[PS]Application of Mercury Injection Capillary Pressure to Mudrocks: Conformance and Compression Corrections*

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Abstract

Mercury injection capillary pressure (MICP) is a commonly used technique for measurement of porosity, pore throat size distribution, and injection pressure vs. mercury saturation for many types of rocks. The latter two are correlated to and can be used to estimate permeability. Problems for MICP application in mudrocks are associated with two types of system errors: conformance and compression effects. These two sources of error are well recognized, but quantitative analysis of the two sources of error is lacking, and standard procedures to correct them do not exist.

In this study, a new method for conformance and compression corrections was developed, and permeability was estimated based on the corrected MICP data. The method was applied to five Eagle Ford Shale samples. Conformance correction is based on comparison of mercury injection volume vs. pressure curves between epoxy-coated and uncoated block samples. An epoxy with high compressive strength was used for sample coating. Bulk compressibility of the samples was measured using the epoxy-coated samples in MICP. Compression correction is based on the calculation of compression before and after mercury intrusion at each pressure step in the MICP experiment. Solid-phase and pore compressions were defined and quantified. Compression corrections on porosity, pore throat size distribution, and injection pressure vs. mercury saturation were performed. Results show that compression effect, although regarded as one of the major sources of error, is generally insignificant with compressibility values for the samples in a level of 1E-7 psi-1. Conformance effect and correction is more important for porosity and permeability estimation. MICP-based porosity results were compared to helium porosity. Permeability was estimated based on the corrected MICP saturation curve and a regression-type equation from literature. Estimated permeability values are comparable with the laboratory measured values for Eagle Ford Shale samples. Because intact core plug samples are not required in MICP experiment as in the pulse/pressure decay method, the corrected MICP-based method can serve as an easier and faster way for permeability evaluation of mudrock samples.

Reference Cited

Peng, S., B. Loucks, T. Zhang, and J. Shultz, 2017, Application of Mercury Injection Capillary Pressure to Mudrocks: Conformance and Compression Corrections: Marine and Petroleum Geology, v. 88, p. 30-40.

Application of Mercury Injection Capillary Pressure to Mudrocks: Conformance and Compression Corrections

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Problem Statement and Objectives

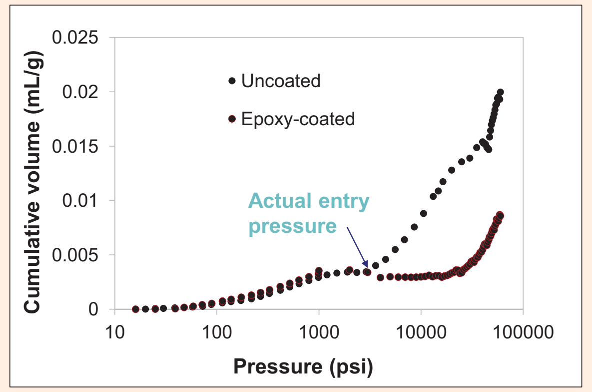
- Mercury injection capillary pressure (MICP) is a commonly-used technique for pore system characterization;
- MICP can provide not only pore volume and porosity, but also pore throat size volumetric distribution and capillary pressure vs. saturation;
- Two types of measurement errors have been recognized to affect the measurement of porosity in mudrock, that is, conformance and compression;
- In this study, a new method is developed for conformance and compression corrections based on bulk sample compressibility and a conceptual model of compression in mercury intrusion.

Samples

- Five Eagle Ford Shale samples. Table below includes mineralogy and TOC. Unit is %.

Sample #	Quartz	Calcite	Clay mineral	TOC
1	33.8	31.4	20.2	2.6
2	17	62.2	13.6	4.9
3	9.8	66.6	19.6	3.7
4	15.1	65.1	10.5	3.2
5	5.9	89	3.2	1.1

Conformance Correction



- Uncoated sample: Volume change caused by bulk compression and Hg pore intrusion
- Coated sample: Volume change only caused by bulk compression
- Coating epoxy: high compressive strength

Figure 1. Conformance correction for sample 1. Pressure at the deviation point between the plots of epoxy-coated and uncoated samples, as indicated by the arrow denotes the actual entry pressure.

Figure 2. Epoxy-coated block samples after MICP test. The coating remained intact after high-pressure MICP test.

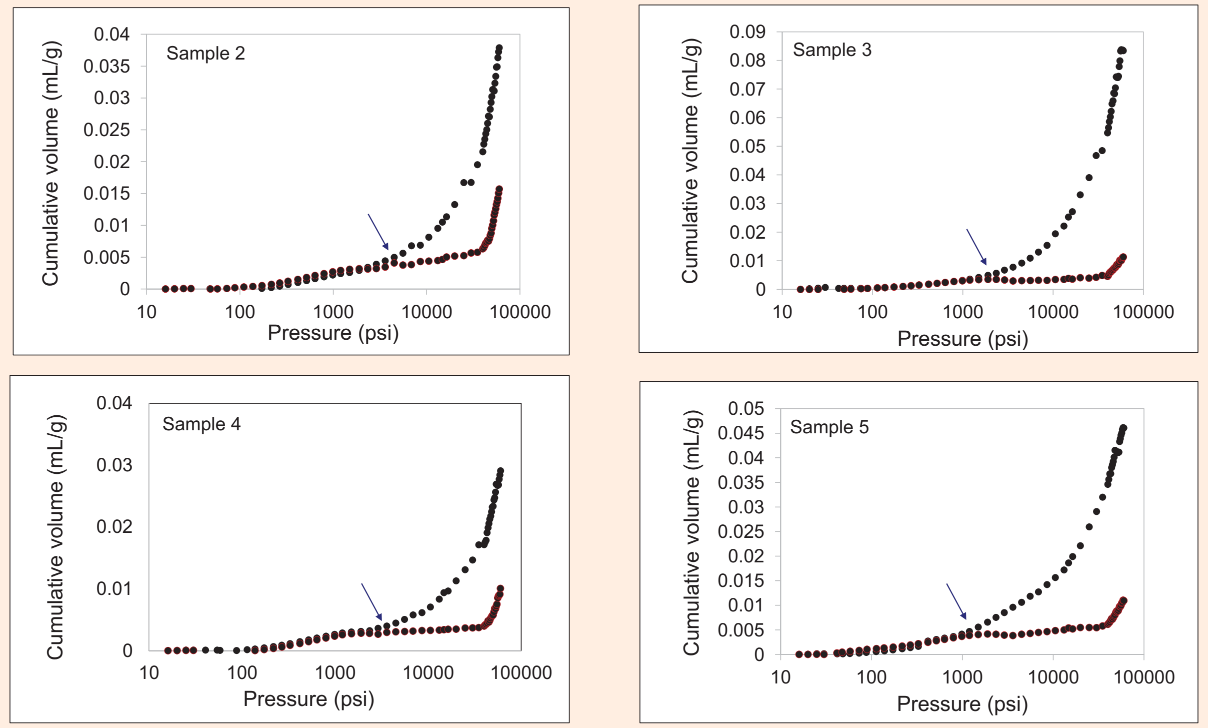


Figure 3. Conformance correction for samples 2-4. Actual entry pressure, denoted by the arrows, for the four samples ranges from ~1000 to 3500 psi, corresponding to pore throat diameters of 65-200 nm.

Results after Conformance Correction

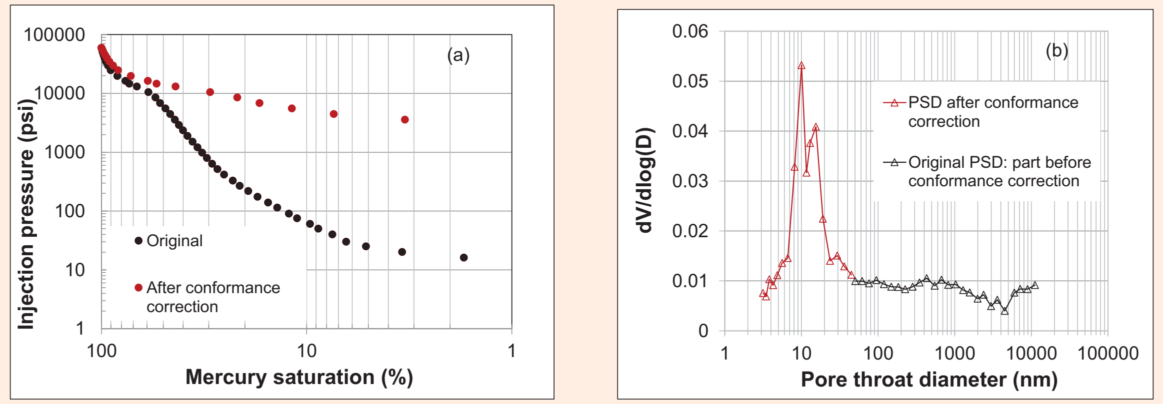
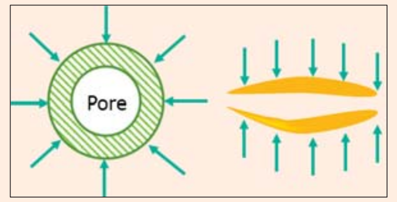


Figure 4. Comparisons of MICP data with and without conformance corrections for sample 1. (a) Capillary pressure curves and (b) pore throat size distribution (PSD) before and after conformance correction. In (b), the combination of the red and black curves is the original pore throat size distribution before conformance correction.

Compression Correction

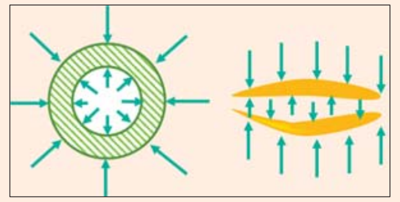
A conceptual model



$$\left(\frac{\Delta V}{V}\right)_1 = \int_{P_e}^{P_{D\_bef}} f_D(P)C(P)dP$$

C: jacketed bulk compressibility; compression of both pore and solid

- Phase I compression before mercury intrusion.
- Mercury injection causes compression of both solids and pores.



$$\left(\frac{\Delta V}{V}\right)_2 = \int_{P_{D\_aft}}^{P_{max}} f_D(P)C'(P)dP$$

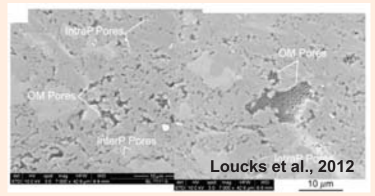
C': unjacketed bulk compressibility; compression of only solid

- Phase II compression after mercury intrusion.
- No further pore compression and only solid compression occurs after mercury intrusion.

Determination of *C* and *C'* for two Barnett samples

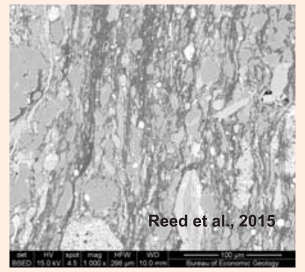
- *C*
  - From MICP test using a coated mature Barnett sample
  - The sample has 90% organic matter pores
  - Compression includes both pores and solids

Mature Barnett sample



- *C'*
  - From MICP test of three coated immature Barnett samples
  - The samples have minimal pores
  - Compression only contributed by solids

Immature Barnett sample



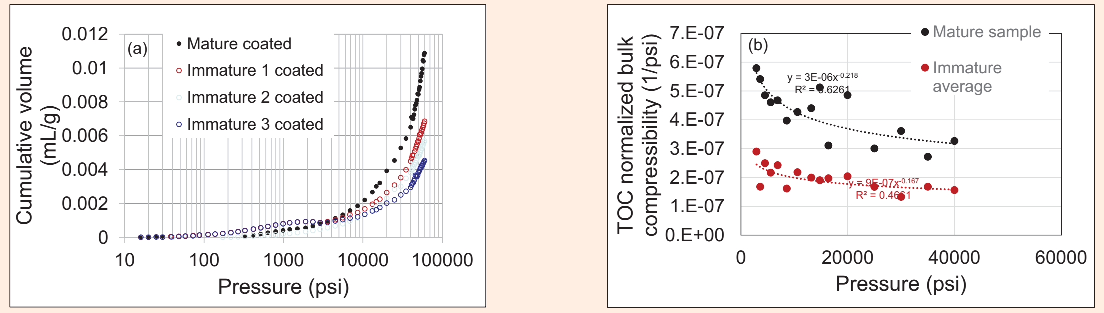


Figure 5. Measurements of compression of mature and immature Barnett Shale samples. (a) Cumulative injection volume under different pressures. (b) Calculated compressibility of the mature Barnett Shale sample and the average of the three immature samples.

Total compression correction

- Pore compression: not included in correction when comparing to helium porosity

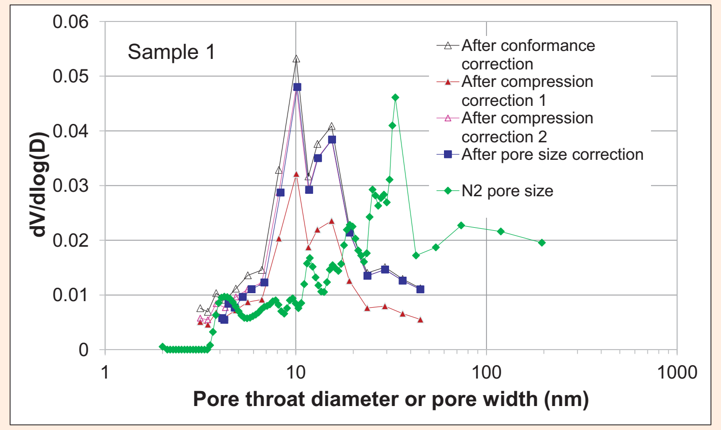
$$\left(\frac{\Delta V}{V}\right)_1 = \int_{P_e}^{P_{D\_bef}} f_D(P)C(P)dP \Rightarrow \left(\frac{\Delta V}{V}\right)_1 = \int_{P_e}^{P_{D\_bef}} f_D(P)C'(P)dP$$

$$\left(\frac{\Delta V}{V}\right)_{Total} = \int_{P_e}^{P_{D\_bef}} f_D(P)C'(P)dP + \int_{P_{D\_aft}}^{P_{max}} f_D(P)C'(P)dP = \int_{P_e}^{P_{max}} f_D(P)C'(P)dP$$

Determination of *C* and *C'* for Eagle Ford samples

- *C* can be calculated based on cumulative volume vs. pressure data obtained from the MICP for epoxy-coated samples
- it is difficult to measure *C'* using MICP because it is difficult to differentiate the mercury injection volume caused by solid compression from those caused by pore compression.
- We used two indirect methods for defining *C'* for the five Eagle Ford samples. The first method (correction 1) is to use the *C'* value measured on the immature Barnett Shale samples as *C'* for the Eagle Ford samples (method 1). The second method (correction 2) uses the ratio of *C'/C* obtained from the immature and mature Barnett Shale samples and assumes the ratio holds for other shale samples.

Results after Compression Correction



- Correction 2 honors the difference of compressibility between different shale samples
- Comparable with N_2 pore size distribution after correction 2 in respect of pore volume

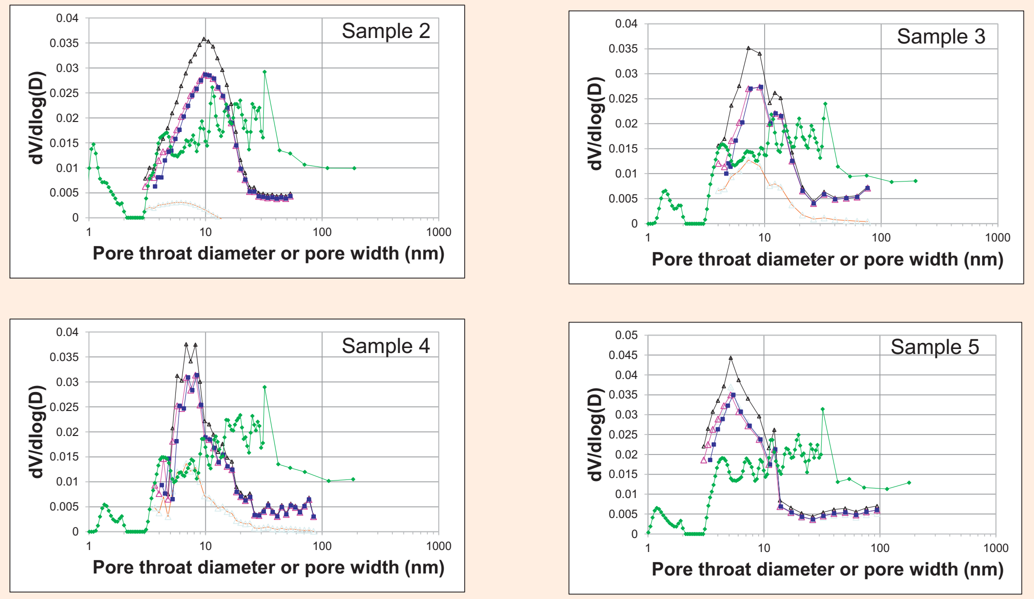
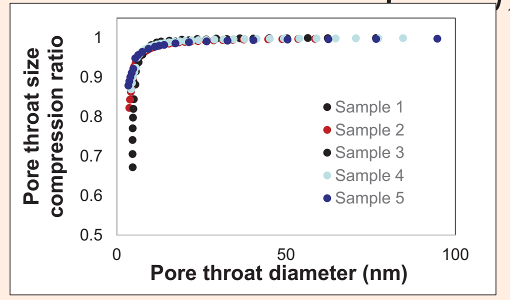


Figure 6. Pore throat size distribution after conformance and compression corrections, and pore size distribution from N_2 adsorption.

- Pore throat size distribution (MICP) is different from pore size distribution (N_2 adsorption)
  - Pore throat size distribution: contains information of connection
  - Pore size distribution: a geometric measure
- Pore volumes from pore or pore throat size distribution curve are similar
  - $\int \frac{dV}{dlog(D)} dlog(D)$

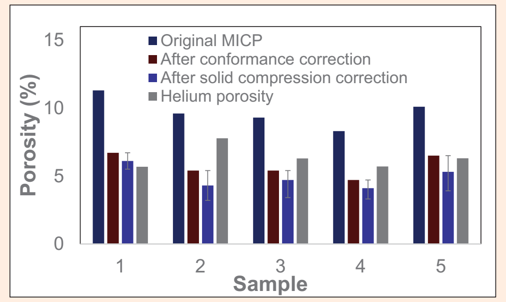
Pore throat size compression and correction

$$\left(\frac{\Delta V_{pore}}{V}\right) = \int^{P_{D\_bef}} f_D(C - C')dP$$



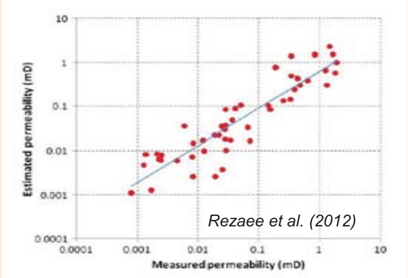
- Pore compression based on original pore size
  - $a^3 = 1 - \frac{\Delta V_{pore}}{V_{pore}}$
- Smaller pores have larger pore compression
- The largest compression α: 0.65 to 0.86
- Overall pore compression effect on pore throat size distribution (blue curves in Fig. 6: not significant

Porosity after corrections

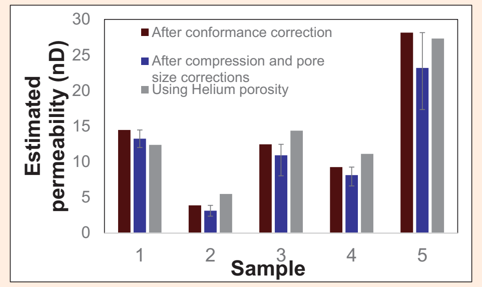


- MICP without correction overestimates the porosity
- Sample 1: MICP corrected porosity is similar to helium porosity
- The other samples: MICP corrected porosity is smaller
  - Pores corrected through <3 nm pore throat (Fig. 6)

Permeability estimation based on MICP



- $logk = -1.92 + 0.949logPhi + 2.18logr_{10}$
  - Phi: porosity (%),
  - r_{10}: pore throat radius (µm) corresponding to 10 percentile of the mercury saturation
- Mainly to examine the influence of conformance and compression corrections on permeability calculation



- Conformance correction: significant effect on permeability estimate
  - Permeability in mD level without conformance correction (not shown in the figure)
- After conformance correction:
  - Difference in permeability estimates is small
  - In the range of 5-30 nD

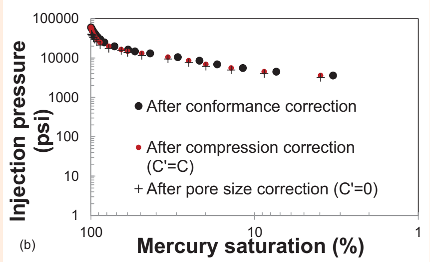


Figure 7. Sensitivity analysis of *C'* on capillary pressure curves for two extreme cases, i.e., *C'=C* and *C'=0*. Different *C'* values have minor influence on capillary pressure curves.

Conclusions

- A new method of conformance and compression corrections is established
  - Determined actual Hg entry pressure
  - Quantified compression effect
- MICP porosity after corrections
  - Similar with helium porosity for samples without <3 nm pores
  - Smaller than helium porosity for samples with <3 nm pores
- MICP-based permeability estimate after corrections
  - Falls in a reasonable range for Eagle Ford Shale
  - Conformance correction is more important than compression correction

References: Peng, S., B. Loucks, T. Zhang, J. Shultz, 2017. Application of Mercury Injection Capillary Pressure to Mudrocks: Conformance and Compression Corrections. Marine and Petroleum Geology, 88, 30-40. And references therein.

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