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CRISP: A New Method for Determining Petrophysical Properties in Athabasca Oil Sands Plays

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Introduction

Representative laboratory measurement of petrophysical properties in unconsolidated media remains a challenging prospect. The nature of unconsolidated media often limits consistent and reliable measurement since grains can and do shift against one another, changing the porosity and permeability in response to drilling, sample extraction, and analysis. These issues are of high importance for production engineering in the Athabasca Oil Sands, a region of vast resources of heavy oil and bitumen contained within largely unconsolidated sand reservoirs.

Traditional routine petrophysical properties analysis in unconsolidated reservoirs includes residual saturation measurement by Dean Stark analysis, and porosity and permeability measurement by Net Overburden (NOB) sleeved plug analysis. The NOB method tends to yield porosity and permeability results in excess of reasonable expectations for these reservoirs, and with poor conformance with other sources of measurement such as geophysical well logs. Special Core Analysis (SCAL) projects are generally a much more accurate and representative approach for measuring porosity and permeability, but also carry a vastly higher cost, making routine and widespread use prohibitive.

AGAT continues to develop a new approach for measurement of porosity and permeability specifically for oil sands reservoirs. This approach, which involves both a newly developed device and a methodology built around it, is termed “Cyclically Restored In Situ Petrophysics”, or CRISP. CRISP is a significant step up from traditional Net Overburden (NOB) sleeved plug analysis in terms of repeatability, consistency, and types of data output. Recent comparative analytical testing alongside NOB analyses in the Lloydminster Formation has provided additional insight and evidence as to the efficacy of the new approach. CRISP is designed to be a routine analysis, requiring minimal sample material or special handling, and with comparable processing time to the NOB analysis.

This presentation will describe the underlying principles of CRISP, the essentials of the procedure and equipment, and the results of testing and validation programs to date.

Method Overview and Principles

The precise nature of grain arrangements in situ within unconsolidated reservoirs cannot be fully known. Even in well-recovered and processed core, the native-state reservoir textures and petrophysical properties are disrupted subtly but irrevocably at multiple stages of sample recovery. Processes such as drilling, core recovery, handling, preservation, and sampling all can introduce changes to oil sands core, which is plastic in nature.

Cemented zones and concretions present in formations that are otherwise unconsolidated could offer preservation of some true in situ grain relationships but only if they developed very recently after glacial packing of the sediment. Otherwise, they will represent the pre-packing grain arrangements. Investigations have shown that cemented zones also may involve diagenetic modification of the detrital sediment, removing certain phases as new ones are introduced, and so do not represent virgin-state grain relationships reliably.

The CRISP approach fundamentally aims to restore grain relationships that reflect in situ conditions. Restoration of grain relationships is achieved through a cyclic packing process which mimics ancient burial conditions and the repeated cycles of application and removal of glacial overburden pressure through the Pleistocene.

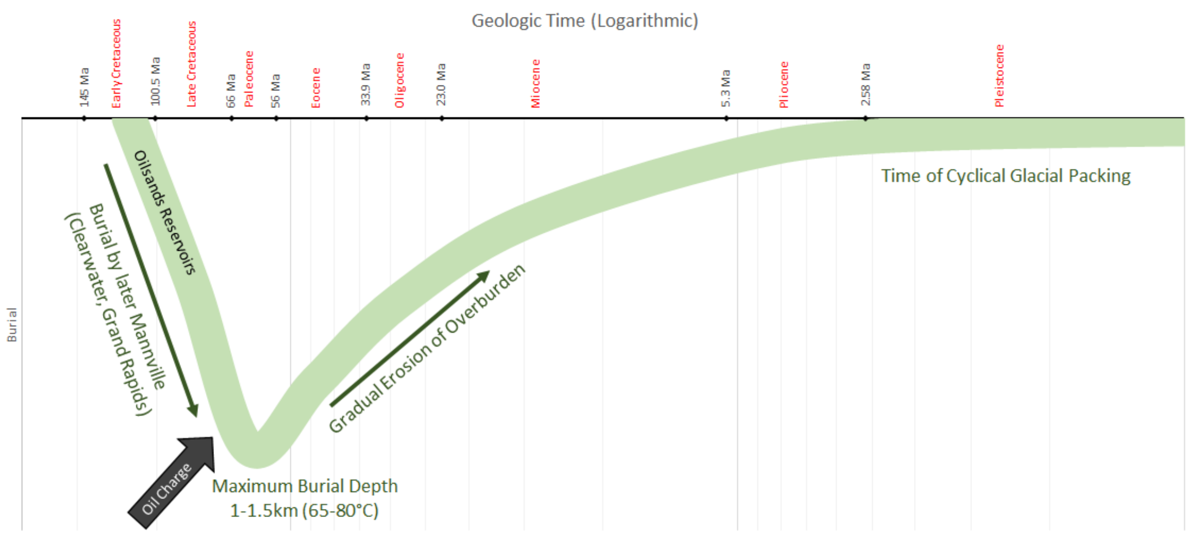
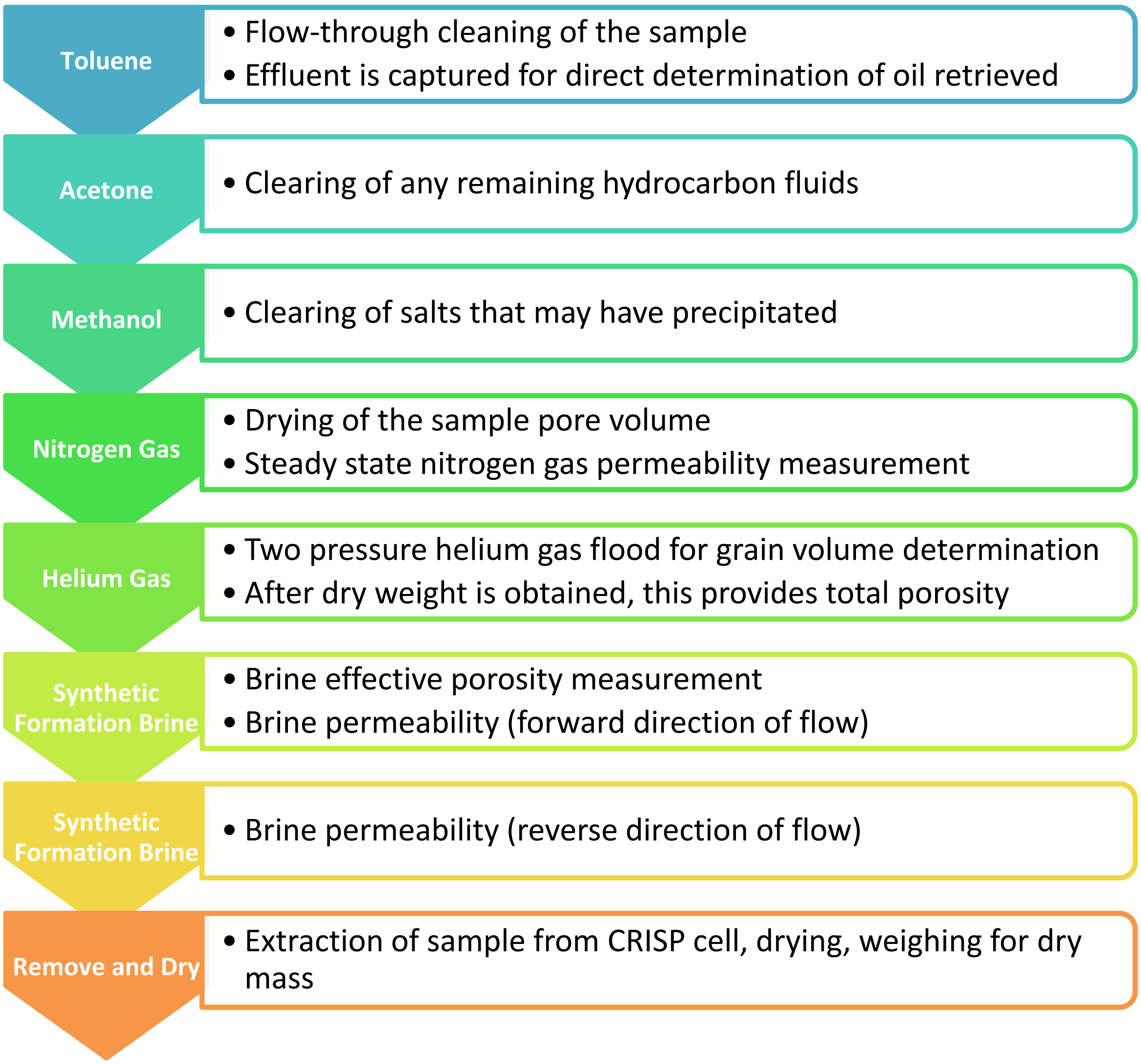


Figure 1: General illustration of burial history of heavy oil and bitumen reservoirs of the Mannville Group. Note logarithmic time scale. Maximum burial depths and timing after Adams et al. (2006).

The CRISP device developed by AGAT and industry partners involves a customized uniaxial piston cylinder cell capable of withstanding high pressure and maintaining a tight seal. A 1 inch plug, obtained by the same sampling approach as the standard NOB plug process, is weighed and loaded longitudinally into the cell. At both ends of the plug are located a screen and a mandrel.

The piston is driven by a hydraulic ram to apply longitudinal confining pressure to the sample within the cell. Pressure is applied through multiple cycles of loading and unloading, until maximum historical overburden pressure conditions and packing have been reached. The bulk volume is then obtained with high accuracy from the cylindrical shape of the cell and the precisely known position of the piston. Computed Tomography (CT) scans of the entire cell show that excellent cylinder shape is consistently obtained for samples within the device. Cylinder dimensions achieved with the CRISP device are in stark contrast to the imperfect cylinders obtained by the NOB plug method, also confirmed using CT scanning.

The CRISP analytical process involves several stages of application of both liquid and gas permeants. There is flexibility in the order and specific nature of working fluids applied, but the standard approach developed is as follows:



The dry and clean sand grains can then be used for further testing, such as particle size analysis and mineralogy. The retained toluene effluent can be analyzed by direct determination methods to obtain a mass-percent oil for the sample. With the mass of the dry grains and the oil measured, the water can be determined by mass-difference, providing an equivalent measurement to a Dean Stark analysis.

The test can be run on plugs cut in any orientation relative to the core axis. Some fines are expected to be produced into the effluent but are minimized with the applied screens in the CRISP sample setup.

Results and Discussion

The output from CRISP testing provides a vastly wider range of parameters than other routine petrophysical tests for oil sands reservoirs. In particular the method directly yields:

- Porosities
    - Helium (total)
    - Brine (effective)
- Permeability
    - Toluene liquid
    - N_2 gas
    - Brine forward
    - Brine reverse
- Bulk and grain densities
- Mineral, oil, and water mass fractions by weight, direct determination, and weight-difference, respectively

Initial testing on approximately 900 samples has demonstrated exceptional method repeatability and precision. The forward/reverse brine repeatability is very high, with variance of 0.71%. The accuracy was tested by running Berea Sand standards and showed a standard error of 4.4%, well within the expected 6% error. For oil sands reservoir sands the accuracy is still under verification but initial indications show excellent agreement with SCAL and geophysical log ranges for typical oil sands.

A 2021 R&D program continues to investigate the new approach with direct comparison to the NOB plug analysis method. At 75 locations in a single Lloydminster Formation core four plugs were taken, two oriented vertically and two horizontally. From these plugs both vertical and horizontal NOB and CRISP analyses have been completed.

For a given depth, the porosity values in representative oil sands plugs should have high agreement irrespective of orientation. Therefore, a comparison of vertical and horizontal plug porosity provides insight into the reliability of a given method. Better or consistent methods will produce data scattering closer to the 1:1 line, with lower variance (higher R^2 value). Figure 2 shows this relationship for the new method and for the NOB plug analysis method.

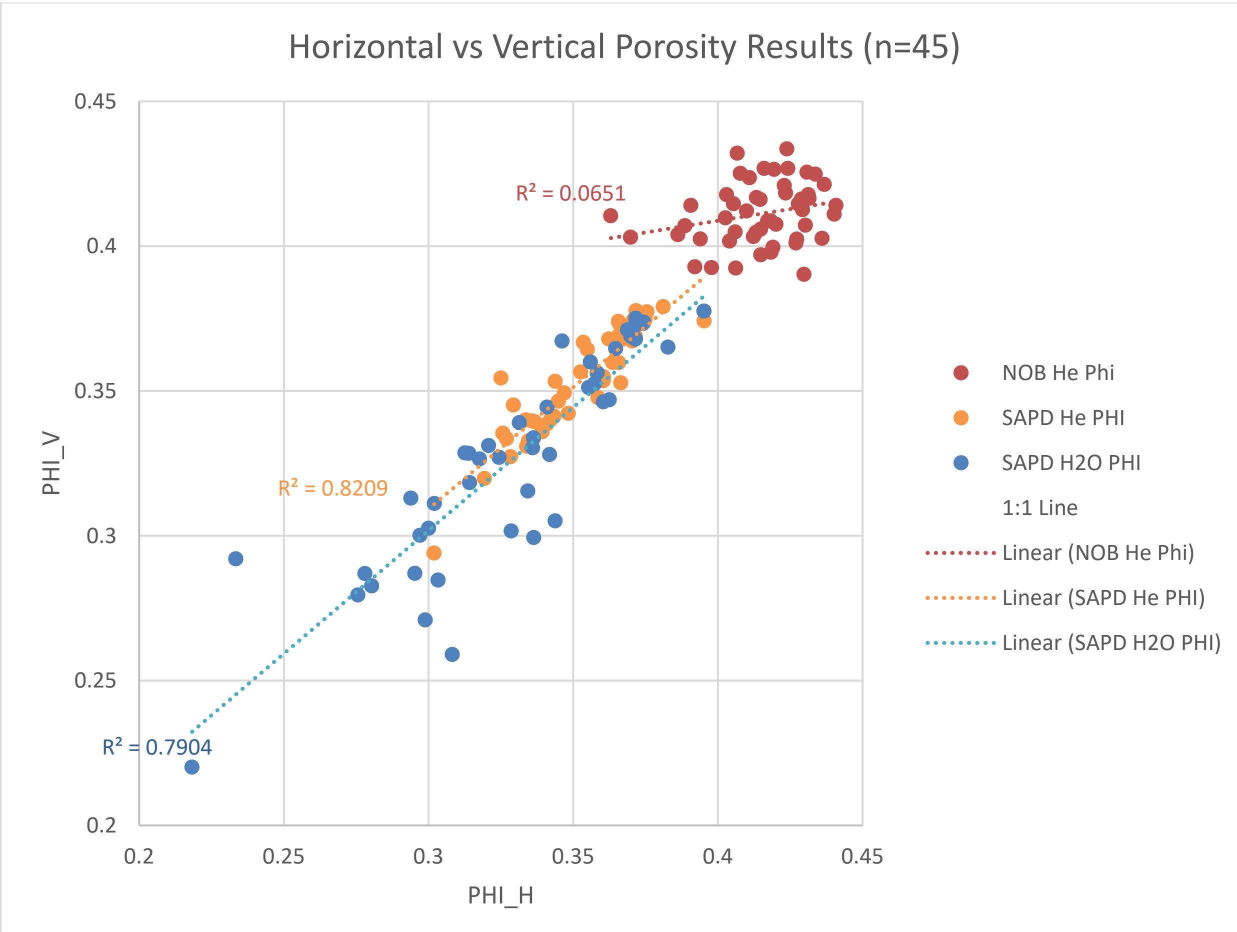


Figure 2: Porosity concordance between horizontally and vertically oriented plugs at the same sample position, for the new method and the NOB plug method.

Figure 2 illustrates the significant advancement afforded by the new method when compared to the NOB plug approach. The NOB plug results consistently show porosities that are unrealistic for reservoir conditions, and poor agreement between horizontal and vertical plugs from the same depth positions. CRISP results show significantly better agreement, plotting close to the 1:1 relationship and with high R^2 values. The porosity values of the CRISP method are also consistently lower than the NOB method, showing a porosity range that is likely more representative of in situ porosities.

The repeatability and consistency of the new method's measurement of permeability are demonstrated by the forward and reverse brine permeability data. Figure 3 shows this data for the first few batches of the latest test series. The results are remarkably consistent through a large range of permeability values, plotting directly on the 1:1 line and with exceptionally limited variance.

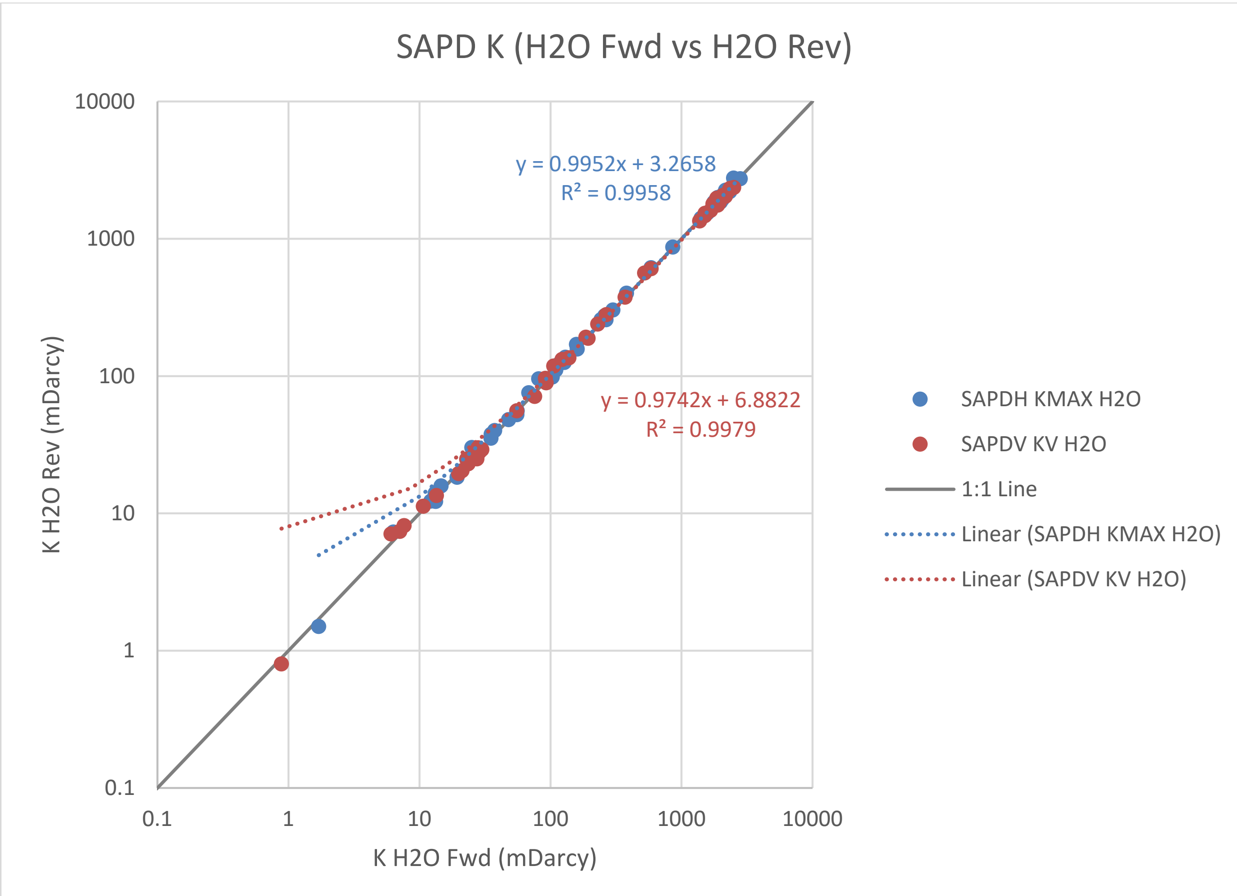


Figure 3: Concordance between forward and reverse synthetic formation brine permeabilities using the new method. KMAX values (horizontally oriented plugs) and KV values (vertically oriented plugs) are plotted as separate series.

CRISP represents a significant improvement in the precision of petrophysical measurements compared to other routine tests applied to unconsolidated reservoirs. Evidence suggests it also provides an equivalent improvement in accuracy, with respect to in situ petrophysical properties, but this is more challenging to quantifiably demonstrate. It is our opinion that cyclically packing the sample simulates the burial and glacial pressure history of the formation, creating samples with grain relationships that are a vastly better approximation of in situ texture.

The method yields a rich array of results for each sample, including data that is typically only obtained via Special Core Analysis testing programs. CRISP also uses the same format of extracted plug as the NOB method, does not require pre-cleaning by solvent extraction, and requires approximately one day to run.

Ongoing Development

We continue to develop this method and have several near-term R&D goals. Particular objectives are deeper method validation, automation for process efficiency, and analysis and interpretation of flow-meter data to seek additional reportable parameters and quality assurance and control indicators. We seek industry partnerships and expertise to continue development of the device and process, with the objective of assisting oil sands and heavy oil operators in obtaining reliable and representative routine petrophysical properties measurement.

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