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Geochemical Tools Applied to Thermal Recovery Operations

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Summary

Biodegraded oil columns commonly exhibit gradients in both chemical composition and physical properties, providing a unique opportunity to map resource quality and better define and predict fluid property distributions both laterally and vertically. A baseline study in typical biodegraded oil reservoirs displays progressive deterioration in both oil viscosity and composition such that the most altered and viscous oils are typically encountered in close proximity to the oil-water transition zone, i.e., at the bottom of an oil column. A baseline data set is created on fresh core samples to acquire the most reliable dead-oil viscosity measurements and corresponding geochemical data to build correlation matrices. The baseline data set may be utilized for a number of geological applications suitable for thermal recovery operations, including (1) determining the vertical aspect of horizontal wells relative to the oil column, (2) monitoring steam chamber growth during steam-assisted gravity drainage (SAGD), (3) allocating production during thermal recovery operations, and (4) identifying neoformed compounds generated during steam-bitumen interactions. We present example case studies performed on the oil sands of Alberta, Canada.

Introduction

The world's petroleum inventory is dominated by heavy oil and bitumen that are formed by microbial degradation of conventional crude oils over geological timescales (Larter et al., 2008). Biodegradation of the oils gives spatially variable molecular signatures related to the level of degradation. In addition, gradients in oil composition and fluid properties result from preferential biodegradation of hydrocarbons in the oil-water transition zone typically located at the base of an oil column (e.g., Bennett et al., 2013). These gradients are further impacted by geological baffles and barriers, which compartmentalise reservoir compositions and fluid properties (Fustic et al., 2011).

A wide variety of sample materials may be recovered from petroleum reservoirs (cores, sidewall cores, cuttings and produced oils). Therefore, it is important to employ analytical procedures that follow a single consistent protocol to ensure statistical conformance amongst the sample suite and avoid potential issues, such as batching, that impact the chemometric results. Standard oils are used to validate viscosity data and hydrocarbon composition data and ensure the results meet expectations set by statistical guidelines. However, all the work and results are in vain if the original studies are performed on samples that have been stored for periods of time (even a few weeks) because it has been established that oil properties such as viscosity deteriorate during storage (Adams et al., 2008). Measurements of dead-oil viscosity are performed as close as possible to the time when the core was recovered from the reservoir to minimize loss of volatile components. Since the revision of the protocol for securing samples for dead-oil viscosity measurements, we typically find strong correlations between hydrocarbon composition and viscosity, i.e., increasing alteration of the oil composition correlates with increasingly viscous oils. We describe the opportunities that exist for gathering useful information from cuttings samples and produced oils from thermal recovery operations in cases where a baseline study of viscosity and hydrocarbon composition has been conducted on fresh core samples obtained from a vertical cored well.

Method

Approximately 50-mg produced bitumen or solvent extracts of oils, core or cuttings was dissolved in a small amount of dichloromethane (DCM) and transferred, along with standard compounds (for quantitation), onto a polar solid-phase-extraction (SPE) column using a clean pipette. The total hydrocarbon fraction (THC) was eluted with hexane first and DCM later, and the collected eluate was combined in the same vial. The THC fraction was analysed by gas chromatography-mass spectrometry (GCMS).

Examples

1. HORIZONTAL WELL PLACEMENT

After the thickness of pay has been established and the location of the oil-water contact or transition zone is known, horizontal wells are placed as close to the bottom of the oil column as possible to maximise pay. Because the composition of the oil generally shows significant increases in alteration in the lower part of the oil column (see Figure 1), the placement of the horizontal well may be indicated by the composition of cuttings collected from locations along the wellbore. Figure 1 shows the profiles of the dead-oil viscosity and chemical composition, i.e., methyldibenzothiophenes (MDBTs), that are generated from the core samples from a vertical well. The viscosity increases down the oil column, and the increasing viscosity is matched by a concomitant decrease in the MDBT concentration data and also their distributions, which show increasingly altered compositions (*m*/*z* 198). As biodegradation of the MDBTs is occurring, the more biodegradation-resistant compounds, such as pentamethylnaphthalenes (P), display increasing prominence in the *m*/*z* 198 fingerprint compared to the MDBTs (Figure 1).

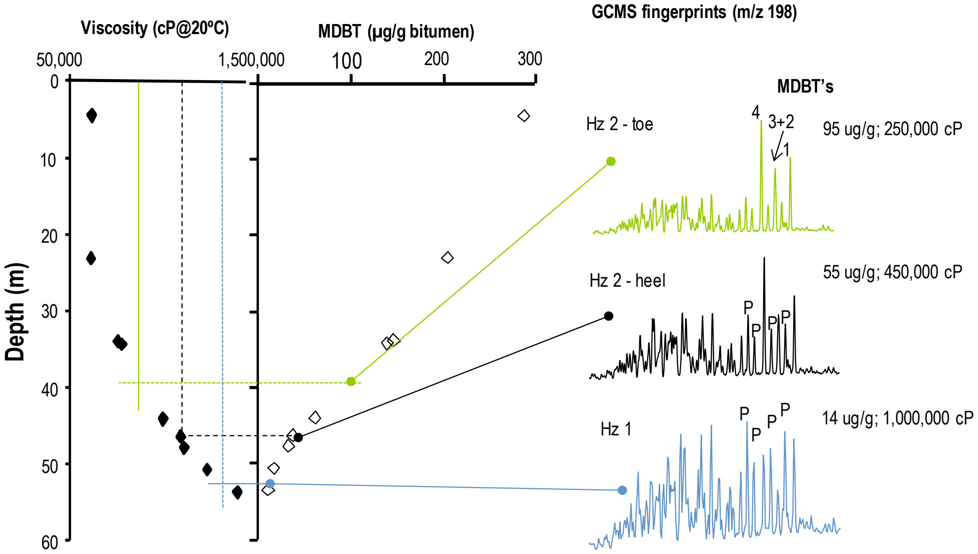

Figure 1. The distributions and summed concentrations of methyldibenzothiophenes (MDBTs) in cuttings from two horizontal wells (Hz 1 and Hz 2) and the depth correspondence where the MDBT concentrations are compared to the concentration and viscosity data from the vertical cored well.

Figure 1 shows the composition of the cuttings from horizontal well Hz 1, which was placed close to the oil-water contact at the lowest point in the reservoir. The fingerprint and concentrations of MDBTs (14 µg/g bitumen) reflect an advanced level of biodegradation corresponding to the composition of the core obtained from the bottom of the oil column at 53.5 m (Figure 1). The depth correspondence of the MDBT concentrations (14 µg/g bitumen) from well Hz 1 against the vertical well falls within the two samples originating from the bottom of the cored well and a viscosity of approximately 1,000,000 cP (at 20 ºC).

A second horizontal well (Hz 2) was drilled at a location (relative to well Hz 1) higher in the oil column. Not surprisingly, the composition of the cuttings extracts displays an overall improvement in composition compared to well Hz 1. The concentrations of the MDBTs from well Hz 2 were in the range 95 to 55 µg/g bitumen from heel to toe, showing an overall decrease in oil quality and changes in the relative abundance of MDBTs versus pentamethylnapthalenes along the horizontal wellbore (Figure 1). The concentrations of MDBTs from the cuttings representing the heel of well Hz 2 was plotted on the MDBT concentration profile for well V1, corresponding to a depth approximately 46 m from the top of the oil column and correlating with viscosity of approximately 450,000 cP (at 20 ºC), while the cuttings extract representing the toe corresponds to a depth of 40 m correlating with a viscosity of 250,000 cP (at 20 ºC). Thus, not only is the quality of the bitumen in Hz 2 an improvement on that in well Hz 1, there is an indication of lateral variation in oil quality along the wellbore of Hz 2 reflected in the changes in composition of cuttings samples heel relative to toe. In this case, based on improving oil quality from heel towards toe the trajectory of the horizontal well Hz 2 is advancing higher into the oil column or that oil quality is varying laterally across the reservoir.

A contour map was constructed for six horizontal wells (H1–H6) based on the viscosity data predicted from the hydrocarbon composition data obtained from the cuttings (100-m spacing) extracts relative to the baseline data set (correlation based on viscosity and hydrocarbon composition data) from a vertical well (Figure 2). In this example, the blue coloration corresponds to relatively low viscosities and indicates that two wells (e.g., H3 and H4) were placed in the oil column. The red/magenta colors associated with the higher relative viscosity results from well H2 indicate the well may have been placed in close proximity to the transition zone which may impact the performance of the well during production.

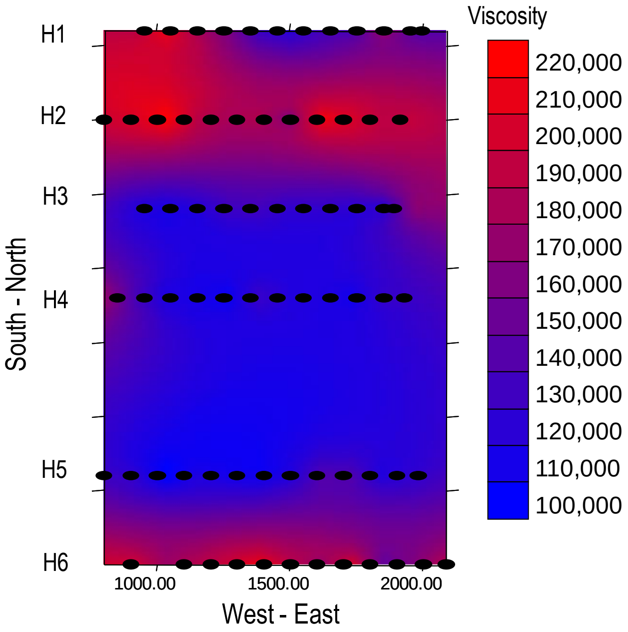

Figure 2. Contour map of predicted viscosity (cP at 20 ºC) data. Each sample is represented by a black circle.

2. THERMAL PRODUCTION

In thermal recovery operations such as steam-assisted gravity drainage (SAGD) and cyclic steam stimulation (CSS), steam chamber growth may be monitored by sampling the produced fluids and comparing them to oils collected from nearby vertical and horizontal wells. As the steam chamber grows, less degraded, better-quality oil will be produced from vertical compositionally graded reservoirs. In Figure 3, the first produced oil following SAGD production, referred to as produced oil 1 (PO1), shows a composition similar to the compositional data from the baseline data set at 37.0 m. A produced oil was collected several months later, and the resulting composition of the oil, referred to as produced oil 2 (PO2) shows an improvement in composition compared to PO1 indicating that production is likely being swept from higher in the oil column. The composition of PO2 corresponds to the sample analysed from 15.2 m depth (Figure 3), which confirms the vertical progress of the steam chamber.

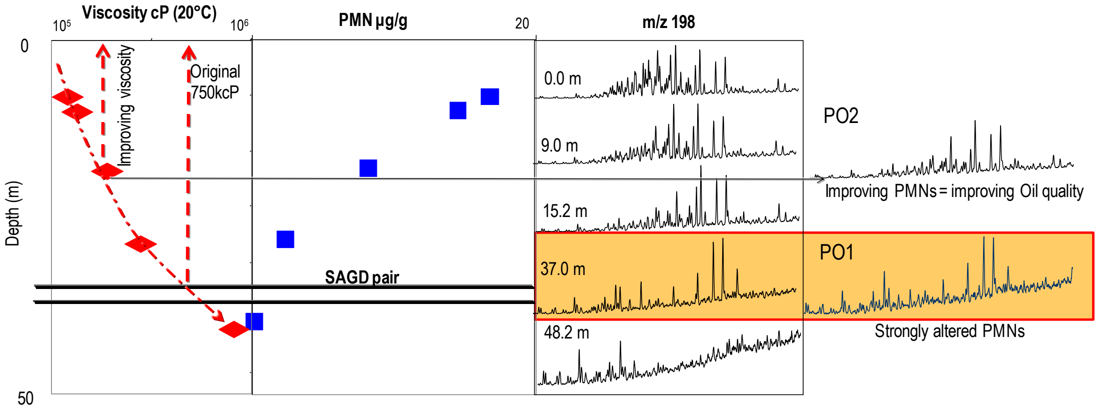

Figure 3. Improving oil composition (right) resulting from the vertical advancement of the production sweep during SAGD.

During thermal recovery processes, the composition of the oil may show neoformed compounds. The presence of enhanced contributions of 2-methylanthracene is commonly attributed to thermal interactions, and alkylphenols are also known thermal products (Larter and Bennett, 2011). Increasing thermal stress leads to the presence of alkylbenzothiophenes whereas progressing to higher temperatures, a suite of *n*-alkanes and alkylbenzenes are generated. The calibration of neoformed compounds relative to temperature may provide an opportunity to indicate the conditions encountered during the interaction of steam and bitumen, thereby providing an indication of steam quality delivered to the reservoir.

Conclusions

The variation in hydrocarbon composition and oil viscosity encountered in heavy oil and oil sands reservoirs provides unique opportunities to map the variation in resource quality both laterally and vertically to better define fluid property distributions after a reliable baseline data set is generated. Following the establishment of a baseline data set on a vertical well, the compositions of cuttings from horizontal wells may be used to define the vertical aspect of the horizontal wells. Meanwhile, the analysis of produced oils during thermal projects may provide an indication of vertical progress of the steam chamber advancement during SAGD. In addition, the identification of thermal proxies in the production stream may indicate the temperature conditions encountered during steam-bitumen interactions in the subsurface.

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