Integration geoConvention 2013 geoscience engineering partnership

Remote reservoir monitoring in oil sands: From feasibility study to baseline datasets

Richard Tøndel*, Stefan Dümmong, Hartmut Schütt, Alexandre Ducrocq and Andrew Williams, Statoil
Jon Ingham and Robert Godfrey, Schlumberger
Douglas LaBrecque, Multi-Phase Technologies

Summary

A joint research project between Statoil and Schlumberger is focusing on permanent cross-well geophysical methods for reservoir monitoring during steam assisted gravity drainage (SAGD). In 2009, a feasibility study indicated detectable differences in seismic and electrical reservoir properties based on expected changes in temperature and fluid saturation during oil production. Based on these results, several geophysical reservoir monitoring methods were evaluated. These included cross-well seismic, vertical seismic profiling (VSP), and electrical resistivity tomography (ERT). The modeling study was followed by an installation of a permanent cross-well system at Statoil's Leismer Demonstration Area (LDA) in Alberta, Canada, in 2010. After the system was successfully installed and tested, baseline datasets were acquired through an established data link, also allowing for remote monitoring throughout the calendar year. ERT datasets can now be acquired without personnel on site, while seismic acquisitions require a moving source on the surface or a cross-well seismic source and receiver array deployed on wireline. Comparisons of

1) conventional 3D surface seismic
2) 3D VSP
3) cross-well seismic

show an increase in resolution and frequency content from 1) to 3) as expected. The ERT baseline results indicate clear separation between zones of high and low resistivity, in addition to noisy data parts focused around the wells where minor electrical leakages occur. During 2012, different time-lapse studies have been executed to reveal how these different methods can monitor the reservoir during SAGD. The permanent cross-well system will also contribute to the understanding of planned solvent co-injection tests at LDA. Ultimately, answers will be obtained as to whether these technologies can be further developed to provide reservoir monitoring capacity of larger areas of oil sand reservoir.

Introduction

With the acquisition of North American Oil Sands Corporation, Statoil entered the Athabasca oil sands region in 2007. The Kai Kos Dehseh project covers 1,110 square kilometers and is shared between Statoil (60%) and PTTEP (40%). First oil from Leismer Demonstration Area was produced in early 2011, aiming for 20,000 BPD from 23 horizontal well pairs by SAGD.

A number of research projects have been initiated since Statoil entered the oil sands. This paper will focus on one of them; a Statoil-Schlumberger collaboration evaluating permanent cross-well geophysical methods for reservoir monitoring purposes. Following a feasibility study, a permanent cross-well system was installed at LDA in 2010. Different data types from the Leismer reservoir are now acquired continuously through an internal network link.

Theory

Key factors during the initial screening of cross-well technologies were high-temperature capabilities, possibilities for permanent deployment and costs. The most important factor was, however, how detectable an expected time-lapse contrast would be compared to the background model.

After the initial screening, three permanent cross-well methods were evaluated in the feasibility study: Electromagnetics (EM), electrical resistivity tomography (ERT) and seismic. Both cross-well measurements and vertical seismic profiling (VSP) were considered as seismic solutions.

It has been described that steam flooding of a heavy oil reservoir will decrease formation resistivity by a factor 2 to 10 (Ranganayaki et al. 1992 & Engelmark 2007). This is promising for the ERT method, which commonly has been used for environmental monitoring, but also during oil production (Daily et al. 2004). Electrical property modeling indicated that ERT would be able to detect changes in the oil sand reservoir, caused by a combination of increased temperature and reduced oil saturation. The feasibility study indicated that EM methods are less likely to give clear time-lapse images under the current reservoir conditions.

Seismic property modeling (Kato et al. 2008) indicated detectable changes in both compressional and shear velocities, mainly caused by saturation and temperature effects, respectively.

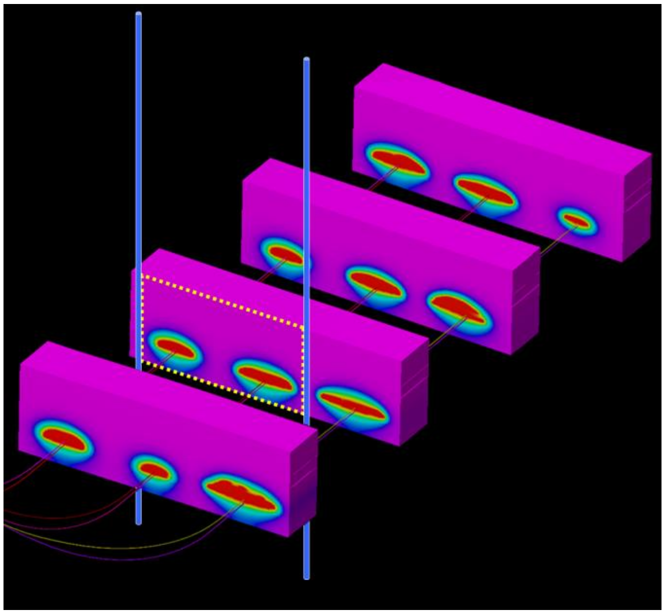

Figure 1: Cross-well experiment layout. Two vertical observation wells (blue) were planned drilled straddling two horizontal production/injection pairs. Distance between producers is 100 meters, while the distance between the observation wells is 150 meters. Color scale represents increasing temperatures during SAGD, warm colors are high temperatures.

Implementation

Using results from the feasibility study, conventional observation well design and extensive material testing, a two-well system was developed, see Figure 1. The material testing, downhole sensor adaption and field tests were key factors in this phase, where the two main challenges were the potential high temperatures during SAGD and the need for electrically insulated well casing (Tøndel et al. 2011). Finally, two wells were drilled and instrumented as described in table 1.

In addition to the ERT electrodes and three-component geophones, a distributed temperature sensing (DTS) system was installed in both wells. Two pressure/temperature gauges were also installed in the eastern observation well. With the exception of geophones and geophone cables, all downhole components were rated for temperatures above 250^{o}C.

Sensors	West well	East well
3C geophones	32	32
ERT electrodes	32	32
DTS	Cont.	Cont.
P&T gauges	-	2

Table 1: Permanently installed sensors attached to the outside of the electrically insulated steel casing in the two observation wells at Leismer Demonstration Area

Remote monitoring

Surface conditions in the Kai Kos Dehseh area vary during the year, and conventional geophysical mapping can only take place during winter time. In order to increase flexibility and minimize environmental footprints, it was decided to install an instrument cabinet at site, a fully equipped and electrically powered unit. Figure 2 shows a schematic view of the cabinet and its components, which allows for frequent remote monitoring using all sensors listed in Table 1. Seismic surveys still require a moving source on the surface, while ERT datasets are acquired weekly without personnel on site.

Figure 2: Schematic view of the instrument cabinet located close to the two observation wells at LDA. All instruments can be controlled through the Statoil network to record data throughout the year. In addition to recording instruments, the cabinet is equipped with data servers, an uninterruptible power supply (UPS), air conditioning and more. The arrow in the middle is approximately 1 meter.

Baseline datasets

After a period of acquisition parameter testing, an ERT baseline dataset was acquired in early 2011. This 2D section shows a clear separation between the high resistive oil sand reservoir and the surrounding low resistivity zones, as seen in Figure 3. The signal-to-noise level in the data is lower along the two vertical wells, probably due to small imperfections in the electrical insulation material during well completion. The S/N ratio improves significantly when a time-lapse approach is used; i.e. when repeated measurements are referenced to the baseline model. The current focus is now on time-lapse analysis and how to establish a processing algorithm for generating robust and frequent results for production interpretation purposes.

Immediately after drilling and completing the two observation wells, a seismic cross-well section was acquired, using a wireline source in the west well and a wireline receiver array in the east well. This high-resolution dataset, shown in the left part of Figure 4, will be used as geometrical constraint during ERT inversions, and might also serve as a baseline for future time-lapse studies.

A section from the 3D VSP acquisition is shown in the right part of Figure 4. This dataset was acquired through approximately 3,400 source points distributed over a one square kilometer area centered on the two observation wells.

As can be seen, the resolution is higher on the left section of Figure 4, however the right image coverage is extending beyond the area between the two observation wells. It should also be noted that the resolution capabilities of the 3D VSP are higher than those of the conventional surface seismic data, due to the fact that all receivers are permanently located within the borehole. Figure 4 also shows that the main reflectors between the cross-well and the 3D VSP datasets are well aligned, allowing for joint interpretation of the subsurface features.

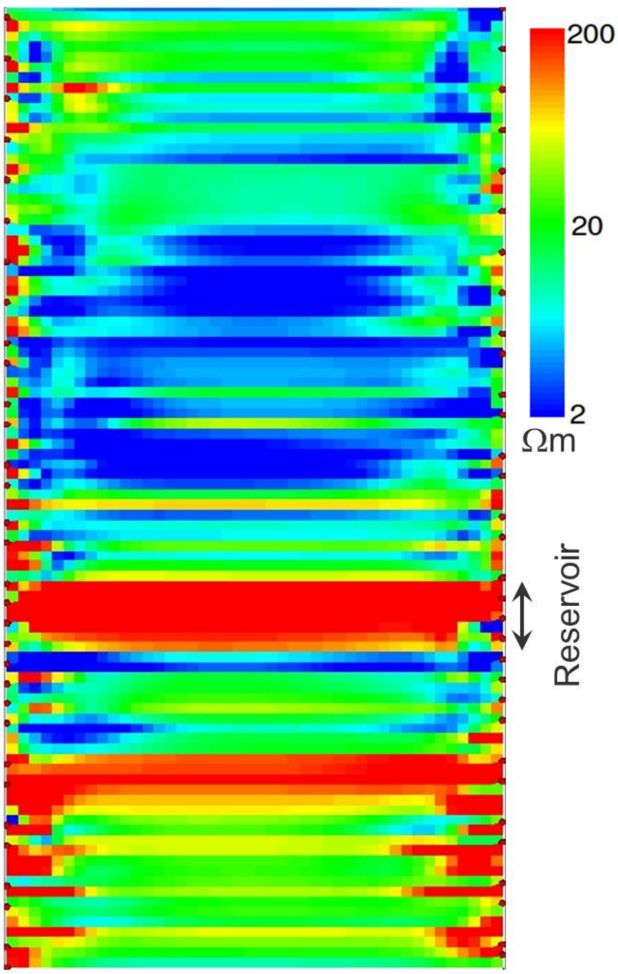

Figure 3 (left): ERT baseline image between the two observation wells. Color scale is in Ωm, varying from high (oil sand reservoir and parts of Devonian) to low (mainly water-filled sandstone). Red circles along edges represent ERT electrode locations. The 2D section is 150 m wide and covers a depth interval of approximately 420 m. Noise along well bores is probably due to minor electrical leakages caused by imperfections in the insulation material.

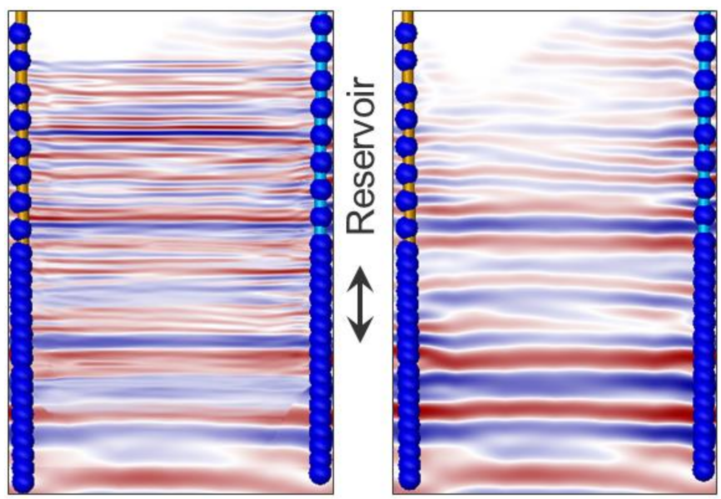

Figure 4 (above): Seismic cross-well section (left) and corresponding section from the 3D VSP baseline acquisition (right). The reservoir interval is approximately 40 m. The two observation wells and permanent three-component geophones can be found along the edges of the two sections.

Conclusions

A permanent cross-well geophysical system has been installed on Statoil and PTTEP's Leismer Development Area in Canada. Baseline datasets have been acquired through an established remote link, allowing for frequent data acquisitions throughout the year independent of surface conditions.

Several time-lapse studies are initiated, aiming at understanding how acoustic and electric reservoir parameters vary during SAGD. Results from these studies will increase the understanding of each technology's potential and how different data types can be integrated to allow for robust and reliable remote monitoring of oil sand reservoirs.

Acknowledgements

The authors would like to thank Statoil, PTTEP and Schlumberger for permission to present this work.

References

Ranganayaki, R.P., Akturk, S.E. and Fryer, S.M., 1992, Formation resistivity variation due to steam flooding: A log study, Geophysics, **57**, 488-494

Engelmark, F., 2007, Time-Lapse Monitoring of Steam Assisted Gravity Drainage (SAGD) of Heavy Oil using Multi-Transient Electro-Magnetics (MTEM), CSPG CSEG Joint Convention

Daily, W., Ramirez, A., Binley, A. and LaBrecque, D., 2004, Electrical Resistivity Tomography, The Leading Edge **23**, 438-442

Kato, A., Onozuka, S. and Nakayama, T., 2008, Elastic property changes in a bitumen reservoir during steam injection, The Leading Edge **9**, 1124-1131

Tøndel, R., Ingham, J., LaBrecque, D., Schütt, H., McCormick, D., Godfrey, R., Rivero, J.A., Dingwall, S. and Williams, A., 2011, Reservoir monitoring in oil sands: Developing a permanent cross-well system, 81st Annual International Meeting, SEG, Expanded Abstracts **30**, 4077-4080