Modeling and Mapping SAGD Steam Chamber Evolution in a Heavy Oil Reservoir using 4D-3C Seismic

Loren M. Zeigler*, Colorado School of Mines, Golden, Colorado

lzeigler@mines.edu

Kelsey Schiltz, Colorado School of Mines, Golden, Colorado

kschlitz@mines.edu

and

David Gray, Nexen Inc., Calgary, Alberta, Canada

Summary

The field of study is a part of the Athabasca Oil Sands located in northeastern Alberta. The target reservoir for this study is located at 180-250 meters depth in the lower Cretaceous McMurray formation. The McMurray is a tidally influenced fluvial deposit that occurred near the southern margin of the Western Interior Seaway (Hubbard et al., 2011). This oil has a very high viscosity (1-8 million cP) and low API gravity (6-9°) and is thus considered to be an unconventional play requiring specialized production techniques. In this case, Steam Assisted Gravity Drainage (SAGD) is being used to produce the oil. This is an in-situ method that injects steam using vertically stacked horizontal wells, causing viscosity to decrease and oil to begin to flow. The data that will be used consists of a very large well database of roughly 50 wells that are within our survey, 30 of which have been successfully tied to the seismic. Our survey is 2.5 km2 and consists of time-lapse compressional (PP) and converted (PS) wave data.

In an ideal homogenous reservoir, this steam chamber created by the SAGD process would form perfectly as an inverted triangle shape. However, the McMurray sandstone is notoriously heterogeneous consisting of very large scale channels that can be mud filled, as well as complex small scale shale bodies. These heterogeneities can be baffles or barriers with the potential to greatly impede the growth of the steam chamber. A thick or laterally continuous zone of shale can prevent the steam chamber from flourishing, however a small shale lens may only slow down its progression. Furthermore, there are three fronts that move through the reservoir during SAGD; Pressure, heat, and finally steam. When the first steam is injected into the reservoir, it automatically turns to back into hot water when it hits the relatively cold reservoir rock. This sends a strong and fast pressure pulse into the reservoir. Pressure typically moves faster than temperature and can affect a larger area of the reservoir, however there isn't a distinct way to try and distinguish this front. Next, a conductive heat front flows through the reservoir ahead of the steam front. The heat front begins warming the rock and fluids in preparation for the approaching steam. Ideally, if we are to fully interpret steam chamber growth and heterogeneities in the reservoir, the steam front must be distinguishable from the heat front.

The main objectives of this work are to model property changes during steaming, create a reservoir model from joint inversion of 4D PP & PS seismic volumes, relate in-situ fluids and rock properties to the seismic response, and determine where steam versus heat is going in the reservoir. Modeling the properties of heavy oils is more difficult than typical light oils. The unique characteristics of heavy oil means that at low temperatures, the viscoelastic bitumen actually has an effective shear modulus and

will propagate a shear wave. Once the bitumen has been steamed for production, it becomes a true liquid, the shear modulus will go to zero, and it will act like typical light oil. The point at which the shear modulus goes to zero is called the liquid point. This point is the critical temperature at which the bitumen will begin to flow and be producible. The FLAG equations created by Batzle & Han will be used to understand the changes that occur in the velocity, density, and moduli of the oil. (Batzle & Han, 2000) These parameters will be incorporated into Gassmann's equation to model reservoir changes due to production. A modified version will be used to model the oil at low temperatures when it's acts as a quasi-solid.

The goal of Joint Inversion is to analyze PP and PS pre-stack CDP gathers to better invert the seismic trace for p-impedance (Z_p), s-impedance (Z_s), and density (ρ) by incorporating the fact that Z_s and ρ are related to Z_p. (Hampson, et al, 2005) The results from this work will be used to obtain p-wave velocity, converted wave velocity, and density which will then be formulated to calculate bulk and shear modulus of the reservoir. The difference between bulk and shear modulus should be the actual steam chamber, excluding conductive heat. Shear and bulk modulus are both a function of pressure and temperature, however bulk modulus is also a function of fluid. The shear modulus acts as an indicator of the heat front due to the fact that it goes to zero at a specific temperature, regardless of whether or not the steam has reached the oil yet.

References

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