Experimental research on velocity and density properties of heavy oil mixed with hydrocarbon solvent

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Summary

The velocities and densities of heavy oil mixed with hydrocarbon solvent (diluent 12 wt% and propane 88 wt%) were measured and analyzed for a wide range of temperatures from 8°C to 90°C, pressures from 1 MPa to 48 MPa, and mixed hydrocarbon solvent from 5wt% to 80wt%. Velocities and densities of the mixture decrease with increasing temperature, decreasing pressure, and increasing weight fraction of the solvent. The 6 wt% of the solvent shows the highest effect to reduce velocity and density, and then, the effect reduces gradually.

Introduction

Solvent based recovery methods for heavy oils can significantly reduce viscosity of heavy oil, and have been recognized suitable for deeper reservoirs, which are capable to achieve high recovery rates, and avoid high temperature reactions and / or high water requirements, which often occurred in a steam based methods (Jiang, 1997). In addition, solvent is reusable. Usually, solvents mainly include toluene, and hydrocarbon gas/liquid (HC solvent). Recently CO_2 has also been recognized as additional solvent candidate.

In order to design and optimize solvent-based processes, we need to monitor how solvents work with heavy oil. Seismic method is the first choice for monitoring reservoir performance of the solvent based processing. As we known that acoustic properties of solvent-heavy oil mixture are a fundamental issue to be solved. We have focused on different solvents, mainly propane (C_3H_8) and light hydrocarbon based solvents. In this abstract we present experimental results on properties of heavy oil mixed with hydrocarbon solvent including P-wave velocity and density, and analysis of solvent efficiency to reduce heavy oil viscosity.

Experimental design and methodology

In order to investigate solvent effect within a wide range of in-situ condition, the samples were prepared to cover from heavy oil rich to solvent rich end.

Sample preparation

We used weight percentage to prepare samples. The volume percentages of the data used in the measurement have been converted with the given pressure and temperature conditions.

The sample of heavy oil and light hydrocarbon diluent were provided by our sponsors. The heavy oil with density, $\rho_0 = 1.0009\ \text{g/cc}$ ($API = 10$). The diluents mainly include pentane, hexane+. HC solvent is composed of diluent 12 wt% and propane 88 wt%. The propane is laboratory grade with purity > 99.7%.

Eight samples were prepared including heavy oil, HC solvent and six oil-solvent mixture as listed in the table1. The volume fractions of samples are based on the conditions of T =13°C, and P = 3 MPa.

sample	Two Components (Bitumen+Solvent)			
	Volume Fraction		weight Fraction	
	Solvent	Bitumen	Solvent	Bitumen
1	11%	89%	6%	94%
2	19%	81%	11%	89%
3	25%	76%	15%	85%
4	32%	68%	20%	80%
5	44%	56%	29%	71%
6	88%	12%	80%	20%

Table1. Prepared samples of heavy oil mixed with HC solvent.

Measurement conditions

Ultrasonic velocity and density of heavy oil, solvent, and heavy oil with solvent mixtures were investigated under the following conditions for single liquid phase:

Temperature from 8°C to 90°C (46.4°F to 194°F).
Pressure from 1MPa to 48MPa (145 psi to 7000 psi).

The density of heavy oil at the standard condition is calculated from the measured data at room condition using a density bottle.

From weight fraction to volume fraction at in-situ condition

Since weight fraction keeps constant for fluid with a single liquid phase, at a given temperature and pressure condition, the volume fraction of the solvent, $f_{v\_solvent}$, can be estimated from its weight fraction and measured densities of the mixture and solvent,

$$f_{v\_solvent} = f_{w\_solvent} \frac{\rho}{\rho_{solvent}},$$

DOI http://dx.doi.org/10.1190/segam2015-5925321.1

where ρ is mixture's density, $\rho_{solvent}$ is solvent's density, and $f_{w\_solvent}$ is weight fraction of the solvent.

Experimental result and analysis

Velocity data and properties

Velocities were measured on 8 samples including heavy oil, solvent, and their mixtures with different weight fraction. Measured data are shown in Figure 1.

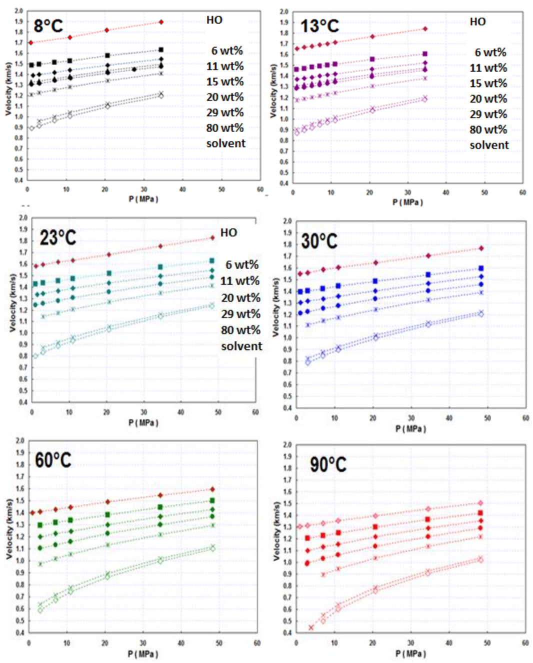

Figure 1. Measured velocity data.

Pressure effect

Pressure effects on velocity of fluids mainly depend on API gravity. The measured data reveal that velocities of heavy oil show lower pressure effects, and velocities of the solvent show higher pressure effects. The trend of the pressure effect changes gradually with increasing solvent fraction. With increasing temperature, pressure effect tends to be increasing. The similar trend of the pressure effect has observed on density data with smaller gradient.

Temperature effect

Velocity deduction is strongly temperature dependent as revealed by the measured data. Figure 2 shows velocity data at the measurement ranges. Figure 3 shows efficiency of injected solvent by the percentages of velocity deduction vs. volume fractions. When temperature is lower than the liquid point, the lower the temperature is, the more the velocity reduces. 10% velocity deduction corresponds to 6 wt% solvent in the mixture at 8°C. With temperature increasing to and above the liquid point, solvent effect decreases, and velocity of mixture maintains nearly linear relation with solvent percentage. That means at the quasi-solid state, around 6 wt% or less fraction of HC solvent will dilute viscosity of the heavy oil to that of conventional oil at the experimental temperature and pressure ranges.

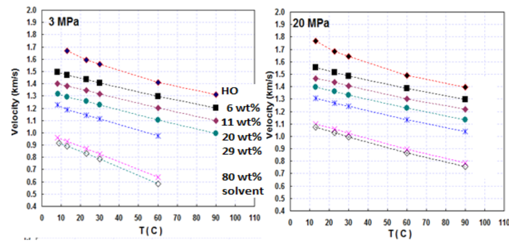

Figure 2. Measured data show temperature effect on velocity of heavy oil.

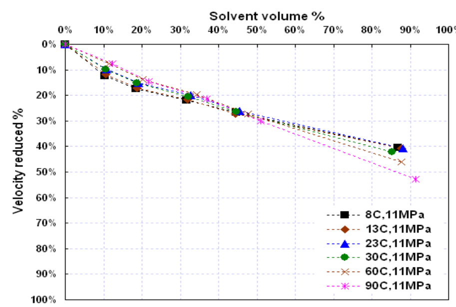

Figure 3. Temperature impact on the solvent's effect.

Solvent effect

1. HC solvent

Measured data reveal that the heavy oil mixed with a little solvent dramatically decreases velocity of heavy oil. The most efficiency is happened only by mixing heavy oil with a few percent of solvent. Figure 4 shows an example of velocity vs. temperature measured at 11 MPa. The blue symbols are velocities of heavy oil before it is mixed with solvent. The blue line is velocity of conventional oil, which keeps a linear correlation with temperature. With temperature decreasing, the upward deviation of heavy oil velocity from the velocity of conventional oil shows the beginning of nonlinear behaviors of heavy oil velocity. The temperature at the deviation point was defined as its liquid

DOI http://dx.doi.org/10.1190/segam2015-5925321.1

point (Han et al., 2008). With temperature decreasing and crossing its liquid point, the heavy oil changes from liquid to quasi-solid state. The red symbols shows measured velocity of heavy oil mixed with different percentage of HC solvent at 13°C and 11 MPa. About 6 wt% fraction of the HC solvent reduces velocity of heavy oil to the velocity near the liquid point. The temperature at its liquid point is 39°C, which is matched with the up deviation point of measured data. At 13°C and 11 MPa, the 6 wt% of solvent reduces viscosity of the heavy oil from its original about 100,000cP to 1,000cP, which is viscosity at its liquid point.

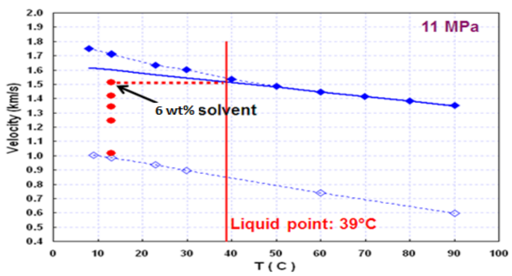

Figure 4. At 13°C and 11 MPa, 6 wt% solvent can reduce the velocity to its liquid point velocity.

2. Estimate viscosity from measured velocity

Main purpose of injecting solvent is to increase flowability of heavy oil by reducing its viscosity. Temperature effect on velocity of heavy oil is strongly correlated with the viscosity-temperature correlation of heavy oil (Han et al., 2008). Basically, we can use measured velocity data to estimate viscosity and EOR efficiency of the HC solvent.

The viscosity-temperature correlation of the heavy oil can be estimated by the viscosity model Vis-2011(Liu et al., 2011) (Figure 5). Previously we defined the liquid point of temperature corresponding to P-wave velocity about 1.5 km/s (Han et al, 2008). The temperature of the liquid point can also be estimated by the viscosity model. Using the relation of velocity with viscosity, we can correlate velocity, viscosity, and solvent volume percentage or weight percentage by drawing a line where velocity is equal to 1.5 km/s. Above the line, velocities indicate that the heavy oil is in quasi-solid state with viscosity higher than that of conventional oil. To reduce the viscosity to near 1,000 cP, the corresponded volume fraction of solvent can be estimated at in-situ temperature and pressure condition (Figure 6).

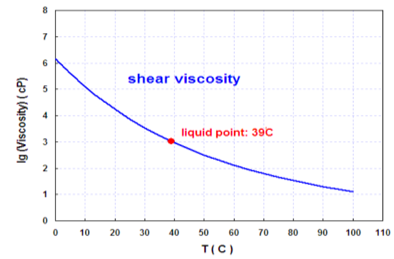

Figure 5. The heavy oil's viscosity and liquid point.

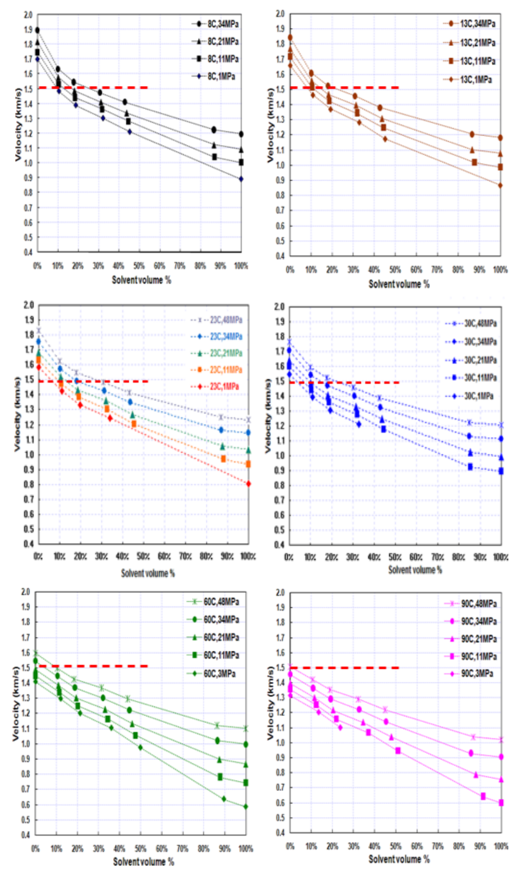

Figure 6. Measured velocities of heavy oil mixed with HC solvent.

DOI http://dx.doi.org/10.1190/segam2015-5925321.1

Density data and properties

We measured densities of the eight samples in the wide range of pressure from 3 MPa to 48 MPa, and temperature from 8°C to 90°C. Among them we only measured density at 8°C and 3 MPa, and at 13°C and pressure from 3 MPa to 21 MPa. Measured densities are shown in Figure 7.

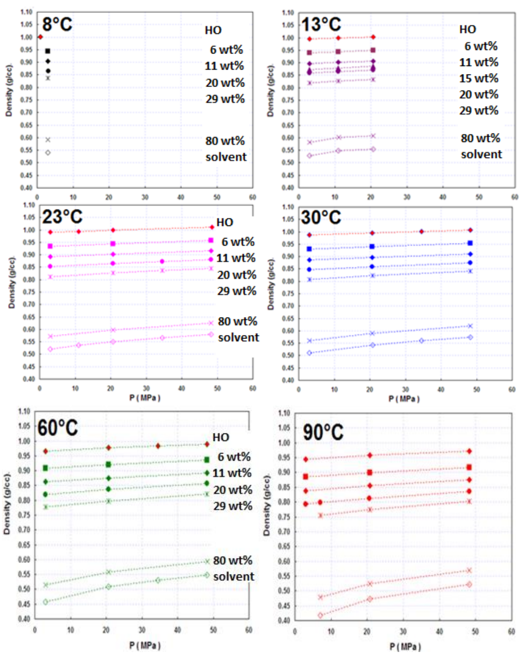

Figure 7. Measured density data.

Unlike the temperature effect on the velocity of the heavy oil, density-temperature correlation still keeps the linear trend when temperature decreases across the liquid point and then into quasi solid state. With viscosity increasing, there is no nonlinear deviation observed (Figure 8).

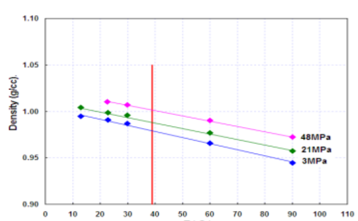

Figure 8. The heavy oil's density and liquid point.

Since density of heavy oil isn't sensitive to viscosity change, when heavy oil is mixed with HC solvent, its density still maintains the linear trends of the pressure and temperature effect. Generally, density of mixture decreases with temperature increasing and pressure decreasing (Figure 9).

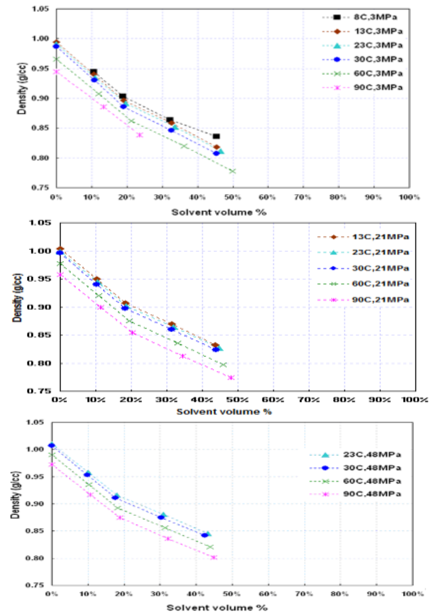

Figure 9. Measured density.

Conclusions

1. The greatest velocity reductions were achieved with only about 6 wt% of HC solvent mixed.
2. About 6 wt% of HC solvent mixed with the heavy oil decreases its viscosity of quasi solid state to that of its liquid point. The flowability of the mixture may be similar to that of conventional oil when temperature is near or above the liquid point.
3. In-situ temperature significantly impacts the HC solvent effect. The lower temperature is, the greater the velocity is reduced by the HC solvent. With temperature up to and above the liquid point, the solvent effect cannot be observed clearly, and behaviors of mixture are alike to those of conventional oil.
4. The relation of HC solvent's in-situ volume percentage with velocity reduction was estimated for a wide range of temperature and pressure conditions.
5. Unlike solvent and temperature effects on velocity, density of heavy oil and its mixture with HC solvent still maintain linear trends within the investigated ranges.

Acknowledgements

This research has been supported by the "Fluids/DHI" consortium, which is collaborated between University of Houston and Colorado School of Mines, and sponsored by oil industries all over the world. We appreciate our sponsors for providing the samples.

DOI http://dx.doi.org/10.1190/segam2015-5925321.1

EDITED REFERENCES

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