

4D study of secondary recovery utilizing THAI[®] from a Saskatchewan heavy oil reservoir

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Summary

Heavy oil recoveries in most heavy oil reservoirs in Western Canada are usually less than 10% under primary recovery schemes (native pressure and oil saturation). Thermal methods have been utilized in the Saskatchewan heavy oil region by many operators as a profitable alternative to traditional enhanced oil recovery (EOR) schemes. Petrobank Energy and Resources utilizes Toe to Heel Air Injection (THAI[®]), a patented in-situ combustion technology, to recover large amounts of the remaining resource while upgrading the oil in-situ. Lab results show that THAI can recover up to 65% with an average upgrade of $\sim 8^\circ$ API, while field results show an average of $\sim 4^\circ$ API upgrade with recovery amounts still being monitored with time (Kendall and Wikel, 2011).

Thermal recovery methods are well suited to monitoring with time lapse seismic. Recent published data shows that heavy oil velocities decrease with added temperature in the lab (Han and Batzle, 2006) and other time lapse case studies show observable and tested time lapse responses when monitoring THAI with seismic (Kendall, 2009; Kendall and Wikel, 2011). In addition, 4D-3C seismic can aid in caprock integrity monitoring via overburden stress change through time (Wikel et al, 2012). This case study will outline the utilization of a non purpose shot 3D baseline (1995) being interpolated and re-processed to act as a baseline to a recent purpose shot time lapse (2011) near Petrobanks Kerrobert, Saskatchewan THAI facility. Results show an observable compressional wave time lapse response due to the THAI process, which allows us to monitor temperature and gas migration in active THAI projects. Also, a time lapse response from primary production due to a secondary gas cap in both vertical and horizontal wells is present as well. This secondary gas cap is the result of the reservoir dropping below the bubble point where gas comes out of solution. The unexpected presence of primary depletion anomalies makes future time lapse shoots over aging heavy oil fields with similar oil properties a possibility for targeted infill drilling.

Introduction

Heavy oil reservoirs in Saskatchewan present a relevant case study in primary recovery versus secondary recovery potential in the world of heavy oil (heavy oil being oils that have a 10-22^o API gravity). In most heavy oil reservoirs, the oils viscosity is too high (>5,000 cP) under native reservoir conditions to flow efficiently and at commercial rates for long periods of time (>5 years). The water saturation, viscosity contrast of oil to water, drawdown, and relative permeability of the oil to water can also cause early water coning and large amounts of water production through time. To further complicate matters, large amounts of sand can also be produced as well. Oil recovery in Petrobanks Kerrobert field from primary production is 1.5%, which leaves a substantial amount of resource for secondary recovery schemes. In light oil reservoirs, secondary recovery most often takes the form of water flooding or natural gas injection, while CO₂ floods and polymer floods are employed for heavier oil EOR schemes or tertiary recovery. Most heavy oils, however, have high viscosities that limit the

effectiveness of the aforementioned EOR schemes (Thomas et al, 1999). Therefore, many operators in Western Canada opt for thermal methods to recover heavy oil remaining in the reservoir after primary depletion has become uneconomic.

The Mannville Group within the Saskatchewan heavy oil region is an ideal target for secondary production, as primary production produced only 1.5% of original oil in place in the Kerrobert Waseca reservoir of interest. This low production is due mostly to the high viscosity of the oil and presence of bottom water. The Waseca sandstone channel is the target reservoir in this case study, reservoir parameters are as shown in table 1. An overview of the area is shown in Figure 1.

Formation	Waseca Member
Reservoir Top Depth	758 to 774m
Oil pay thickness	Western wells 15 to 20m, eastern wells 25 to 30m
Porosity	32%
Oil saturation	80%
Permeability	2 to 6 Darcy
Bottom water thickness	10 to 20 m
Oil API gravity at 15.6 °C	9.9 to 11, average 10.5
Oil viscosity at 20 °C	21170 to 89350 cSt, average 49415 cSt
Reservoir pressure	3500 to 4000 kPa
Horizontal well elevations	2 to 6 m above oil water contact

Table 1: Kerrobert reservoir properties

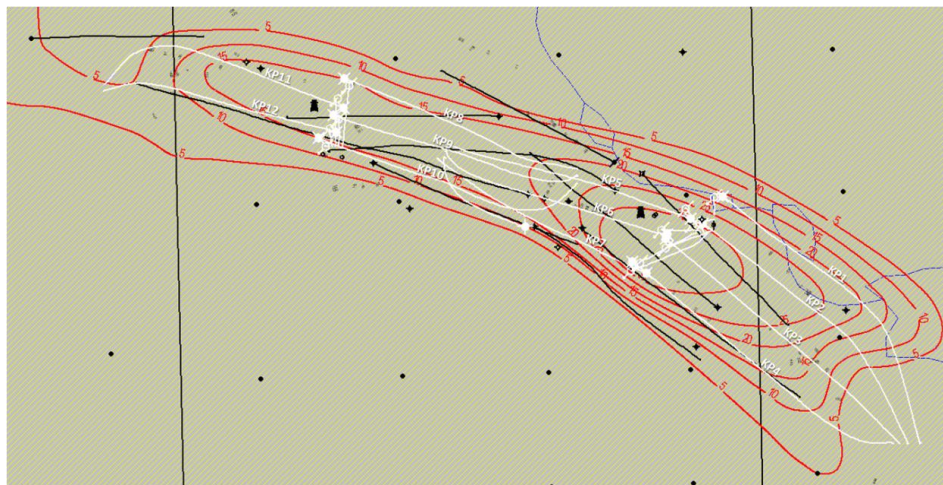


Figure 1: Kerrobert field layout. Black wells are primary production verticals and horizontals, white wells are Petrobank Kerrobert THAI wells, and the red contours are Waseca sandstone net oil pay (in 5 meter increments).

Toe-to-Heel-Air-Injection (THAI) is an in-situ controlled-combustion process that cracks, upgrades, and mobilizes heavy oil. Compressed air is injected into the reservoir after a pre-injection-heating-cycle (steam) brings the reservoir up to an appropriate temperature (90⁰) for combustion to occur. The bitumen is then cracked leaving a coke zone that becomes the fuel for the process. In front of the coke zone is a mobilized and upgraded oil zone that is then produced by a horizontal well through gravity drainage. The THAI process does not require gas or water as in SAGD except in the pre-ignition start-up phase (Kendall, 2009).

Method

3D-3C seismic data was utilized to monitor both the advancement of the THAI front through the reservoir and caprock integrity through time with future shoots. The purpose shot time lapse in 2011

utilized a digital 3C acquisition system with dense line spacing for 15x15m bin sizes. This shoot will act as the first time lapse 3C baseline, however, 3D existed in the area (1995 vintage) that was re-oriented to the new 2011 shoot geometry and interpolated to match the tighter line spacing. The parameters for the two shoots are shown below in table 2. Of note are the different sources, line layout (and orientation as well), in addition to being shot in different seasons.

	1995 survey	2011 survey
Geophones	OYO GS20DX	ION Digital 3C
Source	Vibroseis: 8 swps @ 8 sec (8-100 Hz- 3DB/OCT)	Dynamite: .5 kg @ 12m
Line spacing	250 x 150 m	150 x 90 m
Bin size (m)	25 x 25 m	15x15
Month	April	October

Table 2: Kerrobert seismic shoot parameters.

This resulted in a pseudo-baseline survey that was shot before much of the primary production in this region occurred. This will allow us to not only assess the movement of the THAI front, but also to assess the degree of primary depletion present in the reservoir due to secondary gas coming from primary production.

Examples

The results of the Kerrobert 4D are shown below in figure 2. The 2011 Waseca base has been differenced from the 1995 Waseca base horizon to produce this simple time delay map. The time delays in this map are a result of velocity decrease in the Waseca reservoir from combustion heat (correlated to wellbore temperatures) and combustion gas presence. In addition to this, several anomalies exist at vertical wells and legacy primary production horizontals that are not associated with the THAI process. Secondary gas from initial production has caused this time lapse anomaly to occur as production drops the reservoir pressure, causing gas to come out of solution (once pressure drops below the bubble point).

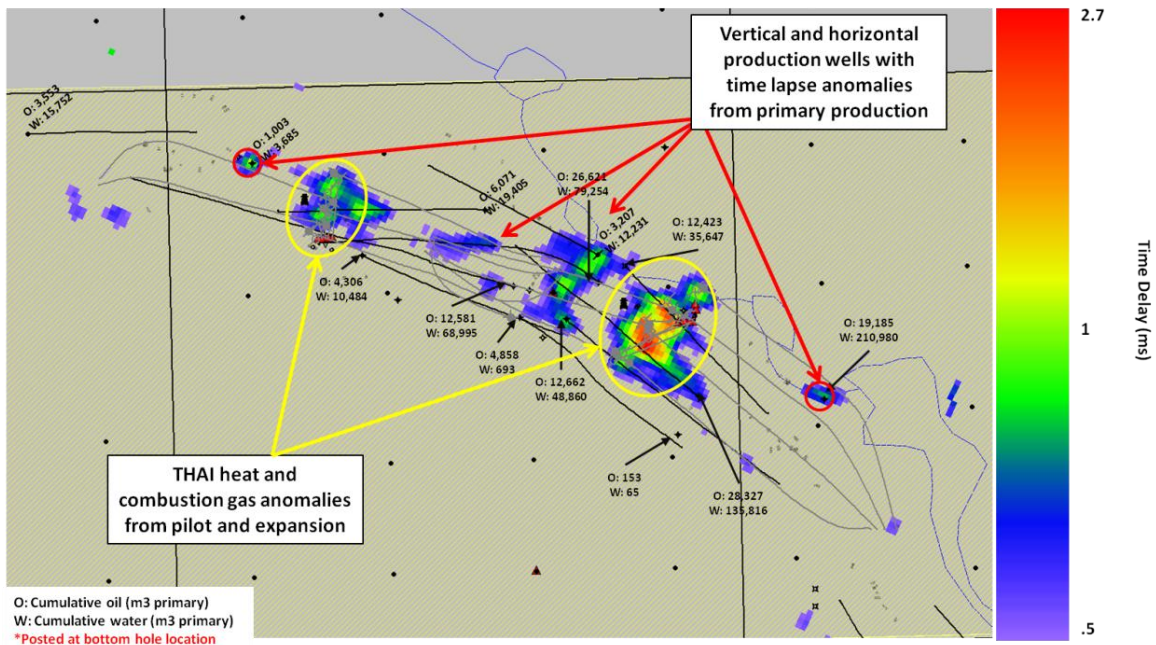


Figure 2: Kerrobert Waseca base time delay map showing THAI anomalies circled in yellow and primary production anomalies from secondary gas with red arrows. Primary production for wells is shown as noted.

Conclusions

4D compressional wave seismic is used to monitor THAI front growth and movement in the reservoir with good agreement between the seismic anomalies and temperature measurements from the reservoir. In addition, an unexpected response from primary production in the area is visible on the 4D as a result of secondary gas from initial production. These anomalies can be used in the future to constrain reservoirs with similar oil compositions and secondary gas to justify down spacing and constrain drainage areas in older fields.

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