INVESTIGATION OF RESERVOIR ROCK PROPERTIES MEASUREMENT METHODS FOR CONVENTIONAL SANDSTONE AND UNCONVENTIONAL BAKKEN SHALE

by Chiang Cheng Siew, Tadesse Teklu

Abstract

The ability to accurately measure rock properties is important to oil and gas field development since the implementation of resources, production forecasts, and the economics of the reservoir are derived from this foundation. This study measured the porosity and permeability of 118 sandstone and 10 Bakken shale samples using a variety of non-destructive methods that are used in industry and can provide a basis for more complex techniques. Measuring these properties can be difficult depending on the composition of the reservoir rock, especially for unconventional shale due to their tight and complex structure. Many of the oil and gas reservoirs are sandstone and carbonates, but significant quantities of oil and gas are produced from low-permeability unconventional shale reservoirs that have been developed in recent years around the world.

Introduction

The capacity of a rock to contain fluids is governed by the porosity, and the ease of fluid movement is measured by the permeability. Rocks are permeable when they are porous, but they may be porous without being permeable, thus porosity and permeability do not necessarily have a quantitative relationship to one another. In this study, conventional sandstone and unconventional shale were tested in various core analysis methods under stress representative of reservoir conditions, and the accuracy and efficiency of each method was used to compare the different methodologies and the behavior of each reservoir core. Sandstone consists of sand-sized grains of minerals that are mostly uniform in size, and shale consists of fine-grained sedimentary rock formed with the compaction of silt and clay-sized minerals. As a reference for the experiments, the densities for sandstone collected from the equipment were compared to the standard density of sandstone of 2.65 g/cm^3. Shale, on the other hand, does not have a consistent density due to its composition and biogenic material. Figure 1 to the right shows the microscopic structure of shale on the left side and sandstone on the right side, and it is possible to observe that shale has a smaller pore throat compared to sandstone.

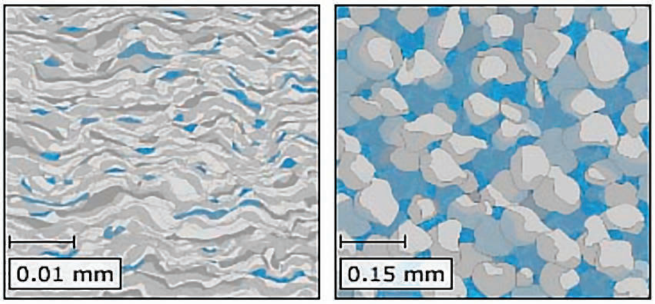

Figure 1: The shale pore throat separation of 0.01 mm is shown on the left side and the sandstone pore throat separation of 0.15 mm is shown on the right side.

Methodology

Techniques used to measure porosity and permeability focused on applications of Boyle's Law, Darcy's Law, Archie's equation and the Resistivity equation. A variety of equipment common in industry was utilized. This includes the Core Measuring System-300 (CMS-300), the UltraPycnometer-1200e, and Ruska Permeameter. Other methods used were fluid saturation with a brine solution and resistivity analysis.

$$P_1V_1 = P_2V_2$$

Boyle's Law

$$Q = \frac{-kA\Delta P}{\mu L}$$

Darcy's Law

$$F = \frac{\rho_o}{\rho_w} = \frac{a}{\phi m}$$

Archie's Equation

$$R = \rho * \frac{L}{A}$$

Resistivity Equation

All methods mentioned above were applied to the sandstone core samples, but only the CMS-300 and pycnometer could be used to measure shale samples due to the tightness of the cores. Using the CMS - 300, samples were placed under high confining pressure to observe the sandstone and shale's response to overburden.

Results

In this study, the porosities from the CMS-300, Pycnometer, and calculations from the basic core data were plotted for comparison.

- CMS-300 vs Estimated Porosity (Figure 2) for sandstone shows a moderate spread associated with the heterogeneity of the core samples. This was useful since this prediction of porosity values gave us a better working understanding of the nature of our samples.
- CMS-300 vs Pycnometer for shale (Figure 3) appears to have the closest spread centered about the trendline showing a general agreement of the porosity measurements. For sandstone (Figure 1) shows a moderate spread of the data points.
- Resistivity analysis was excluded from this visualization since measured values were far from the ideal-line and associated with significant error.

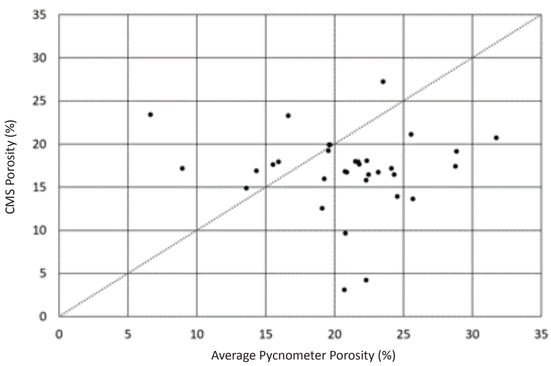

Figure 1. 1-inch Sandston Cores: CMS vs Pycnometer Porosites (%)

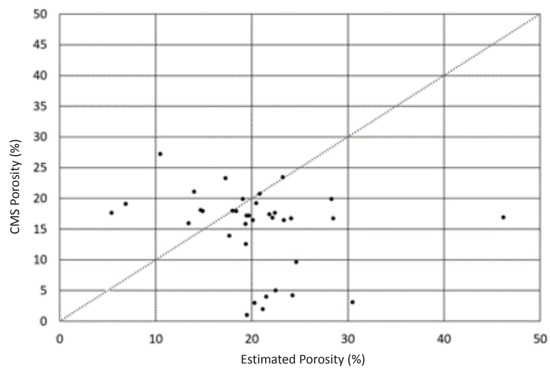

Figure 2. 1-inch Sandstone Cores: CMS v Estimated (%)

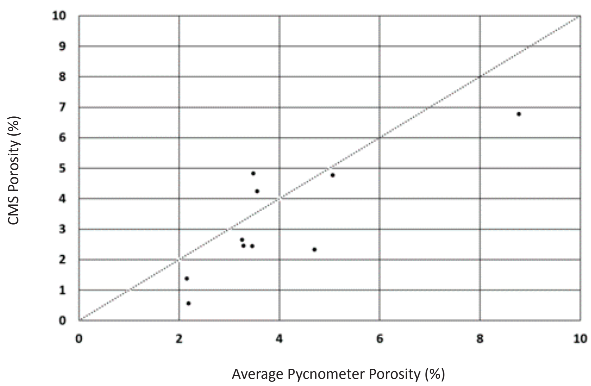

Figure 3. 1-inch Shale Cores: CMS vs Pycnometer Porosites (%)

Increasing the pressure of the CMS-300 would tend to decrease the porosity and permeability of the core sample due to the constraint of the pore spaces, but this trend was limited for the Bakken shale core samples.

The plots on the right side, which highlight permeability vs net stress show how it was possible to observe the decreasing trend of permeability as pressure increases for every shale core sample (with the smallest permeability of 0.001 mD for shale 3 and the largest permeability of 0.0706 mD for shale 2).

This data correlation is important to understand the behavior of shale reservoirs in the field, and to make the distinct differences between sandstone and shale reservoirs. Sandstone cores are mostly conducted in undergraduate laboratories across the United States, but this research was able to conduct experiments with shale to further develop the understanding of the needs for hydraulic fracturing in shale formations.

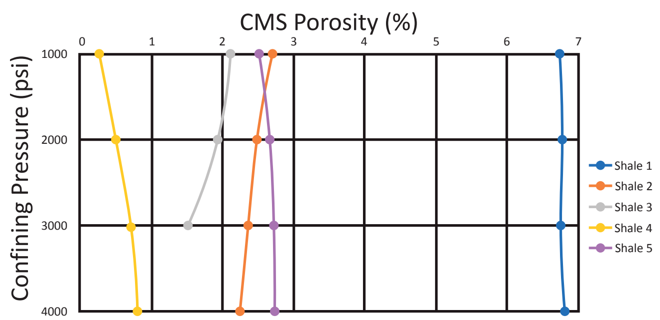

Figure 4. Shale Porosity Reaction to Overburden

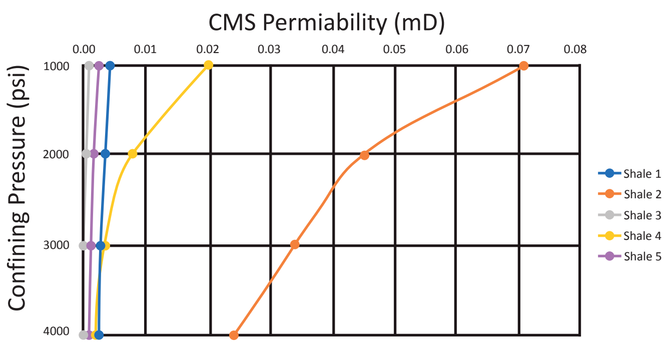

Figure 5. Shale Permiability Reaction to Overburden

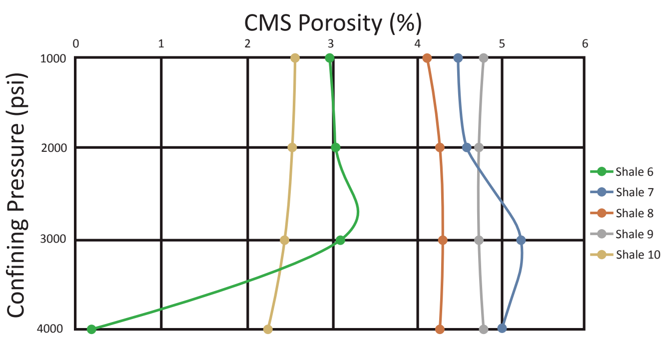

Figure 6. Shale Porosity Reaction to Overburden

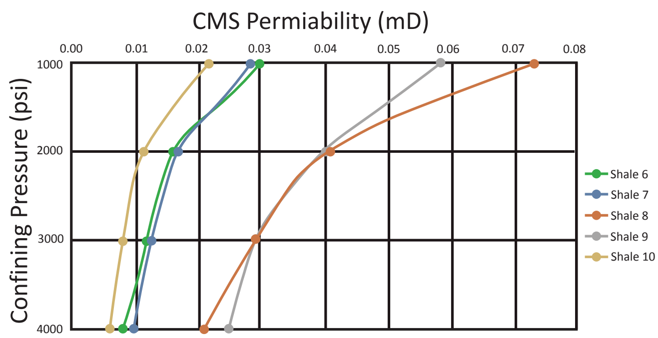

Figure 7. Shale Permiability Reaction to Overburden

Conclusions and Recommendations

An important consideration is that while porosity is a scalar attribute, permeability can be considered a vector, meaning that measurements of this property are path dependent. The CMS and Pycnometer are our most accurate tools. For future research, it is recommended to utilize the CMS-300 and Pycnometer equipment due to their accuracy in values for porosity and permeability compared to other equipment due to less tolerance to human error, but the estimated values using core basic data is a good start for preliminary understanding of core samples. The methods used in this study could be applied to other core samples such as limestone and dolomite. Drilling into shale formations has been growing, and it is important for undergraduate students to perform experiments in these unconventional reservoirs in the lab. Since the discovery of oil and gas, universities have been using conventional core samples to assist in the understanding of petroleum engineering, however the same tools used for sandstones could also be used for shale core samples. In conclusion, there must be a push for educational systems to implement unconventional core sample studies in curriculum in order for students to catch up with the developing oil and gas industry.

References

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About the Author

Siew Chiang is currently a junior at Mines, studying petroleum engineering with a minor in economics. She conducted the research under the Petroleum Engineering Department together with Erik Villar under the supervision of Dr. Tadesse Teklu. Siew had the objective to explore the main rock properties that are essential in the production of oil and gas from both sandstone and shale reservoirs, and experiment with the technical equipment used in the petroleum industry. After graduating from Mines in 2021, Siew plans to apply her research experience and knowledge gained to graduate school.