Measured Velocity Data on Heavy Oil Sands

De-hua Han*
University of Houston, Houston, TX
dhan@uh.edu

and

Huizhu Zhao and Qiuliang Yao
University of Houston, Houston, TX, United States

Summary

We have summarized measured data on heavy oil sands from several different reservoirs. Data show both systematic correlation with measured conditions as well as significant scatters.

SUMMARY

Lithology	SAMPLE NUMBER	DEPTH (meters)	POROSITY	BULK DEN (g/cc) (Dry)	BULK DEN (g/cc) (as is)	BULK DEN (g/cc) (Brine satuation)	GRAIN DEN (g/cc)	SATURATION-
Oil sands	OB11V		40.10%	1.570	1.955	1.971	2.62	0.955
Oil sands	OB17V1		38.30%	1.617	1.929	2.000	2.62	0.922
Oil sands	OB17V2		37.90%	1.628	1.941	2.006	2.62	0.827
Oil sands	A1		40.80%	1.550	1.955	1.960	2.62	0.980
Oil sands	A2		37.00%	1.642	1.996	2.014	2.61	0.949
Oil sands	B1		40.00%	1.591	1.912	1.991	2.65	0.834
Oil sands	B2		37.20%	1.661	1.978	2.036	2.65	0.908
Oil sands	F		33.30%	1.754	2.040	2.087	2.63	0.858
Oil sands	G		35.50%	1.696	2.001	2.051	2.63	0.861
Oil sands	H		26.00%	1.946	2.125	2.207	2.63	0.684
Oil sands	I		34.30%	1.728	2.003	2.071	2.63	0.801
Wet Sands	J-2		33.50%	1.749	2.026	2.085	2.63	0.826
Shale	1	354.71	19.00%	2.147	2.147	2.336	2.65	0.000
Oil sands	2	355.11	39.70%	1.598	1.786	1.994	2.65	0.475
Oil sands	3	364.20	39.60%	1.602	1.901	1.997	2.65	0.756
Oil sands	4	325.55	39.30%	1.596	1.834	1.990	2.63	0.602
Oil sands	5	375.30	39.30%	1.596	1.916	1.990	2.63	0.812
Oil sands	#3-2	364.20	39.70%	1.592	1.932	1.989	2.64	0.857

Table 1: Summarize rock parameters measured on heavy oil samples and others

Samples

We have received three groups of oil sands samples from different fields in Alberta, Canada with shallow depth less than 500 m and almost no cementation (Table 1). The first group of samples is frozen and wrapped with tin tube by a service company. The other two groups are slab cores and we prepared the plugs samples from slab cores with hand-crafted method.

Heavy Oil Velocity and Density

We have measured velocity of three oil samples from below 0°C, up-to 260°C. Figure 1 shows oil velocity decreases with increasing temperature. It also shows three trends: at low temperature (<70 °C), measured velocity is higher than predicted by oil calculator in the FLAG, and the gradient reduces with increasing temperature. At temperature between 70°C to 180°C, velocity data matches with those predicted by FLAG, and decrease with a constant gradient (~3.2 m/s per °C). At high temperature (>180°C) measured velocities tend to systematically higher than predicted by Flag program and show a low gradient to decrease with respect to increase temperature. Figure 1 also shows measured S-wave velocity with the reflection method. S-wave velocity becomes too small to be measured when temperature is higher than 70 °C, which shows as indicator of the liquid point.

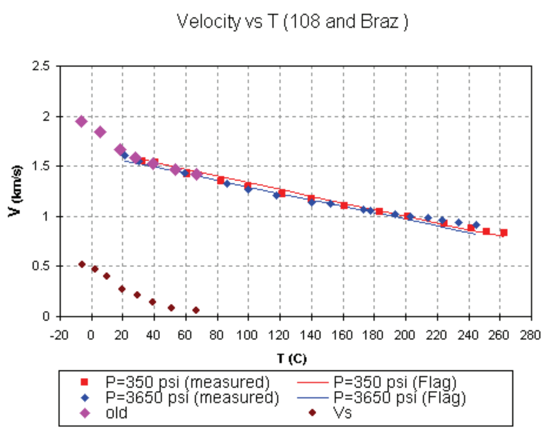

Figure 1: Measure Vp and Vs data versus temperature on two heavy oil samples.

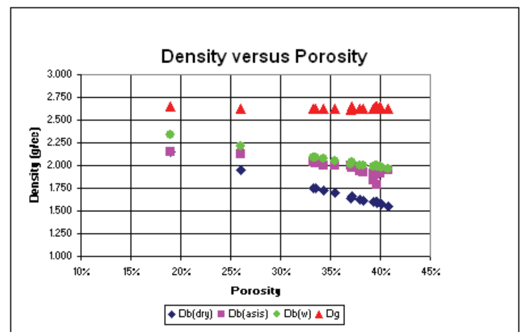

Figure 2: Measure bulk density, grain density and porosity.

Porosity, Density and Saturation

We have mentioned difficulties to measure rock parameters on heavy oil sands (Han et. al., 2007). With careful measurements of sample weight, volume, injected water…, and assumption for grain density, we have calculated reasonable data for "as is" dry density, "as is" water saturation density, and porosity. In addition, we have cleaned heavy oil out in a few samples. We have measured porosity and grain density of those samples. Over all, we are fairly confident for measured data. In general, error of porosity is less than 2% porosity unit, error of bulk density and grain density is less than 2%, error of P-wave velocity, S-wave velocity and oil saturation are less than 2%, 5%, and 0% respectively. Figure 2 shows measured density as a function of porosity. Data show consistency and suggest fairly clean sand sample we have measured. We have observed different grain size and sorting distribution, and variation of oil saturation. We do not have shaly sample. But we have one wet sand sample with some cements and a shale sample (dry).

P-Wave Velocity

Figure 3 shows measured Vp data. Dry sand samples with fine grain size were cleaned from highly oil saturated samples. They have low velocity (1.1 to 1.5 km/s), which represents a low compaction at shallow depth. Water saturation increases the Vp of sand samples to around 2.1 km/s. It is typical for the unconsolidated sands. Sample J has high velocity because of better cementation on the wet sand.

Vp on "as is" water saturated sand is slightly higher than those on "as is" dry sands. Only small amount water is needed to saturate samples because samples are highly oil saturated. This suggests that frame of "as is" sample is very stiff and air packets, or water saturation has much less effect on velocity of heavy oil sand samples at room temperature. In addition, velocities of "as is" samples is significantly higher than those of water saturated sands.

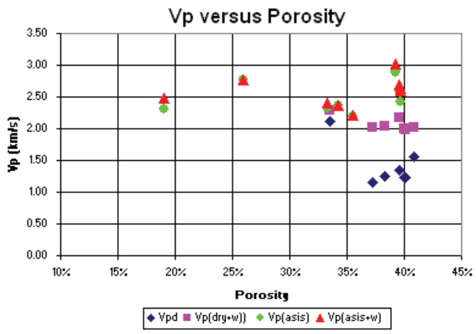

Figure 3: Measure Vp data versus porosity at Pd of 5 MPa.

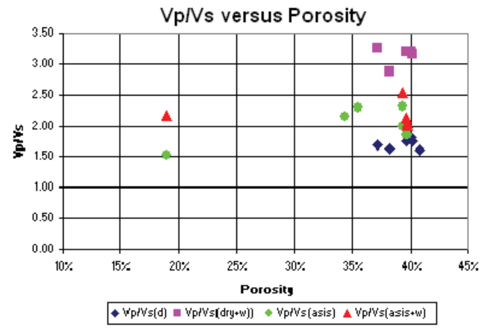

Figure 4: Measure Vp / Vs ratio versus porosity

Vp/ Vs Ratio

Dry Vp/Vs ratio has lowest value around 1.6 and water sand have highest value over 3, and oil sands have Vp/Vs ratio ranged from 1.8 to 2.5 as shown in Figure 4. Vp/Vs ratio versus P-wave impedance shows a better separation in Figure 5.

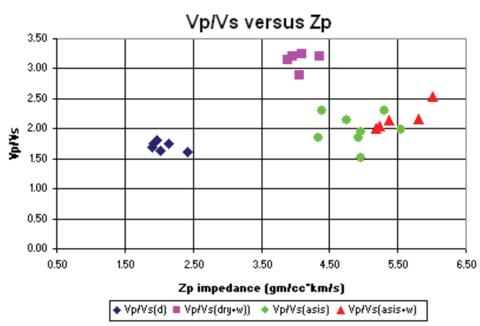

Figure 5: Measure Vp / Vs ratio versus P-wave impedance.

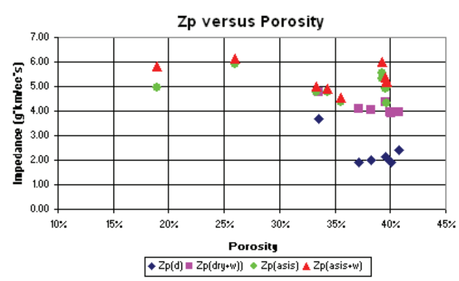

Figure 6: P-wave impedance versus porosity

P-Wave Impedance

Figure 6 shows calculated P impedance versus porosity. Oil sands have highest impedance in comparison with water sands.

Modulus

Modulus is calculated based on velocity and density data. Figure 7 shows bulk modulus versus porosity. Again "as is" oil sands have highest value in comparison with water saturated sands. Dry sands show lowest bulk modulus. Figure 8 shows that shear modulus of both dry or "as is" oil sands are not affected by water saturation and remained a constant. It is interesting that in shale sample, the water saturated shear modulus is much lower than that of the dry one, which suggests strong chemical interaction between water and shale frame.

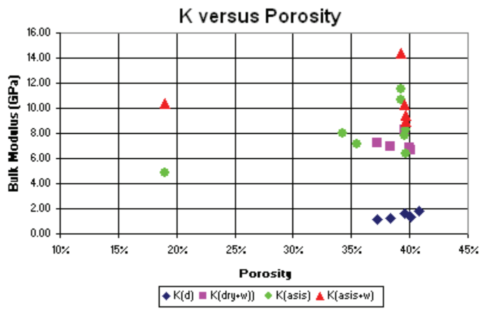

Figure 7: Bulk Modulus verssu porosity

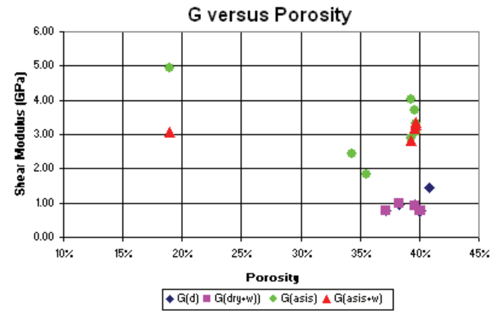

Figure 8: Shear modulus versus porosity

Temperature Effect

We have measured P-wave velocity as function of temperature on all of the oil samples. Unfortunately, we have difficulty to measure reliable S-wave velocity, especially for saturated samples. Figure 9 shows measured P and S-wave velocities as a function of temperature. P-wave velocity shows a linear decrease (4 m/s per °C) with increasing temperature above 70 °C. Below 70 °C, P-wave velocity deviates from the linear trend, with a increasing gradient towards the low temperature end. S-wave velocity data show a similar trend as that of P-wave velocity at low temperature (< 70 °C), but almost flat with only slight decrease with increasing temperature over 70 °C. 70 °C appears as the phase transition point (the liquid point) for this sample, which is consistent with measured data on heavy oil (see figure 1). As we expected, velocity of heavy oil sands is mainly controlled by the oil properties.

Finally, we summarize all the velocity data as function of temperature in the Figure 10. P-wave velocities show significant scatters, especially at low temperature range. But all Vp data also exhibit a similar trend with respect to the temperature change.

1) Decreases with high gradient (10 m/s per °C) at low temperature range(< 60 °C) then turn to linearly decrease with increasing temperature with a constant gradient around 4 m/s per °C. The measured oil data (Figure 1) suggest that the linear trend may end at temperature 180 °C and turn to lower gradient at higher temperature.
2) Large scatters of Vp at low temperature seem less relevant to porosity or oil saturation, but more related to oil and sand grain contact, oil or water wet, oil modulus, and sand compaction and texture.
3) Velocity data tend to have smaller scatters at high temperature with heavy oil in the liquid phase. Most velocity data at 150 °C range from 1.6 and 1.7 km/s.

The high Vp of sample H may due to better compaction (26% porosity) with large grain size and poor sorting in texture.

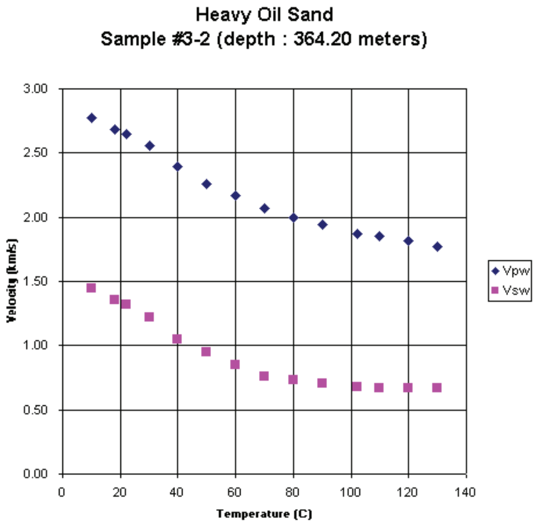

Figure 9: Measure Vp and Vs data versus temperature

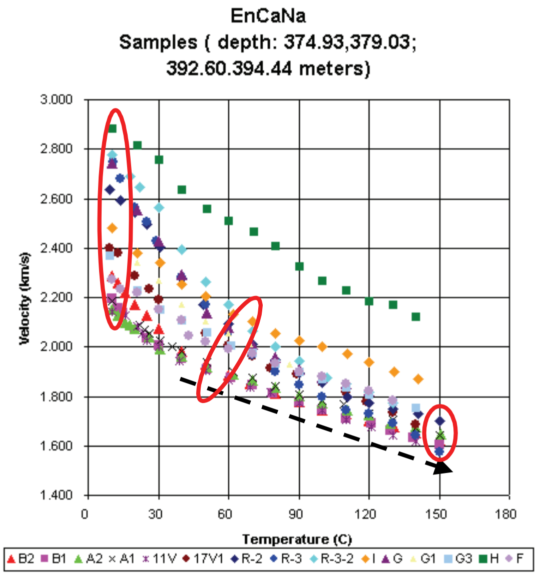

Figure 10: Summarize all (15) the Vp data versus temperature

Acknowledgements

Thanks for the support from EnCana and other sponsors of Fluids/DHI consortium.

References

De-hua Han, Qiuliang Yao, and Huizhu Zhao, 2007, Challenges in Heavy Oil Sand Measurements, annual report for Fluids/DHI consortium.