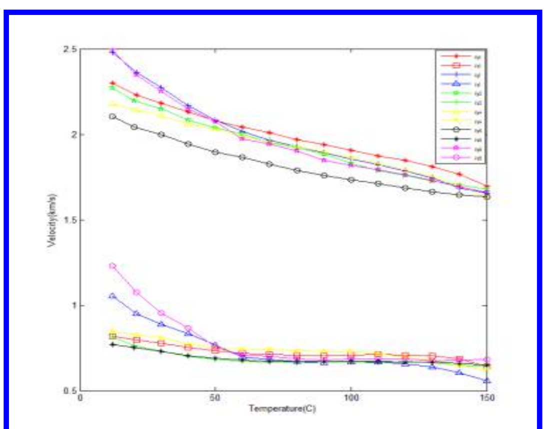

Figure 9. Alberta heavy oil sands velocities change with different temperature.

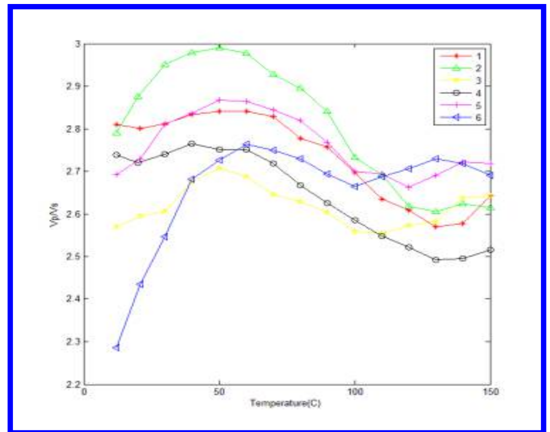

Figure 10. Alberta heavy oil sands Vp/Vs ratio change with different temperature.

Figure 7 and 9 respectively display the velocities of heavy oil sand samples from Alaska and Alberta, and Figure 8 and 10 show the corresponding Vp/Vs ratio variation with changing temperature.

As can be seen in Figure 7 and 9, both the Alaska and Alberta oil sands have temperature turning points where the velocity trends display obvious changes. For Alaska samples, the turning point is around 60^0C, while for Alberta oil sands, the turning point is also around 60^0C. These points are the liquid point (Han et al., 2006). When temperature is below liquid point, Vp and Vs decrease with increasing temperature at a large gradient, while above this point, Vp decreases at a much smaller gradient and Vs keeps almost constant. The Vp/Vs ratio in Figure 8 and 10 gives a more clear indication, since Vp/Vs ratio reaches a peak near this point.

When temperature is below liquid point, both Vp and Vs decrease with increasing temperature, but Vs decreases faster (Batzle et al., 2006). So the Vp/Vs ratio increases with temperature. Above liquid point, heavy oil viscosity is quite low, and it is in liquid state, similar as water. Hence, the oil sand Vs keeps constant – the rock shear modulus is the shear modulus of the frame, which does not change with temperature. On the other side, the oil bulk modulus will continue to decrease, although at a smaller rate, because the oil volume with expand with rising temperature. Therefore, the Vp/Vs raio will decrease with temperature, and thus Vp/Vs ratio reaches the peak at liquid point. This temperature-sensitive property of Vp/Vs ratio may suggest it as a temperature indicator.

Although Figure 7 and 9 show similar trend, when compared individually, it can be found that they still have difference. Alaska oil sands have larger velocities (both P- and S-wave velocities) than Alberta oil sands on average.

At about 20^{0}C, Alaska oil sands have Vp around 2.5 km/s and Vs around 1.2 km/s, whereas Alberta oil sands have Vp around 2.3 km/s (but it has a larger gradient) and Vs around 0.8 km/s; At about 150^{0}C, Alaska sands have Vp around 2.1 km/s and Vs around 0.9 km/s, whereas Alberta sands have Vp around 1.7 km/s and Vs around 0.7 km/s. Besides the velocity difference, the Vp/Vs ratios are also distinct. As shown in Figure 8 and 10, for Alaska oil sands, even at about 60^{0}C where Vp/Vs ratio reaches its maximum value, the value is between 2.4-2.5, whereas Alberta oil sands have a Vp/Vs ratio around 2.7-3.0, much larger than that of Alaska samples, which is also related to the depth. The deeper depth of Alaska sands make them better compacted, and thus have smaller Vp/Vs ratio.

A typical comparison is shown in Figure 11. The two samples have similar porosities around 38%. The difference is that the API of Alaska oil is 12 and depth is 1273 m, while the API of Alberta oil is 8 and depth is 400 m.

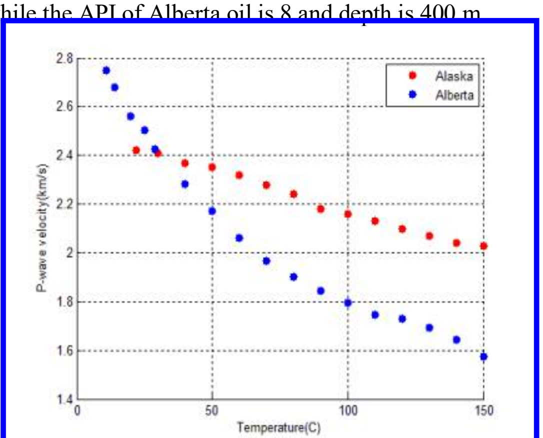

Figure 11. Alaska and Alberta heavy oil sands velocities versus temperature.

As can be seen in Figure 11, when temperature is below 30^{0}C, Alberta sample has larger Vp than Alaska sample. As temperature increases, both of the two samples show a decrease of Vp. However, Alberta oil sand has a more drastic drop, while Alaska sample only shows a gentle decrease. When temperature reaches 150^{0}C, Alaska sample has a Vp over 2.0 km/s, while Alberta sample has a Vp below 1.6 km/s, which, we think, is caused by compaction effect. Since Alaska oil sands are buried deeper than Alberta oil sands, the overburden pressure would be larger, hence the Alaska oil sands must be better compacted. That means the Alaska oil sands have more grain contacts than Alberta sands, even they have similar porosity. At low temperature, the heavy oil viscosity is so low that it's very stiff with high moduli. Under such situation, the heavy oil sands properties are dominated by the heavy oil properties. Since the Alberta heavy oil has smaller API value, which means it has larger density and higher viscosity, it has larger bulk modulus and shear modulus than Alaska heavy oil. Hence, at low temperature, the Alberta sands have larger velocity than the Alaska sands. However, as temperature increases, heavy oil viscosity decreases quickly and its moduli also decrease. Gradually, it turns to liquid. At a temperature of 150^{0}C, heavy oil is completely liquid - it acts as pore fluid, only supports pore pressure, rather than overburden pressure. In such case, it is the sand frame that dominates the oil sands properties. And as mentioned above, the Alaska oil sands are buried deeper with better compaction and stiffer frame, and thus have larger moduli than Alberta oil sands. Therefore its velocity is larger.

Conclusions

Heavy oil sands are generally buried at shallow depth. For Alaska samples, the depth is around 1200 m, while for Alberta samples, the depth is around 400 m.

Heavy oil sands have very high porosities, even higher than critical porosity (37%). Alaska oil sands and Alberta oil sands have similar porosities between 32% and 43%.

There is a temperature turning point (liquid point) of both Vp and Vs. For temperature below the liquid point, both Vp and Vs decrease with increasing temperature; for temperature above the liquid point, Vp decreases almost linearly with increasing temperature, while Vs keeps constant. Alaska oil sands and Alberta sands have similar liquid point near 60^{0}C, but Alaska oil sands have larger velocities overall.

Vp/Vs ratio has a peak value at the liquid point, which is caused by the oil sands velocities at different temperature. This property may suggest Vp/Vs ratio as an indicator of temperature. Alberta oil sands have larger Vp/Vs ratio than Alaska oil sands, owing to its shallower depth.

At low temperature, Alberta oil sands have larger Vp than Alaska oil sands. With increasing temperature, Alberta oil sands show a sharp drop of Vp, whereas Alaska oil sands display a gentle decrease. At high temperature, Alaska oil sands have larger Vp than Alberta oil sands, which are related to the oil properties and rock compaction. At low temperature, it's the heavy oil property (viscosity) that dominates the oil sands properties, while at high temperature, it's the sand frame property (compaction) that dominates.

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EDITED REFERENCES

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