Interpreting Permeability from Mercury Injection Capillary Pressure Data*

Alton A. Brown¹

Search and Discovery Article #41660 (2015)**
Posted August 17, 2015

*Adapted from poster presentation given at AAPG 2015 Annual Convention and Exhibition, Denver, Colorado, May 31 – June 3, 2015
**Datapages © 2015 Serial rights given by author. For all other rights contact author directly.

¹Consultant, Richardson, TX, USA (altonabrown@yahoo.com)

Abstract

Laminar flow theory predicts a strong correlation between permeability and pore-throat distribution as revealed by Mercury Injection Capillary Pressure (MICP) data. Previous studies have developed relationships between MICP data and permeability; however, the permeabilities predicted by different methods can differ substantially from the measured permeabilities and from each other, especially in low permeability samples of interest for unconventional reservoirs. The purposes of this study are to evaluate why there is such large scatter, identify algorithms that best predict permeability over a wide range of permeabilities, and evaluate what type of permeability is actually measured by MICP data. Precision of permeability predictions is low due to insufficient MICP pressure measurements, assumption of MICP curve shape, permeability anisotropy of geological samples, and low precision and accuracy of permeability measurement of tight rocks. Four methods for estimating permeability from MICP data are found to have small bias and reasonable precision over a wide range of permeability: the modified Purcell, the Katz-Thompson Lc, Katz-Thompson Lh, and the Swanson methods. A weighted average of these permeability estimates corrects for accuracy problems and increases permeability estimate precision. However, this MICP-predicted average permeability still varies from measured Klinkenberg-corrected steady permeability by an average of a factor of two. This mismatch may be more apparent than real. Restoring reservoir stress prior to conventional permeability measurement fails to remove completely the core damage caused by microfractures created during extraction, preparation, and storage of tight rock samples from deep boreholes. MICP permeabilities are estimated from the pore-throat distributions, which do not include the significant flow contributions from microfractures. Difference between MICP permeability estimates and measured permeability of tight samples may be caused by the inability of conventional permeability analysis to remove damage effects by stress restoration. If so, MICP permeability estimates are as good as or better than permeability measured from tight, subsurface samples. MICP permeability is either the ambient matrix permeability or a stressed matrix permeability, depending on the relative magnitude of in situ reservoir stress and Hg pressure at threshold saturation.
Microporous Porosity Model: The Microporous and Mesoporous Analysis System (MIPS) is a method used to estimate the amount of microporous material in a sample. The MIPS analysis provides information on the distribution of micropores and mesopores, which are important for understanding the permeability of a material. MIPS is an automated method that provides a comprehensive analysis of the pore structure, including the pore size distribution, which is critical for understanding the transport properties of a material. MIPS is a valuable tool for characterizing the pore structure of a wide range of materials, from geological samples to engineered materials.

Microporous Porosity Theory: Mohammad A. Raza and Yehia M. Mostafa (2013) have developed a theoretical framework for understanding the transport properties of microporous materials. This framework includes the application of Darcy's law, which describes the flow of a fluid through a porous medium, to microporous materials. The authors have also developed a microporous porosity model that incorporates the effects of micropore structure on fluid transport. This model provides a quantitative description of the relationship between micropore structure and fluid transport properties, which is critical for understanding the behavior of microporous materials in a wide range of applications.

Microporous Porosity Applications: Microporous materials have a wide range of applications, including in the development of new materials for water treatment, gas storage, and energy storage. Microporous materials are also used in the food industry, where they are used to control the release of volatile compounds in food products. Microporous materials are also used in the pharmaceutical industry, where they are used to control the release of drugs.

Microporous Porosity Characterization: Microporous porosity can be characterized using a variety of techniques, including mercury intrusion porosimetry (MIP), nitrogen adsorption-desorption, and small-angle X-ray scattering (SAXS). These techniques provide information on the size and distribution of micropores, which is critical for understanding the transport properties of a material. Microporous porosity can also be characterized using scanning electron microscopy (SEM) and transmission electron microscopy (TEM), which provide information on the morphology and structure of microporous materials.

Microporous Porosity Future Directions: Future studies on microporous porosity should focus on developing new techniques for characterizing microporous materials, as well as on developing new models for predicting the transport properties of microporous materials. These studies will be critical for advancing our understanding of microporous materials and for developing new applications for these materials.
Presented at AAPG Annual Meeting, Denver, 2015

Previous literature studies have provided more comprehensive tests of MICP permeability prediction models than that presented here. See Comi ... bility samples and to use these insights to correct the low permeability MICP estimates to better match steady permeability test measurements.

**Permeability and Stress**

Prior to its extraction, mercury permeability measured with capillary injection techniques is often corrected for confining stress effects. How the pressure is applied to the core during MICP testing, and the pressure at which the test is conducted, will influence the permeability measurement. This is because permeability is a function of both pressure and stress, and the MICP test procedure itself will stress the core. The permeability measurement is therefore a function of pressure, stress, and the core itself. The permeability measurement can be corrected for stress effects to yield a more accurate estimate of permeability without the influence of stress.

**Adjusting MICP Permeability to Constant Stress**

The effectiveness of a permeability correction is evaluated by the MICP permeability prediction model. The MICP permeability model is a function of the confining stress used during the MICP test. The permeability measured with capillary injection techniques is often corrected for confining stress effects. How the pressure is applied to the core during MICP testing, and the pressure at which the test is conducted, will influence the permeability measurement. This is because permeability is a function of both pressure and stress, and the MICP test procedure itself will stress the core. The permeability measurement is therefore a function of pressure, stress, and the core itself. The permeability measurement can be corrected for stress effects to yield a more accurate estimate of permeability without the influence of stress.

**Model for Stress Effects on MICP Permeability**

Stress effects on MICP permeability have been observed in previous studies. The MICP permeability prediction model includes the confining stress effect. The permeability measured with capillary injection techniques is often corrected for confining stress effects. How the pressure is applied to the core during MICP testing, and the pressure at which the test is conducted, will influence the permeability measurement. This is because permeability is a function of both pressure and stress, and the MICP test procedure itself will stress the core. The permeability measurement is therefore a function of pressure, stress, and the core itself. The permeability measurement can be corrected for stress effects to yield a more accurate estimate of permeability without the influence of stress.

**Integrating MICP Permeability From Mercury Injection Capillary Pressure Data**

The MICP permeability prediction model is used to correct the low permeability samples to a weighted average of all confining stress values. This weighted average provides a more accurate estimate of permeability. The permeability measured with capillary injection techniques is often corrected for confining stress effects. How the pressure is applied to the core during MICP testing, and the pressure at which the test is conducted, will influence the permeability measurement. This is because permeability is a function of both pressure and stress, and the MICP test procedure itself will stress the core. The permeability measurement is therefore a function of pressure, stress, and the core itself. The permeability measurement can be corrected for stress effects to yield a more accurate estimate of permeability without the influence of stress.

**Summary Observations, DOE Data Test**

- MICP permeability estimates for samples with less than 0.1 micrometers are not as consistent as other estimates and estimates based on pressure measurements below 300 psi.
- MICP permeability estimates are within 0.1 micrometers of the DOE reference method for samples with greater than 0.1 micrometers.
- The DOE reference method requires the range of micrometer values for each sample.
- MICP permeability measurements are more consistent than other pressures for samples with greater than 0.1 micrometers.
- MICP permeability estimates are similar to the DOE standard permeability measurements for samples with greater than 0.1 micrometers.
- The DOE reference method requires the range of micrometer values for each sample.
- MICP permeability measurements are more consistent than other pressures for samples with greater than 0.1 micrometers.

**Permeability and Stress**

Micron-sized pores within individual grains can influence the overall permeability of a sample. This is because permeability is a function of both pressure and stress, and the MICP test procedure itself will stress the core. The permeability measurement is therefore a function of pressure, stress, and the core itself. The permeability measurement can be corrected for stress effects to yield a more accurate estimate of permeability without the influence of stress.

**Stress State During MICP Measurement**

Stress state during MICP testing can affect the permeability measurement. This is because permeability is a function of both pressure and stress, and the MICP test procedure itself will stress the core. The permeability measurement is therefore a function of pressure, stress, and the core itself. The permeability measurement can be corrected for stress effects to yield a more accurate estimate of permeability without the influence of stress.

**Adjusting MICP Permeability to Constant Stress**

The effectiveness of a permeability correction is evaluated by the MICP permeability prediction model. The MICP permeability model is a function of the confining stress used during the MICP test. The permeability measured with capillary injection techniques is often corrected for confining stress effects. How the pressure is applied to the core during MICP testing, and the pressure at which the test is conducted, will influence the permeability measurement. This is because permeability is a function of both pressure and stress, and the MICP test procedure itself will stress the core. The permeability measurement is therefore a function of pressure, stress, and the core itself. The permeability measurement can be corrected for stress effects to yield a more accurate estimate of permeability without the influence of stress.

**Permeability and Stress**

Micron-sized pores within individual grains can influence the overall permeability of a sample. This is because permeability is a function of both pressure and stress, and the MICP test procedure itself will stress the core. The permeability measurement is therefore a function of pressure, stress, and the core itself. The permeability measurement can be corrected for stress effects to yield a more accurate estimate of permeability without the influence of stress.
The presented text is a scientific article discussing the interpretation of permeability from Mercury Injection Capillary Pressure (MICP) data. The text details the methods used to measure permeability, the factors affecting it, and how to interpret the data. The article also includes figures and tables to illustrate the concepts discussed.

---

**Summary and Conclusions**

The main results for this study are the following (in descending order):

1. MICP permeability estimates are measured using a coating stress-dependency equal to the log-hysteresis throughout. Tight matrix permeability is a strong primary exercise. Different matrix permeability estimates can be adjusted to the stress in a linear relationship. Most petrographic studies report pore aspect ratios and not throat aspect ratios. The permeability ratio is approximately twice the ratio of tubular to sheet tortuosity ratio. The aspect ratio cancels out, and the permeability ratio is approximately the ratio of sheet to tubular throat width.

2. Fracture permeability was assumed to be at least ten times greater than matrix permeability for any L value. Fracture permeability was scaled using the fracture frequency needed to reach this permeability (Figure 24). Fracture frequency of 5 to 40 fractures/cm explain most permeability assuming fracture width 2.5 times L value. The calculated parameter is the fracture frequency needed to reach this permeability (Figure 24). Fracture frequency of 5 to 40 fractures/cm explain most permeability assuming fracture width 2.5 times L value.

3. The permeability of a single bare pore throat of width is a factor of pore throat of fractures. In light of the results in Figures 18 and 20, the permeability ratio is approximately the ratio of sheet to tubular throat width. The aspect ratio cancels out, and the permeability ratio is approximately the ratio of sheet to tubular throat width.

4. The permeability of a single bare pore throat of width is a factor of pore throat of fractures. In light of the results in Figures 18 and 20, the permeability ratio is approximately the ratio of sheet to tubular throat width. The aspect ratio cancels out, and the permeability ratio is approximately the ratio of sheet to tubular throat width.

5. The permeability of a single bare pore throat of width is a factor of pore throat of fractures. In light of the results in Figures 18 and 20, the permeability ratio is approximately the ratio of sheet to tubular throat width. The aspect ratio cancels out, and the permeability ratio is approximately the ratio of sheet to tubular throat width.

6. The permeability of a single bare pore throat of width is a factor of pore throat of fractures. In light of the results in Figures 18 and 20, the permeability ratio is approximately the ratio of sheet to tubular throat width. The aspect ratio cancels out, and the permeability ratio is approximately the ratio of sheet to tubular throat width.

---

**Possible Causes for Scattered Data**

Possible scatter is caused by a range of factors, including:

1. Fracture frequency for fractures this narrow is probably unreasonable for intact plug samples. This indicates that a fracture system, if present in the plug, has effective apertures much larger than L. This frequency is reasonable for typical plug samples. Much higher fracture frequency is needed (40–500 fractures/cm) to match permeability where fracture width equals L (sheet). The sheet K-TL ratio can be estimated by dividing the stress-corrected sheet L by T. The aspect ratio cancels out, and the permeability ratio is approximately the ratio of sheet to tubular throat width.

2. Fracture permeability was assumed to be at least ten times greater than matrix permeability for any L value. Fracture permeability was scaled using the fracture frequency needed to reach this permeability (Figure 24). Fracture frequency of 5 to 40 fractures/cm explain most permeability assuming fracture width 2.5 times L value.

3. Fracture permeability was assumed to be at least ten times greater than matrix permeability for any L value. Fracture permeability was scaled using the fracture frequency needed to reach this permeability (Figure 24). Fracture frequency of 5 to 40 fractures/cm explain most permeability assuming fracture width 2.5 times L value.

4. Fracture permeability was assumed to be at least ten times greater than matrix permeability for any L value. Fracture permeability was scaled using the fracture frequency needed to reach this permeability (Figure 24). Fracture frequency of 5 to 40 fractures/cm explain most permeability assuming fracture width 2.5 times L value.

5. Fracture permeability was assumed to be at least ten times greater than matrix permeability for any L value. Fracture permeability was scaled using the fracture frequency needed to reach this permeability (Figure 24). Fracture frequency of 5 to 40 fractures/cm explain most permeability assuming fracture width 2.5 times L value.

---

**References**


---

**Acknowledgments**

I thank Alan Rynes for measuring the O:/air experiments and the University of Oregon for funding this project. This project was completed under the guidance of Dr. Alan Rynes and Dr. John Butler. I also thank the reviewer for their constructive comments and suggestions. This work was supported by the Department of Energy, Office of Basic Energy Sciences, Geosciences Division, under Award Number DE-FG02-07ER16003 (DOE).

---

**Table of Contents**

1. Introduction
2. Methodology
3. Results
4. Discussion
5. Conclusion

---

**Keywords**

Permeability, Mercury Injection Capillary Pressure, Scattering, Fractures

---

**Graphs and Figures**

[Graphs and figures are not transcribed but are referenced in the text.]

---

**Citation**

[Include citation details if required by the guidelines.]