geoconvention Virtual Event September 13 - 15 2021

Advances in Reservoir Monitoring in Steam Floods Using Multidetector Pulsed Neutron Tools

Paul Pavlakos
Weatherford International

Summary

Canada has the 3rd largest proven oil reserves in the world and 97% of these are in the Alberta and Saskatchewan oil sands. Mining occurs in the shallower oil deposits, however most of the bitumen is produced in-situ using steam assisted gravity drainage (SAGD) techniques. Other than DTS temperature surveys, the most economic and efficient method for monitoring the steam chamber and reservoir saturations is by pulsed neutron logging. While pulsed neutron tools have been widely used in the industry for decades, recent advancements with multidetector pulsed neutron technology (MDPN) enable a much more detailed description of reservoir fluids. Improved MPND tool design combined with advanced calibration methods result in consistent and reliable signal responses. Additionally, pre-job data collection and predictive modeling provide targeted logging plans optimizing formation saturation evaluation and reservoir characterization. From the MDPN results, oil sands producers can adjust the steam injection to improve project efficiency, economics, and reduce carbon footprint.

Innovative Approach to MDPN Analysis

Improvements in tool designs include larger detector arrays with up to 4 high-efficiency $LaBr_3$ (lanthanum bromide) detectors as well as a fast neutron detection. The extra-long spacing of detectors enables larger volumes of investigation resulting in a higher measurement sensitivity to reservoir properties. The tool described in this paper generates simultaneous burst and capture measurements as well as elemental spectroscopy data, providing sigma, carbon/oxygen (C/O) and gas surveys. Depending on project objectives, different fit-for-purpose modes can be selected with variations on the timing bins in the inelastic and capture spectra. Gas and steam saturations can be derived from the capture ratio and the burst ratio from the proximal-long spaced detectors increasing sensitivity to gas saturations compared to traditional pulsed neutron systems dependent on near-far detector capture ratios. While traditional sigma measurements are recorded, sigma is no longer an intrinsic input for fluid saturations in SAGD wells, primarily because of the low salinity of formation waters. Instead, a mixed mode approach with measurements of C/O and capture/burst ratios is used to maximize the use of the recorded data. Implementation of flasked thermal housings rated at 260 C enable SAGD evaluation. The flask also acts as a neutron moderator enabling the flasked tool to be logged in a dry hole which is typically problematic for all neutron-type tools. Monthly tool calibration ensure consistency in responses from tool to tool.

While improvements in hardware are critical, advancements in pre-job planning and simulation are equally important. Specifically, 3D MCNP (Monte Carlo N-Particle) modeling predicts the tool response taking into consideration wellbore geometry, borehole fluids, formation fluids (PVT data) and lithology. The resulting MCNP prediction provides a synthetic coherence envelope that is superimposed with porosity and the measured curve. This technique also serves as a quality control as coherence is observed when the measured data follows the modeled envelope trend as it expands and contracts with varying porosity. Typical models will include coherence envelopes for C/O, gas/water and quartz/calcite ratios. The overall result is an improved reliability in the petrophysical analysis and saturations providing an accurate description of current in-situ fluids.

Figures 1 and 2 illustrate the MCNP forward models used to calculate gas saturations from the proximal-long burst ratios for various reservoir fluids. The methane model in Figure 1 is combined with the liquid lines (oil and water) and consists of different methane densities. For this illustration, the CO_2 and steam models contain only the different densities of the gases without the liquid lines.

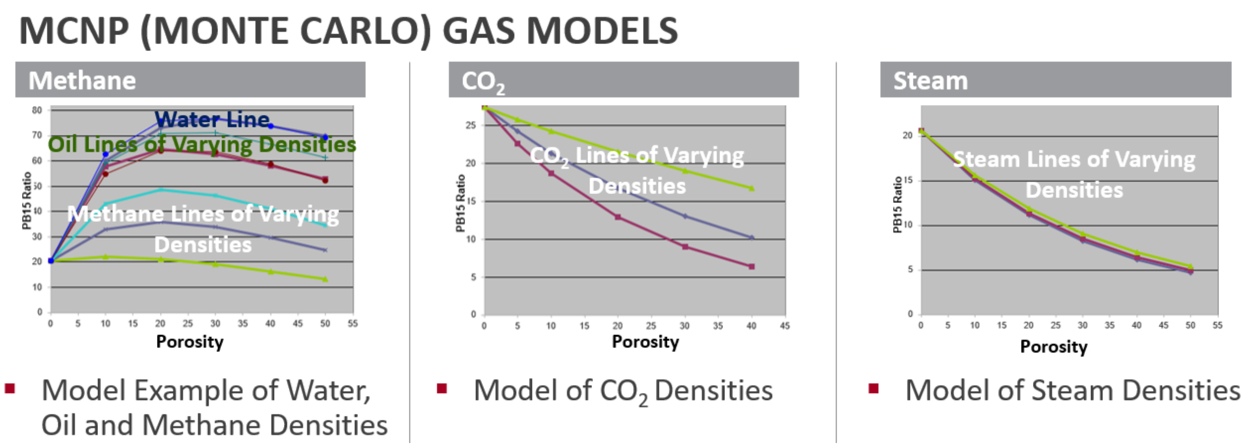

Figure 1: Several examples of MCNP models for gas, Proximal-Long Burst Ratio vs Porosity: i) Methane displaying water/oil lines with various methane densities, ii) CO_2 with various densities, iii) steam with various densities.

The models are combined with the porosity to create a synthetic envelope defining the end points for water and gas (Figure 2). The measured proximal-long ratios from the instrument are superimposed onto the envelope for the calculation of the respective saturations and, in conjunction with the envelopes, provide the petrophysicist a quality control check based on the data coherence.

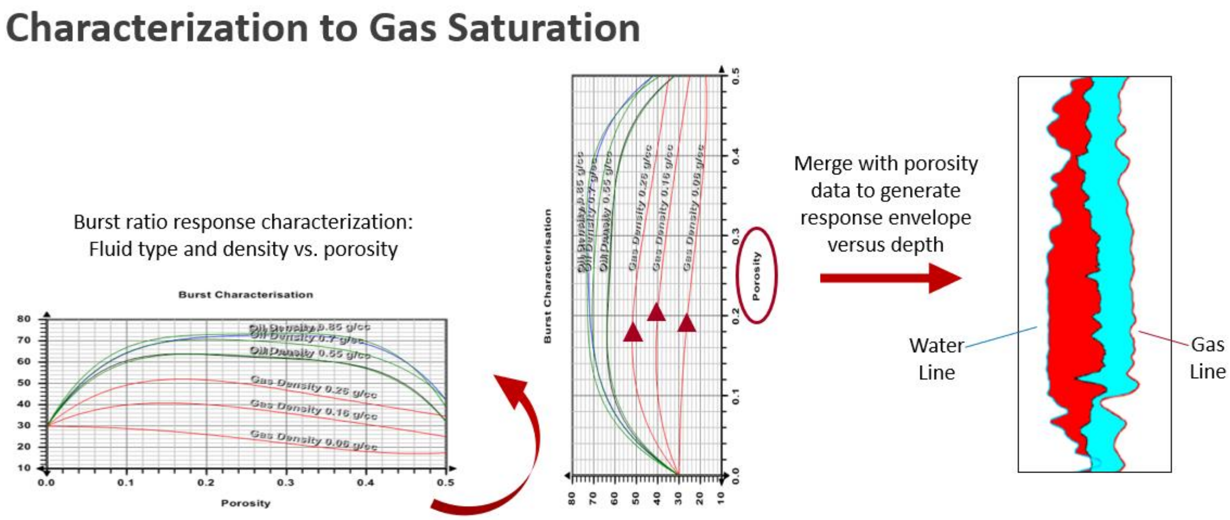

Figure 2: The MCNP predictive models are combined with porosity to generate a response envelope for gas and water.

The C/O model has also seen improvements from the traditional single lithology fan chart. Current C/O models take into consideration carbonates by using elemental calcium to silica ratio as well. Thus, carbon in the lithology is corrected for so that the C/O saturation is due to hydrocarbons only. Like the gas envelope, the C/O model illustrated in Figure 3 is merged with porosity to provide end points for oil and water.

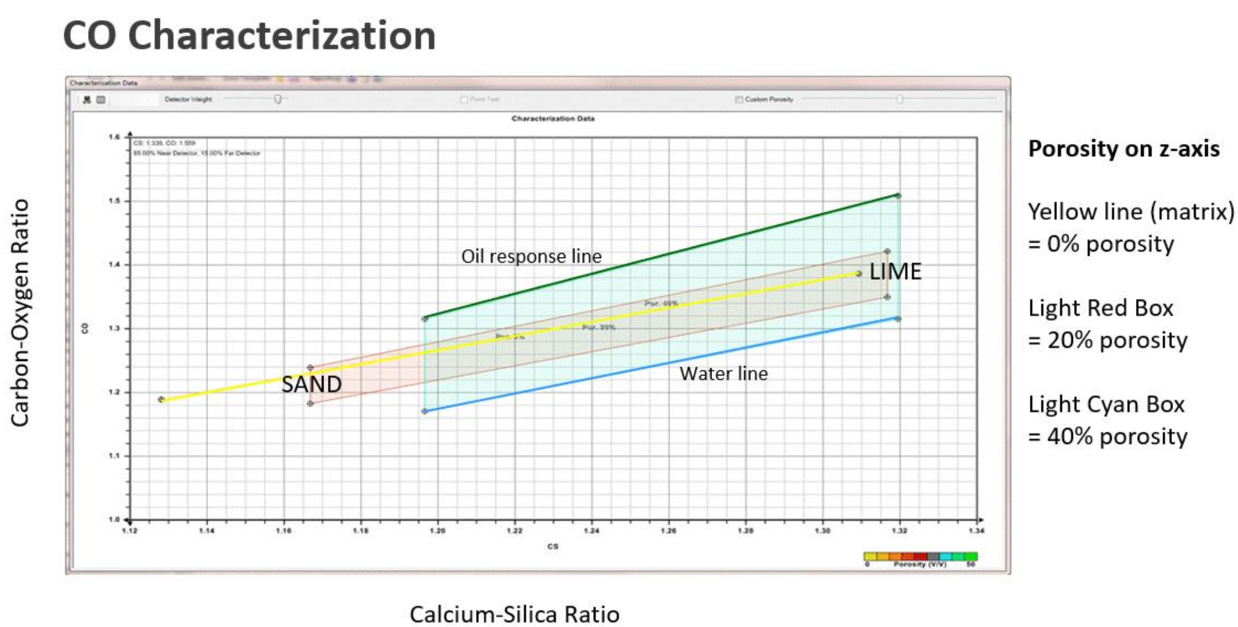

Figure 3: Carbon oxygen model: C/O vs Ca/Si, porosity on z-axis (into the page). The C/O modeled envelope will expand and contract with porosity providing end points for oil/water saturation calculation.

Figure 4 is an example of a petrophysical analysis using an MDPN instrument computed with software that includes the coherence envelopes used for saturations and quality control, OH and CH porosities, saturations, and comparisons of original reservoir fluids to current. For multi-year project monitoring, a time lapse comparison of fluids is critical for the understanding of the steam chamber movement and the remaining oil in place.

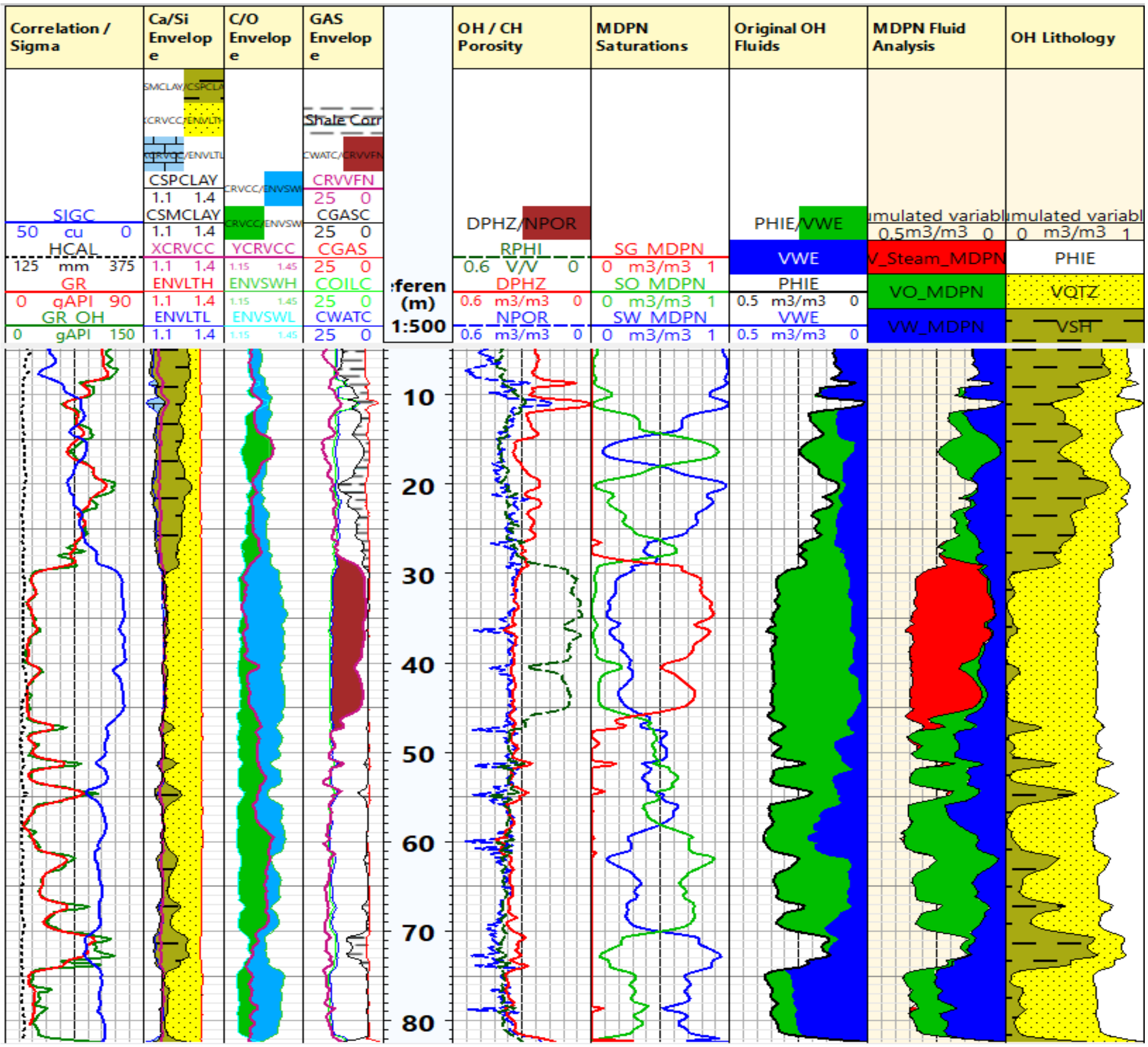

Figure 4: Oil sands MDPN example. Coherence envelopes from the models are used as data QC and provide the petrophysicist with endpoints for specific measurements. XCRVCC is measured Ca/Si ratio from the tool. YCRVCC is measured C/O ratio from the tool. CRVVFN is measured proximal-long capture ratio from the tool. Saturations and fluid volumes are then computed from the measured responses and the predictive models.

Conclusions

In conclusion, substantial advances have been made to pulsed neutron technologies and to their petrophysical workflows enabling a better understanding of the reservoir fluids in the oil sands. These results enable producers to fine tune the steam injection and improve on the overall economics of the project. MCNP predictive models for specific wellbore conditions generate coherence envelopes that enable data QC, diminish guess work and interpretation subjectivity, and increase consistency in interpretation results.

Acknowledgements

The author would like to thank Cenovus and Weatherford for the use of information and data.

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