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An Integrated Geomechanical, Petrophysical and Petrographical Study to Evaluate the Efficacy of a Plug Cleaning Technique for Ultra-Low Permeability Rocks

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Abstract

Core analysis practices recommend removal of residual fluids before laboratory measurements of porosity, permeability, and fluid saturations. The most common methods used for core cleaning are Dean-Stark and Soxhlet extraction. While these techniques are adequate for conventional rocks, they are -a) time consuming and b) may induce micro-fractures in unconventionals with ultra-low permeability, thus affecting permeability and porosity measurement. In order to reduce the cost and time of fluid extraction and measuring permeability for such rocks, the GRI crushed-rock technique was proposed. However, the crushing process may destroy connected micro-pores which would not be accounted for in subsequent measurements.

A cleaning method for ultra-low permeability rocks involving multiple cycles of pressurized CO_2 driven extraction has been previously proposed. The method employs automated gradual pressure release to avoid parting or fracturing the weak planes or the rock matrix during the CO_2 phase change. However, it is critical to ascertain that the permeability increase is resulting from removal of fluids alone and not due to induced fractures.

The paper seeks to investigate the effect of the supercritical CO_2 based cleaning process on the samples. The method undertaken is a multidisciplinary look utilizing a strength index, mineralogical composition, and studying the pore attributes and oil content before and after cleaning. Brazilian tensile strength is utilized as an index and is measured on multiple plugs at the same depth to assess whether samples develop fractures during cleaning. X-Ray Diffraction (XRD) is performed to characterize minerological composition while LECO TOC method and rock-eval pyrolysis are utilized to determine oil content. Pore attribute characterization is done by Scanning Electron Microscopy (SEM) and thin section study.

Source rock analysis confirmed the extraction of pore fluids. Preliminary results showed that tensile strength did not decrease significantly following fluid extraction. Comparison of the strength index before and after cleaning showed that a lower decrease in tensile strength is associated solely with the cleaning

process while a bigger difference indicates presence of fractures. Additional pore attribute and mineralogical studies supported the results observed in the strength index characterization.

The suggested additions to the previously proposed cleaning method address uncertainties in core cleaning and help to enable representative measurement of petrophysical properties of ultra-tight rocks. The integrated study combining strength index characterization, petrographical and source rock analysis provides a comprehensive validation method for the effectiveness of the Huff & Puff cleaning technique.

Introduction

Permeability measurement in tight oil reservoirs is an important input for geological models to predict reservoir production and help optimize well stimulation techniques. More specifically, the sustainable economic success of a reservoir depends in a big part on the connectivity of the pores and matrix permeability (Tomomewo et al. 2020; Alamooti 2020). In order to measure permeability of tight rocks, crushed-rock based technique is widely used. However, the crushing process may destroy rock fabric, texture and connected micro-pores which would not be accounted for in subsequent measurements (Rosen et al. 2014; Handwerger et. al. 2011). Measuring the permeability under stressed conditions in intact rock is more representative of the subsurface flow as the rock fabric and spore structure are maintained. Rosen et al. (2014) proposed a method and designed a precise equipment to measure steady state permeability using supercritical fluids in intact cylindrical plugs at isostatic reservoir stress.

Core cleaning must be conducted to completely remove hydrocarbons, water, and possible mud contamination from pore volume of the samples before core analysis measurements, i.e., porosity, permeability, and fluid saturations measurements. There are different methods used in the petroleum industry for core cleaning such as distillation/extraction, flow-through cleaning, centrifuge flushing, supercritical fluid extraction, critical-point drying, and gas-driven-solvent extraction (American Petroleum Institute, 1998). Particularly, Dean-Stark and Soxhlet extraction are the most common distillation/extraction methods used for core cleaning. However, these techniques usually take long durations. For instance, Soltani et al. (2019), mentioned in their study that it will take 9–16 weeks to clean carbonate rocks using the Soxhlet extractor. It takes even longer period of times to clean unconventional rocks such as shales when using distillation/extraction methods (Stewart 1952; Conley and Burrows 1956).

Not only Dean-Stark and Soxhlet extraction are time-consuming, these may also induce damage in the form of micro-fractures or partings in unconventionals with ultra-low permeability, thus affecting permeability and porosity measurement. It is important to keep in mind that an effective cleaning method will be one that causes minimal damage to the rock when removing oil from plug samples. Moreover, McPhee et al. (2015); Ahmed et al. (2018); Jelavić et al. (2018) mentioned in their studies that hot Soxhlet extraction can damage rocks with clay or sensitive minerals. More specifically, the origin of damage can be dehydration of clays or gypsum or rock erosion during the cleaning process itself (Soltani et al. 2019).

In order to reduce the cost and time of fluid extraction for low to ultra-low permeability rocks, the GRI crushed-rock technique was proposed (Guidry et al. 1996). However, due to crushing the rock and its drawbacks, an alternative technique for removal of fluids of ultra-low permeability rocks using intact plug samples was previously proposed (Guedez et al. 2019). The method uses pressurized CO_2 which is later released in a controlled manner for water and hydrocarbon extraction and to avoid parting or fracturing of the weak planes or rock matrix during the CO_2 phase change. This paper looks to investigate the effect of the supercritical CO_2 on the samples, as well as show that this CO_2 driven extraction method is not creating fractures in the samples by using Brazilian test, X-Ray Diffraction, SEM, thin section (TS) analysis, LECO TOC test and Rock-Eval pyrolysis. The study also seeks to demonstrate, that the permeability increase after cleaning, is resulting from removal of fluids alone and not due to induced fractures.

Samples from different low permeability formations were used for this study. Results indicated a significant decrease in oil content after cleaning. Furthermore, results from the strength index characterization, pore