PMI Pulse Decay Permeameter for Shale Rock Characterization

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This document describes the application of Pulse Decay Permeameter to measure gas permeability of unconventional rock samples. Multiple tests were performed using different types of shale plugs. The presented results were given to demonstrate the reliability and practical performance of the instrument.

Introduction

The PMI Pulse Decay Permeameter is designed to measure the gas permeability for tight rocks, gas or oil shale samples with ultra-low permeability, in nano-Darcy range. The gas permeability is determined by pulse decay technique, which allows the measurement more rapid and accurate compare with conventional steady-state method.

The system provided with a software for the data acquisition and system control, from which the measurement can be operated both automatically and manually. During the pulse decay period, the differential pressure (ΔP) across the sample, the downstream pressure (P2), and elapsed time are monitored. With or without considering the adsorption effect, permeability is calculated from a linear regression performed on the pressure time data, the properties of core sample and gas, and gas reservoir volume.

Specifications

- Permeability range: 1 nD to 0.1 mD
- Confining pressure: Up to 10,000 psi
- Core diameter: 1 inch or 1.5 inch
- Core length: 2 to 3 inch
- Temperature: Ambient
- Pore pressure: Max 2,000 psi
- Pressure accuracy: 0.1% FS
- Power: 110/220 VAC, 50/60 Hz
- Size: 44” (H) × 27” (W) × 33” (D)

Setup and Measurements

Fig. 1 shows the PMI developed Pulse Decay Permeameter, APDP-10K. It consists of two upstream gas reservoirs with different sizes, two downstream gas reservoirs with different sizes, a pressure transducer for measuring the downstream pressure, a differential pressure transducer for measuring the pressure difference between the two small reservoirs, a pressure gauge for measuring the confining pressure, a core sample holder, a hand hydraulic pump, and valves.

Fig. 1: PMI Pulse Decay Permeameter

When performing a test, the core sample is placed into the core holder and confining pressure is applied. With all valves open, the Pulse Decay Permeameter system, including all reservoirs, plumbing and sample, is filled with gas to a desired pore pressure, then close the fill in valve. When the system pressure becomes stable, close the by-pass valve. With the needle valve nearly closed, open vent valve and allow the downstream pressure to bleed off to develop a target differential pressure, typically less than 50 psi. Then close the vent valve and monitor the differential pressure and downstream pressure. When the mean pore pressure becomes constant, close the two valves that close to the inlet and outlet of the core holder. The test will be end when ΔP drops to zero and data will be saved. Then develop a semi-log pulse-decay plot, log differential pressure (ΔP) times mean pressure (Pm) versus time (t) and determine the slope of the beginning linear portion of the generated curve. With or without considering the adsorption effect, the pulse decay permeability is calculated from the slope, core sample properties, gas compressibility and viscosity, and gas reservoir volumes.

Performance Test

Four types of outcrop shale samples were used for operating the performance test: Marcellus, Eagle Ford, Barnett, and Mancos, shown as Fig. 2. The permeability of each sample was measured two times to verify the accuracy and repeatability of the instrument. Nitrogen was used as the gas source. All tests were performed at room temperature. The operating parameters are given in Table 1.

Table 1. Operating parameters

Parameter	Value
Temperature, °C	24
Atmospheric pressure, psia	13.5
Gas source	N_2
Gas viscosity, cP	0.0176
Gas compressibility, psi^{-1}	0.0009381
Mean pore pressure, psi	1,050
Confining pressure, psi	4,000
Upstream volume, cc	54.8
Downstream volume, cc	29.57

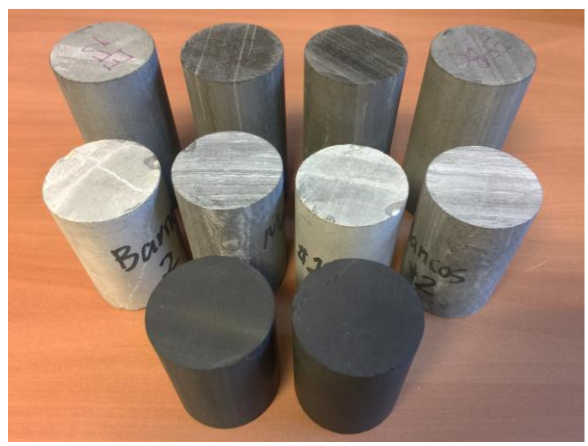

Fig. 2: Core plug samples used for PDP test

Results

Twenty series of tests were performed on ten shale core samples. The permeability of each sample was measured twice at same operating conditions. The sample information and permeability results are given in Table 2. Figs. 3 to 22 show the pressure profiles and slope determination graphs for each pulse decay test.

Table 2. Core sample dimensions and test results

Test No.	Sample ID	Length (cm)	Diameter (cm)	Pm (psig)	Slope	k (nD)
1	Marcellus #1	5.09	3.77	1016	- 0.0000475	100.9
2	Marcellus #1	5.09	3.77	1037	- 0.0000519	110.3
3	Marcellus #2	5.10	3.76	1045	- 0.0000854	182.8
4	Marcellus #2	5.10	3.76	1050	- 0.0000821	175.7
5	Eagle Ford #1	7.62	3.77	1026	- 0.0017071	5438.5
6	Eagle Ford #1	7.62	3.77	1041	- 0.0017205	5481.2
7	Eagle Ford #2	7.60	3.74	1011	- 0.0000338	108.9
8	Eagle Ford #2	7.60	3.74	1039	- 0.0000324	104.4
9	Eagle Ford #3	7.61	3.76	1039	- 0.0003298	1050.7
10	Eagle Ford #3	7.61	3.76	1037	- 0.0003319	1057.4
11	Eagle Ford #4	7.63	3.77	1023	- 0.0000463	147.4
12	Eagle Ford #4	7.63	3.77	1049	- 0.0000457	145.5
13	Barnett #1	5.65	3.85	1068	- 0.0001363	307.7
14	Barnett #1	5.65	3.85	1082	- 0.0001419	320.3
15	Barnett #2	5.78	3.86	1076	- 0.0001390	320.8
16	Barnett #2	5.78	3.86	1099	- 0.0001423	328.4
17	Mancos #1	6.03	3.76	1076	- 0.0000403	101.8
18	Mancos #1	6.03	3.76	1098	- 0.0000362	91.5
19	Mancos #2	5.83	3.76	1064	- 0.0000374	91.7
20	Mancos #2	5.83	3.76	1086	- 0.0000372	90.9

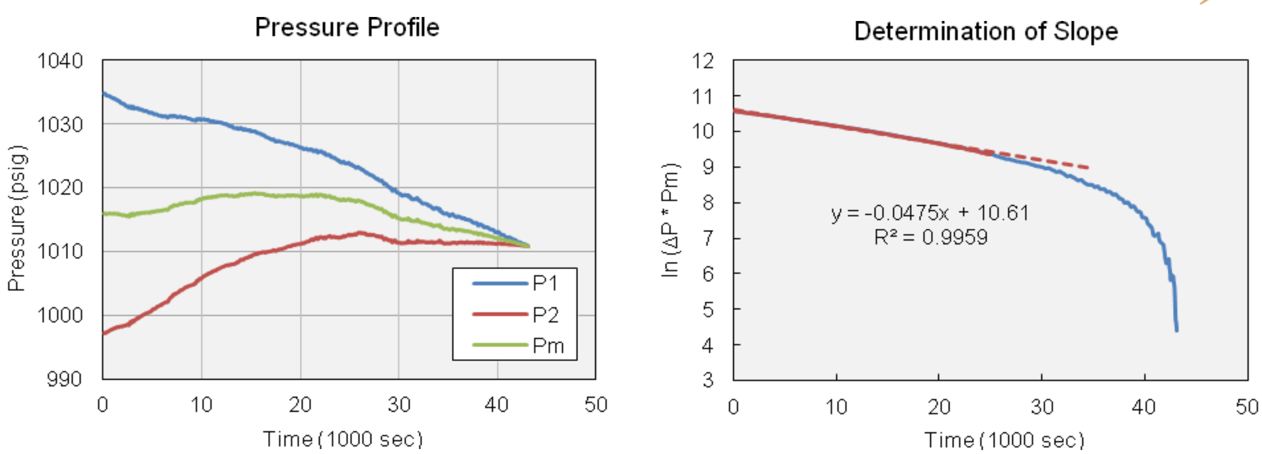

Fig. 3: Experimental data for test 1(core Marcellus #1)

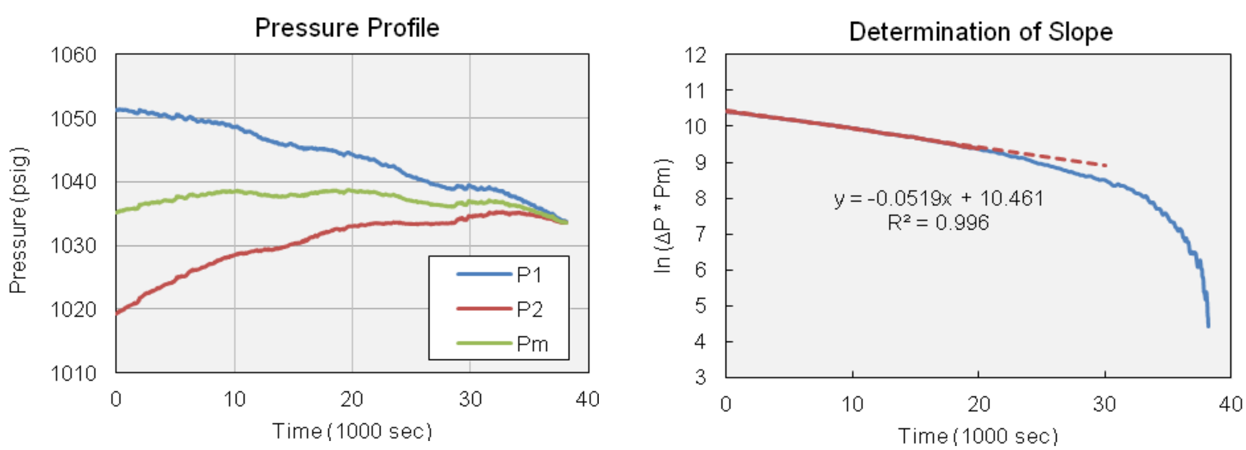

Fig. 4: Experimental data for test 2 (core Marcellus #1)

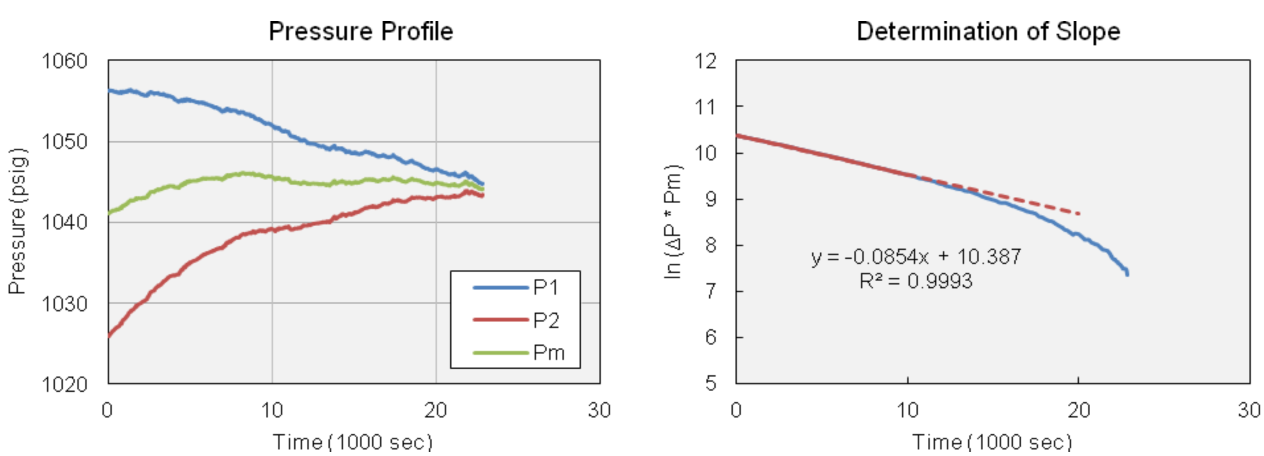

Fig. 5: Experimental data for test 3 (core Marcellus #2)

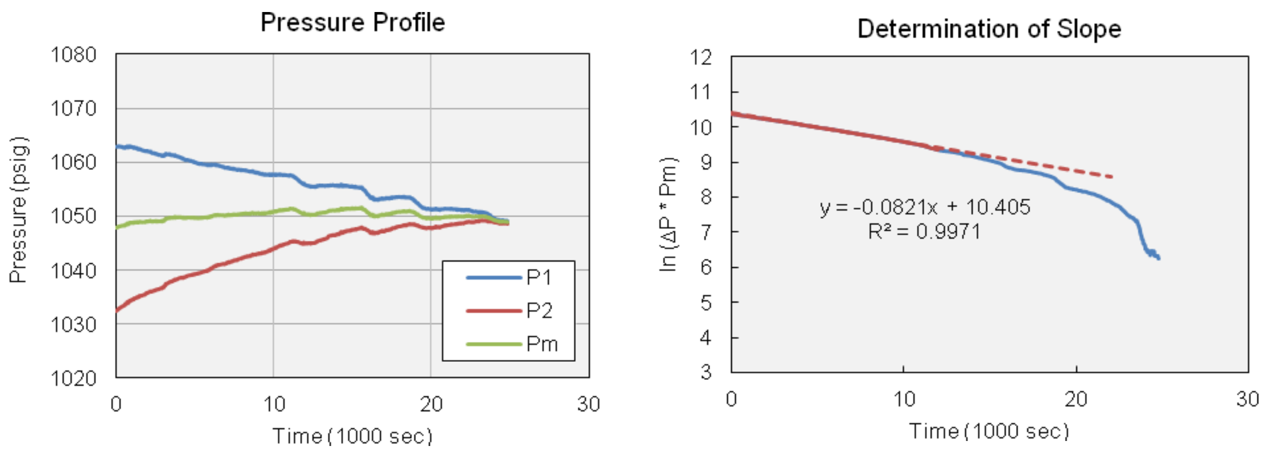

Fig. 6: Experimental data for test 4 (core Marcellus #2)

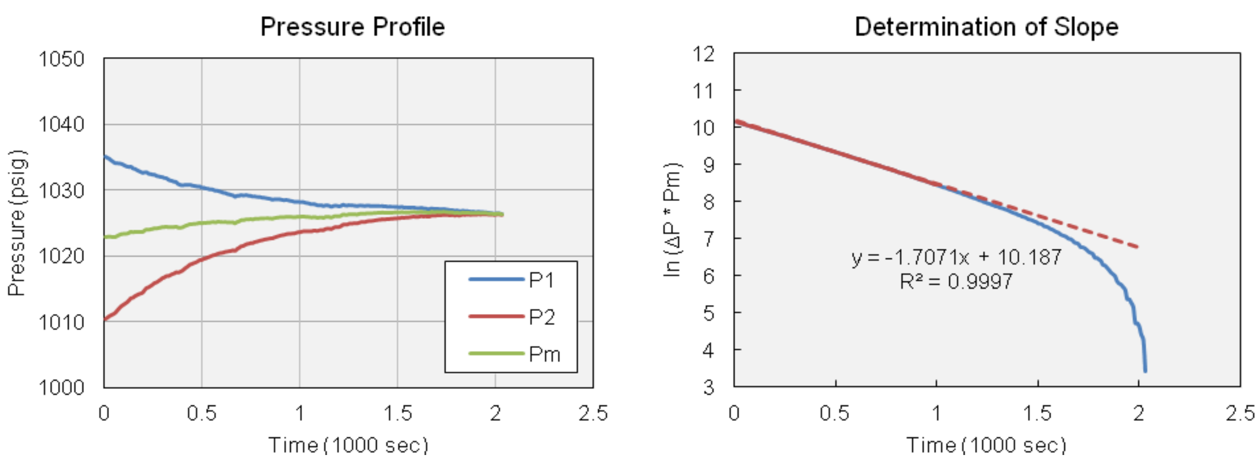

Fig. 7: Experimental data for test 5 (core Eagle Ford #1)

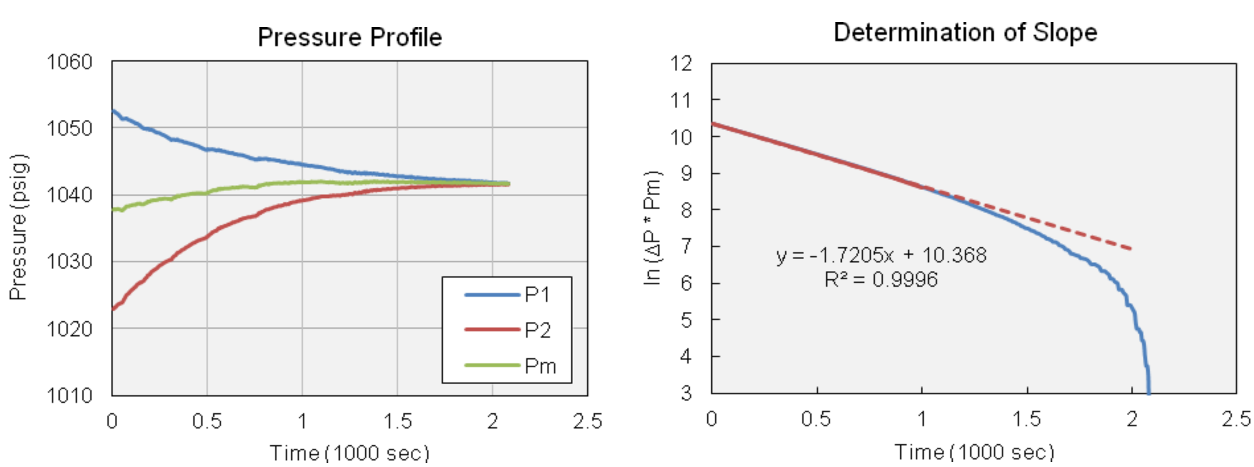

Fig. 8: Experimental data for test 6 (core Eagle Ford #1)

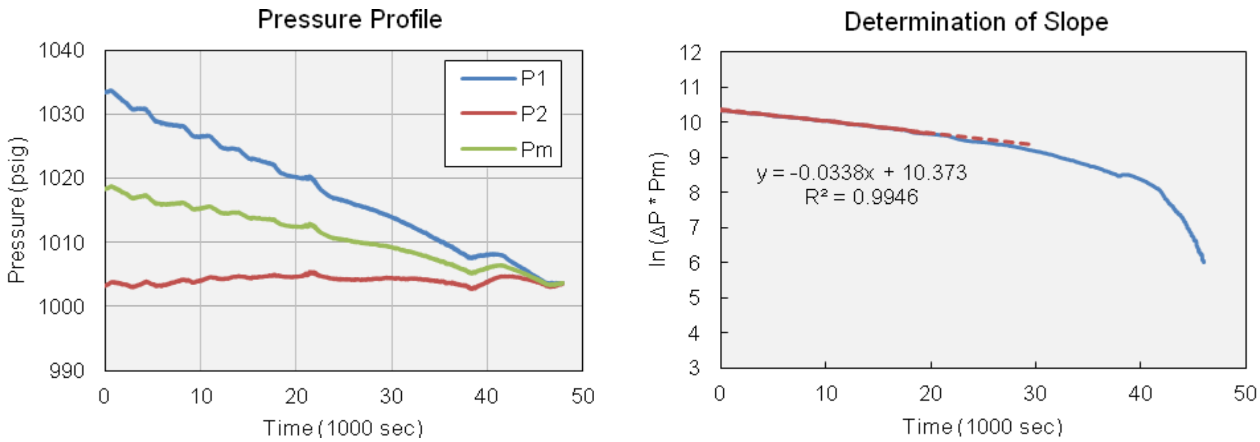

Fig. 9: Experimental data for test 7 (core Eagle Ford #2)

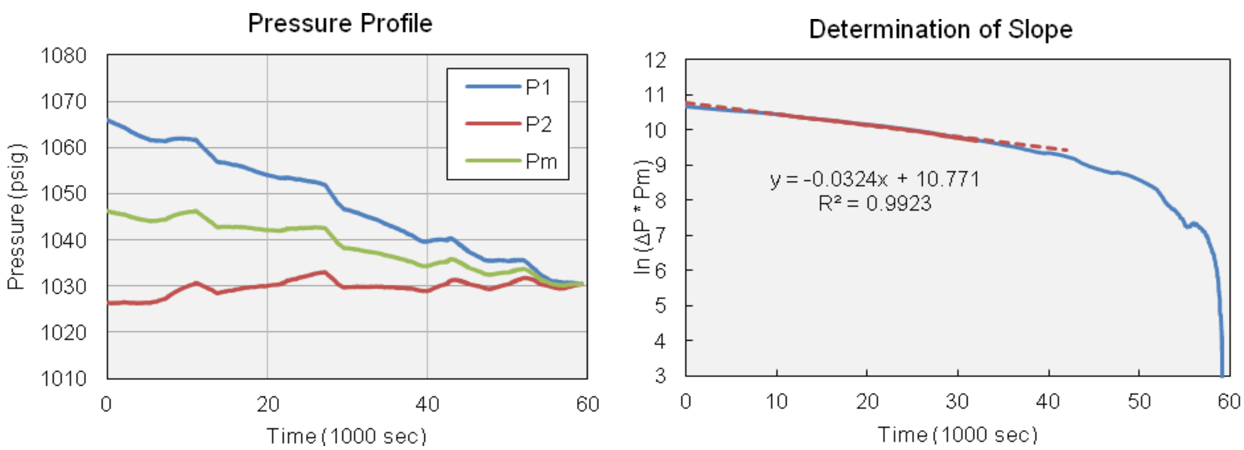

Fig. 10: Experimental data for test 8 (core Eagle Ford #2)

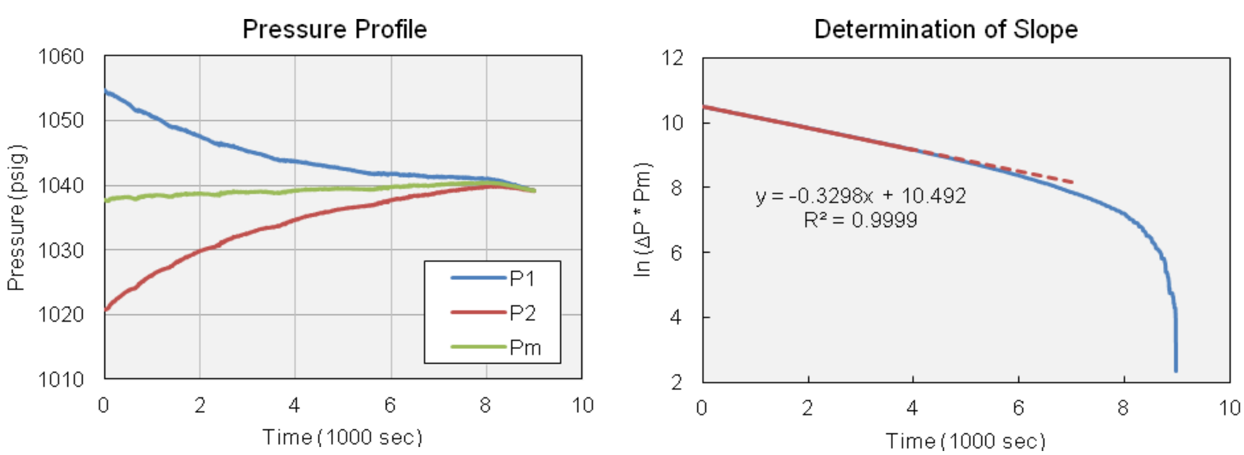

Fig. 11: Experimental data for test 9 (core Eagle Ford #3)

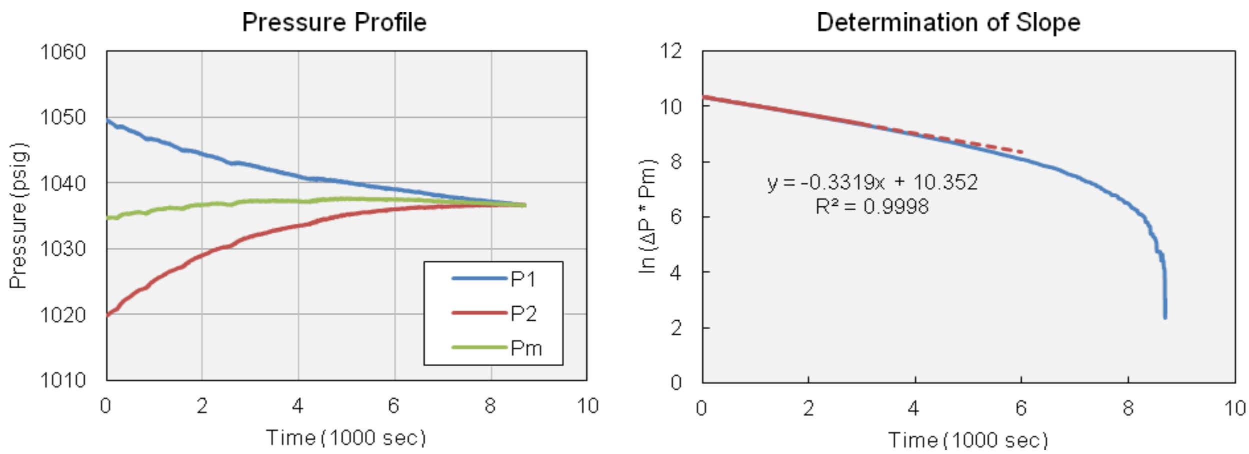

Fig. 12: Experimental data for test 10 (core Eagle Ford #3)

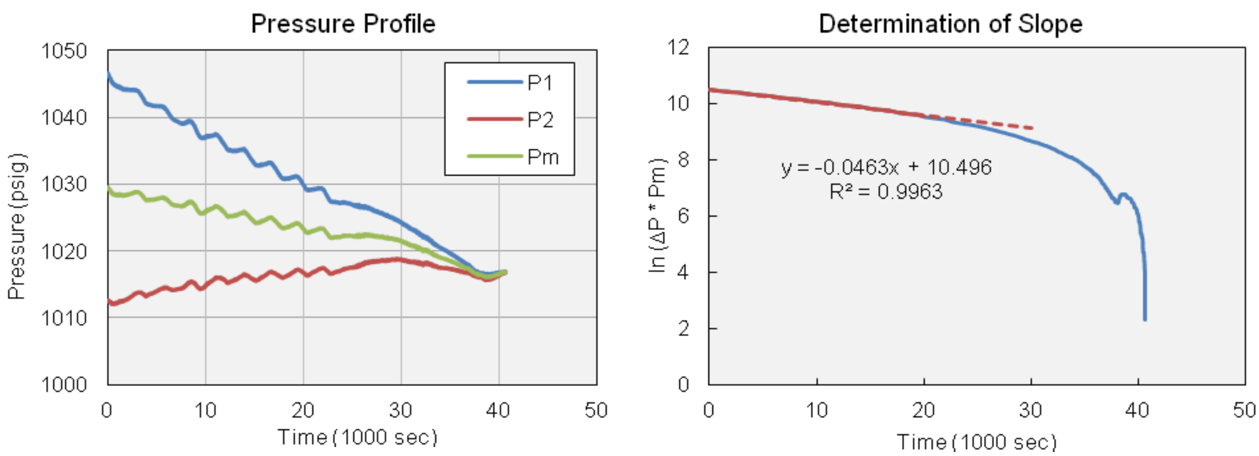

Fig. 13: Experimental data for test 11 (core Eagle Ford #4)

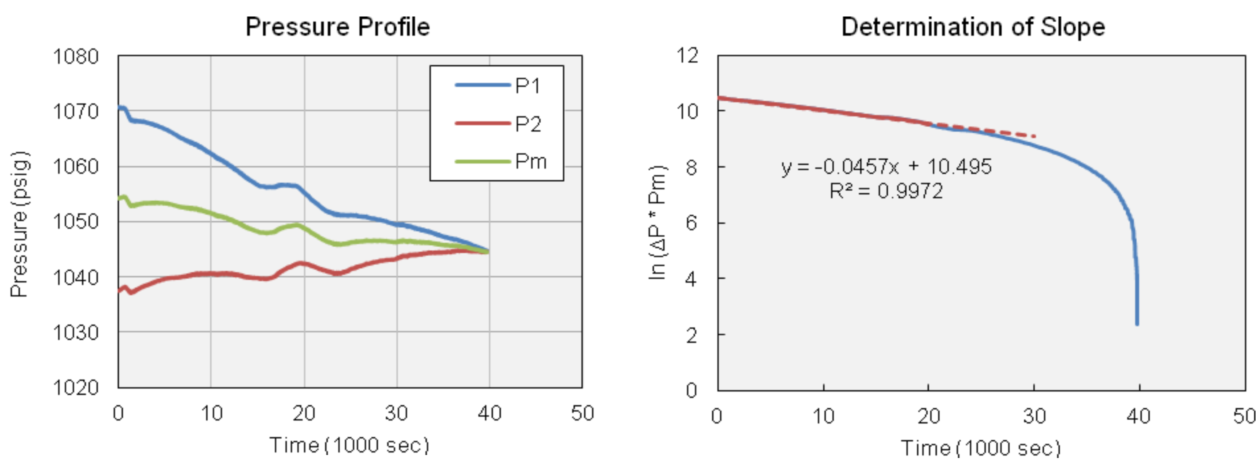

Fig. 14: Experimental data for test 12 (core Eagle Ford #4)

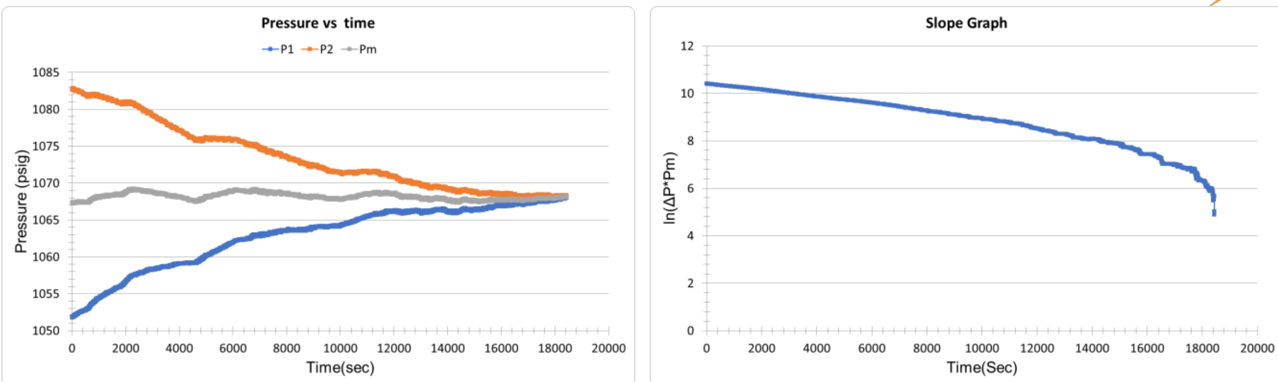

Fig. 15: Experimental data for test 13 (core Barnett #1)

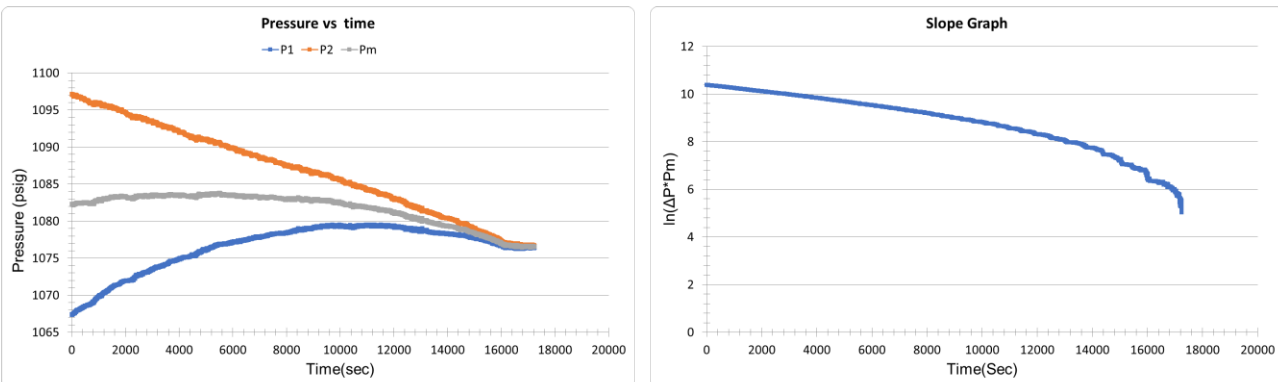

Fig. 16: Experimental data for test 14 (core Barnett #1)

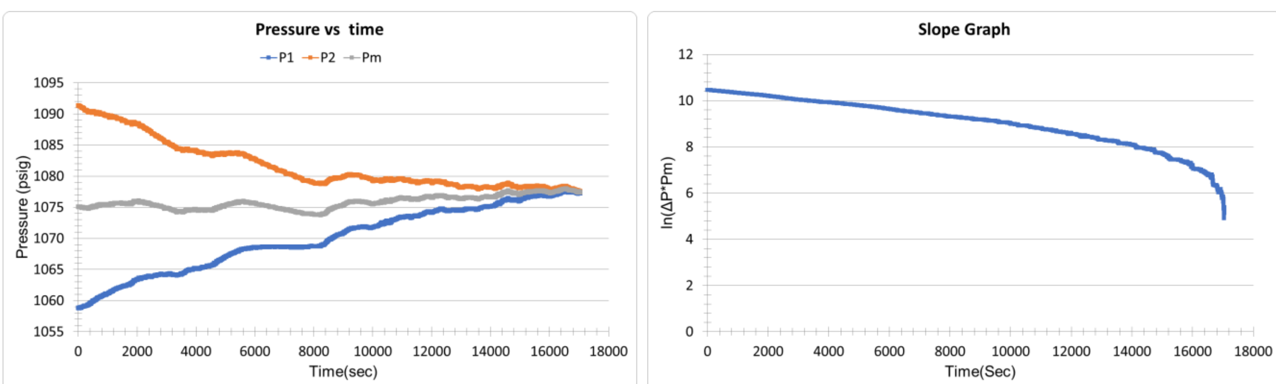

Fig. 17: Experimental data for test 15 (core Barnett #2)

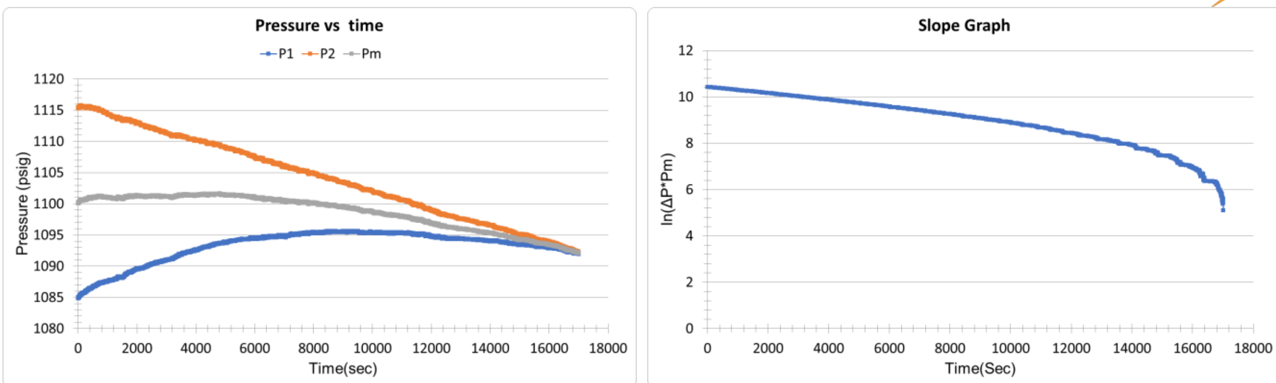

Fig. 18: Experimental data for test 16 (core Barnett #2)

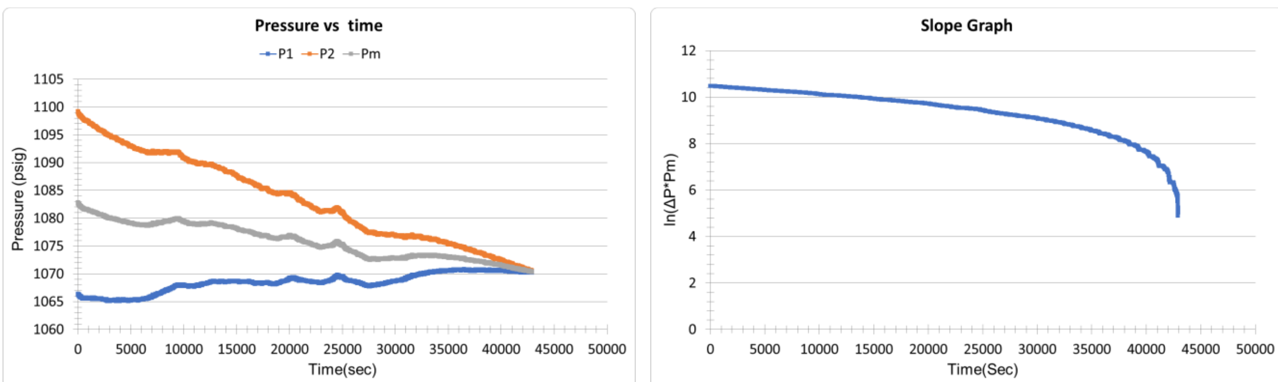

Fig. 19: Experimental data for test 17 (core Mancos #1)

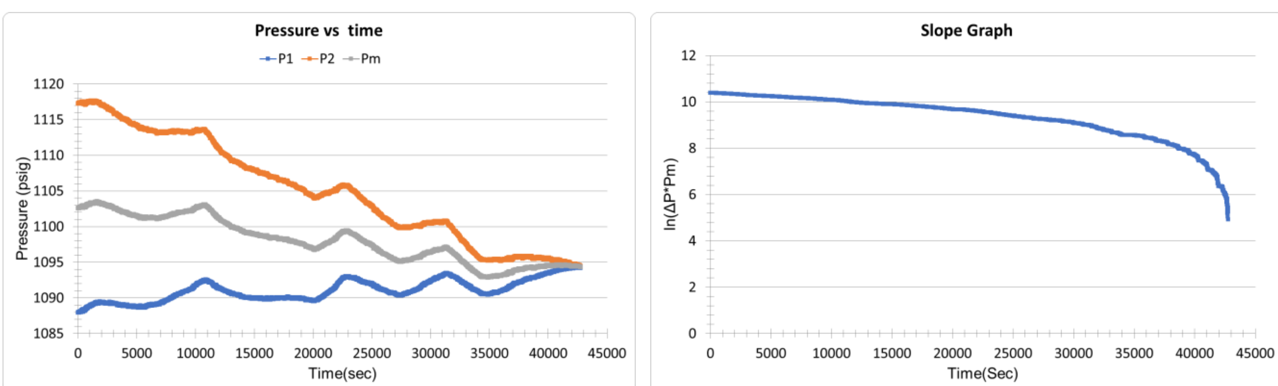

Fig. 20: Experimental data for test 18 (core Mancos #1)

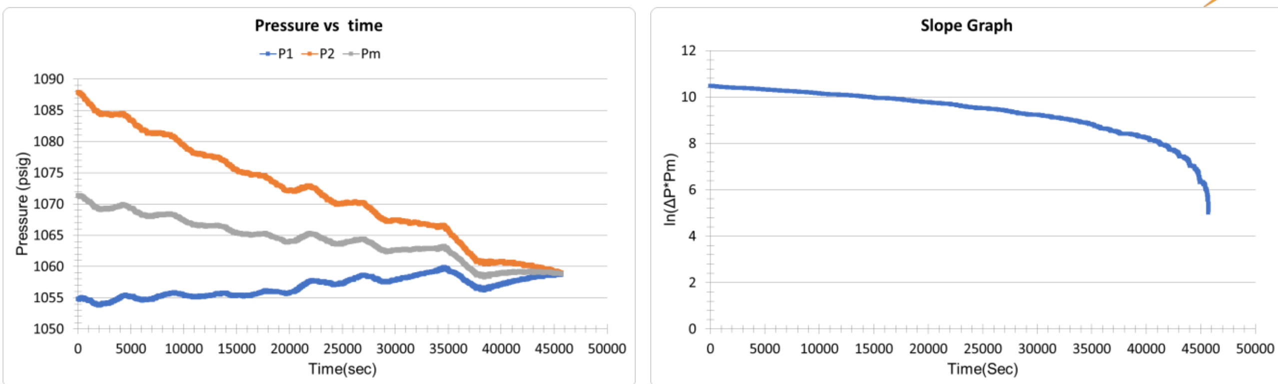

Fig. 21: Experimental data for test 19 (core Mancos #2)

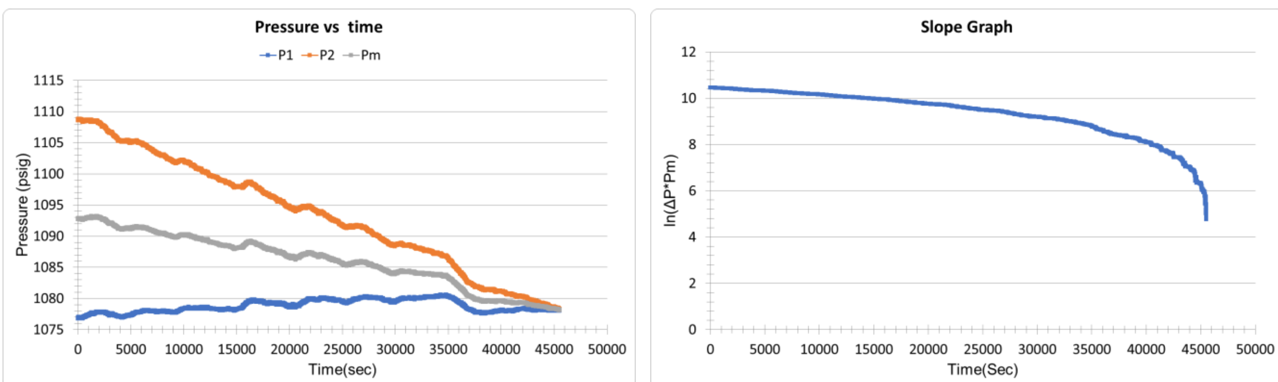

Fig. 22: Experimental data for test 20 (core Mancos #2)

Conclusion

This report introduces the design specifications and application of PMI Pulse Decay Permeameter. Different types of shale samples were used to conduct the performance test and experimental data were presented. The consistency of results proved the reliability and repeatability of PMI's Pulse Decay Permeameter.

Reference

American Petroleum Institute. "Recommended Practices for Core Analysis" API-RP40 (Second Edition, February 1998)

Jones, S. C. "A technique for faster pulse-decay permeability measurements in tight rocks." *SPE Formation Evaluation* 12.01 (1997): 19-26.