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Porosity, Single-Phase Permeability, and Capillary Pressure Data from Preliminary Laboratory Experiments on Selected Samples from Marker Bed 139 at the Waste Isolation Pilot Plant

Volume 3 of 3: Appendices C, D, E, and F

Susan M. Howarth, Tracy Christian-Frear

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Volume 3 of 3: Appendices C, D, E and F

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Tracy Christian-Frear

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ABSTRACT

This volume contains the mineralogy, porosity, and permeability results from the Marker Bed 139 specimens evaluated by TerraTek, Inc. This volume also documents the brine recipe used by RE/SPEC, Inc., the parameter package submitted to Performance Assessment based on all the data, and a memo on the mixed Brooks and Corey two-phase characteristic curves.

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Appendix C.
Data Report: TerraTek Inc.

The following appendix section includes Appendix C and Appendices C-A through C-E.

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Appendix C

Characterization of MB139 at WIPP

Errata Sheet

Total porosity data for sample EP2 is not included in the data report because the mass loss during crushing was excessive.

The liquid permeability data are included in the data report as "scoping only" because the saturation data (Table 8) were characterized as scoping only in the laboratory notebooks.

The following errors in the Appendix, *Characterization of MB139 at WIPP*, are noted:

1. Table 3: Sample designations should not have a "-" separating the letters from the numerals (e.g., PX-1 should be PX1).
2. Table 4: Rows 8 and 9 of the data indicate PX4 should be PX3.
3. Table 6: Sample B's grain volume ($V_{g\text{ eff}}$) should be 773.00, not 723.00 cc.
4. Table 6: Sample E's effective porosity (ϕ_{eff}) should be 1.45, not 1.55%.

The following modifications should be made to the references on page C-82 in Appendix C.

Ref. No.	Comment
1	copy of Davies, 1991 on file in SWCF as WPO#26169
2	authors are A.M. Petrovic, J.E. Siebert, and P.E. Rieke; journal title is <i>Soil Science Society of America Journal</i> Vol. 46, no. 3; copy on file in SWCF as WPO#42627
3	authors are P.K. Hunt, P. Engler, and C. Bajsarowicz; journal title is <i>Journal of Petroleum Technology</i> Vol. 40, no. 9; copy on file in SWCF as WPO#45565
4	authors are G.O. Brown, M.L. Stone, and J.E. Gazin; journal title is <i>Water Resources Research</i> Vol. 29, no. 2; copy on file in SWCF as WPO#42086
5	authors are R.A. Johns, J.S. Steude, L.M. Castanier, and P.V. Roberts; journal title is <i>Journal of Geophysical Research</i> Vol. 98, no. B2; copy on file in SWCF as WPO#40567
6	the existence of Vinegar and Hill could not be verified (company confidential document); cited on p. C-14.
7	the publication date for this ISRM method is 1981
8	correct publisher of Taylor, 1982 is University Science Books, Mill Valley, CA
9	the publisher location for <i>Handbook of Chemistry and Physics</i> is Boca Raton, FL

The following modifications should be made to the references in Appendix C-A: Procedures.

Page No.	Change
C-86	reference 1: existence of Operator's Manual 961036 could not be verified
C-87	reference 2: publisher location is Swarthmore, PA
C-87	reference 4: correct name of second author is R.C. Reynolds, Jr.
C-91	reference 9: cited pages are on file in SWCF
C-91	reference 10: cited pages are on file in SWCF

CHARACTERIZATION OF MARKER BED 139 AT WIPP

**Final Report
Contract AD-3656**

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**TR94-20
December, 1993**

Table of Contents

1.0 Introduction	C-11
2.0 Core Receipt and Inspection	C-11
3.0 X-Ray CT Non-Destructive Core Analysis	C-14
3.1 Application of a Second Generation CT Scanner	C-14
3.2 Exploratory Application of a Third Generation CT Scanner	C-23
4.0 Sample Preparation	C-30
5.0 XRD Analyses	C-34
6.0 Petrography	C-36
6.1 Overview	C-37
6.2 Petrographic Descriptions	C-38
6.2.1 Sample PX1.	C-38
6.2.2 Sample PX2.	C-39
6.2.3 Sample PX3.	C-39
6.2.4 Sample PX4.	C-39
6.2.5 Sample PX5.	C-40
6.2.6 Sample PX6.	C-40
7.0 Effective Porosity, Total Porosity, and Saturation	C-71
8.0 Single Phase Permeability	C-74
8.1 Gas Single-Phase Permeability	C-74
8.2 Liquid Single-Phase Permeability	C-74
9.0 Summary and Recommendations	C-80
10.0 References	C-82
APPENDIX C-A: Procedures	C-83
A.1 X-Ray Computerized Tomography	C-84
A.1.1 Background.	C-84
A.1.2 TerraTek's CT Facility.	C-84
A.1.3 Operating Procedures.	C-85
A.1.4 Imaging of fluid flow through cores.	C-86
A.2 X-Ray Diffraction (XRD) Analyses	C-87
A.3 Petrographic Analyses	C-87
A.4 Porosity Measurement	C-88

A.4.1	Gas porosimetry.	C-91
A.4.2	Bulk volume.	C-91
A.4.3	Powdering for measurement of total porosity.	C-91
A.5	Liquid Saturation	C-92
A.6	Gas Single-Phase Permeability	C-92
A.7	Liquid Single-Phase Permeability	C-93
A.8	Calibration Facilities and Instrumentation	C-93
APPENDIX C-B:	Index of CT Cross-sectional Images from Whole Core Scan (E1X-08) ..	C-97
APPENDIX C-C:	Drying History of Samples A-F & EP1-8	C-99
APPENDIX C-D:	Gas Permeability Spreadsheets	C-105
APPENDIX C-E:	Liquid Permeability Spreadsheets	C-179

List of Tables

Table 1.	Sample Identification	C-30
Table 2.	Drying Times	C-35
Table 3.	XRD Semi-Quantitative Mineralogic Analyses	C-35
Table 4.	Modal Analyses	C-36
Table 5.	Grain Size, Sorting, and Porosity from 300-Point Count	C-37
Table 6.	Bulk Volume, Effective Grain Volume, and Effective Porosity	C-72
Table 7.	Bulk Density, Grain Density, and Total Porosity	C-73
Table 8.	Liquid (OMS) Saturation	C-73
Table 9.	Single Phase Gas Permeability	C-75
Table 9.	Single Phase Gas Permeability (continued)	C-76
Table 9.	Single Phase Gas Permeability (continued)	C-77
Table 10.	Single Phase Klinkenberg Gas Permeability	C-78
Table 11.	Single Phase Liquid Permeability vs Calculated Klinkenberg Permeability ...	C-79
Table B1.	Index of CT Images for E1X08	C-98

List of Figures

Figure 1.	As-received MB139 Core E1X07	C-12
Figure 2.	As-received MB139 Core E1X08	C-13
Figure 3.	Representative cross-sectional images of E1X08-3.	C-15
Figure 4.	Representative cross-sectional images of E1X08-4.	C-16
Figure 5.	Representative cross-sectional images of E1X08-5.	C-17
Figure 6.	Representative cross-sectional images of E1X08-6.	C-18
Figure 7a.	Longitudinal reconstruction of E1X08-4 (3.55-4.13 feet).	C-19
Figure 7b.	Longitudinal reconstruction of E1X08-4 (4.14-4.72 feet).	C-20
Figure 7c.	Longitudinal reconstruction of E1X08-4 (4.73-5.33 feet).	C-21
Figure 7d.	Longitudinal reconstruction of E1X08-4 (5.34-5.94 feet).	C-22
Figure 8.	Examples of coring-induced damage as evidenced by CT cross-sectional images in tuff cores from the tunnel beds in Rainer Mesa, Nevada Test Site. (Images furnished with permission of Dr. B.L. Ristvet, Defense Nuclear Agency).	C-24
Figure 9.	CT cross-sectional images from E1X08-4 showing linear features of comparatively low density. Such features, possibly pre-existing healed fractures, were very rare in the E1X08 images.	C-25
Figure 10a.	Raw image from E1X08-5 (salt) acquired with a third-generation Philips 60/TX CT scanner. Beam-hardening, as evidenced by the bright ring on the sample perimeter, is present.	C-26
Figure 10b.	Image shown in Figure 10a following post-processing with CORESCAN TM to eliminate beam-hardening artifacts.	C-27
Figure 11a.	Raw image from E1X08-4 (anhydrite with mudrock) acquired with a third-generation Philips 60/TX CT scanner. Beam-hardening, as evidenced by the bright ring on the sample perimeter, is present.	C-28

Figure 11b.	Image shown in Figure 11a following post-processing with CORESCAN™ to eliminate beam-hardening artifacts.	C-29
Figure 12.	Experimental program.	C-31
Figure 13.	Documentation of sample preparation from core E1X08-4.	C-32
Figure 14.	Documentation of sample preparation from core E1X07-4.	C-33
Figure 15.	Schematic illustrating PX sample preparation. Thin sections were prepared parallel to O1-O3. O1 is horizontal (parallel to bedding) and O2 and O3 are vertical and mutually perpendicular. XRD analyses were conducted on half of the O2 split.	C-34
Figure 16.	Grain size histogram for PX1	C-41
Figure 17.	Grain size histogram for PX2	C-44
Figure 18.	Grain size histogram for PX3	C-47
Figure 19.	Grain size histogram for PX4	C-50
Figure 20.	Grain size histogram for PX5	C-53
Figure 21.	Grain size histogram for PX6	C-56
Figure A1a.	Documentation of thin section preparation from PX samples from core E1X08-4.	C-89
Figure A1b.	Documentation of thin section preparation from PX samples from core E1X07-4.	C-90
Figure A2.	Schematic of experimental system for gas permeability measurement.	C-94
Figure A3.	Schematic of experimental system for liquid permeability measurement. ...	C-95

1.0 Introduction

The Waste Isolation Pilot Plant (WIPP) is the U.S. Department of Energy's planned repository for transuranic waste generated by defense programs. The WIPP is located 660 m underground in the Salado Formation which consists of thick halite with interbeds of minerals such as clay and anhydrite. The polycrystalline Salado salt contains 0.1 to 1% brine in intragranular fluid inclusions and as an intergranular pore fluid. The anhydrite interbed layers are expected to contain similar quantities. Quantification of the amount of brine, and its mobility and flow rate are critical for accurate assessment of the long-term performance of the repository. Field tests indicate that the permeability of the Salado anhydrite interbeds is 1 to 2 orders of magnitude greater than that of the halite intervals and sensitivity analyses show that the anhydrite beds would be the favored path for fluid flow [1].

The effort described here focused on characterization of the anhydrite bed known as Marker Bed 139 (MB139) which occurs beneath the planned waste-storage rooms. Laboratory investigations were performed on two cores from MB139 to (1) characterize the lithology and mineralogy; (2) determine total and effective porosity; (3) measure maximum achievable liquid saturation; (3) determine single-phase (both gas and liquid) permeability under varying stress conditions; and (4) explore the use of X-ray computerized axial tomography (CT) for identification and characterization of natural and coring-induced fractures and for tracking fluid flow through cores.

2.0 Core Receipt and Inspection

Two core samples identified as E1X07 and E1X08 were received at TerraTek on November 23, 1992. The core containers were photographed immediately upon receipt and opened for examination on November 25, 1992. The core pieces were sheathed individually in saran wrap, packed in bubble wrap, and sealed in 8" diameter PVC tubes. The first tube contained three 5½" diameter cores with identification and length as follows: E1X07-3 (3'8" to 4'); E1X07-4 (4' to 6'2"); and E1X07-5 (6'2" to 7'5"). The second tube contained four 5½" diameter cores with identification and length as follows: E1X08-3 (2'8" to 3'6"); E1X08-4 (3'6" to 6'); E1X08-5 (6' to 6'4"); and E1X08-6 (6'4" to 7'4½"). Photographs were taken to document conditions during each stage of unwrapping and the cores were noted to be in good condition (Figures 1 and 2).

Bedding was approximately perpendicular to the core axis. Significant lithologic discontinuities were apparent at each of the break points (Figures 1 and 2). Both the upper and lower core pieces from E1X07 and E1X08 (E1X07-3 and E1X07-5; E1X08-3 and E1X08-6) were identified as halite and thus not considered to be part of the marker bed. The lower portion of the marker bed in both cores (~5.8 to 6.2 feet for E1X07; ~6.0 to 6.3 feet for E1X08) was identified as mudrock. The remaining material was identified as anhydrite mixed with mudrock. Core E1X08 was separated into two pieces (identified as E1X08-4 and E1X08-5) at the interface between the mixed anhydrite/mudrock and mudrock zones. Core E1X07 contained no throughgoing fissure at this lithologic discontinuity; however, some partial separation along the bedding plane was apparent along a portion of the circumference (Figure 1).

Figure 1. As-received MB 139 Core E1X07.

Figure 2. As-received MB 139 Core EIX08.

3.0 X-Ray CT Non-Destructive Core Analysis

3.1 Application of a Second Generation CT Scanner

A whole core x-ray computerized tomography (CT) scan was performed on core E1X08 in its as-received condition to investigate the applicability of CT for the identification of natural and coring-induced fractures. The four core pieces (E1X08-3, E1X08-4, E1X08-5, E1X08-6; previously identified as halite, anhydrite with mudrock, mudrock, and halite, respectively) were scanned continuously in TerraTek's Second Generation CT Facility using a beam width of 3 mm and energy of 120 KV (see Appendix A for facility description and operating procedures).

Representative cross-sectional images from each of the core pieces are shown in Figures 3-6 (see Appendix B for an index of cross-sectional images with respect to depth). A vertical reconstruction through core E1X08-4, which traverses the bulk of MB139, is shown in Figure 7. The images from the two cores identified as halite (E1X08-3 and E1X08-6) are of acceptable quality (Figures 3 and 6); however, the images from cores E1X08-4 and E1X08-5 contain severe beam-hardening artifacts (Figures 4 and 5), as evidenced by apparent concentric increases in density.

"Beam hardening" is a term used to describe the selective filtration of the lower energy component of the x-ray beam which occurs as the beam penetrates the sample. Beam-hardening causes the effective energy of the x-ray beam to increase as the beam penetrates the sample; this leads to an artificially high CT number on the sample circumference, which implies an artificially high density. Beam-hardening is a well known characteristic of all x-ray CT scanners since they employ polychromatic x-ray sources [2-5]; however, its effect is usually small for standard geologic cores (i.e., NX- or HQ- size) with low-to-medium densities (i.e., oil/gas reservoir rock).

In second-generation CT scanners such as TerraTek's Ohio Nuclear DeltaScan 100, beam-hardening corrections may be performed using either (1) single energy pre-reconstruction corrections or (2) by "pre-filtering" the x-ray beam to absorb the low-energy portion prior to penetration of the sample [6]. TerraTek's CT facility employs the first technique. A fused quartz sample with a nominal diameter of four inches and density of 2.20 g/cc is scanned and an algorithm which is part of the DeltaScan 100's programming is used to calculate non-linear coefficients which are later used in the DeltaScan's reconstruction algorithm to perform beam-hardening corrections during scanning of the test specimen.

The severe beam hardening which occurred during CT scanning of Core E1X08 was apparently caused by (1) the very large diameter of the core (6 inch); and (2) the relatively high density of the material ($\rho_{\text{anhydrite}} = 2.9\text{-}3.0$ g/cc). The standard beam-hardening correction procedure was therefore inadequate. Attempts to "pre-filter" the x-ray beam by either encasing the core in a hollow aluminum tube (with a nominal wall thickness of $\frac{1}{8}$ inch) or by placing thin aluminum shields (nominally $\frac{3}{8}$ inch) over the x-ray source did not yield significant improvements. Generation of the non-linear coefficients by scanning a 5 inch diameter aluminum sample with a density of 2.70 g/cc also did not yield significant improvements.

Figure 3. Representative cross-sectional images of EIX08-3.

Figure 4. Representative cross-sectional images of E1X08-4.

Figure 5. Representative cross-sectional images of EIX08-5.

Figure 6. Representative cross-sectional images of EIX08-5.

Figure 7a. Longitudinal reconstruction of E1X08-4 (3.55-4.13 feet).

Figure 7b. Longitudinal reconstruction of E1X08-4 (4.14-4.72 feet).

Figure 7c. Longitudinal reconstruction of EIX08-4 (4.73-5.33 feet).

A number of observations may nevertheless be made. First, there is no evidence for substantial coring-induced damage (in the form of circumferential fractures around the core perimeter) in core E1X08 (Figures 3-7). Figure 8 shows several examples where CT scans have successfully identified coring-induced damage in HQ-sized (2¼ inch diameter) core from the tunnel beds in Rainer Mesa, Nevada Test Site (images furnished with permission of Dr. B.L. Ristvet, Defense Nuclear Agency). Furthermore, the occasional chips which occur along the core axis of E1X08 do not appear to be marked by damage zones extending into the intact core. (Note that sample E1X08-5 (6.0 to 6.4 ft), which is classified as mudrock, ultimately fractured into several pieces during handling. The sample broke along what was possibly either a pre-existing healed fracture or bedding plane which may have been unduly stressed during either coring, shipping, and/or handling.) Second, the two whole-core pieces identified as halite, E1X08-3 (2.7 to 3.5 ft) and E1X08-6 (6.3 to 7.4 ft) appear to be very homogeneous both laterally and vertically (Figures 3 and 6). These two core pieces appear to be of substantially lower density than either E1X08-4 (anhydrite/mudrock) and E1X08-5 (mudrock). Third, core piece E1X08-5 (6.0 to 6.4 ft), classified as mudrock, appears to be the densest portion of core E1X08 overall (Figure 5). Images from this core exhibit the grossest beam-hardening. This core piece appears to be remarkably homogeneous both laterally and vertically in the upper section; however, the lower interval exhibits substantial lateral and vertical heterogeneity. Finally, core piece E1X08-4 (3.6 to 6.0 ft) exhibits substantial lateral and cross-sectional heterogeneity across the entire core length (Figure 7). The 5.5 to 6.0 ft interval appears to be highest, and the 3.6 to 3.7 ft interval lowest, in overall density. Narrow linear features of comparatively low density which appear in a few images at both the top and bottom of the core (Figure 9) may be healed fractures.

3.2 Exploratory Application of a Third Generation CT Scanner

Midway through the contract performance period, TerraTek acquired a more advanced third generation Philips 60/TX CT scanner. Advantages of the Philips scanner include a higher maximum operating voltage (140 KV vs 120 KV for the DeltaScan 100) and current (250 mA versus 25 mA for the DeltaScan 100) for the x-ray tube. TerraTek at this time also completed development of a new software package which includes a capability to perform automatic numerical correction for beam-hardening artifacts. Several scans were performed through intact pieces of cores E1X08-5 (halite) and E1X08-4 (anhydrite mixed with mudrock) to investigate whether the more powerful scanner would yield high quality images of very large, dense samples such as the MB139 cores.

The raw images from E1X08-5 and E1X08-4 are shown in Figures 10a and 11a, and the images following processing with CORESCAN™ to correct for beam-hardening are shown in Figures 10b and 11b. The images obtained with the Philips 60/TX scanner are excellent, and many details such as scattered low density inclusions and occasional pockets of a higher density mineral are visible in the halite core (Figure 10b). Similarly, the images from the E1X08-4 (Figure 11b) suggest two dominant mineral phases, possibly anhydrite and halite.

Figure 8. Examples of coring-induced damage as evidenced by CT cross-sectional images in tuff cores from the tunnel beds in Rainer Mesa, Nevada Test Site. (Images furnished with permission of Dr. B.L. Ristvet, Defense Nuclear Agency).

Figure 9. CT cross-sectional images from E1X08-4 showing linear features of comparatively low density. Such features, possibly pre-existing healed fractures, were very rare in the E1X08 images.

Figure 10a. Raw image from E1X08-5 (halite) acquired with a third-generation Philips 60/TX CT scanner. Beam-hardening, as evidenced by the bright ring on the sample perimeter, is present.

Figure 10b. Image shown in Figure 10a following post-processing with CORESCANTM to eliminate beam-hardening artifacts.

Figure 11a. Raw image from E1X08-4 (anhydrite with mudrock) acquired with a third-generation Philips 60/TX CT scanner. Beam-hardening, as evidenced by the bright ring on the sample perimeter, is present.

Figure 11b. Image shown in Figure 11a following post-processing with CORESCAN™ to eliminate beam-hardening artifacts.

4.0 Sample Preparation

Sample preparation focused on core intervals E1X07-4 and E1X08-4. MB139 was considered to include core interval E1X08-5; however, this section was too small for complete characterization. A total of six four-inch diameter samples (hereafter referred to as A-F) and fourteen two-inch diameter samples (hereafter referred to as EP1-8 and PX1-6) were diamond-cored from E1X08-4 and E1X07-4 in an orientation perpendicular to the original core axis. The samples were located such that complete characterization would be performed on three separate intervals of each of the MB139 cores. The experimental program is detailed in Figure 12. The identification of each sample is documented in Figures 13 and 14 and cataloged in Table 1.

Table 1. Sample Identification

Sample	Core	Depth (feet)
A	E1X08	3.63-4.00
B	E1X08	4.47-4.84
C	E1X08	5.34-5.71
D	E1X07	4.14-4.50
E	E1X07	4.64-5.00
F	E1X07	5.19-5.56
EP1	E1X08	3.50-3.63
EP2	E1X08	4.33-4.47
EP3	E1X08	5.05-5.19
EP4	E1X08	5.85-6.00
EP5	E1X07	4.00-4.14
EP6	E1X07	4.50-4.64
EP7	E1X07	5.00-5.14
EP8	E1X07	5.59-5.73
PX1	E1X08	4.00-4.14
PX2	E1X08	4.86-5.00
PX3	E1X08	5.71-5.85
PX4	E1X07	4.00-4.14
PX5	E1X07	5.00-5.14
PX6	E1X07	5.73-5.87

Figure 12. Experimental program.

Figure 13. Documentation of sample preparation from core EIX08-4.

Figure 14. Documentation of sample preparation from core E1X07-4.

The ends of the six four-inch samples were cut with a diamond saw and endground flat and parallel. The ends of eight of the two-inch samples (EP1-8) were cut approximately perpendicular to the core axis with a diamond saw. The remaining six two-inch cores (PX1-6) were cut with a diamond saw into several pieces for petrographic study and X-Ray Diffraction (XRD) analysis (Figure 15, also see Figure A1 Appendix C-A). To avoid any possible reaction with water-sensitive minerals, odorless mineral spirits (OMS) were used as a coolant during diamond-coring and end-grinding. Petrographic samples were vacuum-impregnated with a blue-dye epoxy and used to prepare oversized (approximately $2 \times 1\frac{1}{2}$ inch) thin ($30\mu\text{m}$) sections by an outside agent.

Samples A-F and EP1-8 were dried to constant mass in a constant-humidity oven. Criteria for weight stabilization exceeded ISRM recommendations [7], which define stability as successive mass determinations (4 hr intervals) differing by less than 0.1% of the sample mass. The MB139 samples were dried until no observable systematic mass change occurred. Temperature ranged from approximately 55-66°C and approximate relative humidity varied from 44-54% over the more than 2500 hours required to dry all samples. Total drying times are listed in Table 2 and the drying histories are shown graphically (Appendix C-C) (note that samples were initially removed from the oven after the ISRM criteria [7] were satisfied (at ~200 hours) and then returned to the oven after analysis of the mass measurements suggested that complete drying had not yet been achieved).

Figure 15. Schematic illustrating PX sample preparation. Thin sections were prepared parallel to O1-O3. O1 is horizontal (parallel to bedding) and O2 and O3 are vertical and mutually perpendicular. XRD analyses were conducted on half of the O2 split.

5.0 XRD Analyses

XRD analyses for determination of semi-quantitative mineralogy were performed on samples PX1-3 from E1X08-4 and PX4-6 from E1X07-4 and are reported in Table 3.

Table 2. Drying Times

Sample	Time (hours)
A	1546
B	366
C	918
D	2532
E	558
F	1787
EP1	918
EP2	366
EP3	366
EP4	366
EP5	918
EP6	918
EP7	558
EP8	366

Table 3. XRD Semi-Quantitative Mineralogic Analyses

Sample	Anhydrite (wt%)	Halite (wt%)	Ferroan Dolomite*† (wt%)	Polyhalite*‡ (wt%)	Aragonite (wt%)	Quartz (wt%)
PX-1	70	30	trace	trace	—	—
PX-2	32	68	—	—	—	—
PX-3	98	2	—	—	—	—
PX-4	7	23	≈30	≈28	12	trace†
PX-5	62	38	—	—	—	—
PX-6	81	19	—	—	—	—

* Or another cation-disordered Ca-Mg-Fe carbonate. May be well crystalline.

§ No standards available for quantification. Accuracy estimated at ±20%.

† $K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O$. According to Dana's System of Mineralogy, the salmon-pink color of samples containing this mineral may be due to finely divided inclusions of iron oxide.

‡ Tentative identification.

6.0 Petrography

Petrographic analyses, including a 300-point count for mineral identification and grain (crystal) size measurement, were conducted on eighteen thin sections (see Figure 15 for schematic of the three mutually perpendicular sections prepared from each PX sample and Appendix C-D for documentation of thin-section preparation). Point count data are given in Tables 4 and 5 and histograms of grain size distribution are shown in Figures 16-21. Micrographs illustrating the characteristic mineralogy and texture of each PX sample are shown in Plates 1 to 6.

Table 4. Modal Analyses

Sample	Anhydrite (vol%)	Halite (vol%)	Carbonate* (vol%)	Polyhalite (vol%)	Pyrite (vol%)
PX1-O1	6	<1	5	87	1
PX1-O2	67	20	6	7	—
PX1-O3	33	2	7	56	1
PX2-O1	62	37	2	—	—
PX2-O2	48	51	2	—	—
PX2-O3	67	30	4	—	—
PX3-O1	80	3	16	—	—
PX4-O2	87	1	12	—	—
PX4-O3	86	2	10	—	1
PX4-O1	50	44	1	5	—
PX4-O2	20	12	13	55	—
PX4-O3	27	14	3	57	—
PX5-O1	66	26	9	—	—
PX5-O2	79	18	3	—	—
PX5-O3	75	21	4	—	—
PX6-O1	82	17	<1	—	<1
PX6-O2	81	16	3	—	—
PX6-O3	92	4	4	—	—

* Unidentified very finely crystalline carbonate, possibly dolomite.

6.1 Overview

The dominant minerals in MB 139 are anhydrite, halite, and polyhalite; small amounts of very finely crystalline carbonate (tentatively identified as dolomite) are also present (typically about 5 vol%). The distribution of the major mineral phases, as the marker bed is traversed both laterally and vertically, is highly variable.

Anhydrite is typically finely crystalline, although textural alterations are observed when it is closely associated with halite or polyhalite. Anhydrite adjacent to and within halite crystals is coarser, whereas anhydrite intergrown with polyhalite tends to occur as elongate, tabular crystals. Halite crystals and nodules are usually impure, containing anhydrite and/or carbonate inclusions. Halite occurs as nodules, up to 2-3 cm in diameter, which likely grew displacively in the sediment within anhydrite laminae. Halite also fills space between intergrown polyhalite and

Table 5. Grain Size, Sorting, and Porosity from 300-Point Count

Sample	Median Grain Size (μm)	Sorting (ϕ)	Porosity (%)
PX1-O1	15	0.98	—
PX1-O2	23.5	2.00	—
PX1-O3	20	0.91	—
PX2-O1	66	2.06	—
PX2-O2	64	1.96	—
PX2-O3	39	2.15	—
PX3-O1	16.5	0.85	<1
PX3-O2	13.5	0.83	—
PX3-O3	12.5	0.92	—
PX4-O1	128	1.91	—
PX4-O2	26	1.54	—
PX4-O3	38	1.34	—
PX5-O1	64	1.80	—
PX5-O2	45	2.02	—
PX5-O3	62.5	1.86	—
PX6-O1	17	1.51	—
PX6-O2	17	1.56	—
PX6-O3	16	1.02	—

anhydrite structures. Polyhalite, which dominates specific areas of samples PX1 and PX4 but is absent in the other samples, occurs as narrow, needle-like crystals which form spherulitic to pseudocross-like structures (see Plates 1 and 4). Finely crystalline ($< 8 \mu\text{m}$ grain size) carbonate is a minor phase in all samples and occurs in scattered patches and as thin wisps, which commonly define bedding. This material, which appears dolomitic, is typically microporous, as evidenced by a light blue color in thin section. Very minor pyrite and possible clay minerals are observed in some thin sections, but always constitute $\leq 1\%$ of the bulk composition.

Total porosity in all six samples appears very low ($\leq 2\%$) and poorly connected when observed in 2-D. Microporosity associated with carbonate minerals is the most commonly observed porosity type. Fractures, at angles between 45° and 90° to bedding and with apparent apertures ranging from 10 to $30 \mu\text{m}$, are present in several samples. (Note that since thin sections were prepared at ambient conditions, in situ apertures are probably lower.) A number of bedding parallel fractures (with apertures up to tens of microns) are also observed. High-angle fractures are commonly confined to individual laminae and often terminate at the interface between laminae. Several healed fractures (sometimes filled by anhydrite) were observed.

6.2 Petrographic Descriptions (see Figure 15 for sample locations)

6.2.1 Sample PX1. Mineral distribution varies significantly amongst the three sections. O1 and O3 are dominated by polyhalite, but contain lesser amounts of halite, anhydrite, carbonate (dolomite?), and pyrite. O2 is dominated by anhydrite and halite; polyhalite is present in only a small area of the section.

Polyhalite generally occurs as small spherulites composed of tiny, radiating, needle-like crystals which are intergrown to form a tightly interlocked crystal network. Singular elongate and tabular anhydrite crystals are commonly scattered throughout the polyhalite. Anhydrite is also intergrown with polyhalite in the outer portions of spherulites. Finely crystalline carbonate, probably dolomite, is also intergrown with anhydrite and polyhalite in the outer portions of spherulites. Finely crystalline carbonate also fills spaces between spherulites and occurs in somewhat randomly distributed patches. Halite fills areas between spherulites. Minor pyrite is scattered throughout these areas.

Most of section O2 and one edge of section O3 are dominated by anhydrite and halite. Anhydrite is generally finely crystalline, except when it is located adjacent to halite crystals where an increase in crystal size is apparent. Halite within anhydrite forms irregular nodules which appear to be aligned along bedding planes, which are very irregular. Finely crystalline carbonate material in these areas occurs in small randomly distributed patches and as thin wisps (which define bedding). Some carbonate patches exhibit a somewhat peloidal texture.

Minor microporosity is apparent within some of the finely crystalline carbonate patches and is most abundant in O3, which contains more finely crystalline carbonate than O2 or O1. Both open and healed fractures, with apertures of $10\text{-}30 \mu\text{m}$, are present in anhydrite laminae in O2.

6.2.2 Sample PX2. All sections are very similar and dominated by intergrown anhydrite and halite with minor finely crystalline carbonate. Halite crystals are very large, particularly in O2, and range up to several centimeters in diameter. Note that such large crystals cannot be measured concurrently with the fine-grained material, and histograms constructed for these three sections (Figures 17a-c) are for "matrix" only. Anhydrite ranges from fine to medium crystalline and is generally coarser than in most of the other PX samples. Anhydrite crystals adjacent to halite are typically coarser than those residing in the fine-grained matrix. Carbonate material is finely crystalline and occurs as scattered patches, and in O3 as thin wisps which define bedding. Bedding is not apparent in O1 or O2.

Minor microporosity is seen within patches of finely crystalline carbonate. Several narrow fractures are present on one edge of O3. These fractures are partially within halite crystals and parallel to cleavage. Note that their proximity to the sample edge may suggest a relationship to sample preparation.

6.2.3 Sample PX3. PX3 is dominated by finely crystalline anhydrite which occurs in thin irregular laminae in all sections. Anhydrite appears more finely crystalline in this sample than in any of the other samples: this may be due to the low abundance of halite given the previously noted observation that anhydrite associated with halite is commonly more coarsely crystalline. Finely crystalline carbonate material is second in abundance, occurring in thin wisps along bedding planes and as irregular patches in the anhydrite matrix. Halite is least abundant and forms small irregular nodules within certain anhydrite laminae in O2 and O3, and in the central portion of O1.

Bedding in all three samples is defined by thin, finely crystalline carbonate laminae and appears oriented at about 30° to the core axis in O2. Several thin fractures (partings) parallel to bedding were observed.

Minor microporosity is present within the finely crystalline carbonate material in all sections. Fractures, oriented at about 45° to bedding and with somewhat irregular traces, are present on one end of O1. O3 contains a healed, very narrow fracture which appears confined to several laminae and is oriented at about 80° to vertical.

6.2.4 Sample PX4. PX4 is composed of intergrown polyhalite, halite, anhydrite, and finely crystalline carbonate. Polyhalite occurs as needle-like crystals in spherulitic to pseudo-cross type structures. Elongate anhydrite crystals are intergrown in the outer portions of the spherulites and halite fills space between spherulites. Polyhalite spherulites, containing very little halite or anhydrite, dominate portions of O2 and O3. Anhydrite, in addition to being intergrown with polyhalite, also occurs as equant crystals in the matrix. Finely crystalline carbonate material, which is most abundant in O2, occurs in scattered patches and as thin wisps, which may define bedding. Crystal size is highly variable, and the high sorting (2.94 phi) found for O1 reflects the abundance of elongate crystals.

Only hints of bedding are observed in the PX4 sections. The irregular interface between mixed mineralogy and the polyhalite-dominated areas may represent bedding. Thin wisps of finely crystalline carbonate may define bedding in O2.

Very little porosity, consisting of minor microporosity associated with finely crystalline carbonate, was observed in the PX4 sections.

6.2.5 Sample PX5. PX5 is dominated by admixed anhydrite and halite. Anhydrite occurs as both individual laminae and combined with halite in other laminae. Grains are fine to medium crystalline and appear much coarser than in the underlying sample PX6. As observed previously, anhydrite in close association with halite is usually more coarsely crystalline than in laminae containing only anhydrite. Halite forms nodules within specific laminae in O2 and O3, but appears somewhat randomly oriented in O1 (O1, which is parallel to bedding, may possibly have been prepared from a lamination rich in halite). Carbonate material is finely crystalline and occurs as scattered patches and wisps parallel to laminae.

Bedding is easily recognizable in O2 and O3, but less distinct in thin section O1. Wisps of carbonate material commonly define bedding in this PX sample.

Minor microporosity is present within the finely crystalline carbonate material. One high-angle (to bedding) fracture was observed in an anhydrite lamination in O2. Total porosity appears quite low.

6.2.6 Sample PX6. Sample PX6 is characterized by bedded to laminated anhydrite containing nodular halite. Halite nodules are relatively impure and contain abundant anhydrite inclusions, which may indicate displacive growth in an anhydrite mush prior to lithification. Anhydrite is finely crystalline, except where closely associated with halite. Minor finely crystalline carbonate occurs as wisps parallel to laminations. Minor clay may also be present along some bedding planes. Scattered pyrite framboids were observed in O1.

Bedding is best developed in this sample, although somewhat wavy and discontinuous. Local bedding appears oriented at about 20° to the long dimension (vertical) of thin section P2-O2. Some laminae contain exclusively anhydrite, whereas others contain a mixture of anhydrite and halite. Growth of halite nodules has disrupted some of the original depositional texture.

Total porosity appears low. Microporosity associated with finely crystalline carbonate wisps and patches is most common. Several narrow fractures oriented between 70° and 90° to bedding and with apertures less than 20 µm are present in O2 and O3. Bedding-parallel fractures are present in O2.

FIGURE 16A. GRAIN/CRYSTAL SIZE HISTOGRAM FOR SAMPLE PX1-01.

FIGURE 16B. GRAIN/CRYSTAL SIZE HISTOGRAM FOR SAMPLE PX1-02.

FIGURE 16C. GRAIN/CRYSTAL SIZE HISTOGRAM FOR SAMPLE PX1-03.

FIGURE 17A. GRAIN/CRYSTAL SIZE HISTOGRAM FOR SAMPLE PX2-01.

FIGURE 17B. GRAIN/CRYSTAL SIZE HISTOGRAM FOR SAMPLE PX2-02.

FIGURE 17C. GRAIN/CRYSTAL SIZE HISTOGRAM OF SAMPLE PX2-03.

FIGURE 18A. GRAIN/CRYSTAL SIZE HISTOGRAM FOR SAMPLE PX3-01.

FIGURE 18B. GRAIN/CRYSTAL SIZE HISTOGRAM OF SAMPLE PX3-02.

FIGURE 18C. GRAIN/CRYSTAL SIZE HISTOGRAM OF SAMPLE PX3-03.

FIGURE 19A. GRAIN/CRYSTAL SIZE HISTOGRAM FOR SAMPLE PX4-01.

FIGURE 198. GRAIN/CRYSTAL SIZE HISTOGRAM FOR SAMPLE PX4-02.

FIGURE 19C. GRAIN/CRYSTAL SIZE HISTOGRAM FOR SAMPLE PX4-03.

FIGURE 20A. GRAIN/CRYSTAL SIZE HISTOGRAM FOR SAMPLE PX5-01.

FIGURE 20B. GRAIN/CRYSTAL SIZE HISTOGRAM FOR SAMPLE PX5-02.

FIGURE 20C. GRAIN/CRYSTAL SIZE HISTOGRAM FOR SAMPLE PX5-03.

FIGURE 21A. GRAIN/CRYSTAL SIZE HISTOGRAM FOR SAMPLE PX6-01.

FIGURE 21B. GRAIN/CRYSTAL SIZE HISTOGRAM FOR SAMPLE PX6-02.

FIGURE 21C. GRAIN/CRYSTAL SIZE HISTOGRAM FOR SAMPLE PX6-03.

Plate 1
Sample PX1

- A. General view of thin section PX1-O1 showing intergrown polyhalite spherulites. Each spherulite is composed of tiny, radiating, needle-like crystals. Elongate tabular crystals scattered throughout the view are anhydrite. Finely crystalline carbonate (dolomite?) is also present and appears as dark patches. Plane-polarized light. (40x)
- B. Low magnification view of an open fracture in thin section PX1-O2. This fracture dips at approximately 45° and extends across one corner of the thin section. Anhydrite is the dominant mineral in this portion of the sample. Minor halite (white patches) is also present. Plane-polarized light. (20x)
- C. View of the interface between polyhalite and anhydrite in thin section PX1-O2. The upper portion of the photomicrograph is dominated by anhydrite whereas the lower portion contains more abundant polyhalite. Black patches represent halite (isotropic under crossed nicols). Finely crystalline carbonate (dolomite?) occurs in irregular brownish patches throughout the central portion of the view. Crossed-nicols. (20x)
- D. Overview of thin section PX1-O3 showing abundant polyhalite. Minor amounts of finely crystalline carbonate (dolomite?) are also present. Iron staining (reddish brown color) is present in the lower portion of the view. Plane-polarized light. (40x)

Plate 1

A

B

C

D

Plate 2
Sample PX2

- A. Low magnification view of thin section PX2-O1 showing large halite crystals (lower left) surrounded by more finely crystalline anhydrite. Minor carbonate (dolomite?) appears as dark brown patches within both halite and anhydrite. Many of the halite crystals in this sample are too large to photograph. Plane-polarized light. (20×)
- B. Same view as the previous photomicrograph more clearly showing halite distribution. Significant variation in anhydrite crystal size is also evident. Note high birefringence which is characteristic of anhydrite. Halite is isotropic and appears black. Crossed-nicols. (20×)
- C. Low magnification view of thin section PX2-O2 showing large halite crystals with minor anhydrite around crystal edges and as inclusions. Halite crystals in this thin section are larger than in the other two thin sections from this sample. Crossed-nicols. (20×)
- D. Overview of thin section PX2-O3 showing fractures developed along cleavage planes in relatively large halite crystals. Note fluid inclusion trains along fractures, indicating earlier fractures which have healed. Plane-polarized light. (40×)

Plate 2

A

B

C

D

Plate 3
Sample PX3

- A. Overview of thin section PX3-O1 showing low angle fractures in a matrix composed of anhydrite, carbonate (dolomite?), and halite. Plane-polarized light. (40×)
- B. Low magnification view of thin section PX3-O1 showing the distribution of various mineral components. Halite appears black and forms nodules in the upper portion of the view. Anhydrite and carbonate (dolomite?) occur as inclusions in halite and comprise most of the matrix. Note variation in crystal size. Crossed-nicols. (20×)
- C. Overview of thin section PX3-O2 showing interlaminated halite, anhydrite, and carbonate (dolomite?). Halite appears black and occurs in much larger crystals than either anhydrite or dolomite. Crossed-nicols. (40×)
- D. Low magnification view of thin section PX3-O3 showing irregular anhydrite (white) and carbonate (dolomite?) (dark) laminae. The fracture running from left to right through the central portion of the view is generally parallel to laminations. Plane-polarized light. (20×)

A

B

C

D

Plate 4
Sample PX4

- A. Low magnification view of thin section PX4-O1 showing intergrown halite, polyhalite, and anhydrite. Halite appears white under plane light. Polyhalite along with anhydrite forms relatively large radiating structures. Anhydrite also dominates the matrix between halite and polyhalite crystals. Plane-polarized light. (20×)
- B. More detailed view of thin section PX4-O1. Isotropic halite appears black. Anhydrite occurs as small equant crystals around halite nodules and as elongate needles intergrown with polyhalite. Central portions of the cross-like structures are composed primarily of polyhalite. Crossed-nicols. (40×)
- C. Overview of thin section PX4-O2 showing abundant fibrous polyhalite. Small halite patches (black) are also present on the left side of the view. Minor anhydrite is also present. This thin section is dominated by polyhalite. Crossed-nicols. (40×)
- D. View of intergrown halite, polyhalite, and anhydrite characteristic of thin section PX4-O3. Anhydrite appears in shades of red, yellow, and blue. Note crystal size variation in anhydrite. Polyhalite occurs as needle-like crystals in the central portions of radiating structures. Halite (black) fills space between the other minerals. Crossed-nicols. (40×)

Plate 4

A

B

C

D

Plate 5
Sample PX5

- A. Low magnification view of relatively coarsely crystalline anhydrite with minor halite. Anhydrite in this sample appears coarser than in the overlying or underlying sample. Minor carbonate (dolomite?) appears dark in the lower left. Crossed-nicols. (20×)
- B. Low magnification view of high-angle fractures in thin section PX5-O2. Fractures are near vertical and commonly terminate at the interface between different minerals. Anhydrite and halite are the dominant mineral constituents. Minor carbonate (dolomite?), which appears as small dark patches, is scattered throughout. Plane-polarized light. (20×)
- C. Overview showing the distribution of mineral components in thin section PX5-O3. Halite and anhydrite dominate the upper portion of the view. Many anhydrite crystals appear tabular in this view. Halite fills space between anhydrite crystals. Finely crystalline carbonate, probably dolomite, appears dark and is most abundant in the lower portion of the view. Plane-polarized light. (40×)
- D. Same view as the previous photomicrograph showing mineral distribution. Crossed-nicols. (40×)

Plate 5

A

B

C

D

Plate 6
Sample PX6

- A. Low magnification view of thin section PX6-O1. A narrow high-angle fracture (arrow) in the upper portion of the view terminates at a thin carbonate lamination. Intergrown anhydrite and halite dominate the matrix. Minor pyrite (black patches) is seen in the carbonate lamination in the upper portion of the view. Plane-polarized light. (20×)
- B. Low magnification view showing a near vertical fracture in thin section PX6-O2. A fracture oriented subparallel to bedding is also seen in the upper portion of the view. Some laminae in this sample are dominated by anhydrite, whereas others contain both anhydrite and halite. Crossed-nicols. (20×)
- C. Overview of a lamination containing both halite and anhydrite in thin section PX6-O2. Anhydrite around halite crystals appears more coarsely crystalline than in the matrix away from halite nodules. Crossed-nicols. (40×)
- D. Overview of a healed fracture (arrow) in thin section PX6-O3. This fracture is primarily filled by anhydrite, but a very narrow aperture is present in the center. Anhydrite dominates the matrix. This fracture also appears parallel to narrow open fractures in other portions of the thin section. Plane-polarized light. (40×)

Plate 6

A

B

C

D

7.0 Effective Porosity, Total Porosity, and Saturation

The bulk volumes V_b of the intact samples (A-F and EP1-8) were determined from the volume of fluid displaced when the samples were immersed in water (see Appendix C-A). Samples were first coated with wax to prevent the water from penetrating the sample and the data were corrected for the amount of fluid volume displaced by the wax. (Note that for several samples (A-C, F, and EP4-8) which were later saturated with Odorless Mineral Spirits (OMS), V_b was remeasured by directly submerging the saturated sample in OMS and measuring the mass of fluid displaced. These measurements are believed to be more accurate than the waxed measurements (since they do not require a correction for the amount of fluid displaced by the wax); however, these data are not used in subsequent calculations since they were not available for all samples. We simply make note of the fact that the two sets of measurements for the seven samples all agreed to within 0.30%.)

Boyle's law helium gas porosimetry was used to determine the effective grain volume $V_{g\text{ eff}}$ of the intact samples A-F and EP1-EP8 (Appendix C-A). Data are reported in Table 6, where the effective (i.e. interconnected) porosity ϕ_{eff} is defined by

$$\phi_{\text{eff}} = 1 - \frac{V_{g\text{ eff}}}{V_{\text{bulk}}} \quad (1)$$

Samples EP4-8 were subsequently powdered for determination of total porosity (see Appendix C-A). Because mass is not fully conserved during the (initially violent) powdering process, data are normalized with respect to mass to obtain the bulk density ρ_b (for the intact sample) and the (true) grain density ρ_g for the powdered sample. Data are reported in Table 7, where the total porosity ϕ is defined by

$$\phi = 1 - \frac{\rho_b}{\rho_g} \quad (2)$$

The largest difference between the effective and total porosity for the four samples on which both measurements were performed is 0.2%; however, no discrepancy may be formally identified since the two measurements for all samples agree within the experimental errors. Note that the data for sample EP2 suggests that the total porosity may be somewhat *less* than the effective porosity (again, the two measurements technically agree within the experimental errors). Sample EP2 experienced the largest loss of material loss during the powdering process (19 g, or 8% of the original sample mass). It is likely that this loss of 8 wt% of the original sample is the cause for the slight discrepancy between the measurement of effective versus total porosity for EP2. This inference is consistent with the pervasive heterogeneity which characterizes the MB 139 samples (e.g., Figures 13 and 14 and Section 9).

Samples EP4-8 and samples A, C, and F were vacuum saturated with a non-reactive fluid (odorless mineral spirits) for determination of maximum achievable saturation (Appendix C-A).

Table 6. Bulk Volume, Effective Grain Volume, and Effective Porosity*

Sample	V_b (cc)	$V_{s, eff}$ (cc)	ϕ_{eff} (%)
A	822.84±4.94	807.47±3.23	1.87±0.71
B	776.83±4.66	723.00±3.09	0.49±0.72
C	819.62±4.92	811.31±3.25	1.01±0.71
D	803.84±4.82	798.00±3.19	0.73±0.72
E	843.08±5.06	829.98±3.32	1.55±0.71
F	815.25±4.89	807.09±3.23	1.00±0.71
EP1	83.47±0.50	82.39±0.21	1.29±0.64
EP2	84.39±0.51	83.75±0.21	0.75±0.64
EP3	83.54±0.50	83.19±0.21	0.42±0.64
EP4	83.35±0.50	82.01±0.21	1.60±0.64
EP5	84.85±0.51	83.22±0.21	1.92±0.64
EP6	84.04±0.50	81.74±0.20	2.73±0.63
EP7	83.73±0.50	83.27±0.21	0.55±0.64
EP8	84.52±0.51	83.19±0.21	1.57±0.64

* Quoted uncertainties are derived from formal propagation of random and systematic errors [8]. Sources for systematic error in V_g include pressure transducer accuracy, porosimeter calibration (two constants), and random error is calculated from duplicate measurements. Error in V_b is estimated at 0.6%, based upon comparison of waxed-buoyant measurements with those determined from direct OMS buoyant measurements (see text) and includes an allowance for systematic errors in OMS measurements due to accuracy of digital balances and uncertainty in density of OMS (which was measured directly).

for procedures). Data are reported in Table 8. Calculated saturations for the four smaller samples (EP5-8) are in excess of 100%; however, the associated uncertainties are substantial. The largest source of error, which is not readily quantifiable, apparently results from the moisture-sensitivity of the samples. The samples were moisture-equilibrated in a constant temperature and humidity oven at conditions (60°C, 45% R.H.) which deviated substantially from the ambient conditions. The four EP samples were all found to have experienced some weight gain during the period following the gas porosimetry measurement of effective grain volume and prior to the liquid saturation, even though the samples were plastic-wrapped and stored in ziploc bags during the interim. An additional complication is the change in pore volume, due to a loss of absorbed and/or adsorbed water, which probably occurred during the evacuation process preceding liquid saturation. It is believed that the resultant changes in pore volume, while small in the absolute sense are nevertheless significant relative to the very small pore volume of the EP samples, and the cause of the calculated unphysical (>100%) saturations. Additional support for this hypothesis is offered by the observed inverse relationship between over-saturation and

Table 7. Bulk Density, Grain Density, and Total Porosity*

Sample	ρ_b (g/cc)	ρ_g (g/cc)	ϕ (%)	$M_{original}^\dagger$ (%)
EP1	2.530±0.006	2.566±0.005	1.40±0.30	98
EP2	2.643±0.006	2.658±0.005	0.56±0.29	92
EP3	2.574±0.006	2.585±0.005	0.43±0.30	98
EP4	2.836±0.006	2.882±0.005	1.60±0.49	94

* Quoted uncertainties are derived from formal propagation of random and systematic errors [8]. Error in mass determination includes random errors derived from duplicate measurements and systematic errors due to balance accuracy. Sources for systematic error in V_g include pressure transducer accuracy, porosimeter calibration (two constants), and random error calculated from duplicate measurements. Error in V_b is based upon comparison of waxed-buoyant measurements with those determined from direct OMS buoyant measurements (see text) and includes an allowance for systematic errors in OMS measurements due to accuracy of digital balances and uncertainty in density of OMS (which was measured directly).

† Percentage of original sample mass used for determination of total porosity. (Reduction is due to material losses which occur during the powdering process.)

Table 8. Liquid (OMS) Saturation*

Sample	m_s (g)	m_d (g)	V_b (cc)	$V_{g, eff}$ (cc)	S
EP5	220.998±0.002	219.596±0.002	84.85±0.51	83.22±0.21	1.2±0.3
EP6	222.678±0.004	220.796±0.002	84.04±0.50	81.74±0.20	1.1±0.2
EP7	234.143±0.003	233.502±0.002	83.73±0.50	83.27±0.21	1.9±1.2
EP8	230.016±0.005	228.722±0.002	84.52±0.51	83.19±0.21	1.3±0.4
A	2151.88±0.04	2140.18±0.04	822.84±4.94	807.47±3.23	1.0±0.4
C	2214.84±0.04	2208.66±0.04	819.62±4.92	811.31±3.25	1.0±0.7
F	2333.49±0.04	2327.39±0.04	815.25±4.89	807.09±3.23	1.0±0.7

* Quoted uncertainties are derived from formal propagation of random and systematic errors [8]. Sources for systematic error in m_s and m_d include digital balance accuracy and random error (for m_s) is calculated from duplicate measurements. The density of the saturant (OMS) was measured directly with a calibrated pycnometer and digital balance and is 0.753±0.011 g/cc. Error in fluid density includes uncertainty caused by small temperature fluctuations. Sources for systematic error in $V_{g, eff}$ include pressure transducer accuracy, porosimeter calibration (two constants), and random error calculated from duplicate measurements. Error in V_b is estimated at 0.6%, based upon comparison of waxed-buoyant measurements with those determined from direct OMS buoyant measurements (see text) and includes an allowance for systematic errors in OMS measurements due to accuracy of digital balances and uncertainty in density of OMS (which was measured directly).

pore volume. (Note that for consistency, the "dry" mass used in the saturation calculation is that determined at the time of the effective porosity measurement. Although it is known that the "dry" mass immediately prior to saturation differs, it would be inconsistent to apply this data since the porosity to go along with this second "dry" state is unknown.)

8.0 Single Phase Permeability

8.1 Gas Single-Phase Permeability

Single-phase gas (nitrogen) permeabilities were measured for samples A-F at three effective stress conditions (2, 6, and 10 MPa) using the steady state technique (see Appendix C-A for a schematic of the experimental assembly and procedures). Apparent gas permeabilities k_g were measured at four different mean pore pressures at each effective stress condition (Table 9) and used to calculate Klinkenberg (a.k.a. equivalent liquid) permeabilities k_{∞} (Table 10). (Raw data are compiled in Appendix C-D).

8.2 Liquid Single-Phase Permeability

Single-phase liquid permeabilities k_l were measured at three effective stress conditions (2, 6, and 10 MPa) using the steady state technique (see Appendix C-A for a schematic of the experimental assembly and procedures) for samples A, C, and F (see Section 7.0 and Table 8 above for saturation data). The calculated permeabilities are reported in Table 11. (Raw data are included in Appendix C-E).

The measurements of liquid permeability agree well with the calculated Klinkenberg permeabilities. The differences for seven out of the nine data sets fall within the experimental errors, although the liquid permeabilities do appear, on average, to be systematically lower than the extrapolated Klinkenberg permeabilities.

Table 9. Single Phase Gas Permeability*

Sample	$P_{c, eff}$ (MPa)	$P_{p, mean}$ (MPa)	k_g (μ Da)
A	2	0.2725	12.3 $\pm$ 0.2
		0.3405	11.6 $\pm$ 0.2
		0.4090	11.0 $\pm$ 0.2
		0.4779	10.6 $\pm$ 0.2
	6	0.2728	8.88 $\pm$ 0.14
		0.3397	8.40 $\pm$ 0.13
		0.4105	7.82 $\pm$ 0.12
		0.4787	7.56 $\pm$ 0.12
	10	0.2716	7.29 $\pm$ 0.11
		0.3421	6.84 $\pm$ 0.11
		0.4100	6.55 $\pm$ 0.10
		0.4795	6.31 $\pm$ 0.10
B	2	0.2797	19.8 $\pm$ 0.3
		0.3475	18.5 $\pm$ 0.3
		0.4176	17.5 $\pm$ 0.3
		0.4881	16.8 $\pm$ 0.3
	6	0.2758	13.2 $\pm$ 0.2
		0.3464	12.1 $\pm$ 0.2
		0.4166	11.3 $\pm$ 0.2
		0.4878	10.7 $\pm$ 0.2
	10	0.2755	8.23 $\pm$ 0.13
		0.3452	7.54 $\pm$ 0.11
		0.4159	7.02 $\pm$ 0.11
		0.4867	6.69 $\pm$ 0.10

* Quoted uncertainties are derived from formal propagation of random and systematic errors [8]. Sources for systematic error in k_g include pressure transducer accuracy (differential, gauge, and barometric), accuracy of flow rate measurement (volume and time), caliper accuracy, and uncertainty in temperature measurements. Random error included in flow rate error is calculated from 4 duplicate measurements. Gas viscosity is 0.0176 cp [9].

Table 9. Single Phase Gas Permeability* (continued)

Sample	$P_{c\ off}$ (MPa)	$P_{p\ mean}$ (MPa)	k_g (μ Da)
C	2	0.2871	7.84 $\pm$ 0.12
		0.3559	7.26 $\pm$ 0.11
		0.4224	6.81 $\pm$ 0.10
		0.4940	6.50 $\pm$ 0.10
	6	0.3337	5.41 $\pm$ 0.08
		0.3552	4.86 $\pm$ 0.07
		0.4236	4.49 $\pm$ 0.07
		0.4787	4.25 $\pm$ 0.07
	10	0.3361	4.09 $\pm$ 0.06
		0.3545	3.67 $\pm$ 0.06
		0.4248	3.41 $\pm$ 0.05
		0.4940	3.21 $\pm$ 0.05
D	2	0.4686	0.275 $\pm$ 0.014
		0.5453	0.261 $\pm$ 0.013
		0.6224	0.238 $\pm$ 0.012
		0.6787	0.239 $\pm$ 0.012
	6	0.4743	0.127 $\pm$ 0.007
		0.5439	0.120 $\pm$ 0.006
		0.6142	0.113 $\pm$ 0.006
		0.6875	0.106 $\pm$ 0.005
	10	0.4743	0.088 $\pm$ 0.004
		0.5431	0.083 $\pm$ 0.004
		0.6111	0.080 $\pm$ 0.005
		0.6856	0.078 $\pm$ 0.004

* Quoted uncertainties are derived from formal propagation of random and systematic errors [8]. Sources for systematic error in k_g include pressure transducer accuracy (differential, gauge, and barometric), accuracy of flow rate measurement (volume and time), caliper accuracy, and uncertainty in temperature measurements. Random error included in flow rate error is calculated from 4 duplicate measurements. Gas viscosity is 0.0176 cp [9].

Table 9. Single Phase Gas Permeability* (continued)

Sample	$P_{c\text{ eff}}$ (MPa)	$P_{p\text{ mean}}$ (MPa)	k_g (μDa)
E	2	0.1023	1168 $\pm$ 19
		0.1711	1054 $\pm$ 17
		0.2401	997 $\pm$ 16
		0.3086	927 $\pm$ 15
	6	0.1192	497 $\pm$ 8
		0.1980	426 $\pm$ 7
		0.2660	398 $\pm$ 6
		0.3345	382 $\pm$ 6
	10	0.1290	292 $\pm$ 5
		0.1968	253 $\pm$ 4
		0.2671	218 $\pm$ 4
		0.3342	208 $\pm$ 3
F	2	0.4510	1.77 $\pm$ 0.03
		0.5233	1.69 $\pm$ 0.02
		0.5908	1.62 $\pm$ 0.02
		0.6581	1.57 $\pm$ 0.02
	6	0.4524	1.23 $\pm$ 0.02
		0.5193	1.15 $\pm$ 0.02
		0.5921	1.11 $\pm$ 0.02
		0.6597	1.06 $\pm$ 0.02
	10	0.4525	1.06 $\pm$ 0.016
		0.5176	0.99 $\pm$ 0.01
		0.5911	0.95 $\pm$ 0.01
		0.6636	0.91 $\pm$ 0.01

* Quoted uncertainties are derived from formal propagation of random and systematic errors [8]. Sources for systematic error in k_g include pressure transducer accuracy (differential, gauge, and barometric), accuracy of flow rate measurement (volume and time), caliper accuracy, and uncertainty in temperature measurements. Random error included in flow rate error is calculated from 4 duplicate measurements. Gas viscosity is 0.0176 cp [9].

Table 10. Calculated Klinkenberg Permeability

Sample	$P_{c, eff}$ (MPa)	k_{∞} (μ Da)
A	2	8.36 $\pm$ 0.12
	6	5.76 $\pm$ 0.20
	10	5.05 $\pm$ 0.03
B	2	12.76 $\pm$ 0.09
	6	7.50 $\pm$ 0.12
	10	4.67 $\pm$ 0.04
C	2	4.63 $\pm$ 0.06
	6	2.63 $\pm$ 0.03
	10	2.01 $\pm$ 0.02
D	2	0.147 $\pm$ 0.019
	6	0.060 $\pm$ 0.004
	10	0.055 $\pm$ 0.008
E	2	836 $\pm$ 28
	6	307 $\pm$ 19
	10	155 $\pm$ 8
F	2	1.13 $\pm$ 0.02
	6	0.70 $\pm$ 0.03
	10	0.58 $\pm$ 0.01

Table 11. Single Phase Liquid Permeability* vs Calculated Klinkenberg Permeability

Sample	$P_{c,eff}$ (MPa)	k_i (μ Da)	k_w (μ Da)
A	2	6.75 $\pm$ 1.36	8.36 $\pm$ 0.12
	6	5.76 $\pm$ 0.65	5.76 $\pm$ 0.20
	10	5.37 $\pm$ 0.60	5.05 $\pm$ 0.03
C	2	3.66 $\pm$ 0.40	4.63 $\pm$ 0.06
	6	2.43 $\pm$ 0.27	2.63 $\pm$ 0.03
	10	1.83 $\pm$ 0.20	2.01 $\pm$ 0.02
F	2	1.06 $\pm$ 0.12	1.13 $\pm$ 0.02
	6	0.62 $\pm$ 0.07	0.70 $\pm$ 0.03
	10	0.52 $\pm$ 0.06	0.58 $\pm$ 0.01

* Quoted uncertainties are derived from formal propagation of random and systematic errors [8]. Sources for systematic error in k_i include differential pressure transducer accuracy, accuracy of flow rate measurement (volume and time), caliper accuracy, and uncertainty in fluid viscosity. Random error is calculated from at least 5 duplicate measurements. Experimental measurement of OMS viscosity is 1.29 cp with an assumed maximum uncertainty of 10%.

9.0 Summary and Recommendations

The laboratory investigations demonstrate that Marker Bed 139 is characterized by significant and pervasive heterogeneity. Remarkable heterogeneity occurs as the marker bed is traversed vertically, and some variability is also apparent as the marker bed is traversed laterally. Mineralogy varies dramatically, and although porosity is typically $-0.5-3.0\%$, permeability varies by approximately four orders of magnitude (e.g., from tenths of microdarcies to hundreds of microdarcies at an effective pressure of 2 MPa).

Attempts to use a second-generation x-ray CT scanner to identify natural and coring-induced fractures were unsuccessful, due to the large diameter of the core material (6 inches) and high bulk density (close to 3 g/cc). Several attempts to compensate and/or correct for pronounced image artifacts caused by excessive beam-hardening were unsuccessful. However, preliminary scoping tests which were performed with a more powerful and advanced third-generation CT scanner (acquired midway through the contract performance period) yielded promising results. Thus, with the newer CT technology it may be possible to perform highly detailed non-destructive lithologic evaluations. Also, fractures with apertures on the order of tenths of millimeters should be resolvable with the more advanced scanner.

The marker bed exhibits four distinct mineralogic zones. The upper portion is rich in polyhalite, which is manifested by a conspicuous salmon-pink color. Halite and anhydrite are also major mineral phases in this section, as are dolomite and aragonite. The central region contains both anhydrite and halite, which occur in varying proportions and account for nearly all of the solid phase. The lower portion of this central region is dominated by anhydrite with markedly smaller ($<20\%$) amounts of halite. The very bottom of the marker bed is significantly more fine-grained than the rest of the marker bed; unfortunately, this section is limited in length (4-5") and thus no samples for detailed testing were prepared from this region. CT scans, however, indicate that this region is the densest part of the entire marker bed. Thus, this region may contain nearly 100% anhydrite, or possibly small amounts of very dense impurities such as pyrite (which was identified in thin-section).

The petrographic studies corroborate the general observations above and, moreover, indicate that marked heterogeneity can exist at even the cm scale. For example, the volumetric percentage of various minerals may vary by as much as 20 to 30% for samples prepared from locations separated by only two or three centimeters. The modal analyses based on 300-point counts consistently suggest the occurrence of several vol% (and sometimes as much as 16 vol%) of a carbonate phase, tentatively identified as dolomite, in each of the eighteen thin sections examined. Although the XRD analyses are recognized as only semi-quantitative in nature, the apparent absence of carbonate in four of the six samples tested is conspicuous. Although it is possible that the carbonate material is present only locally, it is more likely that the XRD analyses fail to identify carbonate in the MB139 samples because of variations in crystallinity and possibly mg/fe/ca cation ratios (as compared to the reference standards used to calibrate the diffractometer). Thus, depending upon the level of investigations to be performed in the future, it may be worthwhile to restrict further XRD analyses to a single institution and to invest in the development of a set of standards specific to the WIPP.

Measurements of effective and total porosity consistently indicate that the bulk porosity of the marker bed is quite low, and varies from 0.4% to 2.7%. The measurements of effective versus total porosity agree within the experimental errors. Permeability, however, varies by approximately four orders of magnitude (e.g., from tenths of microdarcies to hundreds of microdarcies at an effective pressure of 2 MPa). A permeability on the order of millidarcies was measured for one sample at an effective stress of 2 MPa and may represent fracture permeability. The other extreme is embodied by a single sample with a permeability on the order of tenths of microdarcies (i.e., hundreds of nanodarcies) at an effective stress of 2 MPa. Four other samples are characterized by permeabilities on the order of microdarcies. The measurements of liquid permeability agree well with calculated Klinkenberg (a.k.a equivalent liquid) permeabilities. The differences for seven out of the nine data sets fall within the experimental errors, although the liquid permeabilities do appear, on average, to be systematically lower than the extrapolated Klinkenberg permeabilities.

Calculations of achievable saturation suggest that complete saturation is probably attained by routine vacuum saturation; however, the experimental errors are significant given the excessively small pore volumes of the samples. Interpretation is further complicated by possible changes in pore volume caused by the apparent adsorption and/or absorption of moisture from the atmosphere which occurred while samples were between various parts of the testing program. Although very small in the absolute sense, the hypothesized changes in pore volume are significant in the relative sense. Thus, it may be advisable to either equilibrate samples to local atmospheric conditions or else make provisions to acquire a constant temperature and constant humidity oven dedicated exclusively to the test program.

10.0 References

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APPENDIX C-A: Procedures

A.1 X-Ray Computerized Tomography

A.1.1 Background. Computerized tomography (CT) is a non-destructive technique for the evaluation of the internal structure of a material. Imaging technology is based on the analysis of the attenuation of x-rays as they pass through a material. This attenuation is due to scattering and adsorption and is characterized by Beer's law:

$$I = I_0 e^{-\alpha x} \quad (3)$$

where I_0 and I are the incident and attenuated x-ray intensity, x is the thickness of the material, and α is the linear attenuation coefficient.

The attenuation of the x-rays is dependant on photoelectric adsorption and Compton scattering. Photoelectric adsorption is dependent on the electron density or the effective atomic number of the material and is a predominant term at x-ray energies below 100 kV. Compton scattering is dependent on the density of the material and becomes a more predominant term at energy levels above 100 kV. Thus, the attenuation coefficient for a material depends upon both the density and effective atomic number of the material as well as the energy level of the x-ray:

$$\alpha = \rho \left(a + \frac{bZ^{3.8}}{E^{3.2}} \right) \quad (4)$$

where ρ is the mass density of the material, Z is the effective atomic number, E is the x-ray energy level, a is the Klein-Nishina coefficient, and b is a constant. At high energy levels, and for materials with similar chemical composition, differences in the effective atomic number are small. Differences in attenuation are thus due primarily to differences in mass density.

A.1.2 TerraTek's CT Facility. At the start of the performance period for this contract, TerraTek's CT facility employed an Ohio Nuclear DeltaScan 100. The DeltaScan 100 is a second generation medical CT imaging machine and TerraTek's scanner was originally built in 1980 for use as a head scanner. No hardware modifications were made to the scanner for use as a material imager. When a test sample is inserted in the scanner, an x-ray source and detector are passed in parallel planes past the sample (called a traverse). The tube and detector are then rotated through a specified number of degrees and another traverse occurs. This is repeated through a 180-degree rotation. A cross-sectional image of the test sample can then be generated by dividing the sample up into small discrete elements (or pixels) and solving a set of linear equations. The linear attenuation coefficient for each element can be determined through reconstruction algorithms intrinsic to the scanner's computer.

The x-ray beam is collimated into three fan shaped beams which are attenuated as they pass through the sample. The width of the beam, which determines the volume of material (voxel) for which linear attenuation coefficients are calculated, can be adjusted from 3 to 10 mm. The attenuated x-rays are measured by three detectors with measurements recorded every 3° in a 180° rotation. Each image requires two minutes to complete the 60 scans. The maximum diameter of a sample is limited to 305 mm. However, with large samples resolution is decreased since

the pixel array is fixed at 256×256 . Also, for some materials the maximum diameter must be reduced to insure successful X-ray penetration.

The data array is composed of CT numbers which are defined as normalized attenuation coefficients for the material being scanned. Cross-sectional images may reveal the presence of open fractures, filled fractures, vugs, and mineral inclusions. Broken or crushed sections of core can be identified before the sample is removed from its packaging, aluminum casing, or rubber sleeves. Vertical reconstructions are built from a series of cross-sectional images. Six contiguous rows or columns (in either the x or y direction) of data elements for each cross section in the series are averaged. For discontinuous scanning, the image is completed by interpolating between scans. The resultant image represents the core as it would appear if it were slabbed through the x or y plane as defined above. The software utilized to process the CT data is Shell Development Company's CATPIX programming, which was licensed to TerraTek in 1987. Although modifications were made to the graphics display software, no modifications were made to the fundamental algorithms used to process the data.

During the performance period for this contract, TerraTek constructed a new, more advanced CT facility employing a third generation Philips 60/TX CT scanner. The Philips 60/TX provides significantly greater resolution and imaging capabilities and TerraTek has since discontinued use of its original second generation CT facility. TerraTek has also developed a software for advanced CT analysis which provides automatic numerical correction for beam-hardening, density and atomic number determination, and many other features. The C++ software is implemented on a Sun SparcStation 10 and marketed under the name CORESCANTM. The new CT facility was used only for exploratory (scoping) work under the present contract, and the operating procedures described below refer to the DeltaScan 100.

A.1.3 Operating Procedures. The scan tube was mounted on to a table designed by Shell Development Company which provides positioning control of the sample to within 0.002 inch. Positions were measured by an Acu-Rite III scale assembly which is mounted onto the table and the scanning sequence (consisting of the number of scans, the distance which the scan table moves between scans, and the feed rate) were programmed into an Aerotech Unidex IIIa Motion Controller. The position of the first scan was indicated by a fixed light source. The gantry system and data acquisition were controlled by a VAX PDP 11/04 computer system. Scan data acquired with the VAX PDP 11/04 was transferred to magnetic tape, and then to a Microvax II GPX color graphics work station.

The data array generated by the scanner is composed of CT numbers which are defined as normalized attenuation coefficients for the material being scanned. CT numbers are defined as follows:

$$CT\# = K \frac{\mu_{PIX} - \mu_{PHA}}{\mu_{PHA}} \quad (5)$$

where μ_{PIX} is the attenuation coefficient of the pixel being measured, μ_{PHA} is the attenuation coefficient of the "phantom" used to generate the non-linear coefficients for the back projection

algorithm, and K is a constant. The phantom used for calibration depends upon the material to be scanned. For example, for medical scanning of human subjects, a phantom filled with distilled, deionized water is used to calibrate the CT number scale so that the CT number of water equals zero. For scanning of geologic materials, TerraTek uses a 4.17 inch diameter fused quartz standard. The fused quartz standard is mounted on a platform so that the standard extends beyond the platform into the plane of the CT scan traverse; essentially, the quartz standard is suspended in air. The nonlinear coefficients are generated by software which is part of the Ohio Nuclear DeltaScan 100 programming such that the CT number of the fused quartz standard is equal to zero.

Consistency is maintained by scanning a second 0.978 inch diameter fused quartz standard in the scan tube immediately after the nonlinear coefficients are obtained. The average CT number of this standard is calculated based upon a Region of Interest (ROI) equal to approximately 80% of the sample diameter (to avoid any data distortion at the circumference of the standard). This standard is then scanned before each programmed sequence of scans and the average CT number is compared to the initial CT value obtained for the standard. Any variance can be corrected for using another routine in the DeltaScan 100 programming.

The manufacturer's general operating procedures¹ for the CT Scanner were adhered to during use.

A.1.4 Imaging of fluid flow through cores. Dynamic flow tests may be performed in which a non-reactive highly attenuating liquid is injected into a core sample and scanned as the fluid front penetrates the sample. A common dopants is sodium iodide. For flow tests which are conducted under elevated hydrostatic pressures, grooved end plugs and mesh screens are mounted on each end of the sample to insure that flow is homogeneous across the sample end faces. The sample and end plugs are then jacketed in a viton sleeve and pressure taps are located at each end of the sample. The pressure taps are connected to a differential pressure transducer and the pressure difference between the upstream and downstream ends is recorded on an X-Y plotter. The sample assembly is then placed in an aluminum pressure vessel and mounted in the scanner.

Before beginning fluid flow, the sample is scanned under hydrostatic stress conditions to establish the initial test condition. This condition is assumed to represent zero saturation. Once the initial conditions have been established, fluid flow begins at a constant rate until a stable differential pressure is achieved. Scanning can be performed intermittently to investigate saturation phenomena such as fingering. Under steady-state flow, the core can be scanned continuously to establish saturation profiling and liquid content distribution. A series of cross-sectional images at steady-state can be displayed perpendicular to the axis of the core and pore fluid imbibition can be identified by variations in the color assignments. The saturation for each location can also be determined along the length of the core.

¹Operator's Manual Delta Scan 100 Series Brain Scanner, Manual No. 961036 Revision B, Technicare Corporation, Ohio, 1980.

A.2 X-Ray Diffraction (XRD) Analyses

XRD analyses were performed by the University Of Utah Research Institute in accordance with guidelines provided in reference texts.^{2,3,4} In preparation for bulk XRD analysis, an approximately 50 gram sample was crushed to <18 mesh (<1 mm) and thoroughly homogenized to ensure that the portion to be analyzed was representative of the whole sample. A one gram split of the crushed sample was then ground in acetone in an agate mortar to <325 mesh (<45 μm). The powdered split was then completely mixed by rolling it on weighing paper. The powder was then x-rayed at $2^\circ 2\theta$ per minute from 10 - $65^\circ 2\theta$ and $1^\circ 2\theta$ per minute from 2 - $10^\circ 2\theta$ using a Phillips XRG-3100 diffractometer.⁵ A quartz standard⁶ was x-rayed at the completion of each sample to monitor drift in x-ray intensity. Diagnostic peaks of minerals identified on the resulting diffractograms were rescanned on duplicate samples. Approximate weight percentages of mineral phases were determined by comparing diagnostic peak intensities with those generated by standard pure phases mixed in various known proportions. Results are reported in weight percent and are the average of three duplicate samples. Variables that can effect calculation of the proportion of each mineral phase in a sample include: matrix absorption, peak overlap, crystallinity and crystal size, amorphous or organic content, absorption factors, chemical substitution, preparation techniques, and detection limits. Although many of these variables can be controlled, some cannot; hence, the results of XRD analysis are semi-quantitative.

A.3 Petrographic Analyses

Petrography was conducted with a Leitz Laborlux 12 Pol polarizing microscope equipped with objectives of $2.5\times$ (0.08 numerical aperture (NA)), $6.3\times$ (0.2 NA), $25\times$ (0.55 NA), and $40\times$ (0.70 NA). Eye pieces were $10\times$, yielding possible magnifications $25\times$, $63\times$, $250\times$, and $400\times$. Photomicrographs were taken with a Nikon Labophot-pol polarizing microscope equipped with objectives of $2\times$ (0.08 NA), $4\times$ (0.2 NA), $10\times$ (0.50 NA), and $20\times$ (0.04 NA). Eye pieces were $10\times$, yielding possible magnifications of $20\times$, $40\times$, $100\times$, and $200\times$. The camera system was a Nikon UFX automatic system with a Nikon FX-35A camera body.

²*Methods & Practices in X-Ray Powder Diffraction*, R. Jenkins (Ed.), JCPDS— International Centre for Diffraction Data, 1986.

³Starkey, H. C., P. D. Blackmon, and P. L. Hauff, The routine mineralogical analysis of clay-bearing samples, *U.S. Geol. Surv. Bull.* 1563, 32p., 1984.

⁴Moore, D. M., and R. C. Reynolds, *X-ray Diffraction and the Identification and Analysis of Clay Minerals*, Oxford University Press, 332p., New York, 1989.

⁵The UURI maintains a service contract with Philips Electronic Instruments which includes two preventive maintenance checks per year.

⁶The quartz standard was supplied as part of the standard stock package when the XRD machine was purchased from Philips Electronic Instruments.

Three mutually perpendicular thin sections were prepared from each PX sample (Figure A1). Sections were mounted on a Leitz #553428 mechanical stage for point count analysis (300 points). Grain/crystal size was measured using a micrometer reticle in the eyepiece which was calibrated to a Zeiss 5+100/100 calibration plate. Size determinations are accurate to approximately 10 μm . Imaging problems necessarily arise with objects whose dimensions are less than the thickness of the thin section.

Minerals were identified using standard petrographic techniques, such as appearance, extinction, birefringence, cleavage, crystal habit, pleochroism, and interference, following reference texts.⁷ Textural parameters follow Blatt et al.⁸ Sample composition and grain/crystal size were determined by point counts of 300 discrete points. Spacing between points was approximately 0.9 mm for the most commonly used objective. As the mechanical stage was moved to each point the object under the cross hairs was identified and diameter (defined as the longest axis for non-spherical objects) was measured for grains and crystals using the micrometer in the eyepiece. Histograms of grain size distribution were constructed using software developed by TerraTek.

A.4 Porosity Measurement

Gas porosimetry was used to determine the bulk ("effective") grain volume $V_{g\text{ eff}}$ of intact samples and the "total" grain volume V_g of powdered samples. The bulk volume V_b of intact samples was calculated from the fluid volume displaced by the submerged test sample (Archimedes principle). Masses of intact or powdered samples are determined with electronic balances. These data were used to calculate the interconnected ("effective") porosity ϕ_{eff} and total porosity ϕ :

$$\phi_{\text{eff}} = 1 - \frac{V_{g\text{ eff}}}{V_b} \quad (6)$$

$$\phi = 1 - \frac{\rho_b}{\rho_g} \quad (7)$$

where the bulk density ρ_b and grain density ρ_g are given by

$$\rho_b = \frac{m_d}{V_b} \quad (8)$$

⁷Deer, W. A., R. A. Howie, and J. Zussman, *An Introduction to the Rock Forming Minerals*, Longmans, Green, and Co., Ltd., London, 1966.

⁸Blatt, H., G. Middleton, and R. Murray, *Origin of Sedimentary Rocks*, Prentice Hall, Inc., New Jersey, 1980.

Figure A1a. Documentation of thin section preparation from PX samples from core E1X08-4.

Figure A1b. Documentation of this section preparation from PX samples from core EIX08-4.

$$\rho_g = \frac{m_d}{V_g} \quad (9)$$

and m_d is the mass of either the dry intact or dry powdered sample. Note that because mass is not fully conserved during the powdering of the sample for determination of total porosity, the ratio of bulk and grain density is used to calculate porosity rather than the ratio of bulk and grain volumes.

A.4.1 Gas porosimetry. Gas porosimetry is based on Boyle's law which holds that for an ideal gas at constant temperature the volume of the gas will vary inversely with pressure:

$$\frac{P_1}{P_2} = \frac{V_2}{V_1} \quad (10)$$

where P_1 is the initial pressure in the initial volume V_1 and P_2 is the final pressure in the final volume V_2 . Calibration of TerraTek's custom-made gas expansion porosimeter was performed using a series of steel billets of known volume. A linear regression was performed to determine the relationship between the measured ratio P_1/P_2 and the sample volume. The measured pressure ratio with the sample in the porosimeter was then used to determine the grain volume $V_{g \text{ eff}}$ of the sample. Two duplicate runs were performed.

A.4.2 Bulk volume. Bulk volume was calculated from the fluid volume displaced when the test sample was submerged in fluid (Archimedes' principle).⁹ The volume of fluid displaced, which is equal to the sample bulk volume, is given by the difference between the weight in air and the buoyant weight divided by the temperature corrected density of the fluid. Samples were coated with wax so that fluid could not penetrate the sample (measurements were corrected for the volume of the wax). (Alternatively, saturated samples may be immersed directly.) The weight measurements are performed with appropriately ranged electronic balances. Temperature of the immersion fluid was measured to 0.1°C immediately following the weight measurements using a thermometer. As a check, the bulk volume of regularly shaped samples was also measured with calipers.¹⁰

A.4.3 Powdering for measurement of total porosity. Samples were crushed and pulverized to 350 mesh (approximately <46 microns) using a shatter box and then dried in a humidity-controlled oven for an additional 24 hours to drive off any adsorbed water the powder may have imbibed (e.g. from atmospheric humidity) during the pulverizing process. Following the second drying period, the powder was allowed to reach ambient temperature in a vacuum chamber.

⁹Rock Characterization, Testing, & Monitoring: ISRM Suggested Methods, E. T. Brown (Ed.), 211p., Pergamon Press, New York. Procedures for water displacement method for determination of bulk volume of solid and porous samples are outlined on p. 82.

¹⁰Rock Characterization, Testing, & Monitoring: ISRM Suggested Methods, E. T. Brown (Ed.), 211p., Pergamon Press, New York. Procedure for determination of bulk volume using the caliper method is given on p. 82.

A.5 Liquid Saturation

Cores were vacuum saturated with a non-reactive liquid, odorless mineral spirits (OMS). Samples were first subjected to vacuum, flooded with CO₂ (to facilitate displacement of any residual air), re-evacuated, and then flooded with OMS while under vacuum. Mass of the samples was measured using an appropriately ranged digital mass balances prior to and following saturation. The saturation S of the samples is given by:

$$S = \frac{\rho_s - \rho_d}{\phi_{eff} \rho_f} = \frac{\frac{(m_s - m_d)}{V_b}}{\frac{V_{\phi_{eff}}}{V_b} \rho_f} = \frac{m_s - m_d}{V_{\phi_{eff}} \rho_f} \quad (11)$$

where ρ_s and ρ_d are the saturated and dry bulk densities, m_s and m_d are the saturated and dry masses, ϕ_{eff} is the effective porosity, $V_{\phi_{eff}}$ is the effective pore volume, ρ_f is the density of the pore fluid, and V_b is the bulk volume. Density of the saturating fluid was measured directly using a calibrated precision pycnometer and appropriately ranged digital balance.

A.6 Gas Single-Phase Permeability

Gas single-phase permeability was measured under hydrostatic confining pressures using the steady-state flow method (Figure A2). The pore fluid was nitrogen gas and samples were jacketed in viton tubing (70 durometer) to prevent bypassing of the sample by the fluid.

Because of the compressibility of gases, the differential form of Darcy's law must be integrated using the condition appropriate for gas flow (i.e. at constant temperature and steady state the product (pressure $\times$ velocity) is constant throughout the sample) to determine the permeability k_g . The gas permeability k_g was calculated from the following equation¹¹:

$$k_g = -\frac{Q_2}{A} \left(\frac{2P_2 L}{P_2^2 - P_1^2} \right) \mu = v_2 \left(\frac{P_2}{P_m} \right) \left(\frac{L}{\Delta P} \right) \mu \quad (12)$$

where $v_2 = Q_2/A$, and Q_2 is the volumetric flow rate (or "discharge") at the downstream end, A is the cross-sectional area of the sample, P_1 and P_2 are the gas pressures at the upstream and downstream reservoirs, μ is the gas viscosity, L is the length of the sample in the macroscopic flow direction, and $P_m = 1/2(P_1 + P_2)$.

Gas permeability varies with the pressure of the gas due to the so-called "slip" effect. The "Klinkenberg permeability" k_w (a.k.a. equivalent liquid permeability) was calculated from the following relation²:

¹¹ e.g., Dullien, F. A. L., *Porous Media—Fluid Transport and Pore Structure*, 2nd ed., Academic Press, New York, 1992.

$$\frac{v_2 P_2 L \mu}{\Delta P P_m} = k_{\infty} \left(1 + \frac{b}{P_m} \right) \quad (13)$$

where b is a constant characteristic of both the gas and porous medium and the permeability. The left hand side of equation 5 was plotted against $1/P_m$ and a straight line was fit to the data; the slope of the line is bk_{∞} and the intercept is k_{∞} .

Mean pore pressures were minimized, but sufficient to cause fluid flow along the sample length. Measurements were made at four different mean pore pressures (increments of approximately 0.07 MPa) to allow for accurate determination of the Klinkenberg permeability. Measurements were repeated four times at each mean pore pressure.

Pressure drops across the core were chosen such that laminar flow was favored. Analysis to verify the existence of Darcian (i.e., laminar viscous) flow was performed for verification. The analysis followed standard industry practice of relating the difference of the squared upstream and downstream pressures ($P_1^2 - P_2^2$) to the basis flow rate Q_{basis} .¹² A strong linear correlation ($R > 0.99$) is evidence of laminar viscous flow.

A.7 Liquid Single-Phase Permeability

Liquid permeabilities were measured for saturated samples at hydrostatic confining pressures using the steady state technique (Figure A3). Permeability k_i is calculated using Darcy's law:

$$Q = \left(\frac{k_i A}{\mu} \right) \left(\frac{\Delta P}{L} \right) \quad (14)$$

where Q is the volumetric flow rate (or "discharge"), A is the cross-sectional area of the sample, L is the length of the sample in the macroscopic flow direction, $\Delta P = P_1 - P_2$ is the hydrostatic pressure drop across the sample length, and μ is the viscosity of the fluid.

Pressure drops across the core were chosen such that laminar flow was assured. The fluid pressure differential was minimized, but sufficient to cause fluid flow along the sample length. Flow measurements were performed at least 5 times.

A.8 Calibration Facilities and Instrumentation

TerraTek operates a calibration lab used to support the various testing groups within the company. The lab maintains calibration standards for force, pressure, mass, displacement, temperature, and voltage. These standards are wholly owned by the Company and are traceable

¹²e.g., *Handbook of Natural Gas Engineering*, D. L. Katz et al., McGraw-Hill Book Company, New York, 1959.

GAS PERMEAMETER

Figure A2. Schematic of experimental system for gas permeability measurement.

LIQUID PERMEAMETER

N_2 = NITROGEN GAS
(STANDARD 304 CU. FT. BOTTLES)

PI = INJECTION PRESSURE TRANSDUCER

1 = ISOLATION VALVE

Pc = CONFINING PRESSURE TRANSDUCER

2 = "SHORTING" VALVE (ISOLATES
INJECTION LINE FROM EXIT LINE)

ΔP = DIFFERENTIAL PRESSURE TRANSDUCER

3 = MICRO-METERING VALVE

T_e = VESSEL TEMPERATURE (FLOW)

Figure A3. Schematic of experimental system for liquid permeability measurement.

to the National Institute of Standards and Technology. Calibration records consisting of certificates, data sheets, reports, and calibration schedules are maintained.

APPENDIX C-B: Index of CT Cross-sectional Images from Whole Core Scan (E1X-08)

Table B1. Index of CT Images for E1X08

Image No.	Depth (feet)
100005	2.706
100015	2.805
100025	2.903
100035	3.002
100045	3.100
100055	3.198
100065	3.297
100110	3.686
100140	3.981
100170	4.277
100200	4.572
100230	4.867
100260	5.163
100290	5.458
100320	5.753
100357	6.029
100367	6.128
100377	6.226
100400	6.452
100410	6.551
100420	6.649
100430	6.747
100440	6.846
100450	6.944
100460	7.043
100470	7.141
100480	7.240

APPENDIX C-C: Drying History of Samples A-F & EP1-8

SAMPLE "A"

SAMPLE "B"

SAMPLE "C"

SAMPLE "D"

SAMPLE "EP5"

SAMPLE "EP6"

SAMPLE "EP7"

SAMPLE "EP8"

APPENDIX C-D: Gas Permeability Spreadsheets

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	2 MPa	290.1 psid	Gas:	N2		
Sample #:	A	Length:	10.117 cm		gas deviation z factors:	ze = 1.0000	zb = 1.0000	
Stress Level #:	1	Diameter:	10.170 cm		Viscosity:	0.0176 cp		
Regime #:	1	Area:	81.233 cm^2					
Pressure Data Filename: 8362AG.S1B								
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt				

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)	
26 May 93	12:51	108	AS1R1a	12.33 psia	1.423 volts	0.870 volts	3.874 volts		1.057 volts	23	22	0.05232	
26 May 93	12:54	108	AS1R1b	12.33 psia	1.423 volts	0.870 volts	3.874 volts		1.057 volts	23	22	0.05232	
26 May 93	12:56	113	AS1R1c	12.33 psia	1.423 volts	0.870 volts	3.874 volts		1.057 volts	23	22	0.05219	
26 May 93	12:58	113	AS1R1d	12.33 psia	1.423 volts	0.870 volts	3.874 volts		1.057 volts	23	22	0.05229	
AVERAGES			AS1R1										
					GUAGE		GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)		(°C)
					1.423 volts	0.870 volts	3.874 volts		1.057 volts	23	22		
					317.1 psig	48.23 psig	42.72 psid	27.20 psig	5.836 psig				
					21.58 atm	3.282 atm	2.907 atm	1.851 atm	0.3971 atm				
				2.187 Mpa	0.3326 Mpa	0.2945 Mpa	0.1875 Mpa	0.04024 Mpa					
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)	
				12.33 psia	329.5 psia	60.56 psia	42.72 psid	39.53 psia	18.17 psia	296	295	0.05228	
				0.8390 atm	22.42 atm	4.121 atm	2.907 atm	2.690 atm	1.236 atm				
0.08501 Mpa	2.272 Mpa	0.4176 Mpa	0.2945 Mpa	0.2725 Mpa	0.1252 Mpa								

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * V_b$
 $Q_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * Q_b$

$$ve = Qe/A = (Pb/Pe) * (Te/Tb) * (ze/zb) * (Qb/A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.117 cm	* 1.0E-2 m/cm 1.012E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8390 atm	* 1.013E+5 Pa/atm 8.499E+04 Pa
ΔP = pressure drop across sample length	2.907 atm	* 1.013E+5 Pa/atm 2.945E+05 Pa
Pm = mean pore pressure (absolute)	2.690 atm	* 1.013E+5 Pa/atm 2.725E+05 Pa
Pe = exit pressure (absolute)	1.236 atm	* 1.013E+5 Pa/atm 1.252E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.05228 cm ³ /s	* 1.0E-6 m ³ /cm ³ 5.228E-08 m ³ /s
ve = flow velocity at sample exit end	4.383E-04 cm/s	* 1.0E-2 m/cm 4.383E-06 m/s
Ka =	1.23E-05 d	* 9.872E-13 m ² /d 1.22E-17 m ²
Ka =	1.23E-02 md	1.22E-13 cm ²
Ka =	1.23E+01 μ d	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	2 Mpa	290.1 psid	Gas:	N2
Sample #:	A	Length:	10.117 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	1	Diameter:	10.170 cm		Viscosity:	0.0176 cp
Regime #:	2	Area:	81.233 cm ²			
Pressure Data Filename:	8362AG.S1B					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)	
26 May 93	15:41	278	AS1R2a	12.30 psia	1.465 volts	1.045 volts	3.851 volts		2.871 volts	23	23	0.06131	
26 May 93	15:45	283	AS1R2b	12.30 psia	1.465 volts	1.045 volts	3.851 volts		2.871 volts	23	23	0.06122	
26 May 93	15:48	283	AS1R2c	12.30 psia	1.466 volts	1.045 volts	3.851 volts		2.872 volts	23	23	0.06125	
26 May 93	15:50	288	AS1R2d	12.30 psia	1.466 volts	1.045 volts	3.851 volts		2.872 volts	23	23	0.06133	
AVERAGES			AS1R2										
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)		
					1.466 volts	1.045 volts	3.851 volts		2.872 volts	23	23		
					326.6 psig	57.94 psig	42.47 psid	37.09 psig	15.854 psig				
					22.22 atm	3.942 atm	2.890 atm	2.524 atm	1.0788 atm				
					2.252 Mpa	0.3995 Mpa	0.2928 Mpa	0.2557 Mpa	0.10931 Mpa				
					ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
					12.3 psia	338.9 psia	70.24 psia	42.47 psid	49.39 psia	28.15 psia	296	296	0.06128
					0.8370 atm	23.06 atm	4.779 atm	2.890 atm	3.361 atm	1.916 atm			
	0.08481 Mpa	2.337 Mpa	0.4843 Mpa	0.2928 Mpa	0.3405 Mpa	0.1941 Mpa							

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$

$Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.117 cm	* 1.0E-2 m/cm 1.012E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8370 atm	* 1.013E+5 Pa/atm 8.478E+04 Pa
ΔP = pressure drop across sample length	2.890 atm	* 1.013E+5 Pa/atm 2.927E+05 Pa
Pm = mean pore pressure (absolute)	3.361 atm	* 1.013E+5 Pa/atm 3.404E+05 Pa
Pe = exit pressure (absolute)	1.916 atm	* 1.013E+5 Pa/atm 1.941E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.06128 cm ³ /s	* 1.0E-6 m ³ /cm ³ 6.128E-08 m ³ /s
ve = flow velocity at sample exit end	3.296E-04 cm/s	* 1.0E-2 m/cm 3.296E-06 m/s
	Ka = 1.16E-05 d	* 9.872E-13 m ² /d 1.14E-17 m ²
	Ka = 1.16E-02 md	1.14E-13 cm ²
	Ka = 1.16E+01 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	2 Mpa	290.1 psid	Gas:	N2
Sample #:	A	Length:	10.117 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	1	Diameter:	10.170 cm		Viscosity:	0.0176 cp
Regime #:	3	Area:	81.233 cm ²			
Pressure Data Filename:	8362AG.S1B					
XDCR calibration factors:	Pc = 222.869 psig/volt	PI = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	PI Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
27 May 93	10:51	1428	AS1R3a	12.30 psia	1.512 volts	1.228 volts	3.904 volts		4.618 volts	23	22	0.07055
27 May 93	10:54	1428	AS1R3b	12.30 psia	1.512 volts	1.228 volts	3.905 volts		4.618 volts	23	22	0.07050
27 May 93	10:57	1433	AS1R3c	12.30 psia	1.512 volts	1.228 volts	3.905 volts		4.618 volts	23	22	0.07053
27 May 93	10:59	1433	AS1R3d	12.30 psia	1.512 volts	1.228 volts	3.905 volts		4.618 volts	23	22	0.07056
AVERAGES			AS1R3									
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					1.512 volts	1.228 volts	3.905 volts		4.618 volts	23	22	
					337.0 psig	68.08 psig	43.06 psid	47.03 psig	25.496 psig			
					22.93 atm	4.633 atm	2.930 atm	3.200 atm	1.7349 atm			
				2.323 Mpa	0.4694 Mpa	0.2969 Mpa	0.3242 Mpa	0.17579 Mpa				
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.3 psia	349.3 psia	80.38 psia	43.06 psid	59.33 psia	37.80 psia	296	295	0.07053
0.8370 atm	23.77 atm	5.470 atm	2.930 atm	4.037 atm	2.572 atm							
0.08481 Mpa	2.408 Mpa	0.5542 Mpa	0.2969 Mpa	0.4090 Mpa	0.2606 Mpa							

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.117 cm	* 1.0E-2 m/cm 1.012E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8370 atm	* 1.013E+5 Pa/atm 8.478E+04 Pa
ΔP = pressure drop across sample length	2.930 atm	* 1.013E+5 Pa/atm 2.968E+05 Pa
Pm = mean pore pressure (absolute)	4.037 atm	* 1.013E+5 Pa/atm 4.089E+05 Pa
Pe = exit pressure (absolute)	2.572 atm	* 1.013E+5 Pa/atm 2.605E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.07053 cm ³ /s	* 1.0E-6 m ³ /cm ³ 7.053E-08 m ³ /s
ve = flow velocity at sample exit end	2.835E-04 cm/s	* 1.0E-2 m/cm 2.835E-06 m/s
Ka =	1.10E-05 d	* 9.872E-13 m ² /d 1.08E-17 m ²
Ka =	1.10E-02 md	1.08E-13 cm ²
Ka =	1.10E+01 μd	

Steady State Gas Permeability Data									
Project #:	8362	Net Effective Stress:	2 Mpa	290.1 psid	Gas:	N2			
Sample #:	A	Length:	10.117 cm		gas deviation z factors:	ze =	1.0000	zb =	1.0000
Stress Level #:	1	Diameter:	10.170 cm		Viscosity:	0.0176 cp			
Regime #:	4	Area:	81.233 cm^2						
Pressure Data Filename:	8362AG.S1B								
XDRCR calibration factors:	Pc =	222.869 psig/volt	Pi =	55.4417 psig/volt	ΔP =	11.0272 psid/volt	Pe =	5.5211 psig/volt	

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pl Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
27 May 93	14:50	1668	AS1R4a	12.29 psia	1.558 volts	1.409 volts	3.920 volts		6.415 volts	23	23	0.08047
27 May 93	14:53	1668	AS1R4b	12.29 psia	1.558 volts	1.409 volts	3.920 volts		6.415 volts	23	23	0.08060
27 May 93	14:55	1673	AS1R4c	12.29 psia	1.559 volts	1.409 volts	3.920 volts		6.414 volts	23	23	0.08053
27 May 93	14:57	1673	AS1R4d	12.29 psia	1.559 volts	1.409 volts	3.920 volts		6.414 volts	23	23	0.08053
AVERAGES			AS1R4									
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					1.559 volts	1.409 volts	3.920 volts		6.415 volts	23	23	
					347.3 psig	78.12 psig	43.23 psid	57.03 psig	35.415 psig			
					23.64 atm	5.316 atm	2.941 atm	3.881 atm	2.4098 atm			
				2.395 Mpa	0.5386 Mpa	0.2980 Mpa	0.3932 Mpa	0.24418 Mpa				
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.29 psia	359.6 psia	90.41 psia	43.23 psid	69.32 psia	47.71 psia	296	296	0.08053
				0.8363 atm	24.47 atm	6.152 atm	2.941 atm	4.717 atm	3.246 atm			
0.08474 Mpa	2.480 Mpa	0.6233 Mpa	0.2980 Mpa	0.4779 Mpa	0.3289 Mpa							

Boyle's Law:

$$Q_e = (Pb/Pe) * (Te/Tb) * (ze/zb) * Qb$$

$$v_e = Q_e/A = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * (O_b/A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.117 cm	* 1.0E-2 m/cm 1.012E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8363 atm	* 1.013E+5 Pa/atm 8.472E+04 Pa
ΔP = pressure drop across sample length	2.941 atm	* 1.013E+5 Pa/atm 2.980E+05 Pa
Pm = mean pore pressure (absolute)	4.717 atm	* 1.013E+5 Pa/atm 4.778E+05 Pa
Pe = exit pressure (absolute)	3.246 atm	* 1.013E+5 Pa/atm 3.288E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.08053 cm ³ /s	* 1.0E-6 m ³ /cm ³ 8.053E-08 m ³ /s
ve = flow velocity at sample exit end	2.554E-04 cm/s	* 1.0E-2 m/cm 2.554E-06 m/s
Ka =	1.06E-05 d	* 9.872E-13 m ² /d 1.05E-17 m ²
Ka =	1.06E-02 md	1.05E-13 cm ²
Ka =	1.06E+01 μ d	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psid	Gas:	N2
Sample #:	A	Length:	10.117 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.170 cm		Viscosity:	0.0176 cp
Regime #:	1	Area:	81.233 cm ²			
Pressure Data Filename:	8362AG.S2A					
XDCR calibration factors:	Pc =	222.869 psig/volt	Pl =	55.4417 psig/volt	ΔP =	11.0272 psid/volt
					Pe =	5.5211 psig/volt

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pl Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
28 May 93	12:17	272	AS2R1a	12.32 psia	4.027 volts	0.866 volts	3.833 volts		1.107 volts	23	23	0.03740
28 May 93	12:20	277	AS2R1b	12.32 psia	4.027 volts	0.866 volts	3.833 volts		1.107 volts	23	23	0.03745
28 May 93	12:23	277	AS2R1c	12.32 psia	4.027 volts	0.866 volts	3.833 volts		1.107 volts	23	23	0.03739
28 May 93	12:25	282	AS2R1d	12.32 psia	4.027 volts	0.866 volts	3.833 volts		1.107 volts	23	23	0.03743
AVERAGES			AS2R1		GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
					12.32 psia	909.8 psia	60.33 psia	42.27 psid	39.57 psia	18.43 psia		
					0.8383 atm	61.91 atm	4.105 atm	2.876 atm	2.692 atm	1.254 atm	296	296
					0.08494 Mpa	6.273 Mpa	0.4160 Mpa	0.2914 Mpa	0.2728 Mpa	0.1271 Mpa		

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law:

$$v_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot v_b$$

$$Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$$

$$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.117 cm	* 1.0E-2 m/cm 1.012E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8383 atm	* 1.013E+5 Pa/atm 8.492E+04 Pa
ΔP = pressure drop across sample length	2.876 atm	* 1.013E+5 Pa/atm 2.913E+05 Pa
Pm = mean pore pressure (absolute)	2.692 atm	* 1.013E+5 Pa/atm 2.727E+05 Pa
Pe = exit pressure (absolute)	1.254 atm	* 1.013E+5 Pa/atm 1.271E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.03742 cm ³ /s	* 1.0E-6 m ³ /cm ³ 3.742E-08 m ³ /s
ve = flow velocity at sample exit end	3.079E-04 cm/s	* 1.0E-2 m/cm 3.079E-06 m/s
Ka =	8.88E-06 d	* 9.872E-13 m ² /d 8.77E-18 m ²
Ka =	8.88E-03 md	8.77E-14 cm ²
Ka =	8.88E+00 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psid	Gas:	N2
Sample #:	A	Length:	10.117 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.170 cm		Viscosity:	0.0176 cp
Regime #:	2	Area:	81.233 cm ²			
Pressure Data Filename:	8362AG.S2A					
XDCR calibration factors:	Pc = 222.869 psig/volt	PI = 55.4417 psig/volt	AP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	PI Inlet Pressure	AP Differential Pressure	Pm Mean Pore Pressure Pe+AP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
28 May 93	14:34	407	AS2R2a	12.30 psia	4.071 volts	1.040 volts	3.829 volts		2.871 volts	23	23	0.04414
28 May 93	14:37	412	AS2R2b	12.30 psia	4.071 volts	1.040 volts	3.829 volts		2.871 volts	23	23	0.04410
28 May 93	14:39	412	AS2R2c	12.30 psia	4.071 volts	1.040 volts	3.829 volts		2.871 volts	23	23	0.04411
28 May 93	14:47	422	AS2R2d	12.30 psia	4.071 volts	1.040 volts	3.830 volts		2.870 volts	23	23	0.04403
AVERAGES			AS2R2									
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					4.071 volts	1.040 volts	3.829 volts		2.871 volts			
					907.3 psig	57.66 psig	42.23 psid	36.96 psig	15.850 psig	23	23	
					61.74 atm	3.923 atm	2.873 atm	2.515 atm	1.0785 atm			
					6.256 Mpa	0.3975 Mpa	0.2911 Mpa	0.2548 Mpa	0.10928 Mpa			
					ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
					12.3 psia	919.6 psia	42.23 psid	49.26 psia	28.15 psia			
					0.8370 atm	62.57 atm	4.760 atm	3.352 atm	1.915 atm	296	296	0.04409
					0.08481 Mpa	6.340 Mpa	0.4824 Mpa	0.3397 Mpa	0.1941 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law:

$$V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$$

$$Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$$

$$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.117 cm	* 1.0E-2 m/cm 1.012E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8370 atm	* 1.013E+5 Pa/atm 8.478E+04 Pa
AP = pressure drop across sample length	2.873 atm	* 1.013E+5 Pa/atm 2.911E+05 Pa
Pm = mean pore pressure (absolute)	3.352 atm	* 1.013E+5 Pa/atm 3.396E+05 Pa
Pe = exit pressure (absolute)	1.915 atm	* 1.013E+5 Pa/atm 1.940E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.04409 cm ³ /s	* 1.0E-6 m ³ /cm ³ 4.409E-08 m ³ /s
ve = flow velocity at sample exit end	2.372E-04 cm/s	* 1.0E-2 m/cm 2.372E-06 m/s
Ka =	8.40E-06 d	* 9.872E-13 m ² /d 8.29E-18 m ²
Ka =	8.40E-03 md	8.29E-14 cm ²
Ka =	8.40E+00 μ d	

Steady State Gas Permeability Data									
Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psid	Gas:	N2			
Sample #:	A	Length:	10.117 cm		gas deviation z factors:	ze =	1.0000	zb =	1.0000
Stress Level #:	2	Diameter:	10.170 cm		Viscosity:	0.0176 cp			
Regime #:	4	Area:	81.233 cm ²						
Pressure Data Filename:	8362AG.S2A								
XDCR calibration factors:	Pc =	222.869	psig/volt	Pi =	55.4417	psig/volt	ΔP =	11.0272	psid/volt
							Pe =	5.5211	psig/volt

[illegible]

Boyle's Law:

$$\begin{aligned} V_e &= (Pb/Pe) * (Te/Tb) * (ze/zb) * Vb \\ Q_e &= (Pb/Pe) * (Te/Tb) * (ze/zb) * Qb \end{aligned}$$

$$v_e = Q_e/A = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * (Q_b/A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.117 cm	* 1.0E-2 m/cm 1.012E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8308 atm	* 1.013E+5 Pa/atm 8.416E+04 Pa
ΔP = pressure drop across sample length	2.907 atm	* 1.013E+5 Pa/atm 2.945E+05 Pa
Pm = mean pore pressure (absolute)	4.725 atm	* 1.013E+5 Pa/atm 4.786E+05 Pa
Pe = exit pressure (absolute)	3.271 atm	* 1.013E+5 Pa/atm 3.314E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.05680 cm ³ /s	* 1.0E-6 m ³ /cm ³ 5.680E-08 m ³ /s
ve = flow velocity at sample exit end	1.782E-04 cm/s	* 1.0E-2 m/cm 1.782E-06 m/s
Ka =	7.56E-06 d	* 9.872E-13 m ² /d 7.46E-18 m ²
Ka =	7.56E-03 md	7.46E-14 cm ²
Ka =	7.56E+00 ud	

C-113

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psid	Gas:	N2
Sample #:	A	Length:	10.117 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.170 cm		Viscosity:	0.0176 cp
Regime #:	1	Area:	81.233 cm ²			
Pressure Data Filename: 8362AG.S3A						
XDCR calibration factors: Pc = 222.869 psig/volt Pi = 55.4417 psig/volt ΔP = 11.0272 psid/volt Pe = 5.5211 psig/volt						

[illegible]

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * V_b$
 $Q_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * Q_b$

$$v_e = Q_e/A = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * (Q_b/A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.117 cm	* 1.0E-2 m/cm 1.012E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8370 atm	* 1.013E+5 Pa/atm 8.478E+04 Pa
ΔP = pressure drop across sample length	2.891 atm	* 1.013E+5 Pa/atm 2.929E+05 Pa
Pm = mean pore pressure (absolute)	2.680 atm	* 1.013E+5 Pa/atm 2.715E+05 Pa
Pe = exit pressure (absolute)	1.235 atm	* 1.013E+5 Pa/atm 1.251E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	294 °K	294 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.03060 cm ³ /s	* 1.0E-6 m ³ /cm ³ 3.060E-08 m ³ /s
ve = flow velocity at sample exit end	2.571E-04 cm/s	* 1.0E-2 m/cm 2.571E-06 m/s
Ka =	7.29E-06 d	* 9.872E-13 m ² /d 7.20E-18 m ²
Ka =	7.29E-03 md	7.20E-14 cm ²
Ka =	7.29E+00 μ d	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psid	Gas:	N2
Sample #:	A	Length:	10.117 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.170 cm		Viscosity:	0.0176 cp
Regime #:	2	Area:	81.233 cm ²			
Pressure Data Filename:	8362AG.S3A					
XDCR calibration factors:	Pc = 222.869 psig/volt	P1 = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	P1 Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
03 Jun 93	14:15	1372	AS3R2a	12.32 psia	6.674 volts	1.047 volts	3.820 volts		2.939 volts	23	22	0.03577
03 Jun 93	14:19	1372	AS3R2b	12.32 psia	6.674 volts	1.047 volts	3.821 volts		2.939 volts	23	22	0.03584
03 Jun 93	14:21	1377	AS3R2c	12.32 psia	6.674 volts	1.047 volts	3.821 volts		2.939 volts	23	22	0.03595
03 Jun 93	14:24	1377	AS3R2d	12.32 psia	6.674 volts	1.047 volts	3.821 volts		2.939 volts	23	22	0.03599
03 Jun 93	14:26	1382	AS3R2e	12.32 psia	6.674 volts	1.047 volts	3.821 volts		2.938 volts	23	22	0.03601
AVERAGES			AS3R2		GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					6.674 volts	1.047 volts	3.821 volts		2.939 volts			
					1487.4 psig	58.05 psig	42.13 psid	37.29 psig	16.225 psig	23	22	
					101.21 atm	3.950 atm	2.867 atm	2.538 atm	1.1041 atm			
					10.255 Mpa	0.4002 Mpa	0.2905 Mpa	0.2571 Mpa	0.11187 Mpa			
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.32 psia	1499.7 psia	70.37 psia	42.13 psid	49.61 psia	28.55 psia			
				0.8383 atm	102.05 atm	4.788 atm	2.867 atm	3.376 atm	1.942 atm	296	295	0.03589
				0.08494 Mpa	10.340 Mpa	0.4852 Mpa	0.2905 Mpa	0.3421 Mpa	0.1968 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.117 cm	* 1.0E-2 m/cm 1.012E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8383 atm	* 1.013E+5 Pa/atm 8.492E+04 Pa
ΔP = pressure drop across sample length	2.867 atm	* 1.013E+5 Pa/atm 2.904E+05 Pa
Pm = mean pore pressure (absolute)	3.376 atm	* 1.013E+5 Pa/atm 3.420E+05 Pa
Pe = exit pressure (absolute)	1.942 atm	* 1.013E+5 Pa/atm 1.968E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.03589 cm ³ /s	* 1.0E-6 m ³ /cm ³ 3.589E-08 m ³ /s
ve = flow velocity at sample exit end	1.913E-04 cm/s	* 1.0E-2 m/cm 1.913E-06 m/s
Ka =	6.84E-06 d	* 9.872E-13 m ² /d 6.75E-18 m ²
Ka =	6.84E-03 md	6.75E-14 cm ²
Ka =	6.84E+00 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psid	Gas:	N2
Sample #:	A	Length:	10.117 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.170 cm		Viscosity:	0.0176 cp
Regime #:	3	Area:	81.233 cm ²			
Pressure Data Filename:	8362AG.S3A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)						
04 Jun 93	09:31	2527	AS3R3a	12.29 psia	6.719 volts	1.229 volts	3.879 volts		4.669 volts	23	21	0.04180						
04 Jun 93	09:39	2532	AS3R3b	12.29 psia	6.719 volts	1.229 volts	3.880 volts		4.669 volts	23	21	0.04169						
04 Jun 93	09:43	2537	AS3R3c	12.29 psia	6.719 volts	1.229 volts	3.879 volts		4.670 volts	23	21	0.04179						
04 Jun 93	09:46	2542	AS3R3d	12.29 psia	6.719 volts	1.229 volts	3.879 volts		4.670 volts	23	21	0.04180						
AVERAGES			AS3R3															
					GUAGE		GUAGE		DIFFERENTIAL		GUAGE		GUAGE		(°C)	(°C)		
					6.719 volts		1.229 volts		3.879 volts		4.670 volts		23	21				
					1497.5 psig		68.14 psig		42.78 psid		47.17 psig				25.781 psig			
					101.90 atm		4.636 atm		2.911 atm		3.210 atm				1.7543 atm			
				10.325 Mpa		0.4698 Mpa		0.2949 Mpa		0.3252 Mpa		0.17775 Mpa						
				ABSOLUTE		ABSOLUTE		ABSOLUTE		DIFFERENTIAL		ABSOLUTE		ABSOLUTE		(°K)	(°K)	(ml/sec)
				12.29 psia		1509.7 psia		80.43 psia		42.78 psid		59.46 psia		38.07 psia		296	294	0.04177
				0.8363 atm		102.73 atm		5.473 atm		2.911 atm		4.046 atm		2.591 atm				
0.08474 Mpa		10.409 Mpa		0.5545 Mpa		0.2949 Mpa		0.4100 Mpa		0.2625 Mpa								

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.117 cm	* 1.0E-2 m/cm 1.012E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8363 atm	* 1.013E+5 Pa/atm 8.472E+04 Pa
ΔP = pressure drop across sample length	2.911 atm	* 1.013E+5 Pa/atm 2.949E+05 Pa
Pm = mean pore pressure (absolute)	4.046 atm	* 1.013E+5 Pa/atm 4.099E+05 Pa
Pe = exit pressure (absolute)	2.591 atm	* 1.013E+5 Pa/atm 2.624E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	294 °K	294 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.04177 cm ³ /s	* 1.0E-6 m ³ /cm ³ 4.177E-08 m ³ /s
ve = flow velocity at sample exit end	1.671E-04 cm/s	* 1.0E-2 m/cm 1.671E-06 m/s
Ka =	6.55E-06 d	* 9.872E-13 m ² /d 6.46E-18 m ²
Ka =	6.55E-03 md	6.46E-14 cm ²
Ka =	6.55E+00 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psid	Gas:	N2
Sample #:	A	Length:	10.117 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.170 cm		Viscosity:	0.0176 cp
Regime #:	4	Area:	81.233 cm ²			
Pressure Data Filename:	8362AG.S3A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)	
04 Jun 93	16:35	2952	AS3R4a	12.23 psia	6.764 volts	1.407 volts	3.857 volts		6.530 volts	23	22	0.04725	
04 Jun 93	16:37	2952	AS3R4b	12.23 psia	6.764 volts	1.407 volts	3.857 volts		6.530 volts	23	22	0.04723	
04 Jun 93	16:39	2957	AS3R4c	12.23 psia	6.764 volts	1.407 volts	3.857 volts		6.530 volts	23	22	0.04720	
04 Jun 93	16:42	2957	AS3R4d	12.23 psia	6.764 volts	1.407 volts	3.857 volts		6.530 volts	23	22	0.04728	
AVERAGES			AS3R4										
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)		
					6.764 volts	1.407 volts	3.857 volts		6.530 volts				
					1507.5 psig	78.01 psig	42.53 psid	57.32 psig	36.053 psig	23	22		
					102.58 atm	5.308 atm	2.894 atm	3.900 atm	2.4532 atm				
					10.394 Mpa	0.5378 Mpa	0.2932 Mpa	0.3952 Mpa	0.24858 Mpa				
					ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
					12.23 psia	1519.7 psia	90.24 psia	42.53 psid	69.55 psia	48.28 psia			
					0.8322 atm	103.41 atm	6.140 atm	2.894 atm	4.732 atm	3.285 atm	296	295	0.04724
					0.08432 Mpa	10.478 Mpa	0.6222 Mpa	0.2932 Mpa	0.4795 Mpa	0.3329 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law:

$$v_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot v_b$$

$$Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$$

$$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.117 cm	* 1.0E-2 m/cm 1.012E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8322 atm	* 1.013E+5 Pa/atm 8.430E+04 Pa
ΔP = pressure drop across sample length	2.894 atm	* 1.013E+5 Pa/atm 2.932E+05 Pa
Pm = mean pore pressure (absolute)	4.732 atm	* 1.013E+5 Pa/atm 4.794E+05 Pa
Pe = exit pressure (absolute)	3.285 atm	* 1.013E+5 Pa/atm 3.328E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.04724 cm ³ /s	* 1.0E-6 m ³ /cm ³ 4.724E-08 m ³ /s
ve = flow velocity at sample exit end	1.478E-04 cm/s	* 1.0E-2 m/cm 1.478E-06 m/s
	Ka = 6.31E-06 d	* 9.872E-13 m ² /d 6.23E-18 m ²
	Ka = 6.31E-03 md	6.23E-14 cm ²
	Ka = 6.31E+00 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	2 Mpa	290.1 psig	Gas:	N2
Sample #:	B	Length:	9.557 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	1	Diameter:	10.171 cm		Viscosity:	0.0176 cp
Regime #:	1	Area:	81.249 cm ²			
Pressure Data Filename:	8362BG.S1B					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
31 Mar 93	11:52	188	BS1R1a	12.39 psia	1.433 volts	0.901 volts	4.009 volts		1.100 volts	25	21	0.09272
31 Mar 93	11:54	193	BS1R1b	12.39 psia	1.431 volts	0.901 volts	4.009 volts		1.100 volts	25	22	0.09407
31 Mar 93	11:56	193	BS1R1c	12.39 psia	1.429 volts	0.901 volts	4.009 volts		1.100 volts	25	22	0.09274
31 Mar 93	11:59	198	BS1R1d	12.39 psia	1.428 volts	0.901 volts	4.009 volts		1.100 volts	25	22	0.09259
AVERAGES			BS1R1							25	22	
AVERAGES			BS1R1							298	295	0.09303

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa·sec/cp 1.760E-05 Pa·sec
L = sample length	9.557 cm	* 1.0E-2 m/cm 9.557E-02 m
A = sample circular cross sectional area	81.249 cm ²	* 1.0E-4 m ² /cm ² 8.125E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8431 atm	* 1.013E+5 Pa/atm 8.540E+04 Pa
ΔP = pressure drop across sample length	3.008 atm	* 1.013E+5 Pa/atm 3.047E+05 Pa
Pm = mean pore pressure (absolute)	2.760 atm	* 1.013E+5 Pa/atm 2.796E+05 Pa
Pe = exit pressure (absolute)	1.256 atm	* 1.013E+5 Pa/atm 1.273E+05 Pa
Te = sample temperature (absolute)	298 °K	298 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.09303 cm ³ /s	* 1.0E-6 m ³ /cm ³ 9.303E-08 m ³ /s
ve = flow velocity at sample exit end	7.769E-04 cm/s	* 1.0E-2 m/cm 7.769E-06 m/s
Ka =	1.98E-05 d	* 9.872E-13 m ² /d 1.95E-17 m ²
Ka =	0.0198 md	1.95E-13 cm ²
Ka =	19.8 μd	

Steady State Gas Permeability Data									
Project #:	8362	Net Effective Stress:	2 Mpa	290.1 psig	Gas:	N2			
Sample #:	B	Length:	9.557 cm		gas deviation z factors:	ze =	1.0000	zb =	1.0000
Stress Level #:	1	Diameter:	10.171 cm		Viscosity:	0.0176 cp			
Regime #:	2	Area:	81.249 cm^2						
Pressure Data Filename:	8362BG.S1B								
XDCR calibration factors:	Pc =	222.869 psig/volt	Pi =	55.4417 psig/volt	ΔP =	11.0272 psid/volt	Pe =	5.5211 psig/volt	

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
31 Mar 93	14:19	338	BS1R2a	12.37 psia	1.476 volts	1.251 volts	5.778 volts		1.118 volts	25	22	0.15462
31 Mar 93	14:23	343	BS1R2b	12.37 psia	1.470 volts	1.251 volts	5.778 volts		1.118 volts	25	22	0.15668
31 Mar 93	14:25	343	BS1R2c	12.37 psia	1.474 volts	1.251 volts	5.777 volts		1.118 volts	25	22	0.15729
31 Mar 93	14:29	348	BS1R2d	12.37 psia	1.473 volts	1.251 volts	5.777 volts		1.119 volts	25	22	0.15613
AVERAGES			BS1R2									
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					1.473 volts	1.251 volts	5.778 volts		1.118 volts	25	22	
					328.3 psig	69.36 psig	63.71 psid	38.03 psig	6.174 psig			
					22.34 atm	4.719 atm	4.335 atm	2.588 atm	0.4201 atm			
					2.264 Mpa	0.4782 Mpa	0.4393 Mpa	0.2622 Mpa	0.04257 Mpa			
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.37 psia	340.7 psia	81.73 psia	63.71 psid	50.40 psia	18.54 psia			
				0.8417 atm	23.18 atm	5.561 atm	4.335 atm	3.429 atm	1.262 atm	298	295	0.15618
				0.08529 Mpa	2.349 Mpa	0.5635 Mpa	0.4393 Mpa	0.3475 Mpa	0.1279 Mpa			

Boyle's Law:

$$V_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * V_b$$

$$Q_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * Q_b$$

$$v_e = Q_e/A = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * (Q_b/A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.557 cm	* 1.0E-2 m/cm 9.557E-02 m
A = sample circular cross sectional area	81.249 cm ²	* 1.0E-4 m ² /cm ² 8.125E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8417 atm	* 1.013E+5 Pa/atm 8.527E+04 Pa
ΔP = pressure drop across sample length	4.335 atm	* 1.013E+5 Pa/atm 4.392E+05 Pa
Pm = mean pore pressure (absolute)	3.429 atm	* 1.013E+5 Pa/atm 3.474E+05 Pa
Pe = exit pressure (absolute)	1.262 atm	* 1.013E+5 Pa/atm 1.278E+05 Pa
Te = sample temperature (absolute)	298 °K	298 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.15618 cm ³ /s	* 1.0E-6 m ³ /cm ³ 1.562E-07 m ³ /s
ve = flow velocity at sample exit end	1.295E-03 cm/s	* 1.0E-2 m/cm 1.295E-05 m/s
Ka =	1.85E-05 d	* 9.872E-13 m ² /d 1.83E-17 m ²
Ka =	0.0185 md	1.83E-13 cm ²
Ka =	18.5 μ d	

Steady State Gas Permeability Data									
Project #:	8362	Net Effective Stress:	2 Mpa	290.1 psig	Gas:	N2			
Sample #:	B	Length:	9.557 cm		gas deviation z factors:	ze =	1.0000	zb =	1.0000
Stress Level #:	1	Diameter:	10.171 cm		Viscosity:	0.0176 cp			
Regime #:	3	Area:	81.249 cm ²						
Pressure Data Filename:	8362BG.S1B								
XDCR calibration factors:	Pc =	222.869 psig/volt	Pi =	55.4417 psig/volt	ΔP =	11.0272 psid/volt	Pe =	5.5211 psig/volt	

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	P1 Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
31 Mar 93	16:23	463	BS1R3a	12.37 psia	1.516 volts	1.600 volts	7.461 volts		1.279 volts	25	22	0.22910
31 Mar 93	16:27	463	BS1R3b	12.37 psia	1.517 volts	1.600 volts	7.460 volts		1.279 volts	25	22	0.23135
31 Mar 93	16:29	468	BS1R3c	12.37 psia	1.517 volts	1.599 volts	7.460 volts		1.279 volts	25	22	0.22949
31 Mar 93	16:31	468	BS1R3d	12.37 psia	1.518 volts	1.599 volts	7.459 volts		1.279 volts	25	22	0.22805
AVERAGES			BS1R3									
										(°C)	(°C)	
										25	22	
										(°K)	(°K)	(ml/sec)
				Absolute	Absolute	Absolute	Differential	Absolute	Absolute			
				12.37 psia	350.5 psia	101.05 psia	82.26 psid	60.56 psia	19.43 psia	298	295	0.22950
				0.8417 atm	23.85 atm	6.876 atm	5.598 atm	4.121 atm	1.322 atm			
				0.08529 Mpa	2.416 Mpa	0.6967 Mpa	0.5672 Mpa	0.4176 Mpa	0.1340 Mpa			

Boyle's Law:
$$V_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * V_b$$
$$Q_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * Q_b$$
$$v_e = Q_e/A = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * (Q_b/A)$$

Parameter	Traditional Units		SI Units
μ = gas viscosity	0.0176 cp	* $1.0\text{E-}3$ Pa*sec/cp	$1.760\text{E-}05$ Pa*sec
L = sample length	9.557 cm	• $1.0\text{E-}2$ m/cm	$9.557\text{E-}02$ m
A = sample circular cross sectional area	81.249 cm ²	* $1.0\text{E-}4$ m ² /cm ²	$8.125\text{E-}03$ m ²
Pb = flow measurement basis pressure (absolute)	0.8417 atm	* $1.013\text{E+}5$ Pa/atm	$8.527\text{E+}04$ Pa
ΔP = pressure drop across sample length	5.598 atm	* $1.013\text{E+}5$ Pa/atm	$5.670\text{E+}05$ Pa
Pm = mean pore pressure (absolute)	4.121 atm	* $1.013\text{E+}5$ Pa/atm	$4.175\text{E+}05$ Pa
Pe = exit pressure (absolute)	1.322 atm	* $1.013\text{E+}5$ Pa/atm	$1.339\text{E+}05$ Pa
Te = sample temperature (absolute)	298 °K		298 °K
Tb = flow measurement basis temperature (absolute)	295 °K		295 °K
ze = gas deviation factor at Pe and Te	1.0000		1.0000
zb = gas deviation factor at Pb and Te	1.0000		1.0000
Qb = flow rate at base conditions	0.22950 cm ³ /s	* $1.0\text{E-}6$ m ³ /cm ³	$2.295\text{E-}07$ m ³ /s
ve = flow velocity at sample exit end	$1.816\text{E-}03$ cm/s	* $1.0\text{E-}2$ m/cm	$1.816\text{E-}05$ m/s
	Ka = $1.75\text{E-}05$ d	• $9.872\text{E-}13$ m ² /d	$1.73\text{E-}17$ m ²
	Ka = 0.0175 md		$1.73\text{E-}13$ cm ²
	Ka = 17.5 μ d		

C-120

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	2 Mpa	290.1 psig	Gas:	N2
Sample #:	B	Length:	9.557 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	1	Diameter:	10.171 cm		Viscosity:	0.0176 cp
Regime #:	4	Area:	81.249 cm ²			
Pressure Data Filename:	8362BG.S1B					
XDCR calibration factors:	Pc =	222.869 psig/volt	Pi =	55.4417 psig/volt	ΔP =	11.0272 psid/volt
					Pe =	5.5211 psig/volt

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)		
01 Apr 93	09:20	1480	BS1R4a	12.28 psia	1.569 volts	1.947 volts	9.099 volts		1.514 volts	25	21	0.31721		
01 Apr 93	09:23	1480	BS1R4b	12.28 psia	1.570 volts	1.947 volts	9.097 volts		1.514 volts	25	22	0.31422		
01 Apr 93	09:25	1485	BS1R4c	12.28 psia	1.570 volts	1.947 volts	9.097 volts		1.514 volts	25	22	0.31496		
01 Apr 93	09:27	1485	BS1R4d	12.28 psia	1.568 volts	1.946 volts	9.096 volts		1.514 volts	25	22	0.31671		
AVERAGES			BS1R4											
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)			
					1.569 volts	1.947 volts	9.097 volts		1.514 volts	25	22			
					349.7 psig	107.93 psig	100.32 psid	58.52 psig	8.359 psig					
					23.80 atm	7.344 atm	6.826 atm	3.982 atm	0.5688 atm					
					2.411 Mpa	0.7442 Mpa	0.6917 Mpa	0.4035 Mpa	0.05763 Mpa					
					ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)		(°K)	(ml/sec)
					12.28 psia	362.0 psia	120.21 psia	100.32 psid	70.80 psia	20.64 psia	298		295	0.31577
0.8356 atm	24.63 atm	8.180 atm	6.826 atm	4.817 atm	1.404 atm									
0.08467 Mpa	2.496 Mpa	0.8288 Mpa	0.6917 Mpa	0.4881 Mpa	0.1423 Mpa									

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law:

$$v_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot v_b$$

$$Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$$

$$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.557 cm	* 1.0E-2 m/cm 9.557E-02 m
A = sample circular cross sectional area	81.249 cm ²	* 1.0E-4 m ² /cm ² 8.125E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8356 atm	* 1.013E+5 Pa/atm 8.465E+04 Pa
ΔP = pressure drop across sample length	6.826 atm	* 1.013E+5 Pa/atm 6.915E+05 Pa
Pm = mean pore pressure (absolute)	4.817 atm	* 1.013E+5 Pa/atm 4.880E+05 Pa
Pe = exit pressure (absolute)	1.404 atm	* 1.013E+5 Pa/atm 1.423E+05 Pa
Te = sample temperature (absolute)	298 °K	298 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.31577 cm ³ /s	* 1.0E-6 m ³ /cm ³ 3.158E-07 m ³ /s
ve = flow velocity at sample exit end	2.338E-03 cm/s	* 1.0E-2 m/cm 2.338E-05 m/s
Ka =	1.68E-05 d	* 9.872E-13 m ² /d 1.66E-17 m ²
Ka =	0.0168 md	1.66E-13 cm ²
Ka =	16.8 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psig	Gas:	N2
Sample #:	B	Length:	9.557 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.171 cm		Viscosity:	0.0176 cp
Regime #:	1	Area:	81.249 cm ²			
Pressure Data Filename:	8362BG.S2A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	AP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	AP Differential Pressure	Pm Mean Pore Pressure Pe+AP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)						
01 Apr 93	14:46	177	BS2R1a	12.23 psia	4.030 volts	0.903 volts	4.135 volts		0.900 volts	25	22	0.06385						
01 Apr 93	14:50	182	BS2R1b	12.23 psia	4.030 volts	0.902 volts	4.135 volts		0.900 volts	25	22	0.06384						
01 Apr 93	14:53	182	BS2R1c	12.23 psia	4.036 volts	0.902 volts	4.135 volts		0.899 volts	25	22	0.06393						
01 Apr 93	14:56	187	BS2R1d	12.23 psia	4.039 volts	0.902 volts	4.135 volts		0.899 volts	25	22	0.06401						
AVERAGES			BS2R1															
				GUAGE		GUAGE		DIFFERENTIAL		GUAGE		GUAGE		(°C)	(°C)			
				4.034 volts		0.902 volts		4.135 volts		0.900 volts				25	22			
				899.0 psig		50.02 psig		45.60 psid		27.76 psig		4.966 psig						
				61.17 atm		3.404 atm		3.103 atm		1.889 atm		0.3379 atm						
				6.198 Mpa		0.3449 Mpa		0.3144 Mpa		0.1914 Mpa		0.03424 Mpa						
				ABSOLUTE		ABSOLUTE		ABSOLUTE		DIFFERENTIAL		ABSOLUTE		ABSOLUTE		(°K)	(°K)	(ml/sec)
				12.23 psia		911.2 psia		62.25 psia		45.60 psid		39.99 psia		17.20 psia		298	295	0.06391
				0.8322 atm		62.01 atm		4.236 atm		3.103 atm		2.721 atm		1.170 atm				
				0.08432 Mpa		6.283 Mpa		0.4292 Mpa		0.3144 Mpa		0.2758 Mpa		0.1186 Mpa				

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.557 cm	* 1.0E-2 m/cm 9.557E-02 m
A = sample circular cross sectional area	81.249 cm ²	* 1.0E-4 m ² /cm ² 8.125E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8322 atm	* 1.013E+5 Pa/atm 8.430E+04 Pa
AP = pressure drop across sample length	3.103 atm	* 1.013E+5 Pa/atm 3.143E+05 Pa
Pm = mean pore pressure (absolute)	2.721 atm	* 1.013E+5 Pa/atm 2.757E+05 Pa
Pe = exit pressure (absolute)	1.170 atm	* 1.013E+5 Pa/atm 1.185E+05 Pa
Te = sample temperature (absolute)	298 °K	298 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.06391 cm ³ /s	* 1.0E-6 m ³ /cm ³ 6.391E-08 m ³ /s
ve = flow velocity at sample exit end	5.651E-04 cm/s	* 1.0E-2 m/cm 5.651E-06 m/s
Ka =	1.32E-05 d	* 9.872E-13 m ² /d 1.30E-17 m ²
Ka =	0.0132 md	1.30E-13 cm ²
Ka =	13.2 μ d	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psig	Gas:	N2
Sample #:	B	Length:	9.557 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.171 cm		Viscosity:	0.0176 cp
Regime #:	2	Area:	81.249 cm ²			
Pressure Data Filename:	8362BG.S2A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)	
01 Apr 93	16:24	272	BS2R2a	12.21 psia	4.072 volts	1.251 volts	5.800 volts		1.097 volts	25	22	0.10411	
01 Apr 93	16:28	277	BS2R2b	12.21 psia	4.064 volts	1.251 volts	5.800 volts		1.098 volts	25	22	0.10400	
01 Apr 93	16:30	277	BS2R2c	12.21 psia	4.063 volts	1.251 volts	5.799 volts		1.098 volts	25	22	0.10349	
01 Apr 93	16:31	282	BS2R2d	12.21 psia	4.061 volts	1.251 volts	5.799 volts		1.098 volts	25	22	0.10360	
AVERAGES			BS2R2										
				GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)			
				4.065 volts	1.251 volts	5.800 volts		1.098 volts					
				906.0 psig	69.36 psig	63.95 psid	38.04 psig	6.061 psig	25	22			
				61.65 atm	4.719 atm	4.352 atm	2.588 atm	0.4124 atm					
				6.246 Mpa	0.4782 Mpa	0.4409 Mpa	0.2623 Mpa	0.04179 Mpa					
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)	
				12.21 psia	918.2 psia	81.57 psia	63.95 psid	50.25 psia	18.27 psia				
				0.8308 atm	62.48 atm	5.550 atm	4.352 atm	3.419 atm	1.243 atm	298	295	0.10380	
0.08419 Mpa	6.331 Mpa	0.5624 Mpa	0.4409 Mpa	0.3464 Mpa	0.1260 Mpa								

Steady State Gas Permeability Data									
Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psig	Gas:	N2			
Sample #:	B	Length:	9.557 cm		gas deviation z factors:	ze =	1.0000	zb =	1.0000
Stress Level #:	2	Diameter:	10.171 cm		Viscosity:	0.0176 cp			
Regime #:	3	Area:	81.249 cm ²						
Pressure Data Filename:	8362BG.S2A								
XDCR calibration factors:	Pc =	222.869 psig/volt	Pi =	55.4417 psig/volt	ΔP =	11.0272 psid/volt	Pe =	5.5211 psig/volt	

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
02 Apr 93	08:40	1253	BS2R3a	12.31 psia	4.120 volts	1.601 volts	7.475 volts		1.248 volts	25	21	0.14744
02 Apr 93	08:42	1253	BS2R3b	12.31 psia	4.113 volts	1.601 volts	7.475 volts		1.250 volts	25	21	0.14782
02 Apr 93	08:44	1253	BS2R3c	12.31 psia	4.115 volts	1.601 volts	7.474 volts		1.250 volts	25	21	0.14792
02 Apr 93	08:46	1258	BS2R3d	12.31 psia	4.117 volts	1.601 volts	7.474 volts		1.251 volts	25	21	0.14804
AVERAGES			BS2R3									
				GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)		
				4.116 volts	1.601 volts	7.475 volts		1.250 volts				
				917.4 psig	88.76 psig	82.42 psid	48.11 psig	6.900 psig	25	21		
				62.42 atm	6.040 atm	5.609 atm	3.274 atm	0.4695 atm				
				6.325 Mpa	0.6120 Mpa	0.5683 Mpa	0.3317 Mpa	0.04757 Mpa				
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.31 psia	929.7 psia	101.07 psia	82.42 psid	60.42 psia	19.21 psia			
				0.8376 atm	63.26 atm	6.878 atm	5.609 atm	4.111 atm	1.307 atm	298	294	0.14778
				0.08487 Mpa	6.410 Mpa	0.6969 Mpa	0.5683 Mpa	0.4166 Mpa	0.1324 Mpa			

Boyle's Law: $V_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * V_b$
 $Q_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * Q_b$

$$v_e = Q_e/A = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * (Q_b/A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.557 cm	* 1.0E-2 m/cm 9.557E-02 m
A = sample circular cross sectional area	81.249 cm ²	* 1.0E-4 m ² /cm ² 8.125E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8376 atm	* 1.013E+5 Pa/atm 8.485E+04 Pa
ΔP = pressure drop across sample length	5.609 atm	* 1.013E+5 Pa/atm 5.681E+05 Pa
Pm = mean pore pressure (absolute)	4.111 atm	* 1.013E+5 Pa/atm 4.165E+05 Pa
Pe = exit pressure (absolute)	1.307 atm	* 1.013E+5 Pa/atm 1.324E+05 Pa
Te = sample temperature (absolute)	298 °K	298 °K
Tb = flow measurement basis temperature (absolute)	294 °K	294 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.14778 cm ³ /s	* 1.0E-6 m ³ /cm ³ 1.478E-07 m ³ /s
ve = flow velocity at sample exit end	1.181E-03 cm/s	* 1.0E-2 m/cm 1.181E-05 m/s
Ka =	1.13E-05 d	* 9.872E-13 m ² /d 1.11E-17 m ²
Ka =	0.0113 md	1.11E-13 cm ²
Ka =	11.3 ud	

C-124

Steady State Gas Permeability Data									
Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psig	Gas:	N2			
Sample #:	B	Length:	9.557 cm		gas deviation z factors:	ze =	1.0000	zb =	1.0000
Stress Level #:	2	Diameter:	10.171 cm		Viscosity:	0.0176 cp			
Regime #:	4	Area:	81.249 cm ²						
Pressure Data Filename:	8362BG.S2A								
XDCR calibration factors:	Pc =	222.869 psig/volt	Pi =	55.4417 psig/volt	ΔP =	11.0272 psid/volt	Pe =	5.5211 psig/volt	

[illegible]

Boyle's Law:

$$V_e = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot V_b$$
$$Q_e = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot Q_b$$
$$v_e = Q_e/A = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot (Q_b/A)$$

Parameter	Traditional Units		SI Units
μ = gas viscosity	0.0176 cp	$\bullet$ 1.0E-3 Pa*sec/cp	1.760E-05 Pa*sec
L = sample length	9.557 cm	$\bullet$ 1.0E-2 m/cm	9.557E-02 m
A = sample circular cross sectional area	81.249 cm ²	$\bullet$ 1.0E-4 m ² /cm ²	8.125E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8383 atm	$\bullet$ 1.013E+5 Pa/atm	8.492E+04 Pa
ΔP = pressure drop across sample length	6.861 atm	$\bullet$ 1.013E+5 Pa/atm	6.950E+05 Pa
Pm = mean pore pressure (absolute)	4.814 atm	$\bullet$ 1.013E+5 Pa/atm	4.876E+05 Pa
Pe = exit pressure (absolute)	1.383 atm	$\bullet$ 1.013E+5 Pa/atm	1.401E+05 Pa
Te = sample temperature (absolute)	298 °K		298 °K
Tb = flow measurement basis temperature (absolute)	295 °K		295 °K
ze = gas deviation factor at Pe and Te	1.0000		1.0000
zb = gas deviation factor at Pb and Te	1.0000		1.0000
Qb = flow rate at base conditions	0.20187 cm ³ /s	$\bullet$ 1.0E-6 m ³ /cm ³	2.019E-07 m ³ /s
ve = flow velocity at sample exit end	1.521E-03 cm/s	$\bullet$ 1.0E-2 m/cm	1.521E-05 m/s
Ka =	1.07E-05 d	$\bullet$ 9.872E-13 m ² /d	1.06E-17 m ²
Ka =	0.0107 md		1.06E-13 cm ²
Ka =	10.7 ud		

Steady State Gas Permeability Data									
Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psig	Gas:	N2			
Sample #:	B	Length:	9.557 cm		gas deviation z factors:	ze =	1.0000	zb =	1.0000
Stress Level #:	3	Diameter:	10.171 cm		Viscosity:	0.0176 cp			
Regime #:	1	Area:	81.249 cm^2						
Pressure Data Filename:		8362BG.S3A							
XDCR calibration factors:		Pc =	222.869 psig/volt	Pi =	55.4417 psig/volt	ΔP =	11.0272 psid/volt	Pe =	5.5211 psig/volt

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)										
05 Apr 93	13:18	4159	BS3R1a	12.23 psia	6.630 volts	0.907 volts	4.132 volts		0.896 volts	25	22	0.03985										
05 Apr 93	13:20	4164	BS3R1b	12.23 psia	6.634 volts	0.907 volts	4.132 volts		0.896 volts	25	22	0.03982										
05 Apr 93	13:23	4164	BS3R1c	12.23 psia	6.633 volts	0.907 volts	4.132 volts		0.896 volts	25	22	0.03990										
05 Apr 93	13:26	4169	BS3R1d	12.23 psia	6.631 volts	0.907 volts	4.132 volts		0.896 volts	25	22	0.03984										
								GUAGE		GUAGE		DIFFERENTIAL		GUAGE		GUAGE		(°C)	(°C)			
								6.632 volts		0.907 volts		4.132 volts		0.896 volts		25	22					
								1478.1 psig		50.29 psig		45.56 psid		27.73 psig					4.947 psig			
								100.58 atm		3.422 atm		3.100 atm		1.887 atm					0.3366 atm			
								10.191 Mpa		0.3467 Mpa		0.3142 Mpa		0.1912 Mpa		0.03411 Mpa						
								ABSOLUTE		ABSOLUTE		ABSOLUTE		DIFFERENTIAL		ABSOLUTE		ABSOLUTE		(°K)	(°K)	(ml/sec)
								12.23 psia		1490.3 psia		62.52 psia		45.56 psid		39.96 psia		17.18 psia		298	295	0.03985
								0.8322 atm		101.41 atm		4.254 atm		3.100 atm		2.719 atm		1.169 atm				
0.08432 Mpa		10.275 Mpa		0.4310 Mpa		0.3142 Mpa		0.2755 Mpa		0.1184 Mpa												

Boyle's Law:

$$V_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * V_b$$

$$Q_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * Q_b$$

$$v_e = Q_e/A = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * (Q_b/A)$$

Parameter	Traditional Units		SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp	1.760E-05 Pa*sec
L = sample length	9.557 cm	* 1.0E-2 m/cm	9.557E-02 m
A = sample circular cross sectional area	81.249 cm ²	* 1.0E-4 m ² /cm ²	8.125E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8322 atm	* 1.013E+5 Pa/atm	8.430E+04 Pa
ΔP = pressure drop across sample length	3.100 atm	* 1.013E+5 Pa/atm	3.141E+05 Pa
Pm = mean pore pressure (absolute)	2.719 atm	* 1.013E+5 Pa/atm	2.754E+05 Pa
Pe = exit pressure (absolute)	1.169 atm	* 1.013E+5 Pa/atm	1.184E+05 Pa
Te = sample temperature (absolute)	298 °K		298 °K
Tb = flow measurement basis temperature (absolute)	295 °K		295 °K
ze = gas deviation factor at Pe and Te	1.0000		1.0000
zb = gas deviation factor at Pb and Te	1.0000		1.0000
Qb = flow rate at base conditions	0.03985 cm ³ /s	* 1.0E-6 m ³ /cm ³	3.985E-08 m ³ /s
ve = flow velocity at sample exit end	3.528E-04 cm/s	* 1.0E-2 m/cm	3.528E-06 m/s
Ka =	8.23E-06 d	* 9.872E-13 m ² /d	8.12E-18 m ²
Ka =	0.0082 md		8.12E-14 cm ²
Ka =	8.23 μ d		

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psig	Gas:	N2
Sample #:	B	Length:	9.557 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.171 cm		Viscosity:	0.0176 cp
Regime #:	2	Area:	81.249 cm ²			
Pressure Data Filename:	8362BG.S3A					
XDCR calibration factors:	Pc =	222.869 psig/volt	PI =	55.4417 psig/volt	AP =	11.0272 psid/volt
					Pe =	5.5211 psig/volt

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	PI Inlet Pressure	AP Differential Pressure	Pm Mean Pore Pressure Pe+AP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
05 Apr 93	16:04	4324	BS3R2a	12.21 psia	6.661 volts	1.252 volts	5.791 volts		1.073 volts	25	22	0.06445
05 Apr 93	16:07	4329	BS3R2b	12.21 psia	6.682 volts	1.252 volts	5.790 volts		1.074 volts	25	22	0.06401
05 Apr 93	16:10	4334	BS3R2c	12.21 psia	6.690 volts	1.252 volts	5.790 volts		1.073 volts	25	22	0.06430
05 Apr 93	16:15	4339	BS3R2d	12.21 psia	6.695 volts	1.252 volts	5.791 volts		1.073 volts	25	22	0.06430
AVERAGES			BS3R2							25	22	
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.21 psia	1501.4 psia	81.62 psia	63.85 psid	50.06 psia	18.14 psia			
				0.8308 atm	102.17 atm	5.554 atm	4.345 atm	3.407 atm	1.234 atm	298	295	0.06427
				0.08419 Mpa	10.352 Mpa	0.5628 Mpa	0.4403 Mpa	0.3452 Mpa	0.1250 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.557 cm	* 1.0E-2 m/cm 9.557E-02 m
A = sample circular cross sectional area	81.249 cm ²	* 1.0E-4 m ² /cm ² 8.125E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8308 atm	* 1.013E+5 Pa/atm 8.416E+04 Pa
AP = pressure drop across sample length	4.345 atm	* 1.013E+5 Pa/atm 4.401E+05 Pa
Pm = mean pore pressure (absolute)	3.407 atm	* 1.013E+5 Pa/atm 3.451E+05 Pa
Pe = exit pressure (absolute)	1.234 atm	* 1.013E+5 Pa/atm 1.250E+05 Pa
Te = sample temperature (absolute)	298 °K	298 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.06427 cm ³ /s	* 1.0E-6 m ³ /cm ³ 6.427E-08 m ³ /s
ve = flow velocity at sample exit end	5.379E-04 cm/s	* 1.0E-2 m/cm 5.379E-06 m/s
Ka =	7.54E-06 d	* 9.872E-13 m ² /d 7.45E-18 m ²
Ka =	0.00754 md	7.45E-14 cm ²
Ka =	7.54 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psig	Gas:	N2
Sample #:	B	Length:	9.557 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.171 cm		Viscosity:	0.0176 cp
Regime #:	3	Area:	81.249 cm ²			
Pressure Data Filename:	8362BG.S3A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
06 Apr 93	10:17	5419	BS3R3a	12.27 psia	6.737 volts	1.602 volts	7.460 volts		1.253 volts	25	22	0.09236
06 Apr 93	10:21	5424	BS3R3b	12.27 psia	6.735 volts	1.602 volts	7.460 volts		1.253 volts	25	22	0.09234
06 Apr 93	10:24	5424	BS3R3c	12.27 psia	6.736 volts	1.602 volts	7.460 volts		1.253 volts	25	22	0.09236
06 Apr 93	10:26	5429	BS3R3d	12.27 psia	6.735 volts	1.602 volts	7.460 volts		1.253 volts	25	22	0.09227
AVERAGES			BS3R3									
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					6.736 volts	1.602 volts	7.460 volts		1.253 volts			
					1501.2 psig	88.82 psig	82.26 psid	48.05 psig	6.918 psig	25	22	
					102.15 atm	6.044 atm	5.598 atm	3.270 atm	0.4707 atm			
					10.350 Mpa	0.6124 Mpa	0.5672 Mpa	0.3313 Mpa	0.04770 Mpa			
					ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
					12.27 psia	1513.5 psia	101.09 psia	60.32 psia	19.19 psia	298	295	0.09233
					0.8349 atm	102.98 atm	6.879 atm	4.104 atm	1.306 atm			
					0.08460 Mpa	10.435 Mpa	0.6970 Mpa	0.4159 Mpa	0.1323 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law:

$$v_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot v_b$$

$$Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$$

$$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.557 cm	* 1.0E-2 m/cm 9.557E-02 m
A = sample circular cross sectional area	81.249 cm ²	* 1.0E-4 m ² /cm ² 8.125E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8349 atm	* 1.013E+5 Pa/atm 8.458E+04 Pa
ΔP = pressure drop across sample length	5.598 atm	* 1.013E+5 Pa/atm 5.670E+05 Pa
Pm = mean pore pressure (absolute)	4.104 atm	* 1.013E+5 Pa/atm 4.158E+05 Pa
Pe = exit pressure (absolute)	1.306 atm	* 1.013E+5 Pa/atm 1.323E+05 Pa
Te = sample temperature (absolute)	298 °K	298 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.09233 cm ³ /s	* 1.0E-6 m ³ /cm ³ 9.233E-08 m ³ /s
ve = flow velocity at sample exit end	7.341E-04 cm/s	* 1.0E-2 m/cm 7.341E-06 m/s
Ka =	7.02E-06 d	* 9.872E-13 m ² /d 6.93E-18 m ²
Ka =	0.00702 md	6.93E-14 cm ²
Ka =	7.02 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psig	Gas:	N2
Sample #:	B	Length:	9.557 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.171 cm		Viscosity:	0.0176 cp
Regime #:	4	Area:	81.249 cm ²			
Pressure Data Filename:	8362BG.S3A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
06 Apr 93	13:39	5619	BS3R4a	12.28 psia	6.776 volts	1.950 volts	9.122 volts		1.451 volts	25	22	0.12571
06 Apr 93	13:42	5624	BS3R4b	12.28 psia	6.780 volts	1.950 volts	9.122 volts		1.451 volts	25	22	0.12590
06 Apr 93	13:44	5624	BS3R4c	12.28 psia	6.777 volts	1.950 volts	9.122 volts		1.451 volts	25	22	0.12598
06 Apr 93	13:46	5629	BS3R4d	12.28 psia	6.776 volts	1.950 volts	9.122 volts		1.451 volts	25	22	0.12571
AVERAGES			BS3R4		GUAGE		DIFFERENTIAL	GUAGE		(°C)		
					6.777 volts	1.950 volts	9.122 volts	58.31 psig	8.011 psig	25	22	
					1510.4 psig	108.11 psig	100.59 psid	0.4020 Mpa	0.05523 Mpa			
					102.78 atm	7.357 atm	6.845 atm	0.4803 atm	1.381 atm			
				ABSOLUTE	ABSOLUTE		DIFFERENTIAL	ABSOLUTE		(°K)		(ml/sec)
					12.28 psia	1522.7 psia	120.39 psia	70.59 psia	20.29 psia			
					0.8356 atm	103.61 atm	8.192 atm	4.803 atm	1.381 atm	298	295	
					0.08467 Mpa	10.499 Mpa	0.8301 Mpa	0.4867 Mpa	0.1399 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.557 cm	* 1.0E-2 m/cm 9.557E-02 m
A = sample circular cross sectional area	81.249 cm ²	* 1.0E-4 m ² /cm ² 8.125E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8356 atm	* 1.013E+5 Pa/atm 8.465E+04 Pa
ΔP = pressure drop across sample length	6.845 atm	* 1.013E+5 Pa/atm 6.934E+05 Pa
Pm = mean pore pressure (absolute)	4.803 atm	* 1.013E+5 Pa/atm 4.866E+05 Pa
Pe = exit pressure (absolute)	1.381 atm	* 1.013E+5 Pa/atm 1.399E+05 Pa
Te = sample temperature (absolute)	298 °K	298 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.12583 cm ³ /s	* 1.0E-6 m ³ /cm ³ 1.258E-07 m ³ /s
ve = flow velocity at sample exit end	9.468E-04 cm/s	* 1.0E-2 m/cm 9.468E-06 m/s
Ka =	6.69E-06 d	* 9.872E-13 m ² /d 6.60E-18 m ²
Ka =	0.00669 md	6.60E-14 cm ²
Ka =	6.69 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	2 Mpa	290.1 psid	Gas:	N2
Sample #:	C	Length:	10.043 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	1	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	1	Area:	81.201 cm ²			
Pressure Data Filename:	8362CG.S1B					
XDCR calibration factors:	Pc = 222.869 psig/volt	PI = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	PI Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
27 Apr 93	13:40	266	CS1R1a	12.36 psia	1.434 volts	0.962 volts	4.416 volts		0.893 volts	23	23	0.04023
27 Apr 93	13:45	271	CS1R1b	12.36 psia	1.434 volts	0.963 volts	4.415 volts		0.894 volts	23	23	0.04023
27 Apr 93	13:49	271	CS1R1c	12.36 psia	1.434 volts	0.963 volts	4.415 volts		0.896 volts	23	23	0.04007
27 Apr 93	13:52	276	CS1R1d	12.36 psia	1.434 volts	0.963 volts	4.415 volts		0.897 volts	23	23	0.04025
AVERAGES			CS1R1									
				GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)		
				1.434 volts	0.963 volts	4.415 volts		0.895 volts				
				319.6 psig	53.38 psig	48.69 psid	29.29 psig	4.941 psig	23	23		
				21.75 atm	3.632 atm	3.313 atm	1.993 atm	0.3362 atm				
				2.204 Mpa	0.3680 Mpa	0.3357 Mpa	0.2019 Mpa	0.03407 Mpa				
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.36 psia	332.0 psia	65.74 psia	48.69 psid	41.65 psia	17.30 psia			
				0.8410 atm	22.59 atm	4.473 atm	3.313 atm	2.834 atm	1.177 atm	296	296	0.04020
0.08522 Mpa	2.289 Mpa	0.4532 Mpa	0.3357 Mpa	0.2871 Mpa	0.1193 Mpa							

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
u = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.043 cm	* 1.0E-2 m/cm 1.004E-01 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8410 atm	* 1.013E+5 Pa/atm 8.520E+04 Pa
ΔP = pressure drop across sample length	3.313 atm	* 1.013E+5 Pa/atm 3.356E+05 Pa
Pm = mean pore pressure (absolute)	2.834 atm	* 1.013E+5 Pa/atm 2.871E+05 Pa
Pe = exit pressure (absolute)	1.177 atm	* 1.013E+5 Pa/atm 1.193E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.04020 cm ³ /s	* 1.0E-6 m ³ /cm ³ 4.020E-08 m ³ /s
ve = flow velocity at sample exit end	3.536E-04 cm/s	* 1.0E-2 m/cm 3.536E-06 m/s
Ka =	7.84E-06 d	* 9.872E-13 m ² /d 7.74E-18 m ²
Ka =	7.84E-03 md	7.74E-14 cm ²
Ka =	7.84E+00 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	2 Mpa	290.1 psid	Gas:	N2
Sample #:	C	Length:	10.043 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	1	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	2	Area:	81.201 cm ²			
Pressure Data Filename:	8362CG.S1B					
XDCR calibration factors:	Pc =	222.869 psig/volt	Pi =	55.4417 psig/volt	ΔP =	11.0272 psid/volt Pe = 5.5211 psig/volt

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)		
27 Apr 93	16:45	451	CS1R2a	12.34 psia	1.477 volts	1.138 volts	4.375 volts		2.745 volts	23	23	0.04577		
27 Apr 93	16:47	451	CS1R2b	12.34 psia	1.478 volts	1.138 volts	4.375 volts		2.745 volts	23	23	0.04583		
27 Apr 93	16:50	456	CS1R2c	12.34 psia	1.478 volts	1.138 volts	4.375 volts		2.745 volts	23	23	0.04571		
27 Apr 93	16:58	461	CS1R2d	12.34 psia	1.478 volts	1.138 volts	4.375 volts		2.743 volts	23	23	0.04579		
27 Apr 93	17:01	466	CS1R2d	12.34 psia	1.479 volts	1.138 volts	4.375 volts		2.743 volts	23	23	0.04568		
AVERAGES			CS1R2											
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)			
					1.478 volts	1.138 volts	4.375 volts	2.744 volts	23	23				
					329.4 psig	63.09 psig	48.24 psid	39.27 psig			15.151 psig			
					22.41 atm	4.293 atm	3.283 atm	2.672 atm			1.0310 atm			
					2.271 Mpa	0.4350 Mpa	0.3326 Mpa	0.2708 Mpa			0.10446 Mpa			
					ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)		(°K)	(ml/sec)
					12.34 psia	341.7 psia	75.43 psia	48.24 psid	51.61 psia	27.49 psia	296		296	0.04578
					0.8397 atm	23.25 atm	5.133 atm	3.283 atm	3.512 atm	1.871 atm				
0.08508 Mpa	2.356 Mpa	0.5201 Mpa	0.3326 Mpa	0.3559 Mpa	0.1895 Mpa									

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.043 cm	* 1.0E-2 m/cm 1.004E-01 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8397 atm	* 1.013E+5 Pa/atm 8.506E+04 Pa
ΔP = pressure drop across sample length	3.283 atm	* 1.013E+5 Pa/atm 3.325E+05 Pa
Pm = mean pore pressure (absolute)	3.512 atm	* 1.013E+5 Pa/atm 3.558E+05 Pa
Pe = exit pressure (absolute)	1.871 atm	* 1.013E+5 Pa/atm 1.895E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.04578 cm ³ /s	* 1.0E-6 m ³ /cm ³ 4.578E-08 m ³ /s
ve = flow velocity at sample exit end	2.531E-04 cm/s	* 1.0E-2 m/cm 2.531E-06 m/s
Ka =	7.26E-06 d	* 9.872E-13 m ² /d 7.16E-18 m ²
Ka =	7.26E-03 md	7.16E-14 cm ²
Ka =	7.26E+00 μd	

Steady State Gas Permeability Data									
Project #:	8362	Net Effective Stress:	2 Mpa	290.1 psid	Gas:	N2			
Sample #:	C	Length:	10.043 cm		gas deviation z factors:	ze =	1.0000	zb =	1.0000
Stress Level #:	1	Diameter:	10.168 cm		Viscosity:	0.0176 cp			
Regime #:	4	Area:	81.201 cm^2						
Pressure Data Filename:	8362CG.S1B								
XDCR calibration factors:	Pc =	222.869 psig/volt	PI =	55.4417 psig/volt	AP =	11.0272 psid/volt	Pe =	5.5211 psig/volt	

[illegible]
$$v_e = Q_e/A = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * (Q_b/A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.043 cm	* 1.0E-2 m/cm 1.004E-01 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8451 atm	* 1.013E+5 Pa/atm 8.561E+04 Pa
ΔP = pressure drop across sample length	3.360 atm	* 1.013E+5 Pa/atm 3.403E+05 Pa
Pm = mean pore pressure (absolute)	4.876 atm	* 1.013E+5 Pa/atm 4.939E+05 Pa
Pe = exit pressure (absolute)	3.196 atm	* 1.013E+5 Pa/atm 3.238E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.05789 cm ³ /s	* 1.0E-6 m ³ /cm ³ 5.789E-08 m ³ /s
ve = flow velocity at sample exit end	1.885E-04 cm/s	* 1.0E-2 m/cm 1.885E-06 m/s
Ka =	6.50E-06 d	* 9.872E-13 m ² /d 6.42E-18 m ²
Ka =	6.50E-03 md	6.42E-14 cm ²
Ka =	6.50E+00 μ d	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psid	Gas:	N2
Sample #:	C	Length:	10.043 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	1	Area:	81.201 cm^2			
Pressure Data Filename:	8362CG.S2A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)	
29 Apr 93	16:26	255	CS2R1a	12.34 psia	4.036 volts	0.956 volts	4.388 volts		0.897 volts	23	23	0.02748	
29 Apr 93	16:30	260	CS2R1b	12.34 psia	4.036 volts	0.956 volts	4.389 volts		0.897 volts	23	23	0.02747	
29 Apr 93	16:34	265	CS2R1c	12.34 psia	4.036 volts	0.956 volts	4.389 volts		0.896 volts	23	23	0.02755	
29 Apr 93	16:38	265	CS2R1d	12.34 psia	4.036 volts	0.956 volts	4.389 volts		0.896 volts	23	23	0.02750	
AVERAGES			CS2R1										
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)		
					4.036 volts	0.956 volts	4.389 volts		0.897 volts	23	23		
					899.5 psig	53.00 psig	48.40 psid	29.15 psig	4.950 psig				
					61.21 atm	3.607 atm	3.293 atm	1.983 atm	0.3368 atm				
					6.202 Mpa	0.3654 Mpa	0.3337 Mpa	0.2010 Mpa	0.03413 Mpa				
					ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
					12.34 psia	911.8 psia	65.34 psia	48.40 psid	41.49 psia	17.29 psia	296	296	0.02750
					0.8397 atm	62.05 atm	4.446 atm	3.293 atm	2.823 atm	1.176 atm			
					0.08508 Mpa	6.287 Mpa	0.4505 Mpa	0.3337 Mpa	0.2860 Mpa	0.1192 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law:

$$V_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * V_b$$

$$Q_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * Q_b$$

$$v_e = Q_e/A = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * (Q_b/A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.043 cm	* 1.0E-2 m/cm 1.004E-01 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8397 atm	* 1.013E+5 Pa/atm 8.506E+04 Pa
ΔP = pressure drop across sample length	3.293 atm	* 1.013E+5 Pa/atm 3.336E+05 Pa
Pm = mean pore pressure (absolute)	2.823 atm	* 1.013E+5 Pa/atm 2.860E+05 Pa
Pe = exit pressure (absolute)	1.176 atm	* 1.013E+5 Pa/atm 1.192E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.02750 cm ³ /s	* 1.0E-6 m ³ /cm ³ 2.750E-08 m ³ /s
ve = flow velocity at sample exit end	2.417E-04 cm/s	* 1.0E-2 m/cm 2.417E-06 m/s
Ka =	5.41E-06 d	* 9.872E-13 m ² /d 5.34E-18 m ²
Ka =	5.41E-03 md	5.34E-14 cm ²
Ka =	5.41E+00 μ d	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psid	Gas:	N2
Sample #:	C	Length:	10.043 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	2	Area:	81.201 cm ²			
Pressure Data Filename:	8362EG.S2A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
30 Apr 93	12:42	1470	CS2R2a	12.33 psia	4.080 volts	1.133 volts	4.367 volts		2.733 volts	23	22	0.03043
30 Apr 93	12:45	1475	CS2R2b	12.33 psia	4.080 volts	1.134 volts	4.366 volts		2.737 volts	23	22	0.03040
30 Apr 93	12:48	1475	CS2R2c	12.33 psia	4.080 volts	1.134 volts	4.365 volts		2.738 volts	23	22	0.03040
30 Apr 93	12:52	1480	CS2R2d	12.33 psia	4.080 volts	1.134 volts	4.365 volts		2.739 volts	23	22	0.03046
AVERAGES			CS2R2							23	22	0.03042
AVERAGES			CS2R2							296	295	0.03042

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$

$Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.043 cm	* 1.0E-2 m/cm 1.004E-01 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8390 atm	* 1.013E+5 Pa/atm 8.499E+04 Pa
ΔP = pressure drop across sample length	3.276 atm	* 1.013E+5 Pa/atm 3.318E+05 Pa
Pm = mean pore pressure (absolute)	3.505 atm	* 1.013E+5 Pa/atm 3.551E+05 Pa
Pe = exit pressure (absolute)	1.867 atm	* 1.013E+5 Pa/atm 1.891E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.03042 cm ³ /s	* 1.0E-6 m ³ /cm ³ 3.042E-08 m ³ /s
ve = flow velocity at sample exit end	1.689E-04 cm/s	* 1.0E-2 m/cm 1.689E-06 m/s
Ka =	4.86E-06 d	* 9.872E-13 m ² /d 4.79E-18 m ²
Ka =	4.86E-03 md	4.79E-14 cm ²
Ka =	4.86E+00 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psid	Gas:	N2
Sample #:	C	Length:	10.043 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	3	Area:	81.201 cm ²			
Pressure Data Filename:	8362CG.S2A					
XDCR calibration factors:	Pc =	222.869 psig/volt	Pi =	55.4417 psig/volt	ΔP =	11.0272 psid/volt Pe = 5.5211 psig/volt

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
03 May 93	12:11	5756	CS2R3a	12.20 psia	4.124 volts	1.316 volts	4.420 volts		4.504 volts	23	23	0.03438
03 May 93	12:15	5761	CS2R3b	12.20 psia	4.124 volts	1.316 volts	4.420 volts		4.503 volts	23	23	0.03440
03 May 93	12:18	5765	CS2R3c	12.20 psia	4.124 volts	1.316 volts	4.421 volts		4.503 volts	23	23	0.03447
03 May 93	12:21	5770	CS2R3d	12.20 psia	4.124 volts	1.316 volts	4.422 volts		4.503 volts	23	23	0.03447
AVERAGES			CS2R3									
				GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)		
				4.124 volts	1.316 volts	4.421 volts		4.503 volts	23	23		
				919.1 psig	72.96 psig	48.75 psid	49.24 psig	24.863 psig				
				62.54 atm	4.965 atm	3.317 atm	3.350 atm	1.6918 atm				
				6.337 Mpa	0.5031 Mpa	0.3361 Mpa	0.3395 Mpa	0.17142 Mpa				
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.2 psia	931.3 psia	85.16 psia	48.75 psid	61.44 psia	37.06 psia	296	296	0.03443
0.8302 atm	63.37 atm	5.795 atm	3.317 atm	4.181 atm	2.522 atm							
0.08412 Mpa	6.421 Mpa	0.5872 Mpa	0.3361 Mpa	0.4236 Mpa	0.2555 Mpa							

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
u = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.043 cm	* 1.0E-2 m/cm 1.004E-01 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8302 atm	* 1.013E+5 Pa/atm 8.409E+04 Pa
ΔP = pressure drop across sample length	3.317 atm	* 1.013E+5 Pa/atm 3.360E+05 Pa
Pm = mean pore pressure (absolute)	4.181 atm	* 1.013E+5 Pa/atm 4.235E+05 Pa
Pe = exit pressure (absolute)	2.522 atm	* 1.013E+5 Pa/atm 2.555E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.03443 cm ³ /s	* 1.0E-6 m ³ /cm ³ 3.443E-08 m ³ /s
ve = flow velocity at sample exit end	1.396E-04 cm/s	* 1.0E-2 m/cm 1.396E-06 m/s
Ka =	4.49E-06 d	* 9.872E-13 m ² /d 4.43E-18 m ²
Ka =	4.49E-03 md	4.43E-14 cm ²
Ka =	4.49E+00 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psid	Gas:	N2
Sample #:	C	Length:	10.043 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	4	Area:	81.201 cm ²			
Pressure Data Filename:	8362CG.S2A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
03 May 93	16:29	6015	CS2R4a	12.12 psia	4.169 volts	1.498 volts	4.431 volts		6.338 volts	23	23	0.03828
03 May 93	16:32	6020	CS2R4b	12.12 psia	4.169 volts	1.498 volts	4.432 volts		6.338 volts	23	23	0.03846
03 May 93	16:35	6025	CS2R4c	12.12 psia	4.169 volts	1.498 volts	4.432 volts		6.338 volts	23	23	0.03843
03 May 93	16:41	6030	CS2R4d	12.12 psia	4.169 volts	1.498 volts	4.433 volts		6.337 volts	23	23	0.03827
03 May 93	16:44	6035	CS2R4e	12.12 psia	4.169 volts	1.498 volts	4.434 volts		6.336 volts	23	23	0.03842
AVERAGES			CS2R4									
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					4.169 volts	1.498 volts	4.432 volts		6.337 volts	23	23	
					929.1 psig	83.05 psig	48.88 psid	59.43 psig	34.989 psig			
					63.22 atm	5.651 atm	3.326 atm	4.044 atm	2.3809 atm			
				6.406 Mpa	0.5726 Mpa	0.3370 Mpa	0.4097 Mpa	0.24124 Mpa				
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.12 psia	941.3 psia	95.17 psia	48.88 psid	71.55 psia	47.11 psia	296	296	0.03836
				0.8247 atm	64.05 atm	6.476 atm	3.326 atm	4.869 atm	3.206 atm			
0.08356 Mpa	6.490 Mpa	0.6562 Mpa	0.3370 Mpa	0.4933 Mpa	0.3248 Mpa							

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.043 cm	* 1.0E-2 m/cm 1.004E-01 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8247 atm	* 1.013E+5 Pa/atm 8.354E+04 Pa
ΔP = pressure drop across sample length	3.326 atm	* 1.013E+5 Pa/atm 3.369E+05 Pa
Pm = mean pore pressure (absolute)	4.869 atm	* 1.013E+5 Pa/atm 4.932E+05 Pa
Pe = exit pressure (absolute)	3.206 atm	* 1.013E+5 Pa/atm 3.247E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.03836 cm ³ /s	* 1.0E-6 m ³ /cm ³ 3.836E-08 m ³ /s
ve = flow velocity at sample exit end	1.215E-04 cm/s	* 1.0E-2 m/cm 1.215E-06 m/s
	Ka = 4.25E-06 d	* 9.872E-13 m ² /d 4.20E-18 m ²
	Ka = 4.25E-03 md	4.20E-14 cm ²
	Ka = 4.25E+00 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psid	Gas:	N2
Sample #:	C	Length:	10.043 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	1	Area:	81.201 cm ²			
Pressure Data Filename:	8362CG.S3A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)	
04 May 93	17:19	350	CS3R1a	12.20 psia	6.638 volts	0.957 volts	4.420 volts		0.876 volts	23	22	0.02110	
04 May 93	17:25	355	CS3R1b	12.20 psia	6.638 volts	0.957 volts	4.420 volts		0.875 volts	23	22	0.02108	
04 May 93	17:29	355	CS3R1c	12.20 psia	6.638 volts	0.957 volts	4.420 volts		0.875 volts	23	22	0.02104	
04 May 93	17:34	360	CS3R1d	12.20 psia	6.638 volts	0.957 volts	4.420 volts		0.875 volts	23	22	0.02105	
AVERAGES			CS3R1										
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)		
					6.638 volts	0.957 volts	4.420 volts		0.875 volts	23	22		
					1479.4 psig	53.06 psig	48.74 psid	29.20 psig	4.832 psig				
					100.67 atm	3.610 atm	3.317 atm	1.987 atm	0.3288 atm				
					10.200 Mpa	0.3658 Mpa	0.3361 Mpa	0.2013 Mpa	0.03332 Mpa				
					ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
					12.2 psia	1491.6 psia	65.26 psia	48.74 psid	41.40 psia	17.03 psia	296	295	0.02107
	0.8302 atm	101.50 atm	4.441 atm	3.317 atm	2.817 atm	1.159 atm							
	0.08412 Mpa	10.284 Mpa	0.4499 Mpa	0.3361 Mpa	0.2855 Mpa	0.1174 Mpa							

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.043 cm	* 1.0E-2 m/cm 1.004E-01 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8302 atm	* 1.013E+5 Pa/atm 8.409E+04 Pa
ΔP = pressure drop across sample length	3.317 atm	* 1.013E+5 Pa/atm 3.360E+05 Pa
Pm = mean pore pressure (absolute)	2.817 atm	* 1.013E+5 Pa/atm 2.854E+05 Pa
Pe = exit pressure (absolute)	1.159 atm	* 1.013E+5 Pa/atm 1.174E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.02107 cm ³ /s	* 1.0E-6 m ³ /cm ³ 2.107E-08 m ³ /s
ve = flow velocity at sample exit end	1.865E-04 cm/s	* 1.0E-2 m/cm 1.865E-06 m/s
Ka =	4.09E-06 d	* 9.872E-13 m ² /d 4.04E-18 m ²
Ka =	4.09E-03 md	4.04E-14 cm ²
Ka =	4.09E+00 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psid	Gas:	N2
Sample #:	C	Length:	10.043 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	2	Area:	81.201 cm ²			
Pressure Data Filename:	8362CG.S3A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	AP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	AP Differential Pressure	Pm Mean Pore Pressure Pe+AP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
05 May 93	13:04	1535	CS3R2a	12.28 psia	6.683 volts	1.138 volts	4.434 volts		2.660 volts	23	21	0.02341
05 May 93	13:10	1540	CS3R2b	12.28 psia	6.683 volts	1.138 volts	4.434 volts		2.660 volts	23	21	0.02325
05 May 93	13:15	1545	CS3R2c	12.28 psia	6.683 volts	1.138 volts	4.434 volts		2.660 volts	23	21	0.02329
05 May 93	13:20	1550	CS3R2d	12.28 psia	6.683 volts	1.138 volts	4.434 volts		2.660 volts	23	21	0.02340
05 May 93	13:25	1555	CS3R2e	12.28 psia	6.683 volts	1.138 volts	4.434 volts		2.660 volts	23	21	0.02330
AVERAGES			CS3R2		GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					6.683 volts	1.138 volts	4.434 volts		2.660 volts			
					1489.4 psig	63.09 psig	48.89 psid	39.13 psig	14.686 psig	23	21	
					101.35 atm	4.293 atm	3.327 atm	2.663 atm	0.9993 atm			
					10.269 Mpa	0.4350 Mpa	0.3371 Mpa	0.2698 Mpa	0.10126 Mpa			
					ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	
					12.28 psia	1501.7 psia	75.37 psia	48.89 psid	51.41 psia	296	294	
					0.8356 atm	102.19 atm	5.129 atm	3.327 atm	3.498 atm			
					0.08467 Mpa	10.354 Mpa	0.5197 Mpa	0.3371 Mpa	0.3545 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law:

$$v_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot v_b$$

$$Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$$

$$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$$

Parameter	Traditional Units	SI Units
u = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.043 cm	* 1.0E-2 m/cm 1.004E-01 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8356 atm	* 1.013E+5 Pa/atm 8.465E+04 Pa
AP = pressure drop across sample length	3.327 atm	* 1.013E+5 Pa/atm 3.370E+05 Pa
Pm = mean pore pressure (absolute)	3.498 atm	* 1.013E+5 Pa/atm 3.544E+05 Pa
Pe = exit pressure (absolute)	1.835 atm	* 1.013E+5 Pa/atm 1.859E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	294 °K	294 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.02334 cm ³ /s	* 1.0E-6 m ³ /cm ³ 2.334E-08 m ³ /s
ve = flow velocity at sample exit end	1.318E-04 cm/s	* 1.0E-2 m/cm 1.318E-06 m/s
Ka =	3.67E-06 d	* 9.872E-13 m ² /d 3.62E-18 m ²
Ka =	3.67E-03 md	3.62E-14 cm ²
Ka =	3.67E+00 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psid	Gas:	N2
Sample #:	C	Length:	10.043 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	3	Area:	81.201 cm ²			
Pressure Data Filename:	8362CG.S3A					
XDCR calibration factors:	Pc = 222.869 psig/volt	PI = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	PI Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
05 May 93	16:56	1765	CS3R3a	12.29 psia	6.728 volts	1.316 volts	4.390 volts		4.549 volts	23	22	0.02584
05 May 93	17:00	1770	CS3R3b	12.29 psia	6.728 volts	1.316 volts	4.390 volts		4.550 volts	23	22	0.02579
05 May 93	17:04	1770	CS3R3c	12.29 psia	6.728 volts	1.316 volts	4.390 volts		4.550 volts	23	22	0.02574
05 May 93	17:04	1775	CS3R3d	12.29 psia	6.728 volts	1.316 volts	4.390 volts		4.550 volts	23	22	0.02571
05 May 93	17:13	1780	CS3R3e	12.29 psia	6.728 volts	1.316 volts	4.390 volts		4.550 volts	23	22	0.02579
AVERAGES			CS3R3		GUAGE	GUAGE	DIFFERENTIAL		GUAGE	GUAGE	(°C)	(°C)
					6.728 volts	1.316 volts	4.390 volts		4.550 volts	23	22	
					1499.5 psig	72.96 psig	48.41 psid	49.32 psig	25.120 psig			
					102.03 atm	4.965 atm	3.294 atm	3.356 atm	1.7093 atm			
					10.338 Mpa	0.5031 Mpa	0.3338 Mpa	0.3401 Mpa	0.17320 Mpa			
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.29 psia	1511.8 psia	85.25 psia	48.41 psid	61.61 psia	37.41 psia	296	295	0.02577
				0.8363 atm	102.87 atm	5.801 atm	3.294 atm	4.193 atm	2.546 atm			
				0.08474 Mpa	10.423 Mpa	0.5878 Mpa	0.3338 Mpa	0.4248 Mpa	0.2579 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $v_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot v_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.043 cm	* 1.0E-2 m/cm 1.004E-01 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8363 atm	* 1.013E+5 Pa/atm 8.472E+04 Pa
ΔP = pressure drop across sample length	3.294 atm	* 1.013E+5 Pa/atm 3.337E+05 Pa
Pm = mean pore pressure (absolute)	4.193 atm	* 1.013E+5 Pa/atm 4.247E+05 Pa
Pe = exit pressure (absolute)	2.546 atm	* 1.013E+5 Pa/atm 2.579E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.02577 cm ³ /s	* 1.0E-6 m ³ /cm ³ 2.577E-08 m ³ /s
ve = flow velocity at sample exit end	1.046E-04 cm/s	* 1.0E-2 m/cm 1.046E-06 m/s
Ka =	3.41E-06 d	* 9.872E-13 m ² /d 3.36E-18 m ²
Ka =	3.41E-03 md	3.36E-14 cm ²
Ka =	3.41E+00 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psid	Gas:	N2
Sample #:	C	Length:	10.043 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	4	Area:	81.201 cm ²			
Pressure Data Filename:	8362CG.S3A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
06 May 93	14:34	3060	CS3R4a	12.29 psia	6.772 volts	1.499 volts	4.422 volts		6.335 volts	23	22	0.02838
06 May 93	14:38	3065	CS3R4b	12.29 psia	6.772 volts	1.499 volts	4.422 volts		6.335 volts	23	22	0.02854
06 May 93	14:43	3070	CS3R4c	12.29 psia	6.772 volts	1.499 volts	4.422 volts		6.336 volts	23	22	0.02851
06 May 93	14:48	3075	CS3R4d	12.29 psia	6.772 volts	1.499 volts	4.422 volts		6.336 volts	23	22	0.02842
06 May 93	14:53	3080	CS3R4e	12.29 psia	6.772 volts	1.499 volts	4.422 volts		6.335 volts	23	22	0.02848
AVERAGES			CS3R4		GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					6.772 volts	1.499 volts	4.422 volts		6.335 volts			
					1509.3 psig	83.11 psig	48.76 psid	59.36 psig	34.978 psig	23	22	
					102.70 atm	5.655 atm	3.318 atm	4.039 atm	2.3801 atm			
					10.406 Mpa	0.5730 Mpa	0.3362 Mpa	0.4093 Mpa	0.24117 Mpa			
					ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	
					12.29 psia	1521.6 psia	95.40 psia	48.76 psid	71.65 psia	47.27 psia	296	295
					0.8363 atm	103.54 atm	6.491 atm	3.318 atm	4.875 atm	3.216 atm		
					0.08474 Mpa	10.491 Mpa	0.6577 Mpa	0.3362 Mpa	0.4940 Mpa	0.3259 Mpa		

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law:

$$v_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$$

$$Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$$

$$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.043 cm	* 1.0E-2 m/cm 1.004E-01 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8363 atm	* 1.013E+5 Pa/atm 8.472E+04 Pa
ΔP = pressure drop across sample length	3.318 atm	* 1.013E+5 Pa/atm 3.361E+05 Pa
Pm = mean pore pressure (absolute)	4.875 atm	* 1.013E+5 Pa/atm 4.939E+05 Pa
Pe = exit pressure (absolute)	3.216 atm	* 1.013E+5 Pa/atm 3.258E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.02846 cm ³ /s	* 1.0E-6 m ³ /cm ³ 2.846E-08 m ³ /s
ve = flow velocity at sample exit end	9.144E-05 cm/s	* 1.0E-2 m/cm 9.144E-07 m/s
Ka =	3.21E-06 d	* 9.872E-13 m ² /d 3.17E-18 m ²
Ka =	3.21E-03 md	3.17E-14 cm ²
Ka =	3.21E+00 μd	

Steady State Gas Permeability Data

Project #:	8362	Target Net Eff.Stress:	2 Mpa	290.1 psid	Gas:	N2
Sample #:	D	Length:	9.886 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	1	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	1	Area:	81.201 cm ²			
Pressure Data Filename:	8362DG.S1A					
XDCR calibration factors:	Pc = 222.869 psig/volt	PI = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	PI Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
12 Jul 93	07:38	4174	DS1R1a	12.29 psia	1.534 volts	1.904 volts	9.176 volts		0.919 volts	23	22	0.004849
12 Jul 93	07:43	4179	DS1R1b	12.29 psia	1.534 volts	1.904 volts	9.176 volts		0.919 volts	23	22	0.004889
12 Jul 93	07:47	4184	DS1R1c	12.29 psia	1.534 volts	1.904 volts	9.176 volts		0.919 volts	23	22	0.004904
12 Jul 93	07:54	4191	DS1R1d	12.29 psia	1.535 volts	1.904 volts	9.176 volts		0.919 volts	23	22	0.004848
12 Jul 93	07:58	4196	DS1R1e	12.29 psia	1.535 volts	1.904 volts	9.178 volts		0.919 volts	23	22	0.004866
AVERAGES			DS1R1		GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					1.534 volts	1.904 volts	9.176 volts		0.919 volts			
					342.0 psig	105.56 psig	101.19 psid	55.67 psig	5.074 psig	23	22	
					23.27 atm	7.183 atm	6.886 atm	3.788 atm	0.3453 atm			
					2.358 Mpa	0.7278 Mpa	0.6977 Mpa	0.3838 Mpa	0.03498 Mpa			
					ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	
					12.29 psia	354.3 psia	117.85 psia	67.96 psia	17.36 psia			
					0.8363 atm	24.11 atm	8.019 atm	4.624 atm	1.182 atm	296	295	0.00487
					0.08474 Mpa	2.443 Mpa	0.8126 Mpa	0.6977 Mpa	0.4686 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot V_b$
 $Q_e = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot Q_b$

$v_e = Q_e/A = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot (Q_b/A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.886 cm	* 1.0E-2 m/cm 9.886E-02 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8363 atm	* 1.013E+5 Pa/atm 8.472E+04 Pa
ΔP = pressure drop across sample length	6.886 atm	* 1.013E+5 Pa/atm 6.975E+05 Pa
Pm = mean pore pressure (absolute)	4.624 atm	* 1.013E+5 Pa/atm 4.684E+05 Pa
Pe = exit pressure (absolute)	1.182 atm	* 1.013E+5 Pa/atm 1.197E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.00487 cm ³ /s	* 1.0E-6 m ³ /cm ³ 4.873E-09 m ³ /s
ve = flow velocity at sample exit end	4.262E-05 cm/s	* 1.0E-2 m/cm 4.262E-07 m/s
Ka =	2.75E-07 d	* 9.872E-13 m ² /d 2.72E-19 m ²
Ka =	2.75E-04 md	2.72E-15 cm ²
Ka =	2.75E-01 μd	
Pc - Pm = Actual N.E.S.	286.3 psid	1.97 MPa

Steady State Gas Permeability Data

Project #:	8362	Target Net Eff.Stress:	2 Mpa	290.1 psid	Gas:	N2
Sample #:	D	Length:	9.886 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	1	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	2	Area:	81.201 cm ²			
Pressure Data Filename:	8362DG.S1A					
XDCR calibration factors:	Pc =	222.869 psig/volt	Pi =	55.4417 psig/volt	ΔP =	11.0272 psid/volt Pe = 5.5211 psig/volt

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
12 Jul 93	12:44	4476	DS1R2a	12.32 psia	1.598 volts	2.102 volts	9.155 volts		2.950 volts	23	23	0.005378
12 Jul 93	12:47	4481	DS1R2b	12.32 psia	1.598 volts	2.102 volts	9.155 volts		2.950 volts	23	23	0.005387
12 Jul 93	12:51	4486	DS1R2c	12.32 psia	1.598 volts	2.102 volts	9.155 volts		2.950 volts	23	23	0.005362
12 Jul 93	12:55	4491	DS1R2d	12.32 psia	1.598 volts	2.102 volts	9.156 volts		2.950 volts	23	23	0.005371
12 Jul 93	13:01	4496	DS1R2e	12.32 psia	1.598 volts	2.102 volts	9.156 volts		2.950 volts	23	23	0.005358
AVERAGES			DS1R2		GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					1.598 volts	2.102 volts	9.155 volts		2.950 volts			
					356.1 psig	116.54 psig	100.96 psid	66.77 psig	16.287 psig	23	23	
					24.23 atm	7.930 atm	6.870 atm	4.543 atm	1.1083 atm			
					2.456 Mpa	0.8035 Mpa	0.6961 Mpa	0.4603 Mpa	0.11230 Mpa			
					ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	
					12.32 psia	368.5 psia	128.86 psia	100.96 psid	79.09 psia	296	296	
					0.8383 atm	25.07 atm	8.768 atm	5.381 atm	1.947 atm			
					0.08494 Mpa	2.540 Mpa	0.8884 Mpa	0.6961 Mpa	0.1972 Mpa			0.00537

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.886 cm	* 1.0E-2 m/cm 9.886E-02 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8383 atm	* 1.013E+5 Pa/atm 8.492E+04 Pa
ΔP = pressure drop across sample length	6.870 atm	* 1.013E+5 Pa/atm 6.959E+05 Pa
Pm = mean pore pressure (absolute)	5.381 atm	* 1.013E+5 Pa/atm 5.451E+05 Pa
Pe = exit pressure (absolute)	1.947 atm	* 1.013E+5 Pa/atm 1.972E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.00537 cm ³ /s	* 1.0E-6 m ³ /cm ³ 5.374E-09 m ³ /s
ve = flow velocity at sample exit end	2.850E-05 cm/s	* 1.0E-2 m/cm 2.850E-07 m/s
Ka =	2.61E-07 d	* 9.872E-13 m ² /d 2.58E-19 m ²
Ka =	2.61E-04 md	2.58E-15 cm ²
Ka =	2.61E-01 μd	
Pc - Pm = Actual N.E.S.	289.4 psid	2.00 MPa

Steady State Gas Permeability Data

Project #:	8362	Target Net Eff.Stress:	2 Mpa	290.1 psid	Gas:	N2
Sample #:	D	Length:	9.886 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	1	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	3	Area:	81.201 cm ²			
Pressure Data Filename:	8362DG.S1A					
XDCR calibration factors:	Pc = 222.869 psig/volt	PI = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
12 Jul 93	17:05	4738	DS1R3a	12.29 psia	1.646 volts	2.277 volts	9.160 volts		4.720 volts	23	23	0.005750
12 Jul 93	17:09	4743	DS1R3b	12.29 psia	1.646 volts	2.277 volts	9.160 volts		4.720 volts	23	23	0.005742
12 Jul 93	17:13	4748	DS1R3c	12.29 psia	1.645 volts	2.277 volts	9.590 volts		4.720 volts	23	23	0.005760
12 Jul 93	17:16	4753	DS1R3d	12.29 psia	1.645 volts	2.277 volts	9.590 volts		4.720 volts	23	23	0.005767
12 Jul 93	17:19	4758	DS1R3e	12.29 psia	1.645 volts	2.277 volts	9.590 volts		4.720 volts	23	23	0.005764
AVERAGES			DS1R3									
				GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)		
				1.645 volts	2.277 volts	9.418 volts		4.720 volts	23	23		
				366.7 psig	126.24 psig	103.85 psid	77.99 psig	26.060 psig				
				24.95 atm	8.590 atm	7.067 atm	5.307 atm	1.7732 atm				
				2.528 Mpa	0.8704 Mpa	0.7160 Mpa	0.5377 Mpa	0.17967 Mpa				
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.29 psia	379.0 psia	138.53 psia	103.85 psid	90.28 psia	38.35 psia	296	296	0.00575
0.8363 atm	25.79 atm	9.426 atm	7.067 atm	6.143 atm	2.610 atm							
0.08474 Mpa	2.613 Mpa	0.9551 Mpa	0.7160 Mpa	0.6224 Mpa	0.2644 Mpa							

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law:

$$V_e = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot V_b$$

$$Q_e = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot Q_b$$

$$v_e = Q_e/A = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot (Q_b/A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.886 cm	* 1.0E-2 m/cm 9.886E-02 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8363 atm	* 1.013E+5 Pa/atm 8.472E+04 Pa
ΔP = pressure drop across sample length	7.067 atm	* 1.013E+5 Pa/atm 7.159E+05 Pa
Pm = mean pore pressure (absolute)	6.143 atm	* 1.013E+5 Pa/atm 6.223E+05 Pa
Pe = exit pressure (absolute)	2.610 atm	* 1.013E+5 Pa/atm 2.643E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.00575 cm ³ /s	* 1.0E-6 m ³ /cm ³ 5.755E-09 m ³ /s
ve = flow velocity at sample exit end	2.271E-05 cm/s	* 1.0E-2 m/cm 2.271E-07 m/s
Ka =	2.38E-07 d	* 9.872E-13 m ² /d 2.34E-19 m ²
Ka =	2.38E-04 md	2.34E-15 cm ²
Ka =	2.38E-01 μd	
Pc - Pm = Actual N.E.S.	288.7 psid	1.99 MPa

Steady State Gas Permeability Data

Project #:	8362	Target Net Eff.Stress:	2 Mpa	290.1 psid	Gas:	N2
Sample #:	D	Length:	9.886 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	1	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	4	Area:	81.201 cm ²			
Pressure Data Filename:	8362DG.S1A					
XDCR calibration factors:	Pc =	222.869 psig/volt	Pi =	55.4417 psig/volt	ΔP =	11.0272 psid/volt Pe = 5.5211 psig/volt

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
13 Jul 93	07:41	5613	DS1R4a	12.33 psia	1.678 volts	2.449 volts	9.158 volts		6.451 volts	23	21	0.006108
13 Jul 93	07:44	5618	DS1R4b	12.33 psia	1.678 volts	2.449 volts	9.158 volts		6.451 volts	23	21	0.006070
13 Jul 93	07:47	5623	DS1R4c	12.33 psia	1.678 volts	2.449 volts	9.159 volts		6.450 volts	23	21	0.006066
13 Jul 93	07:50	5628	DS1R4d	12.33 psia	1.678 volts	2.449 volts	9.159 volts		6.450 volts	23	21	0.006107
13 Jul 93	07:53	5633	DS1R4e	12.33 psia	1.678 volts	2.449 volts	9.158 volts		6.450 volts	23	21	0.006111
AVERAGES			DS1R4									
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					1.678 volts	2.449 volts	9.158 volts	6.450 volts	23	21		
					374.0 psig	135.78 psig	100.99 psid	86.11 psig			35.613 psig	
				25.45 atm	9.239 atm	6.872 atm	5.859 atm	2.4233 atm	296	294		
				2.578 Mpa	0.9361 Mpa	0.6963 Mpa	0.5937 Mpa	0.24555 Mpa				
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.33 psia	386.3 psia	148.11 psia	100.99 psid	98.44 psia	47.94 psia			
0.8390 atm	26.29 atm	10.078 atm	6.872 atm	6.698 atm	3.262 atm	0.00609						
0.08501 Mpa	2.663 Mpa	1.0212 Mpa	0.6963 Mpa	0.6787 Mpa	0.3306 Mpa							

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law:

$$v_e = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot v_b$$

$$Q_e = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot Q_b$$

$$v_e = Q_e/A = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot (Q_b/A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.886 cm	* 1.0E-2 m/cm 9.886E-02 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8390 atm	* 1.013E+5 Pa/atm 8.499E+04 Pa
ΔP = pressure drop across sample length	6.872 atm	* 1.013E+5 Pa/atm 6.961E+05 Pa
Pm = mean pore pressure (absolute)	6.698 atm	* 1.013E+5 Pa/atm 6.785E+05 Pa
Pe = exit pressure (absolute)	3.262 atm	* 1.013E+5 Pa/atm 3.305E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	294 °K	294 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.00609 cm ³ /s	* 1.0E-6 m ³ /cm ³ 6.088E-09 m ³ /s
ve = flow velocity at sample exit end	1.941E-05 cm/s	* 1.0E-2 m/cm 1.941E-07 m/s
Ka =	2.39E-07 d	* 9.872E-13 m ² /d 2.36E-19 m ²
Ka =	2.39E-04 md	2.36E-15 cm ²
Ka =	2.39E-01 μd	
Pc - Pm = Actual N.E.S.	287.9 psid	1.98 MPa

Steady State Gas Permeability Data

Project #:	8362	Target Net Eff.Stress:	6 Mpa	870.2 psid	Gas:	N2
Sample #:	D	Length:	9.886 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	1	Area:	81.201 cm ²			
Pressure Data Filename:	8362DG.S2A					
XDCR calibration factors:	Pc = 222.869 psig/volt	PI = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	PI Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
15 Jul 93	14:47	1353	DS2R1a	12.30 psia	4.158 volts	1.918 volts	9.165 volts		1.078 volts	23	23	0.002292
15 Jul 93	14:51	1358	DS2R1b	12.30 psia	4.158 volts	1.918 volts	9.165 volts		1.078 volts	23	23	0.002289
15 Jul 93	14:56	1363	DS2R1c	12.30 psia	4.158 volts	1.918 volts	9.164 volts		1.079 volts	23	23	0.002281
15 Jul 93	15:01	1368	DS2R1d	12.30 psia	4.158 volts	1.918 volts	9.164 volts		1.080 volts	23	23	0.002275
15 Jul 93	15:06	1373	DS2R1e	12.30 psia	4.158 volts	1.918 volts	9.164 volts		1.081 volts	23	23	0.002287
AVERAGES			DS2R1							(°C)	(°C)	
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE			
					4.158 volts	1.918 volts	9.164 volts		1.079 volts			
					926.7 psig	106.34 psig	101.06 psid	56.49 psig	5.958 psig	23	23	
					63.06 atm	7.236 atm	6.877 atm	3.844 atm	0.4054 atm			
					6.389 Mpa	0.7332 Mpa	0.6968 Mpa	0.3895 Mpa	0.04108 Mpa			
					ABSOLUTE	ABSOLUTE	ABSOLUTE	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
					12.3 psia	939.0 psia	118.64 psia	68.79 psia	18.26 psia			
					0.8370 atm	63.89 atm	8.073 atm	4.681 atm	1.242 atm	296	296	0.00228
					0.08481 Mpa	6.474 Mpa	0.8180 Mpa	0.6968 Mpa	0.4743 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $v_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot v_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.886 cm	* 1.0E-2 m/cm 9.886E-02 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8370 atm	* 1.013E+5 Pa/atm 8.478E+04 Pa
ΔP = pressure drop across sample length	6.877 atm	* 1.013E+5 Pa/atm 6.966E+05 Pa
Pm = mean pore pressure (absolute)	4.681 atm	* 1.013E+5 Pa/atm 4.742E+05 Pa
Pe = exit pressure (absolute)	1.242 atm	* 1.013E+5 Pa/atm 1.259E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.00228 cm ³ /s	* 1.0E-6 m ³ /cm ³ 2.284E-09 m ³ /s
ve = flow velocity at sample exit end	1.895E-05 cm/s	* 1.0E-2 m/cm 1.895E-07 m/s
Ka =	1.27E-07 d	* 9.872E-13 m ² /d 1.26E-19 m ²
Ka =	1.27E-04 md	1.26E-15 cm ²
Ka =	1.27E-01 μd	
Pc - Pm = Actual N.E.S.	870.2 psid	6.00 MPa

Steady State Gas Permeability Data

Project #:	8362	Target Net Eff.Stress:	6 Mpa	870.2 psid	Gas:	N2
Sample #:	D	Length:	9.886 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	2	Area:	81.201 cm ²			
Pressure Data Filename:	8362DG.S2A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pl = 55.4417 psig/volt	AP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pl Inlet Pressure	AP Differential Pressure	Pm Mean Pore Pressure Pe+AP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
16 Jul 93	13:47	2735	DS2R2a	12.36 psia	4.203 volts	2.095 volts	9.129 volts		2.931 volts	23	23	0.002449
16 Jul 93	13:52	2740	DS2R2b	12.36 psia	4.203 volts	2.095 volts	9.131 volts		2.931 volts	23	23	0.002424
16 Jul 93	13:57	2745	DS2R2c	12.36 psia	4.203 volts	2.095 volts	9.132 volts		2.931 volts	23	23	0.002444
16 Jul 93	14:01	2750	DS2R2d	12.36 psia	4.203 volts	2.096 volts	9.132 volts		2.931 volts	23	23	0.002460
16 Jul 93	14:06	2755	DS2R2e	12.36 psia	4.203 volts	2.096 volts	9.133 volts		2.932 volts	23	23	0.002442
AVERAGES			DS2R2		GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					4.203 volts	2.095 volts	9.131 volts	2.931 volts	23	23		
					936.7 psig	116.17 psig	100.69 psid	66.53 psig			16.183 psig	
					63.74 atm	7.905 atm	6.852 atm	4.527 atm			1.1012 atm	
					6.458 Mpa	0.8010 Mpa	0.6943 Mpa	0.4587 Mpa	0.11158 Mpa			
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.36 psia	949.1 psia	128.53 psia	100.69 psid	78.89 psia	28.54 psia	296	296	0.00244
				0.8410 atm	64.58 atm	8.746 atm	6.852 atm	5.368 atm	1.942 atm			
				0.08522 Mpa	6.544 Mpa	0.8862 Mpa	0.6943 Mpa	0.5439 Mpa	0.1968 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law:

$$v_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot v_b$$

$$Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$$

$$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.886 cm	* 1.0E-2 m/cm 9.886E-02 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8410 atm	* 1.013E+5 Pa/atm 8.520E+04 Pa
AP = pressure drop across sample length	6.852 atm	* 1.013E+5 Pa/atm 6.941E+05 Pa
Pm = mean pore pressure (absolute)	5.368 atm	* 1.013E+5 Pa/atm 5.438E+05 Pa
Pe = exit pressure (absolute)	1.942 atm	* 1.013E+5 Pa/atm 1.968E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.00244 cm ³ /s	* 1.0E-6 m ³ /cm ³ 2.444E-09 m ³ /s
ve = flow velocity at sample exit end	1.303E-05 cm/s	* 1.0E-2 m/cm 1.303E-07 m/s
Ka =	1.20E-07 d	* 9.872E-13 m ² /d 1.18E-19 m ²
Ka =	1.20E-04 md	1.18E-15 cm ²
Ka =	1.20E-01 μ d	
Pc - Pm = Actual N.E.S.	870.2 psid	6.00 MPa

Steady State Gas Permeability Data

Project #:	8362	Target Net Eff.Stress:	6 Mpa	870.2 psid	Gas:	N2
Sample #:	D	Length:	9.886 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	3	Area:	81.201 cm ²			
Pressure Data Filename:	8362DG.S2A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
17 Jul 93	14:20	4208	DS2R3a	12.35 psia	4.248 volts	2.270 volts	9.050 volts		4.859 volts	23	23	0.002590
17 Jul 93	14:25	4213	DS2R3b	12.35 psia	4.249 volts	2.271 volts	9.051 volts		4.859 volts	23	23	0.002603
17 Jul 93	14:29	4213	DS2R3c	12.35 psia	4.249 volts	2.271 volts	9.052 volts		4.859 volts	23	23	0.002565
17 Jul 93	14:33	4218	DS2R3d	12.35 psia	4.249 volts	2.271 volts	9.054 volts		4.859 volts	23	23	0.002562
17 Jul 93	14:37	4223	DS2R3e	12.35 psia	4.249 volts	2.271 volts	9.054 volts		4.859 volts	23	23	0.002574
AVERAGES			DS2R3		GAUGE	GAUGE	DIFFERENTIAL	GAUGE	GAUGE	(°C)	(°C)	
					4.249 volts	2.271 volts	9.052 volts	4.859 volts	23	23		
					946.9 psig	125.90 psig	99.82 psid	76.74 psig			26.827 psig	
					64.43 atm	8.567 atm	6.792 atm	5.222 atm			1.8255 atm	
					6.529 Mpa	0.8680 Mpa	0.6882 Mpa	0.5291 Mpa			0.18497 Mpa	
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.35 psia	959.3 psia	138.25 psia	99.82 psid	89.09 psia	39.18 psia	296	296	0.00258
				0.8404 atm	65.27 atm	9.407 atm	6.792 atm	6.062 atm	2.666 atm			
				0.08515 Mpa	6.614 Mpa	0.9532 Mpa	0.6882 Mpa	0.6142 Mpa	0.2701 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.886 cm	* 1.0E-2 m/cm 9.886E-02 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8404 atm	* 1.013E+5 Pa/atm 8.513E+04 Pa
ΔP = pressure drop across sample length	6.792 atm	* 1.013E+5 Pa/atm 6.881E+05 Pa
Pm = mean pore pressure (absolute)	6.062 atm	* 1.013E+5 Pa/atm 6.141E+05 Pa
Pe = exit pressure (absolute)	2.666 atm	* 1.013E+5 Pa/atm 2.700E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.00258 cm ³ /s	* 1.0E-6 m ³ /cm ³ 2.580E-09 m ³ /s
ve = flow velocity at sample exit end	1.002E-05 cm/s	* 1.0E-2 m/cm 1.002E-07 m/s
Ka =	1.13E-07 d	* 9.872E-13 m ² /d 1.11E-19 m ²
Ka =	1.13E-04 md	1.11E-15 cm ²
Ka =	1.13E-01 μd	
Pc - Pm = Actual N.E.S.	870.2 psid	6.00 MPa

Steady State Gas Permeability Data

Project #:	8362	Target Net Eff.Stress:	6 Mpa	870.2 psid	Gas:	N2
Sample #:	D	Length:	9.886 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	4	Area:	81.201 cm ²			
Pressure Data Filename:	8362DG.S2A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
19 Jul 93	17:37	7285	DS2R4a	12.32 psia	4.297 volts	2.454 volts	8.982 volts		6.859 volts	23	23	0.002709
19 Jul 93	17:41	7290	DS2R4b	12.32 psia	4.297 volts	2.454 volts	8.983 volts		6.858 volts	23	23	0.002700
19 Jul 93	17:45	7295	DS2R4c	12.32 psia	4.297 volts	2.454 volts	8.982 volts		6.858 volts	23	23	0.002684
19 Jul 93	17:49	7295	DS2R4d	12.32 psia	4.297 volts	2.454 volts	8.983 volts		6.858 volts	23	23	0.002684
19 Jul 93	17:53	7300	DS2R4e	12.32 psia	4.297 volts	2.454 volts	8.983 volts		6.858 volts	23	23	0.002677
AVERAGES			DS2R4		GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					4.297 volts	2.454 volts	8.983 volts		6.858 volts			
					957.7 psig	136.05 psig	99.05 psid	87.39 psig	37.865 psig	23	23	
					65.17 atm	9.258 atm	6.740 atm	5.947 atm	2.5765 atm			
					6.603 Mpa	0.9381 Mpa	0.6829 Mpa	0.6025 Mpa	0.26107 Mpa			
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
					12.32 psia	970.0 psia	148.37 psia	99.71 psia	50.18 psia			
					0.8383 atm	66.00 atm	10.096 atm	6.785 atm	3.415 atm	296	296	0.00269
					0.08494 Mpa	6.688 Mpa	1.0230 Mpa	0.6829 Mpa	0.3460 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law:

$$V_e = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot V_b$$

$$Q_e = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot Q_b$$

$$v_e = Q_e/A = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot (Q_b/A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.886 cm	* 1.0E-2 m/cm 9.886E-02 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8383 atm	* 1.013E+5 Pa/atm 8.492E+04 Pa
ΔP = pressure drop across sample length	6.740 atm	* 1.013E+5 Pa/atm 6.828E+05 Pa
Pm = mean pore pressure (absolute)	6.785 atm	* 1.013E+5 Pa/atm 6.873E+05 Pa
Pe = exit pressure (absolute)	3.415 atm	* 1.013E+5 Pa/atm 3.459E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.00269 cm ³ /s	* 1.0E-6 m ³ /cm ³ 2.694E-09 m ³ /s
ve = flow velocity at sample exit end	8.146E-06 cm/s	* 1.0E-2 m/cm 8.146E-08 m/s
Ka =	1.06E-07 d	* 9.872E-13 m ² /d 1.04E-19 m ²
Ka =	1.06E-04 md	1.04E-15 cm ²
Ka =	1.06E-01 μd	
Pc - Pm = Actual N.E.S.	870.3 psid	6.00 MPa

Steady State Gas Permeability Data

Project #:	8362	Target Net Eff.Stress:	10 Mpa	1450.4 psid	Gas:	N2
Sample #:	D	Length:	9.886 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	4'	Area:	81.201 cm ²			
Pressure Data Filename:	8362DG.S3A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	AP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	AP Differential Pressure	Pm Mean Pore Pressure Pe+AP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
27 Jul 93	14:36	10262	DS3R4'a	12.40 psia	6.898 volts	2.460 volts	9.088 volts		6.687 volts	23	23	0.002014
27 Jul 93	14:41	10267	DS3R4'b	12.40 psia	6.898 volts	2.460 volts	9.087 volts		6.689 volts	23	23	0.001987
27 Jul 93	14:46	10272	DS3R4'c	12.40 psia	6.898 volts	2.460 volts	9.088 volts		6.688 volts	23	23	0.001970
27 Jul 93	14:52	10277	DS3R4'd	12.40 psia	6.898 volts	2.460 volts	9.089 volts		6.688 volts	23	23	0.001979
27 Jul 93	14:57	10282	DS3R4'e	12.40 psia	6.898 volts	2.460 volts	9.089 volts		6.688 volts	23	23	0.001993
AVERAGES			DS3R4'		GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					6.898 volts	2.460 volts	9.088 volts		6.688 volts			
					1537.4 psig	136.39 psig	100.22 psid	87.03 psig	36.925 psig	23	23	
					104.61 atm	9.281 atm	6.819 atm	5.922 atm	2.5126 atm			
					10.600 Mpa	0.9404 Mpa	0.6910 Mpa	0.6001 Mpa	0.25459 Mpa			
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.4 psia	1549.8 psia	148.79 psia	100.22 psid	99.43 psia	49.33 psia			
				0.8438 atm	105.45 atm	10.124 atm	6.819 atm	6.766 atm	3.356 atm	296	296	0.00199
				0.08550 Mpa	10.685 Mpa	1.0258 Mpa	0.6910 Mpa	0.6856 Mpa	0.3401 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law:

$$v_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot v_b$$

$$Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$$

$$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.886 cm	* 1.0E-2 m/cm 9.886E-02 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8438 atm	* 1.013E+5 Pa/atm 8.547E+04 Pa
AP = pressure drop across sample length	6.819 atm	* 1.013E+5 Pa/atm 6.908E+05 Pa
Pm = mean pore pressure (absolute)	6.766 atm	* 1.013E+5 Pa/atm 6.854E+05 Pa
Pe = exit pressure (absolute)	3.356 atm	* 1.013E+5 Pa/atm 3.400E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.00199 cm ³ /s	* 1.0E-6 m ³ /cm ³ 1.987E-09 m ³ /s
ve = flow velocity at sample exit end	6.152E-06 cm/s	* 1.0E-2 m/cm 6.152E-08 m/s
Ka =	7.79E-08 d	* 9.872E-13 m ² /d 7.69E-20 m ²
Ka =	7.79E-05 md	7.69E-16 cm ²
Ka =	7.79E-02 μ d	
Pc - Pm = Actual N.E.S.	1450.3 psid	10.00 MPa

Steady State Gas Permeability Data

Project #:	8362	Target Net Eff.Stress:	10 Mpa	1450.4 psid	Gas:	N2
Sample #:	D	Length:	9.886 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	3'	Area:	81.201 cm ²			
Pressure Data Filename:	8362DG.S3A					
XDRC calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
28 Jul 93	08:47	11353	DS3R3'a	12.38 psia	6.849 volts	2.270 volts	9.136 volts		4.686 volts	23	22	0.001837
28 Jul 93	08:53	11358	DS3R3'b	12.38 psia	6.849 volts	2.270 volts	9.137 volts		4.687 volts	23	22	0.001822
28 Jul 93	08:58	11363	DS3R3'c	12.38 psia	6.849 volts	2.270 volts	9.137 volts		4.687 volts	23	22	0.001828
28 Jul 93	09:04	11368	DS3R3'd	12.38 psia	6.849 volts	2.270 volts	9.138 volts		4.687 volts	23	22	0.001847
28 Jul 93	09:10	11373	DS3R3'e	12.38 psia	6.849 volts	2.270 volts	9.139 volts		4.688 volts	23	22	0.001831
AVERAGES			DS3R3'									
				GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)		
				6.849 volts	2.270 volts	9.137 volts		4.687 volts	23	22		
				1526.4 psig	125.85 psig	100.76 psid	76.26 psig	25.877 psig				
				103.87 atm	8.564 atm	6.856 atm	5.189 atm	1.7608 atm				
				10.524 Mpa	0.8677 Mpa	0.6947 Mpa	0.5258 Mpa	0.17842 Mpa				
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.38 psia	1538.8 psia	138.23 psia	100.76 psid	88.64 psia	38.26 psia	296	295	0.00183
				0.8424 atm	104.71 atm	9.406 atm	6.856 atm	6.031 atm	2.603 atm			
0.08536 Mpa	10.610 Mpa	0.9531 Mpa	0.6947 Mpa	0.6111 Mpa	0.2638 Mpa							

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.886 cm	* 1.0E-2 m/cm 9.886E-02 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8424 atm	* 1.013E+5 Pa/atm 8.534E+04 Pa
ΔP = pressure drop across sample length	6.856 atm	* 1.013E+5 Pa/atm 6.945E+05 Pa
Pm = mean pore pressure (absolute)	6.031 atm	* 1.013E+5 Pa/atm 6.110E+05 Pa
Pe = exit pressure (absolute)	2.603 atm	* 1.013E+5 Pa/atm 2.637E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.00183 cm ³ /s	* 1.0E-6 m ³ /cm ³ 1.833E-09 m ³ /s
ve = flow velocity at sample exit end	7.330E-06 cm/s	* 1.0E-2 m/cm 7.330E-08 m/s
Ka =	8.03E-08 d	* 9.872E-13 m ² /d 7.93E-20 m ²
Ka =	8.03E-05 md	7.93E-16 cm ²
Ka =	8.03E-02 μd	
Pc - Pm = Actual N.E.S.	1450.2 psid	10.00 MPa

Steady State Gas Permeability Data

Project #:	8362	Target Net Eff.Stress:	10 Mpa	1450.4 psid	Gas:	N2
Sample #:	D	Length:	9.886 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	2'	Area:	81.201 cm ²			
Pressure Data Filename:	8362DG.S3A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
29 Jul 93	10:54	12917	DS3R2'a	12.38 psia	6.805 volts	2.097 volts	9.176 volts		2.860 volts	23	23	0.001712
29 Jul 93	11:00	12922	DS3R2'b	12.38 psia	6.805 volts	2.097 volts	9.175 volts		2.860 volts	23	23	0.001704
29 Jul 93	11:05	12932	DS3R2'c	12.38 psia	6.805 volts	2.097 volts	9.176 volts		2.860 volts	23	23	0.001699
29 Jul 93	11:11	12937	DS3R2'd	12.38 psia	6.805 volts	2.097 volts	9.177 volts		2.860 volts	23	23	0.001699
29 Jul 93	11:21	12947	DS3R2'e	12.38 psia	6.805 volts	2.098 volts	9.177 volts		2.861 volts	23	23	0.001704
AVERAGES			DS3R2'		GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					6.805 volts	2.097 volts	9.176 volts	2.860 volts		23	23	
					1516.6 psig	116.27 psig	101.19 psid	66.39 psig	15.791 psig			
					103.20 atm	7.912 atm	6.885 atm	4.517 atm	1.0745 atm			
					10.457 Mpa	0.8017 Mpa	0.6977 Mpa	0.4577 Mpa	0.10888 Mpa			
					ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	
					12.38 psia	1529.0 psia	128.65 psia	78.77 psia	28.17 psia	296	296	
					0.8424 atm	104.04 atm	8.754 atm	5.360 atm	1.917 atm			
					0.08536 Mpa	10.542 Mpa	0.8870 Mpa	0.5431 Mpa	0.1942 Mpa			0.001704

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$

$Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.886 cm	* 1.0E-2 m/cm 9.886E-02 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8424 atm	* 1.013E+5 Pa/atm 8.534E+04 Pa
ΔP = pressure drop across sample length	6.885 atm	* 1.013E+5 Pa/atm 6.975E+05 Pa
Pm = mean pore pressure (absolute)	5.360 atm	* 1.013E+5 Pa/atm 5.429E+05 Pa
Pe = exit pressure (absolute)	1.917 atm	* 1.013E+5 Pa/atm 1.942E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.00170 cm ³ /s	* 1.0E-6 m ³ /cm ³ 1.704E-09 m ³ /s
ve = flow velocity at sample exit end	9.220E-06 cm/s	* 1.0E-2 m/cm 9.220E-08 m/s
Ka =	8.33E-08 d	* 9.872E-13 m ² /d 8.23E-20 m ²
Ka =	8.33E-05 md	8.23E-16 cm ²
Ka =	8.33E-02 μd	
Pc - Pm = Actual N.E.S.	1450.2 psid	10.00 MPa

Steady State Gas Permeability Data

Project #:	8362	Target Net Eff.Stress:	10 Mpa	1450.4 psid	Gas:	N2
Sample #:	D	Length:	9.886 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.168 cm		Viscosity:	0.0176 cp
Regime #:	1'	Area:	81.201 cm ²			
Pressure Data Filename: 8362DG.S3A						
XDCR calibration factors: Pc = 222.869 psig/volt Pi = 55.4417 psig/volt ΔP = 11.0272 psid/volt Pe = 5.5211 psig/volt						

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
30 Jul 93	15:31	14637	DS3R1'a	12.42 psia	6.758 volts	1.918 volts	9.174 volts		1.048 volts	23	23	0.001578
30 Jul 93	15:37	14642	DS3R1'b	12.42 psia	6.758 volts	1.918 volts	9.174 volts		1.048 volts	23	23	0.001568
30 Jul 93	15:56	14662	DS3R1'c	12.42 psia	6.758 volts	1.918 volts	9.175 volts		1.049 volts	23	23	0.001553
30 Jul 93	16:10	14677	DS3R1'd	12.42 psia	6.758 volts	1.918 volts	9.175 volts		1.050 volts	23	23	0.001544
30 Jul 93	16:16	14682	DS3R1'e	12.42 psia	6.758 volts	1.918 volts	9.175 volts		1.050 volts	23	23	0.001548
AVERAGES			DS3R1'									
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					6.758 volts	1.918 volts	9.175 volts		1.049 volts	23	23	
					1506.1 psig	106.34 psig	101.17 psid	56.38 psig	5.792 psig			
					102.49 atm	7.236 atm	6.884 atm	3.836 atm	0.3941 atm			
				10.385 Mpa	0.7332 Mpa	0.6975 Mpa	0.3887 Mpa	0.03993 Mpa				
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.42 psia	1518.6 psia	118.76 psia	101.17 psid	68.80 psia	18.21 psia	296	296	0.001561
				0.8451 atm	103.33 atm	8.081 atm	6.884 atm	4.681 atm	1.239 atm			
0.08563 Mpa	10.470 Mpa	0.8188 Mpa	0.6975 Mpa	0.4743 Mpa	0.1256 Mpa							

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law:

$$v_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot v_b$$

$$Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$$

$$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	9.886 cm	* 1.0E-2 m/cm 9.886E-02 m
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8451 atm	* 1.013E+5 Pa/atm 8.561E+04 Pa
ΔP = pressure drop across sample length	6.884 atm	* 1.013E+5 Pa/atm 6.974E+05 Pa
Pm = mean pore pressure (absolute)	4.681 atm	* 1.013E+5 Pa/atm 4.742E+05 Pa
Pe = exit pressure (absolute)	1.239 atm	* 1.013E+5 Pa/atm 1.255E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.00156 cm ³ /s	* 1.0E-6 m ³ /cm ³ 1.561E-09 m ³ /s
ve = flow velocity at sample exit end	1.311E-05 cm/s	* 1.0E-2 m/cm 1.311E-07 m/s
Ka =	8.77E-08 d	* 9.872E-13 m ² /d 8.66E-20 m ²
Ka =	8.77E-05 md	8.66E-16 cm ²
Ka =	8.77E-02 μd	
Pc - Pm = Actual N.E.S.	1449.8 psid	10.00 MPa

Steady State Gas Permeability Data									
Project #:	8362	Net Effective Stress:	2 Mpa	290.1 psig	Gas:	N2			
Sample #:	E	Length:	10.358 cm		gas deviation z factors:	ze =	1.0000	zb =	1.0000
Stress Level #:	1	Diameter:	10.175 cm		Viscosity:	0.0176 cp			
Regime #:	1	Area:	81.313 cm^2						
Pressure Data Filename:		8362EG.S1B							
XDCR calibration factors:	Pc =	222.869 psig/volt	Pi =	5.4862 psig/volt	ΔP =	1.6591 psid/volt	Pe =	5.5211 psig/volt	

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
16 Apr 93	11:32	1454	ESIR1a	12.32 psia	1.314 volts	0.729 volts	1.857 volts		0.178 volts	23	22	0.13136
16 Apr 93	11:36	1459	ESIR1b	12.32 psia	1.313 volts	0.729 volts	1.857 volts		0.178 volts	23	22	0.13098
16 Apr 93	11:39	1459	ESIR1c	12.32 psia	1.312 volts	0.729 volts	1.856 volts		0.178 volts	23	22	0.13119
16 Apr 93	11:42	1464	ESIR1d	12.32 psia	1.311 volts	0.729 volts	1.856 volts		0.178 volts	23	22	0.13106
AVERAGES			ESIR1							23	22	
				Absolute	Absolute	Absolute	Differential	Absolute	Absolute	(°K)	(°K)	(ml/sec)
				12.32 psia	304.8 psia	16.32 psia	3.080 psid	14.84 psia	13.30 psia			
				0.8383 atm	20.74 atm	1.110 atm	0.2096 atm	1.010 atm	0.9052 atm	296	295	0.13115
				0.08494 Mpa	2.102 Mpa	0.1125 Mpa	0.02124 Mpa	0.1023 Mpa	0.09172 Mpa			

Boyle's Law: $V_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * V_b$
 $Q_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * Q_b$

$$v_e = Q_e/A = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * (Q_b/A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	$\bullet$ $1.0\text{E-}3$ Pa*sec/cp $1.760\text{E-}05$ Pa*sec
L = sample length	10.358 cm	$\bullet$ $1.0\text{E-}2$ m/cm $1.036\text{E-}01$ m
A = sample circular cross sectional area	81.313 cm^2	$\bullet$ $1.0\text{E-}4$ m^2/cm^2 $8.131\text{E-}03$ m^2
Pb = flow measurement basis pressure (absolute)	0.8383 atm	$\bullet$ $1.013\text{E+}5$ Pa/atm $8.492\text{E+}04$ Pa
ΔP = pressure drop across sample length	0.210 atm	$\bullet$ $1.013\text{E+}5$ Pa/atm $2.123\text{E+}04$ Pa
Pm = mean pore pressure (absolute)	1.010 atm	$\bullet$ $1.013\text{E+}5$ Pa/atm $1.023\text{E+}05$ Pa
Pe = exit pressure (absolute)	0.905 atm	$\bullet$ $1.013\text{E+}5$ Pa/atm $9.170\text{E+}04$ Pa
Te = sample temperature (absolute)	296 $^{\circ}\text{K}$	296 $^{\circ}\text{K}$
Tb = flow measurement basis temperature (absolute)	295 $^{\circ}\text{K}$	295 $^{\circ}\text{K}$
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.13115 cm^3/s	$\bullet$ $1.0\text{E-}6$ m^3/cm^3 $1.311\text{E-}07$ m^3/s
ve = flow velocity at sample exit end	1.499 $\text{E-}03$ cm/s	$\bullet$ $1.0\text{E-}2$ m/cm $1.499\text{E-}05$ m/s
Ka =	1.17 $\text{E-}03$ d	$\bullet$ 9.872 $\text{E-}13$ m^2/d $1.15\text{E-}15$ m^2
Ka =	1.17 md	$1.15\text{E-}11$ cm^2
Ka =	1168 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	2 Mpa	290.1 psig	Gas:	N2
Sample #:	E	Length:	10.358 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	1	Diameter:	10.175 cm		Viscosity:	0.0176 cp
Regime #:	2	Area:	81.313 cm ²			
Pressure Data Filename:	8362EG.S1B					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 5.4862 psig/volt	ΔP = 1.6591 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
16 Apr 93	14:15	1618	ES1R2a	12.32 psia	1.355 volts	2.552 volts	1.895 volts		1.979 volts	23	23	0.20356
16 Apr 93	14:18	1618	ES1R2b	12.32 psia	1.355 volts	2.552 volts	1.894 volts		1.978 volts	23	23	0.20274
16 Apr 93	14:19	1623	ES1R2c	12.32 psia	1.355 volts	2.552 volts	1.895 volts		1.978 volts	23	23	0.20202
16 Apr 93	14:22	1623	ES1R2d	12.32 psia	1.354 volts	2.551 volts	1.894 volts		1.977 volts	23	23	0.20192
16 Apr 93	14:23	1628	ES1R2e	12.32 psia	1.353 volts	2.551 volts	1.894 volts		1.977 volts	23	23	0.20202
AVERAGES			ES1R2		GAUGE	GAUGE	DIFFERENTIAL	GAUGE	GAUGE	(°C)	(°C)	
					1.354 volts	2.552 volts	1.894 volts	12.491 psig	10.9196 psig	23	23	
					301.9 psig	14.00 psig	3.143 psid	0.8500 atm	0.74303 atm			
					20.54 atm	0.953 atm	0.2139 atm	0.08612 Mpa	0.075288 Mpa			
					2.081 Mpa	0.0965 Mpa	0.02167 Mpa	ABSOLUTE	ABSOLUTE	(°K)	(°K)	
					12.32 psia	314.2 psia	26.32 psia	24.81 psia	23.24 psia	296	296	0.20256
					0.8383 atm	21.38 atm	1.791 atm	1.688 atm	1.5814 atm			
					0.08494 Mpa	2.166 Mpa	0.1815 Mpa	0.1711 Mpa	0.16023 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.358 cm	* 1.0E-2 m/cm 1.036E-01 m
A = sample circular cross sectional area	81.313 cm ²	* 1.0E-4 m ² /cm ² 8.131E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8383 atm	* 1.013E+5 Pa/atm 8.492E+04 Pa
ΔP = pressure drop across sample length	0.2139 atm	* 1.013E+5 Pa/atm 2.166E+04 Pa
Pm = mean pore pressure (absolute)	1.688 atm	* 1.013E+5 Pa/atm 1.710E+05 Pa
Pe = exit pressure (absolute)	1.581 atm	* 1.013E+5 Pa/atm 1.602E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.20256 cm ³ /s	* 1.0E-6 m ³ /cm ³ 2.026E-07 m ³ /s
ve = flow velocity at sample exit end	1.321E-03 cm/s	* 1.0E-2 m/cm 1.321E-05 m/s
Ka =	1.05E-03 d	* 9.872E-13 m ² /d 1.04E-15 m ²
Ka =	1.05 md	1.04E-11 cm ²
Ka =	1054 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	2 Mpa	290.1 psig	Gas:	N2
Sample #:	E	Length:	10.358 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	1	Diameter:	10.175 cm		Viscosity:	0.0176 cp
Regime #:	3	Area:	81.313 cm ²			
Pressure Data Filename:	8362EG.S1B					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 5.4862 psig/volt	ΔP = 1.6591 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)	
16 Apr 93	16:30	1753	ES1R3a	12.32 psia	1.405 volts	4.377 volts	1.867 volts		3.796 volts	23	23	0.26508	
16 Apr 93	16:34	1753	ES1R3b	12.32 psia	1.405 volts	4.376 volts	1.866 volts		3.794 volts	23	23	0.26438	
16 Apr 93	16:36	1758	ES1R3c	12.32 psia	1.405 volts	4.377 volts	1.869 volts		3.794 volts	23	23	0.26438	
16 Apr 93	16:37	1758	ES1R3d	12.32 psia	1.404 volts	4.377 volts	1.868 volts		3.795 volts	23	23	0.26560	
AVERAGES			ES1R3										
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)		
					1.405 volts	4.377 volts	1.868 volts		3.795 volts	23	23		
					313.1 psig	24.01 psig	3.098 psid	22.500 psig	20.9512 psig				
					21.30 atm	1.634 atm	0.2108 atm	1.5311 atm	1.42564 atm				
					2.159 Mpa	0.1656 Mpa	0.02136 Mpa	0.15513 Mpa	0.144453 Mpa				
					ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
					12.32 psia	325.4 psia	36.33 psia	3.098 psid	34.82 psia	33.27 psia	296	296	0.26486
	0.8383 atm	22.14 atm	2.2472 atm	0.2108 atm	2.369 atm	2.2640 atm							
	0.08494 Mpa	2.244 Mpa	0.2505 Mpa	0.02136 Mpa	0.2401 Mpa	0.22940 Mpa							

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.358 cm	* 1.0E-2 m/cm 1.036E-01 m
A = sample circular cross sectional area	81.313 cm ²	* 1.0E-4 m ² /cm ² 8.131E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8383 atm	* 1.013E+5 Pa/atm 8.492E+04 Pa
ΔP = pressure drop across sample length	0.2108 atm	* 1.013E+5 Pa/atm 2.136E+04 Pa
Pm = mean pore pressure (absolute)	2.369 atm	* 1.013E+5 Pa/atm 2.400E+05 Pa
Pe = exit pressure (absolute)	2.264 atm	* 1.013E+5 Pa/atm 2.293E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.26486 cm ³ /s	* 1.0E-6 m ³ /cm ³ 2.649E-07 m ³ /s
ve = flow velocity at sample exit end	1.206E-03 cm/s	* 1.0E-2 m/cm 1.206E-05 m/s
Ka =	9.97E-04 d	* 9.872E-13 m ² /d 9.84E-16 m ²
Ka =	1.00 md	9.84E-12 cm ²
Ka =	997 μd	

Steady State Gas Permeability Data									
Project #:	8362	Net Effective Stress:	2 Mpa	290.1 psig	Gas:	N2			
Sample #:	E	Length:	10.358 cm		gas deviation z factors:	ze =	1.0000	zb =	1.0000
Stress Level #:	1	Diameter:	10.175 cm		Viscosity:	0.0176 cp			
Regime #:	4	Area:	81.313 cm ²						
Pressure Data Filename:	8362EG.S1B								
XDCR calibration factors:	Pc =	222.869 psig/volt	Pi =	5.4862 psig/volt	ΔP =	1.6591 psid/volt	Pe =	5.5211 psig/volt	

[illegible]

Boyle's Law:

$$Q_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * Q_b$$

$$v_e = O_e/\lambda = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * (O_b/\lambda)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.358 cm	* 1.0E-2 m/cm 1.036E-01 m
A = sample circular cross sectional area	81.313 cm ²	* 1.0E-4 m ² /cm ² 8.131E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8424 atm	* 1.013E+5 Pa/atm 8.534E+04 Pa
ΔP = pressure drop across sample length	0.2025 atm	* 1.013E+5 Pa/atm 2.051E+04 Pa
Pm = mean pore pressure (absolute)	3.046 atm	* 1.013E+5 Pa/atm 3.085E+05 Pa
Pe = exit pressure (absolute)	2.944 atm	* 1.013E+5 Pa/atm 2.983E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.30269 cm ³ /s	* 1.0E-6 m ³ /cm ³ 3.027E-07 m ³ /s
ve = flow velocity at sample exit end	1.065E-03 cm/s	* 1.0E-2 m/cm 1.065E-05 m/s
Ka =	9.27E-04 d	* 9.872E-13 m ² /d 9.15E-16 m ²
Ka =	0.927 md	9.15E-12 cm ²
Ka =	927 ud	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psig	Gas:	N2
Sample #:	E	Length:	10.358 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.175 cm		Viscosity:	0.0176 cp
Regime #:	1	Area:	81.313 cm ²			
Pressure Data Filename:	8362EG.S2A					
XDCR calibration factors:	Pc =	222.869 psig/volt	Pi =	5.4862 psig/volt	ΔP =	1.6591 psid/volt
					Pe =	5.5211 psig/volt

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)		
20 Apr 93	17:05	421	ES2R1a	12.39 psia	3.933 volts	1.403 volts	1.689 volts		0.886 volts	23	23	0.06384		
20 Apr 93	17:14	426	ES2R1b	12.39 psia	3.931 volts	1.403 volts	1.680 volts		0.887 volts	23	23	0.06322		
20 Apr 93	17:15	431	ES2R1c	12.39 psia	3.934 volts	1.402 volts	1.676 volts		0.888 volts	23	23	0.06337		
20 Apr 93	17:20	436	ES2R1d	12.39 psia	3.936 volts	1.402 volts	1.676 volts		0.888 volts	23	23	0.06324		
20 Apr 93	17:22	436	ES2R1e	12.39 psia	3.938 volts	1.402 volts	1.675 volts		0.888 volts	23	23	0.06324		
AVERAGES			ES2R1			GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)		
						3.934 volts	1.402 volts	1.679 volts		0.887 volts	23	23		
						876.9 psig	7.69 psig	2.79 psid	6.29 psig	4.899 psig				
						59.67 atm	0.524 atm	0.190 atm	0.428 atm	0.3334 atm				
						6.046 Mpa	0.0530 Mpa	0.0192 Mpa	0.0434 Mpa	0.03378 Mpa				
						ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
						12.39 psia	889.2 psia	20.08 psia	2.79 psid	18.68 psia	17.29 psia	296	296	0.06342
						0.8431 atm	60.51 atm	1.367 atm	0.190 atm	1.271 atm	1.176 atm			
						0.08543 Mpa	6.131 Mpa	0.1385 Mpa	0.0192 Mpa	0.1288 Mpa	0.1192 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot V_b$
 $Q_e = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot Q_b$

$v_e = Q_e/A = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot (Q_b/A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.358 cm	* 1.0E-2 m/cm 1.036E-01 m
A = sample circular cross sectional area	81.313 cm ²	* 1.0E-4 m ² /cm ² 8.131E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8431 atm	* 1.013E+5 Pa/atm 8.540E+04 Pa
ΔP = pressure drop across sample length	0.190 atm	* 1.013E+5 Pa/atm 1.920E+04 Pa
Pm = mean pore pressure (absolute)	1.271 atm	* 1.013E+5 Pa/atm 1.288E+05 Pa
Pe = exit pressure (absolute)	1.176 atm	* 1.013E+5 Pa/atm 1.192E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.06342 cm ³ /s	* 1.0E-6 m ³ /cm ³ 6.342E-08 m ³ /s
ve = flow velocity at sample exit end	5.589E-04 cm/s	* 1.0E-2 m/cm 5.589E-06 m/s
	Ka =	4.97E-04 d
	Ka =	4.97E-01 md
	Ka =	4.97E+02 μd

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psig	Gas:	N2
Sample #:	E	Length:	10.358 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.175 cm		Viscosity:	0.0176 cp
Regime #:	2	Area:	81.313 cm ²			
Pressure Data Filename:	8362EG.S2A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pl = 5.4862 psig/volt	ΔP = 1.6591 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
21 Apr 93	10:26	1462	ES2R2a	12.36 psia	3.974 volts	3.265 volts	1.891 volts		2.678 volts	23	23	0.09443
21 Apr 93	10:28	1462	ES2R2b	12.36 psia	3.975 volts	3.265 volts	1.890 volts		2.678 volts	23	23	0.09434
21 Apr 93	10:30	1462	ES2R2c	12.36 psia	3.982 volts	3.265 volts	1.890 volts		2.678 volts	23	23	0.09421
21 Apr 93	10:32	1468	ES2R2d	12.36 psia	3.980 volts	3.266 volts	1.890 volts		2.679 volts	23	23	0.09383
21 Apr 93	10:34	1468	ES2R2e	12.36 psia	3.985 volts	3.266 volts	1.890 volts		2.679 volts	23	23	0.09416
AVERAGES			ES2R2									
					GAUGE	GAUGE	DIFFERENTIAL	GAUGE	GAUGE	(°C)	(°C)	
					3.979 volts	3.265 volts	1.890 volts	2.678 volts	23	23		
					886.8 psig	17.91 psig	3.14 psid	16.36 psig			14.788 psig	
					60.35 atm	1.219 atm	0.213 atm	1.113 atm			1.0062 atm	
				6.115 Mpa	0.1235 Mpa	0.0216 Mpa	0.1128 Mpa	0.10196 Mpa				
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.36 psia	899.2 psia	30.27 psia	3.14 psid	28.72 psia	27.15 psia	296	296	0.09420
				0.8410 atm	61.19 atm	2.060 atm	0.213 atm	1.954 atm	1.847 atm			
				0.08522 Mpa	6.200 Mpa	0.2087 Mpa	0.0216 Mpa	0.1980 Mpa	0.1872 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law:

$$v_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot v_b$$

$$Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$$

$$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.358 cm	* 1.0E-2 m/cm 1.036E-01 m
A = sample circular cross sectional area	81.313 cm ²	* 1.0E-4 m ² /cm ² 8.131E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8410 atm	* 1.013E+5 Pa/atm 8.520E+04 Pa
ΔP = pressure drop across sample length	0.213 atm	* 1.013E+5 Pa/atm 2.162E+04 Pa
Pm = mean pore pressure (absolute)	1.954 atm	* 1.013E+5 Pa/atm 1.979E+05 Pa
Pe = exit pressure (absolute)	1.847 atm	* 1.013E+5 Pa/atm 1.871E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.09420 cm ³ /s	* 1.0E-6 m ³ /cm ³ 9.420E-08 m ³ /s
ve = flow velocity at sample exit end	5.275E-04 cm/s	* 1.0E-2 m/cm 5.275E-06 m/s
Ka =	4.26E-04 d	* 9.872E-13 m ² /d 4.21E-16 m ²
Ka =	4.26E-01 md	4.21E-12 cm ²
Ka =	4.26E+02 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psig	Gas:	N2
Sample #:	E	Length:	10.358 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.175 cm		Viscosity:	0.0176 cp
Regime #:	3	Area:	81.313 cm ²			
Pressure Data Filename:	8362EG.S2A					
XDCR calibration factors:	Pc = 222.869 psig/volt	PI = 5.4862 psig/volt	ΔP = 1.6591 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	PI Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
21 Apr 93	14:42	1716	ES2R3a	12.35 psia	4.022 volts	5.078 volts	1.911 volts		4.463 volts	23	23	0.11980
21 Apr 93	14:44	1716	ES2R3b	12.35 psia	4.023 volts	5.078 volts	1.912 volts		4.463 volts	23	23	0.11958
21 Apr 93	14:46	1721	ES2R3c	12.35 psia	4.023 volts	5.078 volts	1.912 volts		4.462 volts	23	23	0.11930
21 Apr 93	14:47	1721	ES2R3d	12.35 psia	4.023 volts	5.077 volts	1.912 volts		4.462 volts	23	23	0.11965
21 Apr 93	14:49	1726	ES2R3e	12.35 psia	4.023 volts	5.077 volts	1.911 volts		4.462 volts	23	23	0.11947
AVERAGES			ES2R3		GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					4.023 volts	5.078 volts	1.912 volts		4.462 volts			
					896.6 psig	27.86 psig	3.17 psid	26.22 psig	24.637 psig	23	23	
					61.01 atm	1.896 atm	0.216 atm	1.784 atm	1.6765 atm			
					6.182 Mpa	0.1921 Mpa	0.0219 Mpa	0.1808 Mpa	0.16987 Mpa			
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.35 psia	908.9 psia	40.21 psia	3.17 psid	38.57 psia	36.99 psia			
				0.8404 atm	61.85 atm	2.736 atm	0.216 atm	2.625 atm	2.517 atm	296	296	
				0.08515 Mpa	6.267 Mpa	0.2772 Mpa	0.0219 Mpa	0.2660 Mpa	0.2550 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law:

$$v_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot v_b$$

$$Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$$

$$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.358 cm	* 1.0E-2 m/cm 1.036E-01 m
A = sample circular cross sectional area	81.313 cm ²	* 1.0E-4 m ² /cm ² 8.131E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8404 atm	* 1.013E+5 Pa/atm 8.513E+04 Pa
ΔP = pressure drop across sample length	0.216 atm	* 1.013E+5 Pa/atm 2.186E+04 Pa
Pm = mean pore pressure (absolute)	2.625 atm	* 1.013E+5 Pa/atm 2.659E+05 Pa
Pe = exit pressure (absolute)	2.517 atm	* 1.013E+5 Pa/atm 2.550E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.11958 cm ³ /s	* 1.0E-6 m ³ /cm ³ 1.196E-07 m ³ /s
ve = flow velocity at sample exit end	4.910E-04 cm/s	* 1.0E-2 m/cm 4.910E-06 m/s
Ka =	3.98E-04 d	* 9.872E-13 m ² /d 3.93E-16 m ²
Ka =	3.98E-01 md	3.93E-12 cm ²
Ka =	3.98E+02 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psig	Gas:	N2
Sample #:	E	Length:	10.358 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.175 cm		Viscosity:	0.0176 cp
Regime #:	4	Area:	81.313 cm ²			
Pressure Data Filename:	8362EG.S2A					
XDCR calibration factors:	Pc = 222.869 psig/volt	PI = 5.4862 psig/volt	AP = 1.6591 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	AP Differential Pressure	Pm Mean Pore Pressure Pe+AP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)									
21 Apr 93	17:01	1716	ES2R4a	12.34 psia	4.068 volts	6.918 volts	1.982 volts		6.255 volts	23	23	0.14981									
21 Apr 93	17:03	1716	ES2R4b	12.34 psia	4.068 volts	6.917 volts	1.985 volts		6.254 volts	23	23	0.15021									
21 Apr 93	17:05	1721	ES2R4c	12.34 psia	4.068 volts	6.917 volts	1.985 volts		6.253 volts	23	23	0.15032									
21 Apr 93	17:07	1721	ES2R4d	12.34 psia	4.068 volts	6.916 volts	1.985 volts		6.253 volts	23	23	0.15026									
AVERAGES			ES2R4																		
													GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)		
													4.068 volts	6.917 volts	1.984 volts		6.254 volts	23	23		
													906.6 psig	37.95 psig	3.29 psid	36.17 psig	34.528 psig				
													61.69 atm	2.582 atm	0.224 atm	2.461 atm	2.3495 atm				
													6.251 Mpa	0.2616 Mpa	0.0227 Mpa	0.2494 Mpa	0.23806 Mpa				
													ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
													12.34 psia	919.0 psia	50.29 psia	3.29 psid	48.51 psia	46.87 psia	296	296	0.15015
													0.8397 atm	62.53 atm	3.422 atm	0.224 atm	3.301 atm	3.189 atm			
													0.08508 Mpa	6.336 Mpa	0.3467 Mpa	0.0227 Mpa	0.3345 Mpa	0.3231 Mpa			

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psig	Gas:	N2
Sample #:	E	Length:	10.358 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.175 cm		Viscosity:	0.0176 cp
Regime #:	1	Area:	81.313 cm ²			
Pressure Data Filename:	8362EG.S3A					
XDCR calibration factors:	Pc = 222.869 psig/volt	PI = 5.4862 psig/volt	ΔP = 1.6591 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
22 Apr 93	14:17	308	ES3R1a	12.20 psia	6.537 volts	1.497 volts	2.038 volts		0.872 volts	23	23	0.04611
22 Apr 93	14:21	313	ES3R1b	12.20 psia	6.536 volts	1.498 volts	2.042 volts		0.871 volts	23	23	0.04595
22 Apr 93	14:26	318	ES3R1c	12.20 psia	6.537 volts	1.498 volts	2.043 volts		0.871 volts	23	23	0.04615
22 Apr 93	14:30	323	ES3R1d	12.20 psia	6.537 volts	1.498 volts	2.044 volts		0.870 volts	23	23	0.04579
22 Apr 93	14:33	323	ES3R1e	12.20 psia	6.536 volts	1.499 volts	2.045 volts		0.871 volts	23	23	0.04575
AVERAGES			ES3R1									
					GAUGE	GAUGE	DIFFERENTIAL	GAUGE	GAUGE	(°C)	(°C)	
					6.537 volts	1.498 volts	2.042 volts		0.871 volts	23	23	
					1456.8 psig	8.22 psig	3.39 psid	6.50 psig	4.809 psig			
					99.13 atm	0.559 atm	0.231 atm	0.443 atm	0.3272 atm			
				10.044 Mpa	0.0567 Mpa	0.0234 Mpa	0.0448 Mpa	0.03316 Mpa				
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.2 psia	1469.0 psia	20.42 psia	3.39 psid	18.70 psia	17.01 psia	296	296	0.04600
				0.8302 atm	99.96 atm	1.389 atm	0.231 atm	1.273 atm	1.157 atm			
0.08412 Mpa	10.128 Mpa	0.1408 Mpa	0.0234 Mpa	0.1290 Mpa	0.1173 Mpa							

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa·sec/cp 1.760E-05 Pa·sec
L = sample length	10.358 cm	* 1.0E-2 m/cm 1.036E-01 m
A = sample circular cross sectional area	81.313 cm ²	* 1.0E-4 m ² /cm ² 8.131E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8302 atm	* 1.013E+5 Pa/atm 8.409E+04 Pa
ΔP = pressure drop across sample length	0.231 atm	* 1.013E+5 Pa/atm 2.336E+04 Pa
Pm = mean pore pressure (absolute)	1.273 atm	* 1.013E+5 Pa/atm 1.289E+05 Pa
Pe = exit pressure (absolute)	1.157 atm	* 1.013E+5 Pa/atm 1.172E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.04600 cm ³ /s	* 1.0E-6 m ³ /cm ³ 4.600E-08 m ³ /s
ve = flow velocity at sample exit end	4.058E-04 cm/s	* 1.0E-2 m/cm 4.058E-06 m/s
Ka =	2.92E-04 d	* 9.872E-13 m ² /d 2.88E-16 m ²
Ka =	2.92E-01 md	2.88E-12 cm ²
Ka =	2.92E+02 μd	

Steady State Gas Permeability Data						
Project #:	0362	Net Effective Stress:	10 Mpa	1450.4 psig	Gas:	N2
Sample #:	E	Length:	10.358 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.175 cm		Viscosity:	0.0176 cp
Regime #:	2	Area:	81.313 cm ²			
Pressure Data Filename:		8362EG.S3A				
XDCR calibration factors:		Pc = 222.869 psig/volt	P1 = 5.4862 psig/volt	AP = 1.6591 psid/volt	Pe = 5.5211 psig/volt	

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pl Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
22 Apr 93	16:57	468	ES3R2a	12.21 psia	6.582 volts	3.274 volts	1.920 volts		2.671 volts	23	23	0.05722
22 Apr 93	17:00	473	ES3R2b	12.21 psia	6.581 volts	3.274 volts	1.921 volts		2.670 volts	23	23	0.05741
22 Apr 93	17:03	473	ES3R2c	12.21 psia	6.581 volts	3.274 volts	1.922 volts		2.670 volts	23	23	0.05727
22 Apr 93	17:06	478	ES3R2d	12.21 psia	6.581 volts	3.274 volts	1.924 volts		2.669 volts	23	23	0.05731
AVERAGES			ES3R2									
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					6.581 volts	3.274 volts	1.922 volts	2.670 volts		23	23	
					1466.8 psig	17.96 psig	3.19 psid	16.34 psig	14.741 psig			
					99.81 atm	1.222 atm	0.217 atm	1.112 atm	1.0031 atm			
					10.113 Mpa	0.1238 Mpa	0.0220 Mpa	0.1126 Mpa	0.10164 Mpa			
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.21 psia	1479.0 psia	30.17 psia	3.19 psid	28.55 psia	26.95 psia			
				0.8308 atm	100.64 atm	2.053 atm	0.217 atm	1.942 atm	1.834 atm	296	296	0.05730
				0.08419 Mpa	10.197 Mpa	0.2080 Mpa	0.0220 Mpa	0.1968 Mpa	0.1858 Mpa			

Boyle's Law: $V_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * V_b$
 $Q_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * Q_b$
 $v_e = Q_e/\lambda = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * (Q_b/\lambda)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.358 cm	* 1.0E-2 m/cm 1.036E-01 m
A = sample circular cross sectional area	81.313 cm ²	* 1.0E-4 m ² /cm ² 8.131E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8308 atm	* 1.013E+5 Pa/atm 8.416E+04 Pa
ΔP = pressure drop across sample length	0.217 atm	* 1.013E+5 Pa/atm 2.198E+04 Pa
Pm = mean pore pressure (absolute)	1.942 atm	* 1.013E+5 Pa/atm 1.968E+05 Pa
Pe = exit pressure (absolute)	1.834 atm	* 1.013E+5 Pa/atm 1.858E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.05730 cm ³ /s	* 1.0E-6 m ³ /cm ³ 5.730E-08 m ³ /s
ve = flow velocity at sample exit end	3.193E-04 cm/s	* 1.0E-2 m/cm 3.193E-06 m/s
Ka =	2.53E-04 d	* 9.872E-13 m ² /d 2.50E-16 m ²
Ka =	2.53E-01 md	2.50E-12 cm ²
Ka =	2.53E+02 ud	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psid	Gas:	N2
Sample #:	E	Length:	10.358 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.175 cm		Viscosity:	0.0176 cp
Regime #:	3	Area:	81.313 cm ²			
Pressure Data Filename:	8362EG.S3A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 5.4862 psig/volt	AP = 1.6591 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	AP Differential Pressure	Pm Mean Pore Pressure Pe+AP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)						
23 Apr 93	10:55	1547	ES3R3a	12.29 psia	6.630 volts	5.118 volts	1.947 volts		4.497 volts	22	23	0.06744						
23 Apr 93	10:57	1552	ES3R3b	12.29 psia	6.631 volts	5.118 volts	1.947 volts		4.497 volts	22	23	0.06749						
23 Apr 93	11:00	1552	ES3R3c	12.29 psia	6.631 volts	5.118 volts	1.948 volts		4.497 volts	22	23	0.06762						
23 Apr 93	11:03	1557	ES3R3d	12.29 psia	6.631 volts	5.119 volts	1.948 volts		4.497 volts	22	23	0.06758						
AVERAGES			ES3R3															
				GUAGE		GUAGE		DIFFERENTIAL		GUAGE		GUAGE		(°C)	(°C)			
				6.631 volts		5.118 volts		1.948 volts		26.44 psig		4.497 volts		22	23			
				1477.8 psig		28.08 psig		3.23 psid		1.799 atm		24.828 psig						
				100.56 atm		1.911 atm		0.220 atm		1.6895 atm								
				10.189 Mpa		0.1936 Mpa		0.0223 Mpa		0.17119 Mpa								
				ABSOLUTE		ABSOLUTE		ABSOLUTE		DIFFERENTIAL		ABSOLUTE		ABSOLUTE		(°K)	(°K)	(ml/sec)
				12.29 psia		1490.1 psia		40.37 psia		3.23 psid		38.73 psia		37.12 psia		295	296	0.06753
				0.8363 atm		101.39 atm		2.747 atm		0.220 atm		2.636 atm		2.526 atm				
0.08474 Mpa		10.274 Mpa		0.2783 Mpa		0.0223 Mpa		0.2671 Mpa		0.2559 Mpa								

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
u = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.358 cm	* 1.0E-2 m/cm 1.036E-01 m
A = sample circular cross sectional area	81.313 cm ²	* 1.0E-4 m ² /cm ² 8.131E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8363 atm	* 1.013E+5 Pa/atm 8.472E+04 Pa
AP = pressure drop across sample length	0.220 atm	* 1.013E+5 Pa/atm 2.227E+04 Pa
Pm = mean pore pressure (absolute)	2.636 atm	* 1.013E+5 Pa/atm 2.670E+05 Pa
Pe = exit pressure (absolute)	2.526 atm	* 1.013E+5 Pa/atm 2.559E+05 Pa
Te = sample temperature (absolute)	295 °K	295 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.06753 cm ³ /s	* 1.0E-6 m ³ /cm ³ 6.753E-08 m ³ /s
ve = flow velocity at sample exit end	2.741E-04 cm/s	* 1.0E-2 m/cm 2.741E-06 m/s
Ka =	2.18E-04 d	* 9.872E-13 m ² /d 2.15E-16 m ²
Ka =	2.18E-01 md	2.15E-12 cm ²
Ka =	2.18E+02 μd	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psid	Gas:	N2
Sample #:	E	Length:	10.358 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.175 cm		Viscosity:	0.0176 cp
Regime #:	4	Area:	81.313 cm ²			
Pressure Data Filename:	8362EG.S3A					
XDCR calibration factors:	Pc =	222.869 psig/volt	Pl =	5.4862 psig/volt	AP =	1.6591 psid/volt
	Pe =	5.5211 psig/volt				

Date	Time of Day	File Time	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pl Inlet Pressure	AP Differential Pressure	Pm Mean Pore Pressure Pe+AP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)	
23 Apr 93	15:04	1793	ES3R4a	12.25 psia	6.673 volts	6.916 volts	1.932 volts		6.270 volts	23	23	0.08035	
23 Apr 93	15:07	1798	ES3R4b	12.25 psia	6.673 volts	6.916 volts	1.933 volts		6.269 volts	23	23	0.08029	
23 Apr 93	15:10	1803	ES3R4c	12.25 psia	6.673 volts	6.916 volts	1.934 volts		6.269 volts	23	23	0.08014	
23 Apr 93	15:12	1803	ES3R4d	12.25 psia	6.673 volts	6.916 volts	1.934 volts		6.269 volts	23	23	0.08040	
AVERAGES			ES3R4										
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)		
					6.673 volts	6.916 volts	1.933 volts		6.269 volts				
					1487.2 psig	37.94 psig	3.21 psid	36.22 psig	34.613 psig	23	23		
					101.20 atm	2.582 atm	0.218 atm	2.464 atm	2.3553 atm				
					10.254 Mpa	0.2616 Mpa	0.0221 Mpa	0.2497 Mpa	0.23865 Mpa				
					ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
					12.25 psia	1499.5 psia	50.19 psia	3.21 psid	48.47 psia	46.86 psia			
					0.8336 atm	102.03 atm	3.415 atm	0.218 atm	3.298 atm	3.189 atm	296	296	0.08030
					0.08446 Mpa	10.338 Mpa	0.3461 Mpa	0.0221 Mpa	0.3342 Mpa	0.3231 Mpa			

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.358 cm	* 1.0E-2 m/cm 1.036E-01 m
A = sample circular cross sectional area	81.313 cm ²	* 1.0E-4 m ² /cm ² 8.131E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8336 atm	* 1.013E+5 Pa/atm 8.444E+04 Pa
AP = pressure drop across sample length	0.218 atm	* 1.013E+5 Pa/atm 2.211E+04 Pa
Pm = mean pore pressure (absolute)	3.298 atm	* 1.013E+5 Pa/atm 3.341E+05 Pa
Pe = exit pressure (absolute)	3.189 atm	* 1.013E+5 Pa/atm 3.230E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.08030 cm ³ /s	* 1.0E-6 m ³ /cm ³ 8.030E-08 m ³ /s
ve = flow velocity at sample exit end	2.581E-04 cm/s	* 1.0E-2 m/cm 2.581E-06 m/s
Ka =	2.08E-04 d	* 9.872E-13 m ² /d 2.06E-16 m ²
Ka =	2.08E-01 md	2.06E-12 cm ²
Ka =	2.08E+02 ud	

Steady State Gas Permeability Data									
Project #:	8362	Net Effective Stress:	2 Mpa	290.1 psid	Gas:	N2			
Sample #:	F	Length:	10.029 cm		gas deviation z factors:	ze =	1.0000	zb =	1.0000
Stress Level #:	1	Diameter:	10.170 cm		Viscosity:	0.0176 cp			
Regime #:	1	Area:	81.233 cm ²						
Pressure Data Filename:	8362FG.S1A								
XDCR calibration factors:	Pc =	222.869	psig/volt	Pi =	55.4417	psig/volt	ΔP =	11.0272	psid/volt
					Pe =	5.5211	psig/volt		

[illegible]

Boyle's Law:

$$Q_e = (Pb/Pe) * (Te/Tb) * (ze/zb) * Q_b$$

$$v_e = Q_e/\lambda = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * (Q_b/\lambda)$$

Parameter	Traditional Units		SI Units
μ = gas viscosity	0.0176 cp	$\bullet$ 1.0E-3 Pa*sec/cp	1.760E-05 Pa*sec
L = sample length	10.029 cm	$\bullet$ 1.0E-2 m/cm	1.003E-01 m
A = sample circular cross sectional area	81.233 cm ²	$\bullet$ 1.0E-4 m ² /cm ²	8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8390 atm	$\bullet$ 1.013E+5 Pa/atm	8.499E+04 Pa
ΔP = pressure drop across sample length	6.416 atm	$\bullet$ 1.013E+5 Pa/atm	6.500E+05 Pa
Pm = mean pore pressure (absolute)	4.451 atm	$\bullet$ 1.013E+5 Pa/atm	4.508E+05 Pa
Pe = exit pressure (absolute)	1.242 atm	$\bullet$ 1.013E+5 Pa/atm	1.259E+05 Pa
Te = sample temperature (absolute)	296 °K		296 °K
Tb = flow measurement basis temperature (absolute)	294 °K		294 °K
ze = gas deviation factor at Pe and Te	1.0000		1.0000
zb = gas deviation factor at Pb and Te	1.0000		1.0000
Qb = flow rate at base conditions	0.02759 cm ³ /s	$\bullet$ 1.0E-6 m ³ /cm ³	2.759E-08 m ³ /s
ve = flow velocity at sample exit end	2.309E-04 cm/s	$\bullet$ 1.0E-2 m/cm	2.309E-06 m/s
Ka =	1.77E-06 d	$\bullet$ 9.872E-13 m ² /d	1.75E-18 m ²
Ka =	1.77E-03 md		1.75E-14 cm ²
Ka =	1.77E+00 μ d		

Steady State Gas Permeability Data									
Project #:	8362	Net Effective Stress:	2 Mpa	290.1 psid	Gas:	N2			
Sample #:	F	Length:	10.029 cm		gas deviation z factors:	ze =	1.0000	zb =	1.0000
Stress Level #:	1	Diameter:	10.170 cm		Viscosity:	0.0176 cp			
Regime #:	2	Area:	81.233 cm ²						
Pressure Data Filename:		8362FG.S1A							
XDCR calibration factors:	Pc =	222.869 psig/volt	Pi =	55.4417 psig/volt	ΔP =	11.0272 psid/volt	Pe =	5.5211 psig/volt	

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
08 Jun 93	11:52	1226	FS1R2a	12.35 psia	1.584 volts	1.985 volts	8.549 volts		2.971 volts	23	21	0.03051
08 Jun 93	11:56	1226	FS1R2b	12.35 psia	1.584 volts	1.985 volts	8.550 volts		2.971 volts	23	21	0.03048
08 Jun 93	12:00	1231	FS1R2c	12.35 psia	1.584 volts	1.985 volts	8.550 volts		2.971 volts	23	21	0.03040
08 Jun 93	12:04	1231	FS1R2d	12.35 psia	1.584 volts	1.985 volts	8.550 volts		2.971 volts	23	21	0.03041
AVERAGES			FS1R2									
				GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)		
				1.584 volts	1.985 volts	8.550 volts		2.971 volts				
				353.0 psig	110.05 psig	94.28 psid	63.54 psig	16.403 psig	23	21		
				24.02 atm	7.489 atm	6.415 atm	4.324 atm	1.1162 atm				
				2.434 Mpa	0.7588 Mpa	0.6500 Mpa	0.4381 Mpa	0.11310 Mpa				
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.35 psia	365.4 psia	122.40 psia	94.28 psid	75.89 psia	28.75 psia			
				0.8404 atm	24.86 atm	8.329 atm	6.415 atm	5.164 atm	1.957 atm	296	294	0.03045
0.08515 Mpa	2.519 Mpa	0.8439 Mpa	0.6500 Mpa	0.5233 Mpa	0.1982 Mpa							

Boyle's Law:

$$V_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * V_b$$

$$Q_e = (Pb/Pe) \cdot (Te/Tb) \cdot (ze/zb) \cdot Q_b$$

$$ve = Qe/\lambda = (Pb/Pe) * (Te/Tb) * (ze/zb) * (Qb/\lambda)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.029 cm	* 1.0E-2 m/cm 1.003E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8404 atm	* 1.013E+5 Pa/atm 8.513E+04 Pa
ΔP = pressure drop across sample length	6.415 atm	* 1.013E+5 Pa/atm 6.499E+05 Pa
Pm = mean pore pressure (absolute)	5.164 atm	* 1.013E+5 Pa/atm 5.231E+05 Pa
Pe = exit pressure (absolute)	1.957 atm	* 1.013E+5 Pa/atm 1.982E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	294 °K	294 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.03045 cm ³ /s	* 1.0E-6 m ³ /cm ³ 3.045E-08 m ³ /s
ve = flow velocity at sample exit end	1.621E-04 cm/s	* 1.0E-2 m/cm 1.621E-06 m/s
Ka =	1.69E-06 d	* 9.872E-13 m ² /d 1.67E-18 m ²
Ka =	1.69E-03 md	1.67E-14 cm ²
Ka =	1.69E+00 μ d	

Steady State Gas Permeability Data									
Project #:	8362	Net Effective Stress:	2 Mpa	290.1 psid	Gas:	N2			
Sample #:	F	Length:	10.029 cm		gas deviation z factors:	ze =	1.0000	zb =	1.0000
Stress Level #:	1	Diameter:	10.170 cm		Viscosity:	0.0176 cp			
Regime #:	4	Area:	81.233 cm^2						
Pressure Data Filename:	8362FG.S1B								
XDCR calibration factors:	Pc =	222.869 psig/volt	Pi =	55.4417 psig/volt	ΔP =	11.0272 psid/volt	Pe =	5.5211 psig/volt	

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
09 Jun 93	09:09	1132	FS1R4a	12.39 psia	1.674 volts	2.333 volts	8.509 volts		6.545 volts	23	21	0.03535
09 Jun 93	09:11	1137	FS1R4b	12.39 psia	1.674 volts	2.333 volts	8.509 volts		6.546 volts	23	21	0.03532
09 Jun 93	09:14	1132	FS1R4c	12.39 psia	1.674 volts	2.333 volts	8.510 volts		6.546 volts	23	21	0.03532
09 Jun 93	09:18	1142	FS1R4d	12.39 psia	1.674 volts	2.333 volts	8.511 volts		6.547 volts	23	21	0.03539
AVERAGES			FS1R4									
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					1.674 volts	2.333 volts	8.510 volts		6.546 volts	23	21	
					373.1 psig	129.35 psig	93.84 psid	83.06 psig	36.141 psig			
					25.39 atm	8.801 atm	6.385 atm	5.652 atm	2.4592 atm			
					2.572 Mpa	0.8918 Mpa	0.6470 Mpa	0.5727 Mpa	0.24918 Mpa			
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.39 psia	385.5 psia	141.74 psia	93.84 psid	95.45 psia	48.53 psia	296	294	0.03535
				0.8431 atm	26.23 atm	9.644 atm	6.385 atm	6.495 atm	3.302 atm			
				0.08543 Mpa	2.658 Mpa	0.9772 Mpa	0.6470 Mpa	0.6581 Mpa	0.3346 Mpa			

Boyle's Law: $V_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * V_b$
 $Q_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * Q_b$
 $v_e = Q_e/A = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * (Q_b/A)$

Parameter	Traditional Units		SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp	1.760E-05 Pa*sec
L = sample length	10.029 cm	* 1.0E-2 m/cm	1.003E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ²	8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8431 atm	* 1.013E+5 Pa/atm	8.540E+04 Pa
ΔP = pressure drop across sample length	6.385 atm	* 1.013E+5 Pa/atm	6.468E+05 Pa
Pm = mean pore pressure (absolute)	6.495 atm	* 1.013E+5 Pa/atm	6.579E+05 Pa
Pe = exit pressure (absolute)	3.302 atm	* 1.013E+5 Pa/atm	3.345E+05 Pa
Te = sample temperature (absolute)	296 °K		296 °K
Tb = flow measurement basis temperature (absolute)	294 °K		294 °K
ze = gas deviation factor at Pe and Te	1.0000		1.0000
zb = gas deviation factor at Pb and Te	1.0000		1.0000
Qb = flow rate at base conditions	0.03535 cm ³ /s	* 1.0E-6 m ³ /cm ³	3.535E-08 m ³ /s
ve = flow velocity at sample exit end	1.118E-04 cm/s	* 1.0E-2 m/cm	1.118E-06 m/s
Ka =	1.57E-06 d	* 9.872E-13 m ² /d	1.55E-18 m ²
Ka =	1.57E-03 md		1.55E-14 cm ²
Ka =	1.57E+00 μ d		

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psid	Gas:	N2
Sample #:	F	Length:	10.029 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.170 cm		Viscosity:	0.0176 cp
Regime #:	1	Area:	81.233 cm ²			
Pressure Data Filename:	8362FG.S2A					
XDCC calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
09 Jun 93	15:20	230	FS2R1a	12.37 psia	4.142 volts	1.806 volts	8.612 volts		1.044 volts	23	22	0.01939
09 Jun 93	15:25	235	FS2R1b	12.37 psia	4.142 volts	1.806 volts	8.613 volts		1.044 volts	23	22	0.01935
09 Jun 93	15:33	240	FS2R1c	12.37 psia	4.142 volts	1.806 volts	8.613 volts		1.044 volts	23	22	0.01939
09 Jun 93	15:38	245	FS2R1d	12.37 psia	4.142 volts	1.806 volts	8.613 volts		1.044 volts	23	22	0.01934
AVERAGES			FS2R1							23	22	
AVERAGES			FS2R1							296	295	0.01937

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.029 cm	* 1.0E-2 m/cm 1.003E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8417 atm	* 1.013E+5 Pa/atm 8.527E+04 Pa
ΔP = pressure drop across sample length	6.463 atm	* 1.013E+5 Pa/atm 6.547E+05 Pa
Pm = mean pore pressure (absolute)	4.465 atm	* 1.013E+5 Pa/atm 4.523E+05 Pa
Pe = exit pressure (absolute)	1.234 atm	* 1.013E+5 Pa/atm 1.250E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.01937 cm ³ /s	* 1.0E-6 m ³ /cm ³ 1.937E-08 m ³ /s
ve = flow velocity at sample exit end	1.632E-04 cm/s	* 1.0E-2 m/cm 1.632E-06 m/s
Ka =	1.23E-06 d	* 9.872E-13 m ² /d 1.22E-18 m ²
Ka =	1.23E-03 md	1.22E-14 cm ²
Ka =	1.23E+00 μd	

C-170

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psid	Gas:	N2
Sample #:	F	Length:	10.029 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.170 cm		Viscosity:	0.0176 cp
Regime #:	2	Area:	81.233 cm ²			
Pressure Data Filename:	8362FG.S2A					
XDCR calibration factors:	Pc =	222.869 psig/volt	Pi =	55.4417 psig/volt	AP =	11.0272 psid/volt
					Pe =	5.5211 psig/volt

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)	
10 Jun 93	09:38	1325	FS2R2a	12.37 psia	4.187 volts	1.986 volts	8.664 volts		2.748 volts	23	22	0.02084	
10 Jun 93	09:45	1335	FS2R2b	12.37 psia	4.187 volts	1.987 volts	8.666 volts		2.748 volts	23	22	0.02094	
10 Jun 93	09:49	1340	FS2R2c	12.37 psia	4.187 volts	1.987 volts	8.666 volts		2.749 volts	23	22	0.02098	
10 Jun 93	09:54	1340	FS2R2d	12.37 psia	4.187 volts	1.987 volts	8.666 volts		2.749 volts	23	22	0.02091	
10 Jun 93	10:00	1345	FS2R2e	12.37 psia	4.187 volts	1.987 volts	8.667 volts		2.749 volts	23	22	0.02092	
AVERAGES			FS2R2		GUAGE		GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)	
					4.187 volts		1.987 volts	8.666 volts	2.749 volts		23	22	
					933.2 psig		110.15 psig	95.56 psid	15.175 psig				
					63.50 atm		7.495 atm	6.502 atm	1.0326 atm				
					6.434 Mpa		0.7595 Mpa	0.6589 Mpa	0.4341 Mpa	0.10463 Mpa			
				ABSOLUTE		ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
				12.37 psia		945.5 psia	122.52 psia	95.56 psid	75.33 psia	27.55 psia	296	295	0.02092
				0.8417 atm		64.34 atm	8.337 atm	6.502 atm	5.126 atm	1.874 atm			
0.08529 Mpa		6.519 Mpa	0.8448 Mpa	0.6589 Mpa	0.5193 Mpa	0.1899 Mpa							

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law:

$$v_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot v_b$$

$$Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$$

$$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.029 cm	* 1.0E-2 m/cm 1.003E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8417 atm	* 1.013E+5 Pa/atm 8.527E+04 Pa
AP = pressure drop across sample length	6.502 atm	* 1.013E+5 Pa/atm 6.587E+05 Pa
Pm = mean pore pressure (absolute)	5.126 atm	* 1.013E+5 Pa/atm 5.192E+05 Pa
Pe = exit pressure (absolute)	1.874 atm	* 1.013E+5 Pa/atm 1.899E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.02092 cm ³ /s	* 1.0E-6 m ³ /cm ³ 2.092E-08 m ³ /s
ve = flow velocity at sample exit end	1.160E-04 cm/s	* 1.0E-2 m/cm 1.160E-06 m/s
Ka =	1.15E-06 d	* 9.872E-13 m ² /d 1.14E-18 m ²
Ka =	1.15E-03 md	1.14E-14 cm ²
Ka =	1.15E+00 μ d	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psid	Gas:	N2
Sample #:	F	Length:	10.029 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	2	Diameter:	10.170 cm		Viscosity:	0.0176 cp
Regime #:	3	Area:	81.233 cm ²			
Pressure Data Filename:	8362FG.S2A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	AP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	AP Differential Pressure	Pm Mean Pore Pressure Pe+AP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)		
10 Jun 93	16:58	1766	FS2R3a	12.32 psia	4.232 volts	2.170 volts	8.610 volts		4.724 volts	23	22	0.02281		
10 Jun 93	17:02	1771	FS2R3b	12.32 psia	4.232 volts	2.170 volts	8.610 volts		4.723 volts	23	22	0.02288		
10 Jun 93	17:06	1776	FS2R3c	12.32 psia	4.232 volts	2.170 volts	8.609 volts		4.724 volts	23	22	0.02290		
10 Jun 93	17:11	1781	FS2R3d	12.32 psia	4.232 volts	2.170 volts	8.610 volts		4.725 volts	23	22	0.02282		
10 Jun 93	17:15	1786	FS2R3e	12.32 psia	4.232 volts	2.170 volts	8.611 volts		4.724 volts	23	22	0.02279		
AVERAGES			FS2R3											
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)			
					4.232 volts	2.170 volts	8.610 volts		4.724 volts	23	22			
					943.2 psig	120.31 psig	94.94 psid	73.55 psig	26.082 psig					
				64.18 atm	8.186 atm	6.461 atm	5.005 atm	1.7747 atm						
				6.503 Mpa	0.8295 Mpa	0.6546 Mpa	0.5071 Mpa	0.17983 Mpa						
				ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)		
12.32 psia	955.5 psia	132.63 psia	94.94 psid	85.87 psia	38.40 psia	296	295	0.02285						
0.8383 atm	65.02 atm	9.025 atm	6.461 atm	5.843 atm	2.613 atm									
0.08494 Mpa	6.588 Mpa	0.9144 Mpa	0.6546 Mpa	0.5921 Mpa	0.2648 Mpa									

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot V_b$
 $Q_e = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot Q_b$

$v_e = Q_e/A = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot (Q_b/A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.029 cm	* 1.0E-2 m/cm 1.003E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8383 atm	* 1.013E+5 Pa/atm 8.492E+04 Pa
AP = pressure drop across sample length	6.461 atm	* 1.013E+5 Pa/atm 6.545E+05 Pa
Pm = mean pore pressure (absolute)	5.843 atm	* 1.013E+5 Pa/atm 5.919E+05 Pa
Pe = exit pressure (absolute)	2.613 atm	* 1.013E+5 Pa/atm 2.647E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.02285 cm ³ /s	* 1.0E-6 m ³ /cm ³ 2.285E-08 m ³ /s
ve = flow velocity at sample exit end	9.055E-05 cm/s	* 1.0E-2 m/cm 9.055E-07 m/s
Ka =	1.11E-06 d	* 9.872E-13 m ² /d 1.09E-18 m ²
Ka =	1.11E-03 md	1.09E-14 cm ²
Ka =	1.11E+00 μ d	

Steady State Gas Permeability Data									
Project #:	8362	Net Effective Stress:	6 Mpa	870.2 psid	Gas:	N2			
Sample #:	F	Length:	10.029 cm		gas deviation z factors:	ze =	1.0000	zb =	1.0000
Stress Level #:	2	Diameter:	10.170 cm		Viscosity:	0.0176 cp			
Regime #:	4	Area:	81.233 cm ²						
Pressure Data Filename:	8362FG.S2A								
XDCR calibration factors:	Pc =	222.869 psig/volt	Pl =	55.4417 psig/volt	ΔP =	11.0272 psid/volt	Pe =	5.5211 psig/volt	

[illegible]

Boyle's Law:

$$V_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * V_b$$

$$Q_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * Q_b$$

$$v_e = Q_e/A = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot (Q_b/A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.029 cm	* 1.0E-2 m/cm 1.003E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8376 atm	* 1.013E+5 Pa/atm 8.485E+04 Pa
ΔP = pressure drop across sample length	6.401 atm	* 1.013E+5 Pa/atm 6.484E+05 Pa
Pm = mean pore pressure (absolute)	6.510 atm	* 1.013E+5 Pa/atm 6.595E+05 Pa
Pe = exit pressure (absolute)	3.310 atm	* 1.013E+5 Pa/atm 3.353E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.02423 cm ³ /s	* 1.0E-6 m ³ /cm ³ 2.423E-08 m ³ /s
ve = flow velocity at sample exit end	7.573E-05 cm/s	* 1.0E-2 m/cm 7.573E-07 m/s
Ka =	1.06E-06 d	* 9.872E-13 m ² /d 1.05E-18 m ²
Ka =	1.06E-03 md	1.05E-14 cm ²
Ka =	1.06E+00 ud	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psid	Gas:	N2
Sample #:	F	Length:	10.029 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.170 cm		Viscosity:	0.0176 cp
Regime #:	1	Area:	81.233 cm ²			
Pressure Data Filename:	8362FG.S3A					
XDCC calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	AP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	AP Differential Pressure	Pm Mean Pore Pressure Pe+AP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)	
11 Jun 93	15:48	387	FS3R1a	12.27 psia	6.746 volts	1.809 volts	8.631 volts		1.044 volts	23	23	0.01690	
11 Jun 93	15:53	392	FS3R1b	12.27 psia	6.747 volts	1.809 volts	8.631 volts		1.044 volts	23	23	0.01696	
11 Jun 93	15:58	397	FS3R1c	12.27 psia	6.747 volts	1.809 volts	8.632 volts		1.044 volts	23	23	0.01695	
11 Jun 93	16:03	402	FS3R1d	12.27 psia	6.747 volts	1.809 volts	8.633 volts		1.043 volts	23	23	0.01692	
AVERAGES			FS3R1										
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)		
					6.747 volts	1.809 volts	8.632 volts		1.044 volts	23	23		
					1503.6 psig	100.29 psig	95.18 psid	53.35 psig	5.763 psig				
					102.32 atm	6.825 atm	6.477 atm	3.631 atm	0.3921 atm				
					10.367 Mpa	0.6915 Mpa	0.6563 Mpa	0.3679 Mpa	0.03973 Mpa				
					ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
					12.27 psia	1515.9 psia	112.56 psia	95.18 psid	65.62 psia	18.03 psia	296	296	0.01693
	0.8349 atm	103.15 atm	7.660 atm	6.477 atm	4.465 atm	1.227 atm							
	0.08460 Mpa	10.452 Mpa	0.7761 Mpa	0.6563 Mpa	0.4525 Mpa	0.1243 Mpa							

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law:

$$v_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot v_b$$

$$Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$$

$$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.029 cm	* 1.0E-2 m/cm 1.003E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8349 atm	* 1.013E+5 Pa/atm 8.458E+04 Pa
AP = pressure drop across sample length	6.477 atm	* 1.013E+5 Pa/atm 6.561E+05 Pa
Pm = mean pore pressure (absolute)	4.465 atm	* 1.013E+5 Pa/atm 4.524E+05 Pa
Pe = exit pressure (absolute)	1.227 atm	* 1.013E+5 Pa/atm 1.243E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.01693 cm ³ /s	* 1.0E-6 m ³ /cm ³ 1.693E-08 m ³ /s
ve = flow velocity at sample exit end	1.418E-04 cm/s	* 1.0E-2 m/cm 1.418E-06 m/s
Ka =	1.06E-06 d	* 9.872E-13 m ² /d 1.05E-18 m ²
Ka =	1.06E-03 md	1.05E-14 cm ²
Ka =	1.06E+00 μ d	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psid	Gas:	N2
Sample #:	F	Length:	10.029 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.170 cm		Viscosity:	0.0176 cp
Regime #:	2	Area:	81.233 cm ²			
Pressure Data Filename:	8362FG.S3A					
XDCR calibration factors:	Pc = 222.869 psig/volt	Pi = 55.4417 psig/volt	ΔP = 11.0272 psid/volt	Pe = 5.5211 psig/volt		

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)
14 Jun 93	09:29	4330	FS3R2a	12.40 psia	6.791 volts	1.986 volts	8.670 volts		2.719 volts	23	22	0.01790
14 Jun 93	09:33	4335	FS3R2b	12.40 psia	6.790 volts	1.986 volts	8.670 volts		2.720 volts	23	22	0.01791
14 Jun 93	09:39	4340	FS3R2c	12.40 psia	6.790 volts	1.986 volts	8.610 volts		2.721 volts	23	22	0.01785
14 Jun 93	09:44	4345	FS3R2d	12.40 psia	6.790 volts	1.986 volts	8.620 volts		2.721 volts	23	22	0.01792
AVERAGES			FS3R2							23	22	
AVERAGES			FS3R2							296	295	0.01789

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot V_b$
 $Q_e = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot Q_b$

$v_e = Q_e / A = (P_b / P_e) \cdot (T_e / T_b) \cdot (z_e / z_b) \cdot (Q_b / A)$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.029 cm	* 1.0E-2 m/cm 1.003E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8438 atm	* 1.013E+5 Pa/atm 8.547E+04 Pa
ΔP = pressure drop across sample length	6.485 atm	* 1.013E+5 Pa/atm 6.569E+05 Pa
Pm = mean pore pressure (absolute)	5.108 atm	* 1.013E+5 Pa/atm 5.175E+05 Pa
Pe = exit pressure (absolute)	1.866 atm	* 1.013E+5 Pa/atm 1.890E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	295 °K	295 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.01789 cm ³ /s	* 1.0E-6 m ³ /cm ³ 1.789E-08 m ³ /s
ve = flow velocity at sample exit end	9.996E-05 cm/s	* 1.0E-2 m/cm 9.996E-07 m/s
Ka =	9.94E-07 d	* 9.872E-13 m ² /d 9.81E-19 m ²
Ka =	9.94E-04 md	9.81E-15 cm ²
Ka =	9.94E-01 μd	

Steady State Gas Permeability Data									
Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psid	Gas:	N2			
Sample #:	F	Length:	10.029 cm		gas deviation z factors:	ze =	1.0000	zb =	1.0000
Stress Level #:	3	Diameter:	10.170 cm		Viscosity:	0.0176 cp			
Regime #:	3	Area:	81.233 cm ²						
Pressure Data Filename:	8362FG.S3A								
XDCR calibration factors:	Pc =	222.869 psig/volt	Pi =	55.4417 psig/volt	ΔP =	11.0272 psid/volt	Pe =	5.5211 psig/volt	

Date	Time of Day	File Time (min)	Regime #	Pb Barometric Pressure	Pc Confining Pressure	Pi Inlet Pressure	ΔP Differential Pressure	Pm Mean Pore Pressure Pe+ΔP/2	Pe Exit Pressure	Te Flow Temp (°C)	Tb Ambient Temp (°C)	Qb Flow Rate @Pb&Tb (ml/sec)	
14 Jun 93	16:17	4737	FS3R3a	12.34 psia	6.835 volts	2.172 volts	8.644 volts		4.662 volts	23	23	0.01961	
14 Jun 93	16:21	4742	FS3R3b	12.34 psia	6.834 volts	2.172 volts	8.644 volts		4.661 volts	23	23	0.01960	
14 Jun 93	16:26	4747	FS3R3c	12.34 psia	6.834 volts	2.172 volts	8.644 volts		4.661 volts	23	23	0.01959	
14 Jun 93	16:31	4752	FS3R3d	12.34 psia	6.835 volts	2.172 volts	8.645 volts		4.661 volts	23	23	0.01959	
AVERAGES			FS3R3										
					GUAGE	GUAGE	DIFFERENTIAL	GUAGE	GUAGE	(°C)	(°C)		
					6.835 volts	2.172 volts	8.644 volts		4.661 volts	23	23		
					1523.2 psig	120.42 psig	95.32 psid	73.40 psig	25.735 psig				
					103.65 atm	8.194 atm	6.486 atm	4.994 atm	1.7512 atm				
					10.502 Mpa	0.8303 Mpa	0.6572 Mpa	0.5060 Mpa	0.17744 Mpa				
					ABSOLUTE	ABSOLUTE	ABSOLUTE	DIFFERENTIAL	ABSOLUTE	ABSOLUTE	(°K)	(°K)	(ml/sec)
					12.34 psia	1535.5 psia	132.76 psia	95.32 psid	85.74 psia	38.08 psia	296	296	0.01960
					0.8397 atm	104.49 atm	9.034 atm	6.486 atm	5.834 atm	2.591 atm			
					0.08508 Mpa	10.587 Mpa	0.9153 Mpa	0.6572 Mpa	0.5911 Mpa	0.2625 Mpa			

Boyle's Law:

$$V_e = (P_b/P_e) * (T_e/T_b) * (Z_e/Z_b) * V_b$$
$$Q_e = (P_b/P_e) * (T_e/T_b) * (Z_e/Z_b) * Q_b$$

$$y_e = Q_e/A = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot (Q_b/A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.029 cm	* 1.0E-2 m/cm 1.003E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8397 atm	* 1.013E+5 Pa/atm 8.506E+04 Pa
ΔP = pressure drop across sample length	6.486 atm	* 1.013E+5 Pa/atm 6.571E+05 Pa
Pm = mean pore pressure (absolute)	5.834 atm	* 1.013E+5 Pa/atm 5.910E+05 Pa
Pe = exit pressure (absolute)	2.591 atm	* 1.013E+5 Pa/atm 2.625E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.01960 cm ³ /s	* 1.0E-6 m ³ /cm ³ 1.960E-08 m ³ /s
ve = flow velocity at sample exit end	7.818E-05 cm/s	* 1.0E-2 m/cm 7.818E-07 m/s
Ka =	9.45E-07 d	* 9.872E-13 m ² /d 9.33E-19 m ²
Ka =	9.45E-04 md	9.33E-15 cm ²
Ka =	9.45E-01 ud	

Steady State Gas Permeability Data

Project #:	8362	Net Effective Stress:	10 Mpa	1450.4 psid	Gas:	N2
Sample #:	F	Length:	10.029 cm		gas deviation z factors:	ze = 1.0000 zb = 1.0000
Stress Level #:	3	Diameter:	10.170 cm		Viscosity:	0.0176 cp
Regime #:	4	Area:	81.233 cm ²			
Pressure Data Filename: 8362PG.S3A						
XDCR calibration factors:	Pc =	222.869 psig/volt	Pi =	55.4417 psig/volt	ΔP =	11.0272 psid/volt
					Pe =	5.5211 psig/volt

[illegible]

Apparent gas permeability: $K_a = (v_e \cdot P_e \cdot u \cdot L) / (P_m \cdot \Delta P)$

Boyle's Law: $V_e = (P_b/P_e) * (T_e/T_b) * (z_e/z_b) * V_b$

$$Q_e = (Pb/Pe) * (Te/Tb) * (ze/zp) * Qb$$
$$v_e = Q_e/A = (P_b/P_e) \cdot (T_e/T_b) \cdot (z_e/z_b) \cdot (Q_b/A)$$

Parameter	Traditional Units	SI Units
μ = gas viscosity	0.0176 cp	* 1.0E-3 Pa*sec/cp 1.760E-05 Pa*sec
L = sample length	10.029 cm	* 1.0E-2 m/cm 1.003E-01 m
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
Pb = flow measurement basis pressure (absolute)	0.8370 atm	* 1.013E+5 Pa/atm 8.478E+04 Pa
ΔP = pressure drop across sample length	6.308 atm	* 1.013E+5 Pa/atm 6.390E+05 Pa
Pm = mean pore pressure (absolute)	6.549 atm	* 1.013E+5 Pa/atm 6.634E+05 Pa
Pe = exit pressure (absolute)	3.395 atm	* 1.013E+5 Pa/atm 3.439E+05 Pa
Te = sample temperature (absolute)	296 °K	296 °K
Tb = flow measurement basis temperature (absolute)	296 °K	296 °K
ze = gas deviation factor at Pe and Te	1.0000	1.0000
zb = gas deviation factor at Pb and Te	1.0000	1.0000
Qb = flow rate at base conditions	0.02061 cm ³ /s	* 1.0E-6 m ³ /cm ³ 2.061E-08 m ³ /s
ve = flow velocity at sample exit end	6.255E-05 cm/s	* 1.0E-2 m/cm 6.255E-07 m/s
Ka =	9.07E-07 d	* 9.872E-13 m ² /d 8.96E-19 m ²
Ka =	9.07E-04 md	8.96E-15 cm ²
Ka =	9.07E-01 μ d	

APPENDIX C-E: Liquid Permeability Spreadsheets

Steady State Liquid Permeability Data									
Project #:	8362	Target Eff.Stress:	2 Mpa	290.1 psid	Fluid:	Odorless Mineral Spirit			
Sample #:	A	Length:	10.117 cm						
Stress Level #:	1	Diameter:	10.170 cm		Viscosity	1.29 cp @ 23 °C			
		Area:	81.233 cm^2						
Pressure Data Filename:		8362AL.S1B							
XDCR calibration factors:		Pc =	222.869 psig/volt		ΔP =	11.0272 psid/volt			

All measurements made at room temperature of ~23 °C and with 0 psig back pressure

Date	Time of Day	Regime #	Pc Confining Pressure			ΔP Differential Pressure			Pm Mean Pore Pressure ΔP/2		Effective Stress Pc-Pm		Volume Increment	Elapsed Time	Q Flow Rate	K Permeability	
			volts	psig	MPa	volts	psid	MPa	psig	MPa	psid	MPa	ml	sec	ml/sec	μd	m ²
16 Aug 93	12:15	AS1a	1.406	313.4	2.160	4.066	44.84	0.3091	22.42	0.1546	290.9	2.006	0.03	250.42	1.1980E-04	6.31	6.23E-18
16 Aug 93	12:21	AS1b	1.402	312.5	2.154	4.047	44.63	0.3077	22.31	0.1538	290.1	2.001	0.03	241.35	1.2430E-04	6.58	6.49E-18
16 Aug 93	14:31	AS1c	1.398	311.6	2.148	3.896	42.96	0.2962	21.48	0.1481	290.1	2.000	0.03	253.38	1.1840E-04	6.51	6.42E-18
16 Aug 93	14:38	AS1d	1.398	311.6	2.148	3.891	42.91	0.2958	21.45	0.1479	290.1	2.000	0.03	232.92	1.2880E-04	7.09	7.00E-18
16 Aug 93	14:47	AS1e	1.398	311.6	2.148	3.922	43.25	0.2982	21.62	0.1491	289.9	1.999	0.03	228.83	1.3110E-04	7.16	7.07E-18
16 Aug 93	14:50	AS1f	1.398	311.6	2.148	3.926	43.29	0.2985	21.65	0.1492	289.9	1.999	0.03	228.66	1.3120E-04	7.16	7.06E-18
16 Aug 93	14:54	AS1g	1.400	312.0	2.151	3.918	43.20	0.2979	21.60	0.1489	290.4	2.002	0.03	227.10	1.3210E-04	7.22	7.13E-18
16 Aug 93	15:02	AS1h	1.400	312.0	2.151	3.910	43.12	0.2973	21.56	0.1486	290.5	2.003	0.03	268.58	1.1170E-04	6.12	6.04E-18
16 Aug 93	15:04	AS1i	1.400	312.0	2.151	3.912	43.14	0.2974	21.57	0.1487	290.4	2.003	0.03	248.96	1.2050E-04	6.60	6.51E-18
AVERAGES		AS1		312.0	2.151		43.48	0.2998	21.74	0.1499	290.3	2.001			1.2421E-04	6.75	6.66E-18

Darcy's law: $K = (Q \cdot \mu \cdot L) / (\Delta P \cdot A)$

Parameter	Traditional Units	SI Units
Q = volumetric flow rate across A	1.242E-04 cm ³ /s	* 1.0E-6 m ³ /cm ³ 1.242E-10 m ³ /s
μ = fluid viscosity	1.29 cp	* 1.0E-3 Pa*sec/cp 1.29E-03 Pa*sec
L = sample length	10.117 cm	* 1.0E-2 m/cm 1.012E-01 m
ΔP = pressure drop across sample length	2.959 atm	* 1.013E+5 Pa/atm 2.997E+05 Pa
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
K = specific permeability	6.74E-06 d	6.66E-18 m ²
	6.74E-03 md	
	6.74E+00 μd	

Steady State Liquid Permeability Data									
Project #:	8362	Target Eff.Stress:	6 Mpa	870.2 psid	Fluid:	Odorless Mineral Spirit			
Sample #:	A	Length:	10.117 cm						
Stress Level #:	2	Diameter:	10.170 cm		Viscosity	1.29 cp @ 23 °C			
		Area:	81.233 cm^2						
Pressure Data Filename:	8362AL.S2A								
XDCR calibration factors:	Pc =	222.869 psig/volt			ΔP =	11.0272 psid/volt			

All measurements made at room temperature of 23 °C and with 0 psig back pressure

Date	Time of Day	Regime #	Pc Confining Pressure			ΔP Differential Pressure			Pm Mean Pore Pressure ΔP/2		Effective Stress Pc-Pm		Volume Increment	Elapsed Time	Q Flow Rate	K Permeability	
			volts	psig	MPa	volts	psid	MPa	psig	MPa	psid	MPa	ml	sec	ml/sec	μd	m ²
19 Aug 93	13:24	AS2a	4.007	893.0	6.157	4.094	45.15	0.3113	22.57	0.1556	870.5	6.002	0.10	951.27	1.0512E-04	5.50	5.43E-18
19 Aug 93	13:46	AS2b	4.007	893.0	6.157	4.114	45.37	0.3128	22.68	0.1564	870.4	6.001	0.06	553.56	1.0839E-04	5.64	5.57E-18
19 Aug 93	14:19	AS2c	4.007	893.0	6.157	4.087	45.07	0.3107	22.53	0.1554	870.5	6.002	0.07	671.94	1.0418E-04	5.46	5.39E-18
19 Aug 93	14:51	AS2d	4.007	893.0	6.157	4.047	44.63	0.3077	22.31	0.1538	870.7	6.003	0.10	854.49	1.1703E-04	6.19	6.11E-18
19 Aug 93	15:19	AS2e	4.007	893.0	6.157	4.016	44.29	0.3053	22.14	0.1527	870.9	6.005	0.10	890.20	1.1233E-04	5.99	5.91E-18
AVERAGES				893.0	6.157		44.90	0.3096	22.45	0.1548	870.6	6.002			1.0941E-04	5.76	5.68E-18

Darcy's law: $K = (Q \cdot \mu \cdot L) / (\Delta P \cdot A)$

Parameter	Traditional Units	SI Units
Q = volumetric flow rate across A	1.094E-04 cm ³ /s	• 1.0E-6 m ³ /cm ³ 1.094E-10 m ³ /s
μ = fluid viscosity	1.29 cp	• 1.0E-3 Pa*sec/cp 1.29E-03 Pa*sec
L = sample length	10.117 cm	• 1.0E-2 m/cm 1.012E-01 m
ΔP = pressure drop across sample length	3.055 atm	• 1.013E+5 Pa/atm 3.095E+05 Pa
A = sample circular cross sectional area	81.233 cm ²	• 1.0E-4 m ² /cm ² 8.123E-03 m ²
K = specific permeability	5.75E-06 d	5.68E-18 m ²
	5.75E-03 md	
	5.75E+00 μd	

Steady State Liquid Permeability Data				
Project #:	8362	Target Eff.Stress:	10 MPa 1450.4 psid	Fluid: Odorless Mineral Spirit
Sample #:	A	Length:	10.117 cm	
Stress Level #:	3	Diameter:	10.170 cm	Viscosity 1.29 cp @ 23 °C
		Area:	81.233 cm ²	
Pressure Data Filename: 8362AL.S3A				
XDCR calibration factors: Pc = 222.869 psig/volt ΔP = 11.0272 psid/volt				

All measurements made at room temperature of ~23 °C and with 0 psig back pressure

Date	Time of Day	Regime #	Pc Confining Pressure			ΔP Differential Pressure			Pm Mean Pore Pressure ΔP/2		Effective Stress Pc-Pm		Volume Increment	Elapsed Time	Q Flow Rate	K Permeability	
			volts	psig	MPa	volts	psid	MPa	psig	MPa	psid	MPa	ml	sec	ml/sec	μd	m ²
20 Aug 93	14:25	AS3a	6.602	1471.4	10.145	3.780	41.68	0.2874	20.84	0.1437	1450.5	10.001	0.08	874.99	9.1430E-05	5.18	5.11E-18
20 Aug 93	14:57	AS3b	6.604	1471.8	10.148	3.764	41.51	0.2862	20.75	0.1431	1451.1	10.005	0.10	1033.84	9.6727E-05	5.50	5.43E-18
20 Aug 93	15:48	AS3c	6.602	1471.4	10.145	3.743	41.27	0.2846	20.64	0.1423	1450.7	10.003	0.08	892.20	8.9666E-05	5.13	5.06E-18
20 Aug 93	16:18	AS3d	6.602	1471.4	10.145	3.715	40.97	0.2825	20.48	0.1412	1450.9	10.004	0.10	1052.49	9.5013E-05	5.48	5.41E-18
20 Aug 93	17:13	AS3e	6.600	1470.9	10.142	3.668	40.45	0.2789	20.22	0.1394	1450.7	10.002	0.09	948.18	9.4919E-05	5.54	5.47E-18
AVERAGES				1471.4	10.145		41.18	0.2839	20.59	0.1419	1450.8	10.003			9.3551E-05	5.37	5.30E-18

Darcy's law: $K = (Q \cdot \mu \cdot L) / (\Delta P \cdot A)$

Parameter	Traditional Units	SI Units
Q = volumetric flow rate accross A	9.355E-05 cm ³ /s	* 1.0E-6 m ³ /cm ³ 9.355E-11 m ³ /s
μ = fluid viscosity	1.29 cp	* 1.0E-3 Pa*sec/cp 1.29E-03 Pa*sec
L = sample length	10.117 cm	* 1.0E-2 m/cm 1.012E-01 m
ΔP = pressure drop across sample length	2.802 atm	* 1.013E+5 Pa/atm 2.838E+05 Pa
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
K = specific permeability	5.36E-06 d	5.30E-18 m ²
	5.36E-03 md	
	5.36E+00 μd	

Steady State Liquid Permeability Data				
Project #:	8362	Target Eff.Stress:	2 Mpa	290.1 psid
Sample #:	C	Length:	10.043 cm	
Stress Level #:	1	Diameter:	10.168 cm	Viscosity 1.29 cp @ 23 °C
		Area:	81.201 cm ²	
Pressure Data Filename: 8362CL.S1B				
XDCR calibration factors: Pc = 222.869 psig/volt ΔP = 11.0272 psid/volt				

All measurements made at room temperature of ~23 °C and with 0 psig back pressure

Date	Time of Day	Regime #	Pc Confining Pressure			ΔP Differential Pressure			Pm Mean Pore Pressure ΔP/2		Effective Stress Pc-Pm		Volume Increment	Elapsed Time	Q Flow Rate	K Permeability	
			volts	psig	MPa	volts	psid	MPa	psig	MPa	psid	MPa	ml	sec	ml/sec	μd	m ²
28 Aug 93	14:22	CS1a	1.430	318.7	2.197	5.303	58.48	0.4032	29.24	0.2016	289.5	1.996	0.09	968.22	9.2954E-05	3.73	3.68E-18
28 Aug 93	14:49	CS1b	1.431	318.9	2.199	5.311	58.57	0.4038	29.28	0.2019	289.6	1.997	0.10	1090.49	9.1702E-05	3.67	3.62E-18
28 Aug 93	15:24	CS1c	1.437	320.3	2.208	5.191	57.24	0.3947	28.62	0.1973	291.6	2.011	0.09	1007.17	8.9359E-05	3.66	3.61E-18
28 Aug 93	15:58	CS1d	1.432	319.1	2.200	5.033	55.50	0.3827	27.75	0.1913	291.4	2.009	0.09	1065.45	8.4471E-05	3.57	3.52E-18
28 Aug 93	16:36	CS1e	1.429	318.5	2.196	4.792	52.84	0.3643	26.42	0.1822	292.1	2.014	0.09	1095.34	8.2166E-05	3.65	3.60E-18
AVERAGES				319.1	2.200		56.53	0.3897	28.26	0.1949	290.8	2.005			8.8131E-05	3.65	3.61E-18

Darcy's law: $K = (Q \cdot \mu \cdot L) / (\Delta P \cdot A)$

Parameter	Traditional Units	SI Units
Q = volumetric flow rate accross A	8.813E-05 cm ³ /s	* 1.0E-6 m ³ /cm ³ 8.813E-11 m ³ /s
μ = fluid viscosity	1.29 cp	* 1.0E-3 Pa*sec/cp 1.29E-03 Pa*sec
L = sample length	10.043 cm	* 1.0E-2 m/cm 1.004E-01 m
ΔP = pressure drop across sample length	3.846 atm	* 1.013E+5 Pa/atm 3.896E+05 Pa
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
K = specific permeability	3.66E-06 d	3.61E-18 m ²
	3.66E-03 md	
	3.66E+00 μd	

Steady State Liquid Permeability Data																			
Project #:		8362		Target Eff.Stress:		6 Mpa		870.2 psid		Fluid:		Odorless Mineral Spirit							
Sample #:		C		Length:		10.043		cm											
Stress Level #:		2		Diameter:		10.168		cm		Viscosity		1.29 cp @ 23 °C							
				Area:		81.201		cm^2											
Pressure Data Filename:														8362CL.S2A					
XDCR calibration factors: Pc =										222.869		psig/volt		ΔP =		11.0272		psid/volt	

All measurements made at room temperature of ~23 °C and with 0 psig back pressure

Date	Time of Day	Regime #	Pc Confining Pressure			ΔP Differential Pressure			Pm Mean Pore Pressure ΔP/2		Effective Stress Pc-Pm		Volume Increment ml	Elapsed Time sec	Q Flow Rate ml/sec	K Permeability	
			volts	psig	MPa	volts	psid	MPa	psig	MPa	psid	MPa				μd	m ²
29 Aug 93	15:07	CS2a	4.017	895.3	6.173	4.611	50.85	0.3506	25.42	0.1753	869.8	5.997	0.06	1141.38	5.2568E-05	2.42	2.39E-18
29 Aug 93	16:01	CS2b	4.017	895.3	6.173	4.568	50.37	0.3473	25.19	0.1737	870.1	5.999	0.08	1561.78	5.1224E-05	2.38	2.35E-18
29 Aug 93	17:11	CS2c	4.017	895.3	6.173	4.539	50.05	0.3451	25.03	0.1725	870.2	6.000	0.10	1900.76	5.2611E-05	2.46	2.43E-18
30 Aug 93	16:43	CS2d	4.019	895.7	6.176	4.704	51.87	0.3576	25.94	0.1788	869.8	5.997	0.06	1128.34	5.3175E-05	2.40	2.37E-18
30 Aug 93	17:08	CS2e	4.020	895.9	6.177	4.728	52.14	0.3595	26.07	0.1797	869.9	5.998	0.06	1093.75	5.4857E-05	2.47	2.44E-18
AVERAGES				895.5	6.174		51.06	0.3520	25.53	0.1760	870.0	5.998			5.2887E-05	2.43	2.40E-18

Darcy's law: $K = (Q \cdot \mu \cdot L) / (\Delta P \cdot A)$

Parameter	Traditional Units	SI Units
Q = volumetric flow rate accross A	5.289E-05 cm ³ /s	* 1.0E-6 m ³ /cm ³ 5.289E-11 m ³ /s
μ = fluid viscosity	1.29 cp	* 1.0E-3 Pa*sec/cp 1.29E-03 Pa*sec
L = sample length	10.043 cm	* 1.0E-2 m/cm 1.004E-01 m
ΔP = pressure drop across sample length	3.474 atm	* 1.013E+5 Pa/atm 3.519E+05 Pa
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
K = specific permeability	2.43E-06 d	2.40E-18 m ²
	2.43E-03 md	
	2.43E+00 μd	

Steady State Liquid Permeability Data				
Project #:	8362	Target Eff.Stress:	10 Mpa	1450.4 psid
Sample #:	C	Length:	10.043 cm	
Stress Level #:	3	Diameter:	10.168 cm	Viscosity 1.29 cp @ 23 °C
		Area:	81.201 cm ²	
Pressure Data Filename: 8362CL.S3A				
XDCR calibration factors: Pc = 222.869 psig/volt ΔP = 11.0272 psid/volt				

All measurements made at room temperature of ~23 °C and with 0 psig back pressure

Date	Time of Day	Regime #	Pc Confining Pressure			ΔP Differential Pressure			Pm Mean Pore Pressure ΔP/2		Effective Stress Pc-Pm		Volume Increment	Elapsed Time	Q Flow Rate	K Permeability	
			volts	psig	MPa	volts	psid	MPa	psig	MPa	psid	MPa	ml	sec	ml/sec	μd	m ²
01 Sep 93	15:50	CS3a	6.623	1476.1	10.177	4.626	51.01	0.3517	25.51	0.1759	1450.6	10.001	0.08	1968.85	4.0633E-05	1.87	1.84E-18
01 Sep 93	16:25	CS3b	6.624	1476.3	10.179	4.571	50.41	0.3475	25.20	0.1738	1451.1	10.005	0.10	2460.06	4.0649E-05	1.89	1.87E-18
01 Sep 93	17:22	CS3c	6.620	1475.4	10.172	4.537	50.03	0.3449	25.02	0.1725	1450.4	10.000	0.08	2073.88	3.8575E-05	1.81	1.78E-18
01 Sep 93	17:59	CS3d	6.621	1475.6	10.174	4.502	49.64	0.3423	24.82	0.1711	1450.8	10.003	0.08	2080.34	3.8455E-05	1.82	1.79E-18
01 Sep 93	18:40	CS3e	6.618	1474.9	10.169	4.473	49.32	0.3401	24.66	0.1700	1450.3	9.999	0.08	2133.20	3.7502E-05	1.78	1.76E-18
AVERAGES				1475.7	10.174		50.08	0.3453	25.04	0.1727	1450.6	10.002			3.9163E-05	1.83	1.81E-18

Darcy's law: $K = (Q \cdot \mu \cdot L) / (\Delta P \cdot A)$

Parameter	Traditional Units	SI Units
Q = volumetric flow rate accross A	3.916E-05 cm ³ /s	* 1.0E-6 m ³ /cm ³ 3.916E-11 m ³ /s
μ = fluid viscosity	1.29 cp	* 1.0E-3 Pa*sec/cp 1.29E-03 Pa*sec
L = sample length	10.043 cm	* 1.0E-2 m/cm 1.004E-01 m
ΔP = pressure drop across sample length	3.408 atm	* 1.013E+5 Pa/atm 3.452E+05 Pa
A = sample circular cross sectional area	81.201 cm ²	* 1.0E-4 m ² /cm ² 8.120E-03 m ²
K = specific permeability	1.83E-06 d	1.81E-18 m ²
	1.83E-03 md	
	1.83E+00 μd	

Steady State Liquid Permeability Data				
Project #:	8362	Target Eff.Stress:	2 Mpa	290.1 psid
Sample #:	F	Length:	10.029 cm	
Stress Level #:	1	Diameter:	10.170 cm	Viscosity 1.29 cp @ 23 °C
		Area:	81.233 cm ²	
Pressure Data Filename: 8362FL.S1B				
XDCR calibration factors: Pc = 222.663 psig/volt				
AP = 11.0303 psid/volt				

All measurements made at room temperature of ~23 °C and with 0 psig back pressure

Date	Time of Day	Regime #	Pc Confining Pressure			AP Differential Pressure			Pm Mean Pore Pressure ΔP/2		Effective Stress Pc-Pm		Volume Increment	Elapsed Time	Q Flow Rate	K Permeability	
			volts	psig	MPa	volts	psid	MPa	psig	MPa	psid	MPa	ml	sec	ml/sec	μd	m ²
14 Oct 93	13:05	FS1a	1.510	336.2	2.318	8.462	93.34	0.6435	46.67	0.3218	289.6	1.996	0.10	2268.77	4.4077E-05	1.11	1.09E-18
14 Oct 93	13:51	FS1b	1.522	338.9	2.337	8.469	93.42	0.6441	46.71	0.3220	292.2	2.015	0.10	2227.37	4.4896E-05	1.12	1.11E-18
14 Oct 93	14:47	FS1c	1.513	336.9	2.323	8.430	92.99	0.6411	46.49	0.3206	290.4	2.002	0.10	2481.42	4.0300E-05	1.01	1.00E-18
14 Oct 93	16:28	FS1d	1.508	335.8	2.315	8.376	92.39	0.6370	46.19	0.3185	289.6	1.997	0.10	2419.16	4.1337E-05	1.05	1.03E-18
14 Oct 93	17:13	FS1e	1.511	336.4	2.320	8.344	92.04	0.6346	46.02	0.3173	290.4	2.002	0.10	2459.29	4.0662E-05	1.03	1.02E-18
AVERAGES				336.8	2.322		92.83	0.6401	46.42	0.3200	290.4	2.002			4.2254E-05	1.07	1.05E-18

Darcy's law: $K = (Q \cdot \mu \cdot L) / (\Delta P \cdot A)$

Parameter	Traditional Units	SI Units
Q = volumetric flow rate accross A	4.225E-05 cm ³ /s	* 1.0E-6 m ³ /cm ³ 4.225E-11 m ³ /s
μ = fluid viscosity	1.29 cp	* 1.0E-3 Pa*sec/cp 1.29E-03 Pa*sec
L = sample length	10.029 cm	* 1.0E-2 m/cm 1.003E-01 m
ΔP = pressure drop across sample length	6.317 atm	* 1.013E+5 Pa/atm 6.399E+05 Pa
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
K = specific permeability	1.07E-06 d	1.05E-18 m ²
	1.07E-03 md	
	1.07E+00 μd	

Steady State Liquid Permeability Data				
Project #:	8362	Target Eff.Stress:	6 Mpa	870.2 psid
Sample #:	F	Length:	10.029 cm	
Stress Level #:	2	Diameter:	10.170 cm	Viscosity 1.29 cp @ 23 °C
		Area:	81.233 cm ²	
Pressure Data Filename: 8362FL.S2A				
XDCR calibration factors: Pc =			222.663 psig/volt	AP = 11.0303 psid/volt

All measurements made at room temperature of ~23 °C and with 0 psig back pressure

Date	Time of Day	Regime #	Pc Confining Pressure			AP Differential Pressure			Pm Mean Pore Pressure		Effective Stress Pc-Pm		Volume Increment	Elapsed Time	Q Flow Rate	K Permeability	
			volts	psig	MPa	volts	psid	MPa	psig	MPa	psid	MPa	ml	sec	ml/sec	μd	m ²
16 Oct 93	11:59	FS2a	4.119	917.1	6.324	8.367	92.29	0.6363	46.15	0.3182	871.0	6.005	0.09	3705.41	2.4289E-05	0.616	6.08E-19
16 Oct 93	13:05	FS2b	4.121	917.6	6.327	8.551	94.32	0.6503	47.16	0.3252	870.4	6.001	0.08	3230.25	2.4766E-05	0.615	6.07E-19
16 Oct 93	14:02	FS2c	4.123	918.0	6.330	8.564	94.46	0.6513	47.23	0.3257	870.8	6.004	0.09	3557.91	2.5296E-05	0.627	6.19E-19
16 Oct 93	15:05	FS2d	4.124	918.3	6.331	8.560	94.42	0.6510	47.21	0.3255	871.1	6.006	0.07	2719.19	2.5743E-05	0.638	6.30E-19
16 Oct 93	15:55	FS2e	4.123	918.0	6.330	8.552	94.33	0.6504	47.17	0.3252	870.9	6.004	0.06	2392.26	2.5081E-05	0.622	6.14E-19
16 Oct 93	16:39	FS2f	4.121	917.6	6.327	8.549	94.30	0.6502	47.15	0.3251	870.4	6.002	0.06	2406.01	2.4938E-05	0.619	6.11E-19
AVERAGES				917.8	6.328		94.02	0.6482	47.01	0.3241	870.8	6.004			2.5019E-05	0.623	6.15E-19

Darcy's law: $K = (Q \cdot \mu \cdot L) / (\Delta P \cdot A)$

Parameter	Traditional Units	SI Units
Q = volumetric flow rate accross A	2.502E-05 cm ³ /s	* 1.0E-6 m ³ /cm ³ 2.502E-11 m ³ /s
μ = fluid viscosity	1.29 cp	* 1.0E-3 Pa*sec/cp 1.29E-03 Pa*sec
L = sample length	10.029 cm	* 1.0E-2 m/cm 1.003E-01 m
ΔP = pressure drop across sample length	6.398 atm	* 1.013E+5 Pa/atm 6.481E+05 Pa
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
K = specific permeability	6.23E-07 d	6.15E-19 m ²
	6.23E-04 md	
	6.23E-01 μd	

Steady State Liquid Permeability Data				
Project #:	8362	Target Eff.Stress:	10 Mpa	1450.4 psid
Sample #:	F	Length:	10.029 cm	
Stress Level #:	3	Diameter:	10.170 cm	Viscosity 1.29 cp @ 23 °C
		Area:	81.233 cm ²	
Pressure Data Filename: 8362FL.S3A				
XDCR calibration factors: Pc = 222.663 psig/volt				
AP = 11.0303 psid/volt				

All measurements made at room temperature of ~23 °C and with 0 psig back pressure

Date	Time of Day	Regime #	Pc Confining Pressure			AP Differential Pressure			Pm Mean Pore Pressure AP/2		Effective Stress Pc-Pm		Volume Increment	Elapsed Time	Q Flow Rate	K Permeability	
			volts	psig	MPa	volts	psid	MPa	psig	MPa	psid	MPa	ml	sec	ml/sec	μd	m ²
18 Oct 93	13:49	FS3a	6.729	1498.3	10.330	8.551	94.32	0.6503	47.16	0.3252	1451.1	10.005	0.05	2326.95	2.1487E-05	0.533	5.26E-19
18 Oct 93	14:37	FS3b	6.725	1497.4	10.324	8.575	94.58	0.6521	47.29	0.3261	1450.1	9.998	0.08	3757.42	2.1291E-05	0.527	5.20E-19
18 Oct 93	15:44	FS3c	6.729	1498.3	10.330	8.588	94.73	0.6531	47.36	0.3266	1450.9	10.004	0.06	2863.16	2.0956E-05	0.518	5.11E-19
18 Oct 93	16:37	FS3d	6.727	1497.9	10.327	8.592	94.77	0.6534	47.39	0.3267	1450.5	10.001	0.04	1947.66	2.0537E-05	0.507	5.01E-19
19 Oct 93	10:39	FS3e	6.726	1497.6	10.326	8.556	94.38	0.6507	47.19	0.3253	1450.4	10.000	0.08	3976.81	2.0117E-05	0.499	4.93E-19
19 Oct 93	12:05	FS3f	6.732	1499.0	10.335	8.556	94.38	0.6507	47.19	0.3253	1451.8	10.010	0.09	4270.68	2.1074E-05	0.523	5.16E-19
19 Oct 93	13:34	FS3g	6.726	1497.6	10.326	8.576	94.60	0.6522	47.30	0.3261	1450.3	10.000	0.07	3222.61	2.1722E-05	0.537	5.31E-19
AVERAGES				1498.0	10.328		94.54	0.6518	47.27	0.3259	1450.7	10.003			2.1026E-05	0.521	5.14E-19

Darcy's law: $K = (Q \cdot \mu \cdot L) / (\Delta P \cdot A)$

Parameter	Traditional Units	SI Units
Q = volumetric flow rate accross A	2.103E-05 cm ³ /s	* 1.0E-6 m ³ /cm ³ 2.103E-11 m ³ /s
μ = fluid viscosity	1.29 cp	* 1.0E-3 Pa*sec/cp 1.29E-03 Pa*sec
L = sample length	10.029 cm	* 1.0E-2 m/cm 1.003E-01 m
ΔP = pressure drop across sample length	6.433 atm	* 1.013E+5 Pa/atm 6.516E+05 Pa
A = sample circular cross sectional area	81.233 cm ²	* 1.0E-4 m ² /cm ² 8.123E-03 m ²
K = specific permeability	5.21E-07 d	5.14E-19 m ²
	5.21E-04 md	
	5.21E-01 μd	

C-188

Appendix D.
Marker Bed 139 Brine Recipe Documentation

The following information is provided as Appendix D of this document.

Appendix D

Marker Bed 139 Brine Recipe Documentation

Errata Sheet

The following modifications should be made to the reference citations in Appendix D.

Page No.	Change
D-3	the existence of Lab Notebook No. WIPP 04 could not be verified
D-4	the existence of Lab Notebook No. WIPP 02 could not be verified
D-10	the existence of Lab Notebook No. WIPP 04 could not be verified
D-10	the existence of Lab Notebook No. WIPP 02 could not be verified
D-14	the existence of Lab Notebook No. WIPP 04 could not be verified
D-14	the existence of Lab Notebook No. WIPP 02 could not be verified
D-29	the existence of the Chem-Nuclear Geotech reports could not be verified
D-29	Felmy and Weare, 1986 is in Vol. 50, no. 12; copy on file in SWCF as WPO#30421
D-29	copy of Finley et al., 1992 on file in SWCF as WPO#26222
D-30	Harvie and Weare, 1980 is in Vol. 44, no. 7; copy on file in SWCF as WPO#30423
D-30	in Harvie et al, 1984 "Strengths" is plural in the title; paper is in Vol. 48, no. 4; copy on file in SWCF as WPO#30422
D-30	copy of Krumhansl et al., 1991 on file in SWCF as WPO#27786
D-30	copy of McCaffrey et al., 1987 on file in SWCF as WPO#42577
D-30	the existence of the UNC Geotech Analytical Laboratory report could not be verified

Date: 27 March 1993
To: Craig Novak, 6119, and Susan Howarth, 6119
From: *Karen Robinson*
Karen Robinson, 6119
Subject: Status Report on the Preparation of Standard Brines SB-139-A and SB-139-95A

SUMMARY

In February, I prepared 100-mL batches of two synthetic brines. SB-139-A has a composition close to that of an "average" QPB brine and is expected to be saturated with respect to the minerals in Marker Bed 139. SB-139-95A is expected to be slightly undersaturated because the element concentrations are about 95% of those in the first brine. I have calculated the probable compositions of those brines based on the masses of salts used.

I have not yet measured the pH of either brine, but expect to do so by the first week of April. I have not yet confirmed the compositions of the brines by chemical analyses; I hope this will be done in early April.

In the following paragraphs I give some details about the recipes, my procedure, problem areas and recommendations, and what remains to be done.

RECIPES

Craig Novak supplied a recipe for an average QPB brine. Table 1a shows his recipe (amounts of salts needed for 1 liter of brine) as well as the amounts needed for 100 mL of brine (saturated) and the amounts needed for 100 mL of "95%" brine. Table 1b shows the average QPB composition (target composition), the calculated composition based on the "saturated" recipe, and the calculated composition based on the "95%" recipe.

Table 2a shows the masses of salts used (weighed out) for the two brines. Table 2b shows the calculated compositions of those two brines based on the masses of salts used.

PROCEDURE

Detailed notes about my procedure are in my lab notebook (Lab Notebook No. WIPP 04, pp.6-12).

Reagents

Reagent grade salts were used. Some of these (magnesium sulfate, sodium chloride, sodium bromide, and sodium tetraborate) had been dried in the lab oven at 110°C and stored in a desiccator (by S. Yeh or J. Kelly). Others (calcium chloride dihydrate, magnesium chloride hexahydrate, and potassium chloride) were used "as is" from the bottle.

Deionized water from the Barnstead Nanopure A deionizer was used.

Equipment

Reagents were weighed out using the Mettler AE163 balance. The balance was calibrated before use with the internal calibration weight. The calibration was checked with selected standard weights. Details can be found in the balance log book (Lab Notebook No. WIPP 02, p. 24).

Glassware included a 100-mL class-A volumetric flask, glass beakers, and watchglasses.

Plasticware included weighing boats, 125-mL polyethylene bottles, a small plastic funnel, and a teflon stirring rod (which also served as a boiling stick when solutions were heated).

Other equipment included a Thermolyne Nuova 7 stir plate; a Bransonic Ultrasonic bath; a Nalgene hand-operated vacuum pump; a Nalgene filter holder with receiver (Nalge Cat. No. 300-4000); Whatman filter paper (grade 41, size 4.7 cm).

Preparation

In brief, the required amounts of salts were dissolved in deionized water, the volume was adjusted to 100mL in the volumetric flask, and the solution was filtered and transferred to a polyethylene bottle for storage. The step-by-step details for each solution are in Attachment 1.

In practice, preparing saturated and near-saturated solutions is somewhat challenging. Problem areas are discussed below.

PROBLEM AREAS/RECOMMENDATIONS

To prepare a standard solution, one usually dissolves the salt (or salts) in deionized water in a beaker and keeps the volume less than (perhaps half or three-quarters of) the final desired volume. This concentrated solution is then allowed to cool (if necessary) and is transferred quantitatively to the appropriate size volumetric flask. This won't work with a saturated solution. One ends up trying to quantitatively transfer the solution plus the undissolved stuff (a kind of wet slush). Under these conditions it is difficult to be certain that everything was rinsed out of the beaker.

Alternatively, one can put the dry salts directly into the volumetric, add water (a little less than the final desired amount), shake the flask occasionally (to speed mixing), and wait patiently for the salts to dissolve. The problem encountered with the 100-mL volumetric flask was that because of the narrow neck, the salts wouldn't flow freely into the flask; more than 100 mL of water were needed to get all the salts into the flask!

Another problem I noted was that after the volumetric flask was inverted to mix the contents, the brine didn't drain cleanly from the stopper or the neck of the flask. Droplets clung to the neck and eventually salt precipitated out. (The amounts were small and apparently immediately redissolved when the flask was shaken or inverted to mix the contents.) Also, droplets clung to the ground glass stopper, which had to be left ajar to avoid being "cemented" in place.

Recommendation

Attachment 2 gives the procedure that I would try next, if I were asked to prepare another batch.

WORK REMAINING

I still need to measure the pH of the solutions and adjust them to ~6.1 if necessary. I also need to confirm the brine compositions by chemical analysis.

Measurement/Adjustment of pH

I plan to use the Sentron Model 2001 pH System to check the pH of the samples. With this system I can use as little as one drop of solution. This will both conserve the solution and reduce the chance of contamination. If necessary, I'll use reagent grade HCl and NaOH to adjust the pH to ~6.1.

Chemical Analyses

Cations (B, Ca, K, Mg, and Na) will be determined by ICP-MS by Jeff Reich (1824). Anions (Br, Cl, SO₄, and perhaps HCO₃) will be determined by ion chromatography by John Kelly (6119). Fred will pay for the ICP-MS analyses. I will need to dilute the samples to the appropriate concentration ranges for these analyses.

With both of these analytical techniques, the time-consuming (and therefore expensive) part of the procedure is the instrument set-up and calibration. For efficiency, therefore, these brines will be run along with a number of Fred Gelbard's Culebra brines.

I need to do the following: 1) calculate dilutions factors for the SB-139 brines and for Fred's Culebra brines, 2) meet with John to select some of Fred's brines based on the Cl and SO₄ results (John has both the brines and the data), 3) check with Fred to see if he agrees with our selections, 4) check with Jeff Reich to find out when he can do the cation analyses, 5) dilute the samples for cation analyses the morning they will be run, 6) find out when John will be running the IC again, 7) dilute the SB-139 samples for anion analyses.

\karen\misc\sb-139-a.1

copy to: 6119 K. L. Robinson

TABLE 1a: Recipes -- Amounts of Salts Needed

Salt	Amount needed for 1 liter of "saturated" soln (grams)	Amount needed for 100 mL of "saturated" soln (grams)	Amount needed for 100 mL of "95%" solution (grams)
NaHCO ₃	0.00133547	0.000134	0.000127
CaCl ₂ ·2H ₂ O	1.27954	0.12795	0.12156
MgSO ₄	19.92105	1.99210	1.89250
MgCl ₂ ·6H ₂ O	130.606	13.0606	12.4076
KCl	32.395	3.2395	3.0775
NaCl	204.105	20.4105	19.3900
Na ₂ B ₄ O ₇	7.0024	0.70024	0.66523
NaBr	1.87565	0.18756	0.17819

Table 1b: Brine Compositions -- Target and Calculated

Species	Target Comp. Average QPB (mg/L)	Calc'd Comp. "Sat'd" Recipe (mg/L)	Calc'd Comp. "95%" Recipe (mg/L)
HCO ₃	0.970	0.970	0.922
Cl	192171	185391	176121
SO ₄	15898	15898	15103
Na	82315	82315	78199
K	16990	16990	16141
Ca	348.8	348.8	331.4
Mg	19641	19641	18659
B	1505	1505	1430
Br	1457	1457	1384

TABLE 2a: Actual Amounts of Salts Used (Weighed Out)

Salt	Amount used for 100 mL of "saturated" soln (grams)	Amount used for 100 mL of "95%" solution (grams)
NaHCO ₃	0*	0*
CaCl ₂ ·2H ₂ O	0.1284	0.1218
MgSO ₄	1.9921	1.8907
MgCl ₂ ·6H ₂ O	13.0605	12.4072
KCl	3.2412	3.0783
NaCl	20.4109	19.3903
Na ₂ B ₄ O ₇	0.7027	0.66574
NaBr	0.1875	0.1789

* don't have appropriate equipment to accurately measure 0.00013 g of a salt.

Table 2b: Calculated Brine Compositions*

Species	SB-139-A ("Sat'd" Recipe) (mg/L)	SB-139-95A ("95%" Recipe) (mg/L)
HCO ₃	-**	-**
Cl	185390	176120
SO ₄	15890	15080
Na	82320	78200
K	17000	16140
Ca	350	330
Mg	19640	18660
B	1510	1430
Br	1460	1390

* concentrations rounded to nearest 10 mg/L.

** probably equilibrated with atmosphere.

ATTACHMENT 1: Preparation of SB-139-A and SB-139-95A (aka "Dear Diary")

Preparation of SB-139-A

- 02/04/93: Weighed Na₂B₄O₇. Transferred quantitatively to 150 mL beaker with DI water; adjusted volume to ~50 mL; placed in ultrasonic bath ~30 min.
- 02/05/93: Na₂B₄O₇ dissolved overnight. Transferred solution to 100-mL vol. flask. Weighed other salts (CaCl₂·2H₂O, MgCl₂·6H₂O, KCl, NaBr, MgSO₄, NaCl) and transferred to vol. flask. Salts wouldn't dissolve (flask too full to mix and volume >100 mL), so transferred contents of flask to 250-mL beaker and adjusted volume to ~200 mL. Covered with evaporating watchglass and heated gently to dissolve salts. Salts dissolved in ~30 min. Removed watchglass and continued heating to reduce volume. Left covered overnight (not on hot plate).
- 02/08/93: Continued evaporating, uncovered, on hot plate. Reduced volume to ~100 mL. Removed from heat; rinsed walls of beaker with a few mLs of DI water. Left covered overnight.
- 02/09/93: Continued evaporating, uncovered, on hot plate. Reduced volume to ~75 mL (solution plus precipitates). Removed from heat; rinsed walls of beaker with a few mLs of DI water. Left to cool, covered. Transferred contents of beaker to 100-mL vol. flask. A thin cloudy residue remained in the bottom of the beaker. (It wouldn't rinse out, but scrubbed out easily with Alconox and a bottle brush.) Diluted contents of vol. flask to ~99 mL. Left stoppered overnight.
- 02/10/93: Significant quantity of undissolved salt in flask. Inverted several times to mix. Added DI water to within ~2 mm of mark on flask.
- 02/16/93: Salts appeared dissolved but solution was cloudy. Diluted to mark. Inverted to mix. Cleaned 125-mL poly. bottle by soaking in DI water for ~3 hrs. Left to air-dry overnight.
- 02/17/93: Filtered solution through Whatman 41 filter paper. Transferred to clean, dry poly. bottle. Labelled "SB-139-A"; dated 2/17/93.

Preparation of SB-139-95A

- 02/17/93: Weighed Na₂B₄O₇. Transferred quantitatively to 150 mL beaker with DI water; adjusted volume to ~50 mL. Left covered with watch glass.
- 02/18/93: Na₂B₄O₇ dissolved overnight. Weighed other salts (CaCl₂·2H₂O, MgCl₂·6H₂O, KCl, NaBr, MgSO₄, NaCl) and transferred to beaker with Na₂B₄O₇ solution. Put on hot plate to reduce volume to ~80 mL. Rinsed beaker walls with a few mL of DI water. Left covered overnight (not on hot plate).
- 02/19/93: Transferred contents of beaker to 100-mL vol. flask. (Spilled a few mL of the final rinse water -- shouldn't measurably affect final concentrations.) Diluted almost to mark (~5 mm below line). Shook to mix.
- 02/22/93: Small amount of salt remained undissolved. Added a little more DI water.
- 02/23/93: Everything dissolved. Diluted to mark. Mixed. Filtered through Whatman 41 filter paper. Transferred to clean, dry poly. bottle. Labelled "SB-139-95A"; dated 2/23/93.

ATTACHMENT 2: Recommendation

If I were to prepare another batch I would try the following:

- Prepare a larger batch (500 mL or 1 L). This allows the use of a flask with a wider neck.
- Be sure the volumetric flask is clean and dry.
- Transfer the salts to the flask. Use a powder funnel (wide stem) and, if needed, a teflon stirring rod. Save the weighing containers (boats or whatever the salts were in) but don't rinse them yet.
- After all the salts have been transferred (except for the small amounts of residue in the weighing containers), rinse the stirring rod, then the weighing containers, and finally the funnel with deionized water. All rinse water should go into the flask. This ensures that the salts were transferred quantitatively.
- Add deionized water to the flask to just below the neck. Mix the contents by gently swirling the flask (don't invert to mix). Wait patiently for salts to dissolve, swirling occasionally (every half-hour or so during the day).
- When no more salts appear to dissolve (probably after a day or two), add deionized water to within 1 or 2 cm of the mark on the neck of the flask. Mix by tipping the flask. Avoid allowing the solution to touch the stopper. The stopper will not drain completely and is likely to get "cemented" in place by tiny salt crystals.
- Eventually, everything should dissolve (this could take several days). At this point, adjust to the final volume with deionized water, mix the solution thoroughly by inverting the flask, and transfer the solution immediately to a clean, dry plastic bottle.

If this doesn't work, I have some other ideas to try.

Date: 07 June 1993
To: Susan Howarth, 6119
Karen Robinson
From: Karen Robinson, 6119
Subject: Preparation of Standard Brine SB-139-95B

SUMMARY

This memo describes the preparation of the standard brine SB-139-95B. I am giving quite a bit of detail in case you want to use this to generate a brine-preparation procedure for future use. In brief, I prepared 1 liter of brine, adjusted the pH to ~6.1 with HCl, and split the brine into two 500-mL lots. You sent one bottle to Chem Nuclear Geotech for analysis; the other bottle is being stored in 823/2079.

RECIPE

Craig Novak supplied a recipe for an average QPB brine, a brine expected to be saturated with respect to the minerals in Marker Bed 139. The brine described here is slightly undersaturated and contains 95% of the salts recommended by Craig.

Table 1a shows the "95%" recipe and the amounts of salts actually weighed out. Table 1b shows the calculated composition based on the "95%" recipe and the calculated composition based on the amounts of salts actually weighed out.

PROCEDURE

Detailed notes about the preparation are in my lab notebook (Lab Notebook No. WIPP 04, pp.21-23); those notes are summarized in Attachment 1.

Reagents

Reagent grade salts were used. All salts were used "as is" from the bottle (that is, they were not dried in the lab oven).

Deionized water from the Barnstead Nanopure A deionizer was used.

Standard pH buffer solutions were prepared from pHDrion buffer capsules.

Trace-metal grade hydrochloric acid was used to adjust the pH.

Equipment

Reagents were weighed out using the Mettler AE163 balance. The balance was calibrated before use with the internal calibration weight. The calibration was checked with selected standard weights. Details can be found in the balance log book (Lab Notebook No. WIPP 02, p. 25).

Glassware included a 1000-mL class-A volumetric flask and a powder funnel.

Plasticware included weighing boats, 500-mL polyethylene bottles, various plastic beakers, and a teflon stirring rod.

Other equipment included a Thermolyne Nuova 7 stir plate; a magnetic stir bar and stir-bar retriever; and a Sentron model 2001 pH system (meter and probe).

Preparation

In brief, the required amounts of salts were dissolved in deionized water in the volumetric flask; dissolution was speeded by using the magnetic stirrer. The volume was adjusted to 1000 mL in the volumetric flask. The pH was then adjusted by adding ~4 mL of HCl. The solution was then transferred to two 500-mL polyethylene bottles. The step-by-step details are in Attachment 1.

Note that although the final volume of the solution was ~1004 mL (after the pH was adjusted), I used a volume of 1000 mL to calculate the concentrations of the solutes.

WORK REMAINING

As we discussed, I will also prepare one liter of the "saturated" recipe. This work has been delayed somewhat because there wasn't enough NaCl in the lab. More was ordered and has recently arrived. I expect to have the brine prepared and the memo documenting its preparation written by Friday, June 18.

\karen\misc\s-b-139-b.1

copy to: 6119 C. F. Novak
6119 K. L. Robinson

TABLE 1a: Recipes -- Amounts of Salts Needed and Weighed Out

Salt	Amount needed for 1 liter of "95%" soln (grams)	Amount weighed out for SB-139-95B (grams)
NaHCO ₃	0.00127	*
CaCl ₂ ·2H ₂ O	1.2156	1.2144
MgSO ₄	18.9250	18.9238
MgCl ₂ ·6H ₂ O	124.076	124.0775
KCl	30.7753	30.7727
NaCl	193.8998	193.8973
Na ₂ B ₄ O ₇	6.6523	6.6519
NaBr	1.7819	1.7837

* Don't have appropriate equipment to accurately measure 0.00127 g of a salt.

Table 1b: Brine Compositions -- Target and Calculated

Species	Calc'd Comp. "95%" Recipe (mg/L)	Calc'd Comp SB-139-95B* (mg/L)
HCO ₃	0.922	**
Cl	176106	176100
SO ₄	15103	15100
Na	78198	78200
K	16141	16140
Ca	331	330
Mg	18657	18660
B	1430	1430
Br	1384	1390

* Concentrations rounded to nearest 10 mg/L.

** Probably equilibrated with atmosphere.

ATTACHMENT 1: Preparation of SB-139-95B

- 04/30/93: Put ~200 mL deionized water and small magnetic stir bar into 1000-mL volumetric flask.
Weighed Na₂B₄O₇; transferred quantitatively to vol. flask.
Began stirring. Stirred for ~3 hrs. Left standing over weekend.
Weighed other salts (CaCl₂·2H₂O, MgCl₂·6H₂O, KCl, NaCl, MgSO₄, NaBr) into plastic beakers. Covered with parafilm.
- 05/03/93: Resumed stirring.
Quantitatively transferred chloride salts (CaCl₂·2H₂O, MgCl₂·2H₂O, KCl, NaCl) to vol. flask.
Added deionized water to fill flask ~two-thirds.
Stirred ~2 hrs.
Quantitatively transferred remaining salts (MgSO₄, NaBr) to vol. flask.
Continued stirring. At end of work day turned off stirrer and left to stand overnight.
- 05/04/93: Removed stir bar with magnetic stir-bar retriever. Rinsed with deionized water, adding all rinse water to flask.
Diluted with deionized water to volume and inverted to mix thoroughly.
Calibrated pH system with standard buffers 7 and 4. Checked calibration with standard buffer 6.4.
Measured initial pH of solution as 7.0.
Alternately added aliquots of HCl, mixed the solution by inverting the vol. flask, and checked the pH of the solution. After ~4 mL of HCl were added (in 6 unequal increments) the pH of the solution was 6.14.
The final volume of the solution was ~1004 mL. Note that concentrations of solutes were calculated using a volume of 1000 mL. The solution was transferred to two 500-mL polyethylene bottles. One was given to S. Howarth for shipping to ChemNuclear Geotech for chemical analysis. The other is currently stored in 823/2079.

Date: 18 June 1993
To: Susan Howarth, 6119
Karen Robinson
From: Karen Robinson, 6119
Subject: Preparation of Standard Brine SB-139-B

SUMMARY

This memo describes the preparation of the standard brine SB-139-B. I am giving quite a bit of detail in case you want to use this to generate a brine-preparation procedure for future use. In brief, I prepared 1 liter of brine, adjusted the pH to ~6.1 with HCl, and split the brine into two 500-mL lots. I am giving one bottle to you for possible shipment to Chem Nuclear Geotech for analysis; the other bottle is being stored in 823/2079.

RECIPE

Craig Novak supplied a recipe for an average QPB brine, a brine expected to be saturated with respect to the minerals in Marker Bed 139.

Table 1a shows his recipe ("saturated solution") and the amounts of salts actually weighed out. Table 1b shows the calculated composition based on the recipe and the calculated composition based on the amounts of salts actually weighed out.

PROCEDURE

Detailed notes about the preparation are in my lab notebook (Lab Notebook No. WIPP 04, pp.26-27 & 34); those notes are summarized in Attachment 1.

Reagents

Reagent grade salts were used. All salts were used "as is" from the bottle (that is, they were not dried in the lab oven).

Deionized water from the Barnstead Nanopure A deionizer was used.

Standard pH buffer solutions were prepared from pHydrion buffer capsules.

Trace-metal grade hydrochloric acid was used to adjust the pH.

Equipment

Reagents were weighed out using the Mettler AE163 balance. The balance was calibrated before use with the internal calibration weight. The calibration was checked with selected standard weights. Details can be found in the balance log book (Lab Notebook No. WIPP 02, p. 25).

Glassware included a 1000-mL class-A volumetric flask and a powder funnel.

Plasticware included weighing boats, 500-mL polyethylene bottles, various plastic beakers, and a teflon stirring rod.

Other equipment included a Thermolyne Nuova 7 stir plate; a magnetic stir bar and stir-bar retriever; an adjustable Finn timer (1-5 mL), and a Sentron model 2001 pH system (meter and probe).

Preparation

In brief, the required amounts of salts were dissolved in deionized water in the volumetric flask; dissolution was speeded by using the magnetic stirrer. The volume was adjusted to 1000 mL in the volumetric flask. The pH was then adjusted by adding ~4 mL of HCl. The solution was then transferred to two 500-mL polyethylene bottles. The step-by-step details are in Attachment 1.

Note that although the final volume of the solution was ~1004 mL (after the pH was adjusted), I used a volume of 1000 mL to calculate the concentrations of the solutes. Also, I ignored the HCl in calculating the chloride concentration.

\\karen\\misc\\sb-139-b.2

copy to: 6119 C. F. Novak
6119 K. L. Robinson

TABLE 1a: Recipes -- Amounts of Salts Needed and Weighed Out

Salt	Amount needed for 1 liter of "sat'd" soln (grams)	Amount weighed out for SB-139-B (grams)
NaHCO ₃	0.00134	*
CaCl ₂ ·2H ₂ O	1.27954	1.2790
MgSO ₄	19.92105	19.9259
MgCl ₂ ·6H ₂ O	130.606	130.6083
KCl	32.395	32.3960
NaCl	204.105	203.1150
Na ₂ B ₄ O ₇	7.0024	7.0018
NaBr	1.87565	1.8745

* Don't have appropriate equipment to accurately measure 0.00013 g of a salt.

Table 1b: Brine Compositions -- Target and Calculated

Species	Calc'd Comp. "Sat'd" Recipe (mg/L)	Calc'd Comp SB-139-B* (mg/L)
HCO ₃	0.970	**
Cl	185391	184770
SO ₄	15898	15900
Na	82315	81920
K	16990	16990
Ca	349	350
Mg	19641	19640
B	1505	1500
Br	1457	1460

* Concentrations rounded to nearest 10 mg/L.

** Probably equilibrated with atmosphere.

ATTACHMENT 1: Preparation of SB-139-B

- 05/21/93: Put ~200 mL deionized water and small magnetic stir bar into 1000-mL volumetric flask.
Discovered shortage of salts (NaCl, possibly KCl) in lab. Postponed further work until they arrive. Covered vol. flask.
- 06/10/93: Weighed Na₂B₄O₇; transferred quantitatively to vol. flask.
Began stirring. Stirred for ~3 hrs. Left standing over night.
Weighed other salts (CaCl₂·2H₂O, MgCl₂·6H₂O, KCl, NaCl, MgSO₄, NaBr) into plastic beakers. Covered with parafilm.
- 06/11/93: Resumed stirring.
Quantitatively transferred chloride salts (CaCl₂·2H₂O, MgCl₂·2H₂O, KCl, NaCl) to vol. flask.
Added deionized water to fill flask ~two-thirds.
Stirred ~1 hr. Let sit over weekend.
- 06/14/93: Resumed stirring.
Quantitatively transferred remaining salts (MgSO₄, NaBr) to vol. flask. Added deionized water until base of flask was almost full.
Continued stirring. At end of work day turned off stirrer and left to stand overnight.
- 06/15/93: Continued stirring. Let sit overnight.
- 06/16/93: Continued stirring. Left stirring overnight.
- 06/17/93: Stopped stirring.
Removed stir bar with magnetic stir-bar retriever. Rinsed with deionized water, adding all rinse water to flask.
Diluted with deionized water to volume and inverted to mix thoroughly.
- 06/18/93: Calibrated pH system with standard buffers 7 and 4. Checked calibration with standard buffer 6.4.
Measured initial pH of solution as 7.04.
Added 4.0 mL of trace-metal grade HCl, mixed the solution by inverting the vol. flask several times, and checked the pH of the solution. The final pH of the solution was 6.15.
The final volume of the solution was ~1004 mL. Note that concentrations of solutes were calculated using a volume of 1000 mL.
The solution was transferred to two 500-mL polyethylene bottles. One was given to S. Howarth for possible shipment to ChemNuclear Geotech for chemical analysis. The other is currently stored in 823/2079.

Sandia National Laboratories

MANAGED BY MARTIN MARIETTA CORPORATION
FOR THE U. S. DEPARTMENT OF ENERGY

P. O. BOX 5800
ALBUQUERQUE, NEW MEXICO 87185-1320

date: 26 April 1994

to: Susan M. Howarth, Dept. 6115, MS 1324, 848-0676

from: Craig F. Novak, Dept. 6119, MS 1320, 848-0619

subject: Formulation and Recipe for a "Standard" Marker Bed 139 Brine

A standard brine with little or no potential to dissolve rock from Marker Bed 139 was needed for flow experiments. This memo documents the process used to develop a composition for this standard brine, which will be given the name SB-139-B.

The brines collected in the QPB boreholes in the Q-access drift (Finley et al., 1992) are believed to represent brines from Marker Bed 139. If this is indeed the case, these brine compositions should be in equilibrium with the solids in the marker bed, and thus should not dissolve marker bed material. Chemical analyses of 20 brine samples from these boreholes are available, collected between October 1989 and July 1992. Discussion of these and other Salado brine samples can be found in the memo "Evaluation of Chemical Analysis Data of Brine Samples from the Small Scale Brine inflow Experiments," by Novak, dated 17 June 1993; modified 26 July 1993. The results of the analyses are listed in Table 1, along with an arithmetic average of the element concentrations, in mM and mg/L. This average concentration was used by K.L. Robinson to develop a recipe from which to synthesize SB-139-Brine. Although it cannot be guaranteed that this brine will not cause dissolution of MB139 material, this is a reasonable brine composition for simulating brine from Marker Bed 139.

Reference

Finley, S.J., D.J. Hanson, and R. Parsons. 1992. *Small-Scale Brine Inflow Experiments—Data Report Through 6/6/91*. SAND91-1956. Albuquerque, New Mexico: Sandia National Laboratories.

Table 1. Concentrations used to determine "standard" MB139 composition.

Borehole	Collection Date	Analysis Report*	B, mM	Br, mM	Ca, mM	Cl, mM	K, mM	Mg, mM	Na, mM	SO4, mM
QPB 01	16-Aug-90	UNC3	138	18.1	7.53	5501	426	776	3463	160
QPB 01	20-Sep-90	UNC3	144	18.8	7.88	5614	448	817	3554	166
QPB 02	4-Oct-89	UNC2	139	18.5	7.93	5571	431	813	3596	166
QPB 02	13-Dec-89	UNC1	149	18.8	9.43	5529	453	866	3676	177
QPB 02	20-Jul-90	UNC3	144	18.8	7.83	5472	453	842	3493	165
QPB 02	16-Aug-90	UNC3	145	18.7	7.98	5444	458	819	3443	164
QPB 02	20-Sep-90	UNC3	144	18.6	10.17	5585	436	825	3637	166
QPB 03	16-Jan-90	UNC1	96	13.1	12.64	5487	312	611	4148	133
QPB 03	20-Jul-90	UNC3	140	18.6	7.78	5557	453	842	3633	169
QPB 03	16-Aug-90	UNC3	141	18.6	7.88	5416	460	809	3391	164
QPB 03	20-Sep-90	UNC3	146	18.6	7.68	5529	435	825	3493	165
QPB 04	27-Apr-90	UNC2	130	17.5	9.88	5501	399	767	3650	171
QPB 04	20-Jul-90	UNC3	143	18.6	7.58	5416	472	823	3435	165
QPB 04	16-Aug-90	UNC3	140	18.5	8.83	5501	451	821	3596	168
QPB 04	20-Sep-90	UNC3	144	18.6	11.17	5642	431	821	3639	169
QPB 05	27-Apr-90	UNC2	132	17.4	9.53	5529	409	784	3678	177
QPB 05	15-Jun-90	UNC2	137	18.2	8.03	5501	416	813	3537	164
QPB 05	20-Jul-90	UNC3	140	18.5	8.88	5585	451	821	3554	170
QPB 05	16-Aug-90	UNC3	146	18.8	7.83	5501	427	825	3430	165
QPB 05	20-Sep-90	UNC3	147	18.5	7.81	5360	460	823	3428	164
average, mM			139	18.2	8.71	5512	434	807	3574	165
average, mg/L			1505	1453	349	195419	16971	19618	82159	15888

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 17 June 1993, modified 26 July 1993

to: Elaine D. Gorham, 6119, and J. Foesch, 6119

from: Craig F. Novak, 6119

subject: Evaluation of Chemical Analysis Data of Brine Samples from the Small Scale Brine Inflow Experiments

Summary

This memorandum documents the chemical compositions of 51 Salado brine samples collected as part of the Small Scale Brine Inflow Experiments. The compositions were examined for trends with time, location, and borehole size, but few trends were found. Most of the observed variations in compositions can be explained by the hypothesis of equilibrium evaporation during brine accumulation. Brine compositions are consistent with published data from previous studies of Salado Formation brines.

Introduction

Salado brine samples have been collected as part of the Small-Scale Brine Inflow Experiments (SSBIE), which were intended to provide some understanding of brine flow and transport mechanisms within the Salado Formation. Some of these brine samples have been analyzed for major chemical constituents under the supposition that transport information might be gleaned from the brine compositions. This memorandum examines the chemical analysis data of these brines to determine what can and cannot be learned about Salado transport from

these chemical data. This memorandum does not examine brine inflow rates or borehole humidity data, and considers these quantities only peripherally as they impact interpretation of brine composition data. Comments and conclusions within this memorandum pertain only to the chemical component of the SSBIE, and have no implications for the strictly flow-related portion of these experiments.

The stratigraphic locations and orientations of the SSBIE boreholes are given in Figure 1. Ten boreholes are located in Room D in the north (experimental) end of the facility. Among the Room D boreholes, no brine has accumulated in DBT16 or DBT17. Brine has been withdrawn from all other Room D boreholes, including the nominally 4" diameter vertical boreholes DBT10, DBT11, DBT12, DBT13, DBT14, and DBT15, and from the vertical boreholes DBT31 and DBT32, which were nominally 4" in diameter when drilled, but were later enlarged to nominally 36" in diameter (Finley et al., 1992). Two subhorizontal boreholes from which brine has been sampled are located in the L4 drift, the nominally 4" diameter L4B01 and the nominally 36" diameter L4X01. Five boreholes are located in the Q-access drift approximately halfway between the Air Intake Shaft and the entrance to Room Q. Brine has been collected from all five of these nominally 2" diameter vertical boreholes numbered QPB01, QPB02, QPB03, QPB04, and QPB05. Details about borehole drilling history, brine sampling procedures, and brine inflow rates through 6 June 1991 can be found in Finley et al. (1992).

The stratigraphic units that the boreholes intersect are shown in Figure 1. The large diameter boreholes DBT31 and DBT 32 pass through several halite and argillaceous halite units, while the large borehole L4X01 is entirely within an argillaceous halite unit. The mineralogy of the Salado near the waste facility horizon is examined by Stein (1985), who in particular examined the residues remaining when the NaCl(s) in bulk halite samples was removed by dissolution. One conclusion in this report is "The non-NaCl components of halite [in the Salado Formation]...in the immediate vicinity (e.g., 100 vertical feet) of the WIPP facility horizon...consist[s] of quartz, anhydrite, gypsum, magnesite, polyhalite, and clays, with traces of...other minerals" (p. 20, Stein, 1985). The presence of these accessory minerals is an important consideration in understanding the measured chemical compositions of brines from the SSBIE, as discussed below.

Selected brine samples were submitted for chemical analysis, as reported in UNC Geotech Analytical Laboratory (1990), Chem-Nuclear Geotech Analytical Laboratory (1990), and Chem-Nuclear Geotech Analytical Laboratory (1991). Table 1 gives a summary of these chemical analyses, along with sample collection and analysis dates.

Analyzed Brine Compositions

The composition data from Table 1 are plotted versus bromide concentration in Figure 2, with open symbols denoting small (2" and 4") diameter boreholes and filled symbols denoting large (36") diameter boreholes. Bromide concentration was chosen as the abscissa because dissolved bromide has been shown to act conservatively during seawater evaporation until the bromide concentration is approximately 90 times greater than that in seawater, i.e., up to bromide concentrations of about 65 to 70 mM (McCaffrey et al., 1987). (Conservative behavior in this case means that bromide is not lost from the aqueous phase by precipitation but merely becomes more concentrated in solution as water is removed from the brine.) Because none of the measured bromide concentrations from the SSBIE exceeds 40 mM, it is reasonable to assume that bromide behaved conservatively when Salado brines were formed.

The concentrations of chloride, magnesium, potassium, sulfate, and boron (Figure 2) increase linearly as the bromide concentration increases, while the concentrations of sodium and calcium decrease linearly as the bromide concentration increases. This suggests that the brines are in chemical equilibrium with respect to halite, NaCl(s) , because chemical thermodynamics indicates that the product of the activities ("effective" concentrations) of Na^+ and Cl^- will be constant when in equilibrium with halite. A similar argument holds for Ca^{2+} and SO_4^{2-} and equilibrium with anhydrite, $\text{CaSO}_4(\text{s})$. The presence of both these minerals in the map units that the boreholes intersect supports this suggestion. However, this trend is defined primarily by the data from the large diameter boreholes.

Much less concentration variation is seen when considering only the small diameter boreholes, i.e., the open symbols in Figure 2. This is emphasized by "zooming in" on the concentration ranges that represent all the 2" and 4" diameter

boreholes, as is done in Figure 3. On this expanded scale, the compositions of the Room D small boreholes seem to form a cluster distinct from the Q-access and Room L small boreholes. In this representation, most of the element concentrations in the small diameter boreholes seem to form a linear trend over a very narrow (17-21 mM) bromide concentration range.

Close examination of the potassium and magnesium concentrations in the small diameter boreholes, Figure 3, shows that the Q-access and L4B01 data cluster around bromide concentrations of 17 to 19 mM (with one outlying point at 13 mM), while the Room D data span the range from 19 to 21 mM bromide. The concentrations of most, if not all, other elements exhibit small but distinct differences between the Q-access/L4B01 and Room D populations. It is unlikely that these differences are caused by systematic sampling or analytical errors because samples from most locations were analyzed in the same batches.

In previous analyses of brine composition from the Salado (Stein and Krumhansl, 1988), data were presented in graphical form as Na/Cl mass ratio versus K/Mg mass ratio; the SSBIE data from the small diameter boreholes are plotted thus in Figure 4. In this representation, the samples from the Room D small diameter boreholes cluster tightly in an apparently distinct population from the Q-access and L4B01 samples. The brine compositions from the small diameter boreholes seem to fall into two populations, one for the small DBT boreholes, and one for the small L4 and QPB boreholes. The sodium to chloride mass ratios are approximately the same for all the small boreholes, but the Room D samples are deficient in potassium and enriched in magnesium relative to the L4B01 and Q-access samples, as can be seen from Figure 3. However, the differences in the magnesium to potassium ratios observed for Room D and Room L4/Q-access are likely to be unimportant with regard to the solubility and migration behavior of actinides in Salado brines.

Figure 5 presents Na/Cl versus K/Mg mass ratios for all SSBIE samples, including analyses for brines from large diameter boreholes. Samples from the large diameter boreholes do not cluster with the small boreholes. Some of the brine analyses from the large DBT boreholes fall near the small borehole population, but others do not, generally being depleted in sodium relative to chloride. One of the analyses from the large L4X01 borehole appears to be depleted in sodium relative to

chloride, but the other three L4X01 samples also have lower potassium to magnesium ratios, and appear on Figure 5 to look more similar to the large DBT borehole samples.

The accuracies of the chemical analyses summarized in Table 1 were not reported. However, it is worthwhile to consider approximate "error bars" on these data to determine whether the two data clusters in Figure 5 merge into one population when uncertainties are included. Assume one is interested in the ratio $R=x/y$, where the quantities x and y have associated $\pm a\%$ and $\pm b\%$ uncertainties, respectively. The associated ranges in values for x and y yield as uncertainty bounds on R the smallest ratio $R_s = \frac{(1-a)}{(1+b)} R$ and the largest ratio $R_\ell = \frac{(1+a)}{(1-b)} R$. If a and b are both 5%, then $R_s/R = 0.90$ and $R_\ell/R = 1.10$, giving about a 10% error bar on the final ratio. (A value of 5% may be conservative; if $a = b = 10\%$, the error on the final ratio will be about 20%.) When this 5% error is included with the data (Figure 6), the brines still appear to fall into two distinct populations. The trends described above remain clearly distinguishable even after considering the possible magnitude of errors associated with sampling handling and analysis.

Effects of Evaporation on Brine Compositions

There are several reasons to suspect that water evaporation from the brine may have occurred while brine was accumulating in the boreholes. Figure 2 shows that concentrations in brines from the large diameter boreholes increase linearly with bromide concentration, while concentrations from the small diameter boreholes cluster at the low concentration end of this correlation. When bromide is assumed to behave conservatively during evaporation, this suggests that the brines were concentrated by evaporation in the large diameter boreholes.

The seals for the large boreholes also suggest evaporation may be occurring, as presented in the attached memorandum from Jim Foesch. The L4X01 borehole is closed with a brattice cloth seal that is considered to provide poor isolation of the gas phase within the L4X01 borehole. Humidity measurements within L4X01 and within Room L4 are correlated, suggesting that gas can flow out of and into the borehole as pressure changes within the drift. The DBT31 and DBT32 boreholes

are sealed in a different manner from L4X01, using a 90 cm flange with a rubber gasket. This arrangement provides a better seal than for L4X01, but the seal is still not as good at those on the small diameter boreholes. Thus, loss of water vapor through exchange with the atmosphere is plausible for the L4X01 borehole and the large DBT boreholes.

The total void volume within boreholes relative to brine sample size provides a further suggestion that evaporation may be more important in the large boreholes. Table 2 shows the diameters and lengths of the SSBIE boreholes, along with calculated internal volumes (assuming cylindrical boreholes) and the mass of water needed to bring the air within the borehole to a relative humidity of 75%, the relative humidity approximately in equilibrium with Salado brines. As shown, the mass of water necessary to reach 75% relative humidity is about 1 gram for L4B01 and the small DBT boreholes, and about 0.1 gram for the Q-access boreholes, while it is on the order of 70 grams for DBT31, DBT32, and L4X01. A comparison of these masses of water to the mass of water in the brine samples is given in Table 3. This calculation assumed that about three quarters of the brine mass was H_2O , estimated by assuming a brine density of 1200 g/liter and 300 g/liter total dissolved solids. As Table 3 shows, only for the large diameter boreholes is the mass of water in the air a significant fraction of the mass of water in the collected brine. This means that, if all boreholes were perfectly sealed, and contained dry air (relative humidity 0%) at the start of a test interval, and all water in the air came from brine evaporation, the evaporation would affect the brine compositions only in the large diameter boreholes.

Evaporation Path Modeling

Equilibrium evaporation path modeling was performed to determine whether the hypothesis of water evaporation was consistent with the brine composition data. Three average brines, called $\overline{DBT}$, $\overline{QPB}$, and $\overline{L4B01}$, were defined as the arithmetic average of all samples for every small diameter borehole in a given room or drift. The equilibrium evaporation paths of these brines were calculated with the PHRQPITZ code (Plummer et al., 1988), using the Pitzer specific ion interaction approach and the data set of Felmy and Weare (1986) and Harvie et al. (1984).

Using this code, the three average brines were sequentially evaporated to the following endpoints:

- (1) halite, NaCl(s) , saturation;
- (2) anhydrite, $\text{CaSO}_4\text{(s)}$, saturation in equilibrium with halite;
- (3) polyhalite, $\text{K}_2\text{MgCa}_2(\text{SO}_4)_4 \cdot 2\text{H}_2\text{O(s)}$, saturation in equilibrium with halite and anhydrite; and
- (4) sylvite, KCl(s) , saturation in equilibrium with halite and polyhalite, but not anhydrite.

Anhydrite equilibrium was not maintained in step 4 because more anhydrite would have needed to dissolve than had precipitated in the evaporation sequence. The modeling assumed a closed system, i.e., the model did not allow $\text{CO}_2\text{(g)}$ to dissolve or exsolve. The final solution for the average L4 brine was slightly oversaturated with respect to a borate mineral that has not been observed near the repository horizon in the Salado. The calculated evaporation paths are plotted versus bromide concentration along with the measured concentrations for the large boreholes in Figure 7; three evaporation lines are shown for each element because the three average brine compositions are slightly different.

A comparison of the modeling results with composition data is shown in Figure 7, where the lines represent calculated evaporation paths for the three average brines, the solid squares represent data from the large DBT boreholes, and the filled circles represent data from the large L4 borehole. For all elements except total inorganic carbon (TIC), the calculated evaporation paths of the average brines agree very well with the observed compositions from the large boreholes, indicating that the hypothesis of water evaporation within boreholes is consistent with the data. Calculated evaporation paths are similar for the three different average brines.

The agreement between evaporation path modeling and the data points on Figure 7 provides partial verification and validation of both the chemical model (Felmy and Weare, 1986; Harvie et al., 1984; Harvie and Weare, 1980), and the PHRQPITZ implementation of this chemical model. The SSBIE brines are complex, highly concentrated chemical systems, and are independent from the data used to parameterize the chemical model. Nonetheless, excellent agreement

between the model and data was achieved through straightforward analysis. This provides additional confidence that the methods used above can successfully describe the geochemical behavior of brine constituents in evaporite environments such as the Salado Formation.

The lack of agreement between the modeled and measured TIC data could be attributed to numerous causes. Carbon dioxide may have been lost during brine accumulation while water was evaporating. This explanation is consistent with the lower values measured in the large diameter boreholes relative to the TIC concentrations predicted by the model. Other possible explanations include $\text{CO}_2(\text{g})$ outgassing during sample storage and handling, and errors or uncertainty in pH measurement.

Compositional Trends over Multiple Samples from the Same Borehole

As shown in Table 1, several different brine samples from each of the boreholes were chemically analyzed. The samples were withdrawn at different times to determine whether composition is a function of sampling date. This section examines the data for such variation for the eight boreholes from which three or more brine samples were analyzed. These small diameter boreholes include four from the Q-access drift, and four from Room D. Because the compositional variation of the nominally 36" diameter boreholes was explained above, the 36" borehole data are not discussed here. The time spans represented by data for the boreholes with multiple samples range from five to thirty months. With so few samples, it would be difficult to define temporal trends. However, some regular variation in compositions might become apparent.

Plots of these data for the Room D and Q-access boreholes are given in Figures 8 and 9, respectively. The data were reduced by calculating the average element concentrations for all samples from each borehole, and normalizing individual sample concentrations with respect to this average. This method of data reduction allows direct comparison of the magnitude of compositional variations among different elements. As shown in Figure 8 for boreholes DBT10, DBT11, DBT12, and DBT13, concentrations of all elements except boron and calcium vary by less than ~5% from the borehole average. Boron varies by up to ~10% in DBT12,

and calcium varies by up to ~20%. Figure 9 shows similar plots for QPB02, QPB03, QPB04, and QPB05. Here there is more variation from the average, particularly seen in one QPB03 sample taken on 16 January 1990. However, if this data point is discounted, the variations appear about the same as discussed for the Room D samples. These variations are close to the 5 to 10% analytical variability proposed earlier in this memorandum. Overall, the concentrations in each borehole seem fairly constant across multiple samples; no trends are obvious from either Figure 8 or Figure 9.

No Evidence for Contamination of Salado Brine in Q-access Boreholes

The boreholes in the Q-access drift are located approximately 40 meters from the bottom of the Air Intake Shaft (AIS). Because brines from overlying formations collect in a sump at the bottom of the AIS, and because the sump has occasionally overflowed onto the floor of the excavations, there was concern that brines in Room Q and the Q-access drift could become contaminated with nonSalado brines. Indeed, this was part of the reason for the location of the Q-access boreholes.

The existing brine composition data provide no evidence that nonSalado brine has mixed with Salado brine, or that the brines collecting in the SSBIE boreholes have origins from other than the Salado Formation. Indeed, a comparison of the compositions of SSBIE samples in Figure 2 with those from brine weeps (Figure 2, Krumhansl et al., 1991) shows no significant differences. The brine weeps were located in drift walls one or several meters above the level at which the potential contamination mechanisms could be considered plausible. Thus, because the weep samples can be considered to represent uncontaminated Salado brines, and because the weep samples and the SSBIE samples have similar compositions, it appears that the SSBIE samples are also uncontaminated by brines from other formations.

Conclusions

The brines collected and analyzed as part of the Small Scale Brine Inflow Experiments do show compositional variation. However, much of the variation occurs in brines collected from the large (nominally 36" diameter) boreholes, and

appears to result from evaporation of water during the intervals between withdrawal of brine samples. This hypothesis, water evaporation during brine accumulation, accounts for the majority of compositional variation. Some small differences in element concentrations remain, and may be important if one is attempting to understand the origins of Salado brine. However, the SSBIE were originally intended to measure brine inflow rates; they were not intended to provide data for understanding brine origins or possible compositional variations. The study of brine origins and potential variations in brine compositions would be better conducted within a program specifically designed for those purposes.

The brine composition data examined in this memorandum appear to be an insufficient basis for drawing conclusions about transport in the Salado. Furthermore, these data do not suggest ways in which additional brine composition data may contribute to the development of inferences about brine transport in the Salado. Therefore, there do not appear to be any transport-related technical reasons for continuing to store and analyze brine samples from the SSBIE.

Acknowledgment

K.L. Robinson performed many of the PHRQPITZ simulations presented in this memorandum.

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Table 1. Analyzed concentrations of brine samples from the Small Scale Brine Inflow Experiments

Borehole	Nominal Diameter, inches	Collection Date	Analysis Report*	B, mM	Br, mM	Ca, mM	Cl, mM	K, mM	Mg, mM	Na, mM	SO ₄ , mM
DBT 10	4	16 Dec 87	UNC1	132	19.5	8.68	5571	394	1037	3509	192
DBT 10	4	15 Feb 90	UNC2	136	20.4	6.86	5571	409	1043	3226	197
DBT 10	4	20 Mar 90	UNC1	130	19.5	7.31	5543	407	1053	3326	190
DBT 10	4	21 Jun 90	UNC2	133	20.2	7.13	5557	402	1008	3278	192
DBT 11	4	11 May 88	UNC1	131	19.4	7.33	5614	399	1033	3530	192
DBT 11	4	20 Mar 90	UNC1	136	19.4	6.33	5571	399	1006	3430	190
DBT 11	4	21 Jun 90	UNC3	134	20.2	6.63	5529	422	1064	3307	190
DBT 12	4	18 Jan 90	UNC1	150	20.9	6.71	5543	412	1084	3189	200
DBT 12	4	20 Mar 90	UNC2	133	20.2	7.06	5571	391	1012	3298	191
DBT 12	4	21 Jun 90	UNC2	125	19.5	6.53	5557	380	1004	3389	187
DBT 13	4	21 Jun 90	UNC3	129	19.6	6.48	5529	399	1021	3313	186
DBT 14	4	28 Sep 88	UNC1	127	19.5	8.1	5557	395	1021	3396	188
DBT 14	4	17 May 89	UNC2	130	19.6	6.68	5557	376	992	3339	185
DBT 14	4	1 Nov 89	UNC2	131	20	6.53	5529	381	1008	3333	188
DBT 14	4	16 May 90	UNC2	129	20	6.63	5529	382	1002	3326	186
DBT 14	4	16 Aug 90	UNC3	130	20.1	6.53	5472	398	1025	3254	184
DBT 15	4	27 Jul 88	UNC1	139	20.5	8.03	5585	428	1097	3289	200
DBT 15	4	16 Aug 90	UNC3	139	20	6.43	5585	409	1029	3283	188
DBT 31	4	16 Mar 88	UNC1	153	22	8.08	5599	471	1163	3217	210
DBT 31	36	16 May 90	UNC2	241	38.2	2.52	5966	720	1994	1757	335
DBT 31	36	16 Aug 90	UNC3	215	31.8	3.74	5698	664	1621	2185	276
DBT 32	4	9 Mar 88	UNC2	138	20.2	9	5491	419	1056	3057	197
DBT 32	36	6 Apr 89	UNC1	188	26.8	6.16	5698	541	1533	2687	251
DBT 32	36	16 May 90	UNC2	171	26.5	5.21	5684	504	1374	2678	249
DBT 32	36	16 Aug 90	UNC3	167	25.4	5.09	5585	490	1288	2759	232
QPB 01	2	16 Aug 90	UNC3	138	18.1	7.53	5501	426	776	3463	160
QPB 01	2	20 Sep 90	UNC3	144	18.8	7.88	5614	448	817	3554	166
QPB 02	2	4 Oct 89	UNC2	139	18.5	7.93	5571	431	813	3596	166
QPB 02	2	13 Dec 89	UNC1	149	18.8	9.43	5529	453	866	3676	177
QPB 02	2	20 Jul 90	UNC3	144	18.8	7.83	5472	453	842	3493	165
QPB 02	2	16 Aug 90	UNC3	145	18.7	7.98	5444	458	819	3443	164
QPB 02	2	20 Sep 90	UNC3	144	18.6	10.17	5585	436	825	3637	166
QPB 03	2	16 Jan 90	UNC1	96	13.1	12.64	5487	312	611	4148	133
QPB 03	2	20 Jul 90	UNC3	140	18.6	7.78	5557	453	842	3633	169
QPB 03	2	16 Aug 90	UNC3	141	18.6	7.88	5416	460	809	3391	164
QPB 03	2	20 Sep 90	UNC3	146	18.6	7.68	5529	435	825	3493	165
QPB 04	2	27 Apr 90	UNC2	130	17.5	9.88	5501	399	767	3650	171
QPB 04	2	20 Jul 90	UNC3	143	18.6	7.58	5416	472	823	3435	165
QPB 04	2	16 Aug 90	UNC3	140	18.5	8.83	5501	451	821	3596	168
QPB 04	2	20 Sep 90	UNC3	144	18.6	11.17	5642	431	821	3639	169
QPB 05	2	27 Apr 90	UNC2	132	17.4	9.53	5529	409	784	3678	177
QPB 05	2	15 Jun 90	UNC2	137	18.2	8.03	5501	416	813	3537	164
QPB 05	2	20 Jul 90	UNC3	140	18.5	8.88	5585	451	821	3554	170
QPB 05	2	16 Aug 90	UNC3	146	18.8	7.83	5501	427	825	3430	165
QPB 05	2	20 Sep 90	UNC3	147	18.5	7.81	5360	460	823	3428	164
L4B01	4	21 Jun 89	UNC1	150	19.1	7.98	5529	464	912	3559	178
L4B01	4	14 Dec 89	UNC2	137	18.2	7.78	5543	428	829	3628	171
L4X01	36	13 Jul 89	UNC2	257	35.2	2.54	5853	674	1809	2015	361
L4X01	36	19 Jul 89	UNC1	242	32.7	2.99	5797	726	1831	2309	337
L4X01	36	15 Jun 90	UNC2	239	34.3	3.54	5825	716	1576	2304	291
L4X01	36	20 Jul 90	UNC3	201	29	5.19	5755	646	1265	2728	245

* UNC1: analysis date 20 Jun 90 (UNC Geotech Analytical Laboratory, 1990)
 UNC2: analysis date 21 Nov 90 (Chem-Nuclear Geotech Analytical Laboratory, 1990)
 UNC3: analysis date 29 Jan 91 (Chem-Nuclear Geotech Analytical Laboratory, 1991)

Table 2. Final borehole diameters and lengths, calculated void volumes within boreholes, and the required mass of water necessary to provide 75% relative humidity in the borehole (75% is approximately equilibrium with the initial brines).

Borehole	Diameter, cm	Length, cm	Volume, liters	g H ₂ O needed to saturate air to 75% relative humidity [§]
DBT10	10.2	530	43.3	0.82
DBT11	10.2	460	37.6	0.71
DBT12	10.2	370	30.2	0.57
DBT13	10.2	280	22.9	0.43
DBT14	10.2	560	45.8	0.86
DBT15	10.2	580	47.4	0.90
DBT31	91.4	560	3670	69.44
DBT32	91.4	570	3740	70.68
QPB01	5.1	300	6.13	0.12
QPB02	5.1	310	6.33	0.12
QPB03	5.1	310	6.33	0.12
QPB04	5.1	310	6.33	0.12
QPB05	5.1	310	6.33	0.12
L4B01	10.2	580	47.4	0.90
L4X01	91.4	570	3740	70.68

§ A value of 0.0189 grams H₂O per liter moist air (75% relative humidity) was estimated from the psychrometric chart on p. 20-6 of Perry and Chilton (1973).

Table 3. Calculation of the mass of H₂O required to saturate the air in the SSBIE boreholes to 75% relative humidity, and the ratio of this mass to the mass of water in the brine sample.

Borehole	Nominal Diameter, inches	Collection Date	g Brine in Sample	g H ₂ O needed to saturate air to 75% relative humidity	Ratio of g H ₂ O to reach 75% relative humidity to mass of water in brine sample
DBT 10	4	16 Dec 87	92	0.82	1.2%
DBT 10	4	15 Feb 90	194	0.82	0.6%
DBT 10	4	20 Mar 90	246	0.82	0.4%
DBT 10	4	21 Jun 90	871	0.82	0.1%
DBT 11	4	11 May 88	69	0.71	1.4%
DBT 11	4	20 Mar 90	294	0.71	0.3%
DBT 11	4	21 Jun 90	967	0.71	0.1%
DBT 12	4	18 Jan 90	173	0.57	0.4%
DBT 12	4	20 Mar 90	149	0.57	0.5%
DBT 12	4	21 Jun 90	510	0.57	0.1%
DBT 13	4	21 Jun 90	306	0.43	0.2%
DBT 14	4	28 Sep 88	78	0.86	1.5%
DBT 14	4	17 May 89	144	0.86	0.8%
DBT 14	4	1 Nov 89	200	0.86	0.6%
DBT 14	4	16 May 90	153	0.86	0.8%
DBT 14	4	16 Aug 90	514	0.86	0.2%
DBT 15	4	27 Jul 88	146	0.90	0.8%
DBT 15	4	16 Aug 90	120	0.90	1.0%
DBT 31	4	16 Mar 88	88	0.86	1.3%
DBT 31	36	16 May 90	430	69.44	21.5%
DBT 31	36	16 Aug 90	588	69.44	15.7%
DBT 32	4	9 Mar 88	79	0.87	1.5%
DBT 32	36	6 Apr 89	76	70.68	124.0%
DBT 32	36	16 May 90	520	70.68	18.1%
DBT 32	36	16 Aug 90	590	70.68	16.0%
QPB 01	2	16 Aug 90	147	0.12	0.1%
QPB 01	2	20 Sep 90	207	0.12	0.1%
QPB 02	2	4 Oct 89	191	0.12	0.1%
QPB 02	2	13 Dec 89	56	0.12	0.3%
QPB 02	2	20 Jul 90	2486	0.12	0.0%
QPB 02	2	16 Aug 90	2164	0.12	0.0%
QPB 02	2	20 Sep 90	66	0.12	0.2%
QPB 03	2	16 Jan 90	235	0.12	0.1%
QPB 03	2	20 Jul 90	445	0.12	0.0%
QPB 03	2	16 Aug 90	666	0.12	0.0%
QPB 03	2	20 Sep 90	1027	0.12	0.0%
QPB 04	2	27 Apr 90	55	0.12	0.3%
QPB 04	2	20 Jul 90	103	0.12	0.1%
QPB 04	2	16 Aug 90	80	0.12	0.2%
QPB 04	2	20 Sep 90	107	0.12	0.1%
QPB 05	2	27 Apr 90	74	0.12	0.2%
QPB 05	2	15 Jun 90	1214	0.12	0.0%
QPB 05	2	20 Jul 90	2117	0.12	0.0%
QPB 05	2	16 Aug 90	1713	0.12	0.0%
QPB 05	2	20 Sep 90	2316	0.12	0.0%
L4B01	4	21 Jun 89	30	0.90	4.0%
L4B01	4	14 Dec 89	74	0.90	1.6%
L4X01	36	13 Jul 89	115	70.68	81.9%
L4X01	36	19 Jul 89	108	70.68	87.3%
L4X01	36	15 Jun 90	98	70.68	96.2%
L4X01	36	20 Jul 90	84	70.68	112.2%

TRI-6344-553-0

Figure 1. A schematic representation of the small-scale brine inflow boreholes and the stratigraphic units tested in each borehole (p.3, Finley et al., 1992).

Figure 2. Analyzed concentrations from small (open symbols) and large (filled symbols) boreholes as a function of bromide concentration, which is assumed to be conservative.

Figure 3. Expanded view of analyzed concentrations from small (open symbols) and large (filled symbols) boreholes as a function of bromide concentration, c.f., Figure 2, showing two apparent populations of brine compositions.

Figure 4. Plot of mass ratios of major solutes for the small diameter boreholes.

Figure 5. Plot of mass ratios of major solutes for small and large diameter boreholes, with calculated evaporation paths for average brines calculated from the small diameter borehole samples from Rooms D and L4, and the Q-access drift.

Figure 6. Plot of mass ratios of major solutes for both small and large diameter boreholes, showing the "error bars" that would result from a $\pm 5\%$ analytical accuracy in concentrations.

Figure 7. Comparison of modeled evaporation of average small borehole brines with concentration data from large boreholes.

Figure 8. Percent difference in concentration of analyzed elements in DBT brines as a function of time.

Figure 9. Percent difference in concentration of analyzed elements in QBP brines as a function of time.

Appendix E.
PA Parameter Package: Salado Data/Parameters: Anhydrite Two-Phase Parameters.
Tracy Christian-Frear to SWCF-A, January 31, 1996.

The following information is provided as Appendix E of this document.

Sandia National Laboratories

Albuquerque, New Mexico 87185-1341

date: January 31, 1996
to: SWCF-A Records Center, SWCF-A:WBS 1.2.07.1:PDD:QA:SALADO:PKG
10:Anh 2-Phase Parameters

from: Tracy L. Christian-Frear, MS-1324 (6115)

subject: SALADO PARAMETER PRINCIPAL INVESTIGATOR
DOCUMENTATION PACKAGE FOR: ANHYDRITE TWO-PHASE
PARAMETERS

The attached record package contains the anhydrite two-phase values for the capillary and relative permeability models, the residual gas and brine saturation, the initial brine saturation, pore size distribution parameter and the threshold pressure.

The parameter information provided in this record package was collected by Principal Investigators for input to the WIPP Data Entry Form and for use by Performance Assessment personnel making parameter estimates. The record package was prepared in accordance with WIPP Quality Assurance Procedure (QAP) 17-1, Rev. 1, WIPP QA Records Source Requirements.

Please call me at 848-0704 if you have any questions.

RECORD PACKAGE:

**SALADO PARAMETER PRINCIPAL INVESTIGATOR
DOCUMENTATION PACKAGE FOR:**

ANHYDRITE TWO-PHASE PARAMETERS

Purpose: The parameter information in this package was collected by Principal Investigators for input to the WIPP Data Entry Form and for use by Performance Assessment personnel making parameter estimates.

Date of Record: January 31, 1996

Author/Organization: Tracy L. Christian-Frear
SNL Department 6115 (MS 1324)
(505) 848-0704

Recipient: SWCF-A Records Center

File Code: SWCF-A:WBS 1.2.07.1:PDD:QA:SALADO:PKG 10:Anh 2-Phase Parameters

RECORD PACKAGE:

SALADO PARAMETER PRINCIPAL INVESTIGATOR DOCUMENTATION PACKAGE FOR:

ANHYDRITE TWO-PHASE PARAMETERS

SWCF-A:WBS 1.2.07.1:PDD:QA:SALADO:PKG 10:Anh 2-Phase Parameters

Table of Contents

Record Number	Contents	Number of Pages
1	SALADO DATA/PARAMETERS : ANHYDRITE TWO-PHASE PARAMETERS (Date: December 22, 1996)	7
2	Attachment 1. Capillary Pressure Model Parameters Calc. Sheet	37
3	General Correspondence	0
4	Technical Review of Record Package	1
5	Roadmap to Supporting Documentation	0
6	Memo to PA Parameter Task Leader (attachment not included--same as record 1)	1

Total Number of Pages in Record Package

RECORD 1

SALADO DATA/PARAMETERS : ANHYDRITE TWO-PHASE PARAMETERS

Anhydrite Laboratory Data for two-phase parameters

I. Parameter No. (id):

CAP_MOD: 559, 579, 520
PC_MAX: 561, 582, 522
RELP_MOD: 575, 596, 536
SAT_IBRN: 576, 597, 537
SAT_RBRN: 577, 598, 538
SAT_RGAS: 578, 599, 539
PTHRESH: 573, 594, 534
PCT_A: IDPARAM Unknown at this time
PCT_EXP: IDPARAM Unknown at this time

II. Data/Parameter:

CAP_MOD: Capillary Pressure Model
PC_MAX: Maximum Capillary Pressure
PORE_DIS: Brooks-Corey Pore Distribution Parameter (lambda)
RELP_MOD: Relative Permeability Model
SAT_IBRN: Initial Brine Saturation
SAT_RBRN: Residual Brine Saturation
SAT_RGAS: Residual Gas Saturation
PTHRESH: Threshold Pressure
PCT_A: Threshold Pressure Linear Parameter
PCT_EXP: Threshold Pressure Exponential parameter

III. Parameter id (idpram):

CAP_MOD
PC_MAX
PORE_DIS
RELP_MOD
SAT_IBRN
SAT_RBRN
SAT_RGAS
PTHRESH
PCT_A
PCT_EXP

IV. Material:

Anhydrite

V. Material Id (idmtrl):

S_MB138, S_MB139, S_ANH_AB

SALADO DATA/PARAMETERS : ANHYDRITE TWO-PHASE PARAMETERS

VI. Units:

CAP_MOD: None
PC_MAX: Pa
PORE_DIS: None
RELP_MOD: None
SAT_IBRN: None
SAT_RBRN: None
SAT_RGAS: None
PTHRESH: Pa
PCT_A: Pa/(m²PCT_EXP)
PCT_EXP: None

VII. Distribution Information:

The following are Model Parameters with recommendations:

CAP_MOD: Limit Capillary Pressure to PC_MAX
RELP_MOD: 50% mixed B/C and 50% vG/P characteristic curves
PC_MAX: 1.0 E8 Pa
SAT_IBRN: 1.00

A. Category

PORE_DIS: Normal
SAT_RBRN: Normal
SAT_RGAS: Log Normal
PTHRESH: Normal
PCT_A: Constant
PCT_EXP: Constant

B. Mean

PORE_DIS: 0.6436
SAT_RBRN: 0.084
SAT_RGAS: 0.077
PTHRESH: 5.418 x 10⁵ Pa
PCT_A: 0.26 Pa/m^{-0.348*2}
PCT_EXP: -0.348

C. Median

PORE_DIS: 0.6536
SAT_RBRN: 0.071
SAT_RGAS: 0.055
PTHRESH: 4.958 x 10⁵ Pa
PCT_A: NA
PCT_EXP: NA

SALADO DATA/PARAMETERS : ANHYDRITE TWO-PHASE PARAMETERS

D. Std Deviation

PORE_DIS: 0.1189
SAT_RBRN: 0.055
SAT_RGAS: 0.070
PTHRESH: 1.875×10^5 Pa
PCT_A: NA
PCT_EXP: NA

E. Maximum

PORE_DIS: 0.842
SAT_RBRN: 0.174
SAT_RGAS: 0.197
PTHRESH: 7.8×10^5 Pa
PCT_A: NA
PCT_EXP: NA

F. Minimum

PORE_DIS: 0.491
SAT_RBRN: 0.008
SAT_RGAS: 0.014
PTHRESH: 3.29×10^5 Pa
PCT_A: NA
PCT_EXP: NA

G. Number of data points

6

VIII. Data Collection and Interpretation Information:

A. Data Source Information:

1. Data Source:

WIPP Observational Data

2. Supporting Explanation/Justification for selection in #1 if other than WIPP
Observational Data:

NA

3. References for selection in #1 above if other than WIPP Observational Data:

NA

B. Data Collection (for WIPP Observational Data):

1. Data Collection and Test Method:

Unstressed capillary pressure tests were performed on 6 pairs of specimens. One specimen underwent centrifuge capillary pressure tests and the other specimen underwent mercury injection capillary pressure tests. Prior to the capillary pressure tests, the specimens underwent permeability and porosity testing. The specimens ranged in size from 12.05 to 12.65 cc's. The specimens were cut from whole core taken from 6 underground boreholes at the WIPP. Two of the cores were taken outside Room L3 and the other 4 from E140 Drift at the intersection of N1100 Drift.

2. Assumptions Made During Testing:

- 1) Cores were assumed to be 100% saturated at initiation of capillary pressure tests.**
- 2) Used 140° contact angle for correcting mercury-air data to brine-air repository conditions**
- 3) The data provided here was done using tests conducted at ambient conditions (no stress) and that this data is adequate to describe two-phase conditions at stress.**

3. Standard Error of Measurement of Tests Performed:

Errors are derived from formal propagation of random and systematic errors. Source of errors include pressure transducer accuracy, accuracy of injection rates (time and volume), caliper accuracy, uncertainty in fluid viscosity and uncertainty to the interpretive method. An approximate 10% error in capillary pressure measurements is assumed for these tests.

4. Form of Raw Data:

Pressures, time, lengths and volumes

5. References Related to Data Collection:

Contract numbers:

Rock Physics Assoc. (who contracted Core Labs) AF-3945

PI name(s):

Susan Howarth

Title of approved Test Plan under which data was collected:

Test Plan: Two-Phase Flow Laboratory Program for the Waste Isolation Pilot Plant

SALADO DATA/PARAMETERS : ANHYDRITE TWO-PHASE PARAMETERS

SAND report number:
SAND94-0472

Sandia WIPP Central Files (SWCF) file code for non-SAND references:
SWCF-A:1.1.4.1:HYD/TPF

SWCF code for data package(s):
SWCF-A:1.1.4.1:HYD/TPF

6. QA Status of Data:

a. Are all of the data qualified (Yes or No?)

If Yes, answer questions below to identify method of qualification.

If No, list those data which are not yet qualified.

Yes

b. Was data qualified by QAP 20-3 (Yes or No?)

If Yes for "a" above, give SWCF of qualified data package.

No

c. Was the data the subject of audit/surveillance by SNL or DOE?
(Yes or No; and SNL or DOE?)

If Yes for "c" above, give audit reference number.

Yes - Core Labs audit 94-04

d. Was the data collected under an SNL approved QA Program?

(Yes or No?) If Yes, give title and approval dates of the QA Program(s)

Yes

Test Procedures and Quality Assurance Plan: Porosity, Permeability, and Capillary Pressure Measurements in Anhydrite Samples from the WIPP
Approved by Susan Pickering on 5/28/93

C. Interpretation of Data:

1. Was the interpretation made by reference to previous work (Yes or No?)

If yes, give reference and answer #3 below.

Yes. Air-mercury to air-brine raw data corrected at 140° contact angle made by Joel Walls as outlined in SAND94-0472.

2. Was the interpretation made by using newly performed calculations

(Yes or No?) If, yes, answer questions 3-9 below.

Yes

3. Form of Interpreted Data: (Example: histogram, table of interpreted values)
Tables of data, Curve fits, Histograms, Probability graphs
4. Assumptions Made During Interpretation:
 - 1) Cores were assumed to be 100% saturated at initiation of capillary pressure tests.
 - 2) Used 140° contact angle for correcting mercury-air data to brine-air repository conditions
 - 3) The data provided here was done using tests conducted at ambient conditions (no stress) and that this data is adequate to describe two-phase conditions at stress.
 - 4) The centrifuge data is inadequate to describe Pt and Slr, thus these test results are not used here to determine two-phase parameters.
 - 5) The threshold pressures reported in SAND94-0472 are actually entry pressures (first gas bubble in to a 100% liquid saturated rock). The threshold pressures derived by curve fits to the data (as presented here) are the threshold pressure at the critical (residual) gas saturation. These threshold pressures are consistent with the Brooks and Corey and the vanGenuchten/Parker definition of threshold pressure.
5. Name of Code(s)/Software used to Interpret Data:
Microsoft Excel v. 4.0 and KaleidaGraph v. 3.0.3b2 on a Power Macintosh 8100 using system 7.5.
6. QA Status of Code(s) used to Interpret Data: For Sandia Codes:
 - a. Was the code qualified under QAP 19-1(Yes or No?) NA
 - b. QAP 9-1 (Yes or No?) NA
7. References Related to Data Interpretation:
 - Contract numbers:
Rock Physics Assoc. (who contracted Core Labs) AF-3945
 - SAND report number:
SAND94-0472
 - Sandia WIPP Central Files (SWCF) file code for non-SAND references:
SWCF-A:1.1.4.1;HYD/TPF
 - SWCF code for data package(s):
SWCF-A:1.1.4.1;HYD/TPF

SALADO DATA/PARAMETERS : ANHYDRITE TWO-PHASE PARAMETERS

8. For interpretations made by using newly performed calculations provide documentation that you followed the requirements of QAP 9-1 Appendix B.

NA

9. For routine calculations (not using code) did you follow requirements of QAP 9-5 (Yes or No?) **Yes**

IX. Correlation with other Parameters (List only those not statistically independent of the parameter documented here):

**See Attachment 1:
Sgr and Pt
Pt and permeability**

X. Limitations or qualifications for usage of data by Performance Assessment (PA):

Data was only measured on specimens from MB139 taken from intact rock.

XI. Attachments:

Attachment 1. Capillary Pressure Model Parameters Calc. Sheet
Guidance documents are located in the following SWCF:

SWCF-A:1.2.07.1:PDD:QA:SALADO:CORR:Guidance Documents

X11. Data

Mercury Injection	Sample	Pt (MPa)	Slr (%)	Sgr (%)	Lambda
	5	0.54132	7.262	12.11	0.655
	7	0.78	6.986	7.7729	0.66452
	11	0.45026	17.401	1.3981	0.55775
	13	0.75274	10.861	19.719	0.652
	21	0.32914	0.77846	2.5201	0.49053
	23	0.39724	6.8842	3.2177	0.84178
Statistics		Pt (MPa)	Slr (%)	Sgr(%)	Lambda
Minimum		0.329	0.778	1.398	0.491
Maximum		0.780	17.401	19.719	0.842
Sum		3.251	50.173	46.265	3.862
Points		6	6	6	6
Mean		0.5418	8.3621	7.7108	0.6436
Median		0.4958	7.1240	5.4953	0.6536
Std Deviation		0.1875	5.4908	7.0228	0.1189
Variance		0.0351	30.1492	49.3195	0.0141
Std Error		0.0765	2.2416	2.8670	0.0486
Skewness		0.4327	0.5632	1.1346	0.6365
Kurtosis		-1.8573	1.4753	0.5853	1.2579

RECORD 2

Attachment 1. Capillary Pressure Model Parameters Calc. Sheet

12/20/95

Capillary Pressure Model Params
Calculation Sheet

JHC

12/20/95

Calculation Tracy Christian-Frear

Date: 12/20/95

Checked By: Susan Howarth

Date: 12/24/95

Purpose:

To determine the two-phase capillary pressure characteristic curve that best fits the data, and the parameters for BRAGFLO calculations.
Specific Parameters are: Threshold pressure (Pt), residual brine and gas saturation (Sbr and Sgr),

and the pore size distribution parameter (lambda)

The following is a list of the parameters:

CAP_MOD
PC_MAX
PORE_DIS
RELP_MOD
SAT_IBRN
SAT_RBRN
SAT_RGAS
PCT_A
PCT_EXP

Calculation Description:

Using the 140 degree contact angle corrected mercury injection core data found in SAND94-0472

determine the following by using the standard mixed B/C and vG/P formulas added to the general curve fit equations of KaliedaGraph software (off the shelf software)

- The two-phase characteristic curve (either Brooks/Corey (B/C) or vanGenuchten (vG/P)) that best fits the data;
- The Brooks and Corey (B/C) parameters of Pt, Sgr, Slr, and lambda that best fit the data.
(BRAGFLO generates vG/P parameters from the B/C parameters)
- Determine the initial brine saturation
- Determine the maximum capillary pressure, Pc.
- Based on the value of Pt determine PCT_A and PCT_EXP

I did not start with the values of Pt found in Table 12 of SAND94-0472 because the Pt values are actually entry pressure values (Pe at Saturation=0.999), not threshold pressure as used in the Brooks and Corey or vanGenuchten/Parker characteristic curves (Pt at liquid saturation = 1-Sgr).

I did not start with the values of Slr found in Table 12 of SAND94-0472 because those values may be the result of equipment limitations.

Equations:

Mixed Brooks and Corey (Appendix E of SAND94-0472):

$$P_c = P_t / S_e^{1/\lambda} \quad \text{eqn 1}$$

$$S_e = (S - S_{lr}) / (1 - S_{lr} - S_{gr}) \quad \text{eqn 2}$$

vG/P:

$$P_c = 1/\alpha ((S_e')^{(-1/m)} - 1)^{(1-m)} \quad \text{eqn 3}$$

$$m = \lambda / (\lambda + 1) \quad \text{eqn 4}$$

$$S_e' = (S - S_{lr}) / (1 - S_{lr}) \quad \text{eqn 5}$$

$$\alpha = (1 / (P_t / 0.5^{1/\lambda})) * ((0.5^{(-1/m)} - 1)^{(1-m)}) \quad \text{eqn 6}$$

Threshold Pressure:

$$P_t = PCT_A * k^{PCT_EXP} \quad \text{eqn 7}$$

if PCT_EXP=0, then PCT_A=Pt

rec
12/20/95

Capillary Pressure Model Params Calculation Sheet

Variables:	Description	Determination	KaleidaGraph Curve fit variable
Pc	Capillary Pressure	data	
Pt	Threshold Pressure	data fit	m 1
S	Saturation of brine	data	
Slr	Residual liquid saturation	data fit	m2
Sgr	Residual gas saturation	data fit	m3
lambda	pore-size distribution param	data fit	m4
m	vanGenuchten parameter 1	Fit and calculated from lambda	m6
alpha	vanGenuchten parameter 2	calc and fit	m5
Se and Se	Effective Saturation	calculated	
k	Permeability	data	

Assumptions:

- 1) The centrifuge data is assumed to be inadequate to define the threshold pressure and other parameters because the initial speed was too high to determine Pt, and equipment limitations were such that Slr could not be adequately defined.
- 2) Cores were assumed to be 100% saturated with liquid at initiation of capillary pressure test.
- 3) 140 degree contact angle was best for correcting Mercury-air data to brine-air repository conditions
- 4) The data provided here was done using tests conducted at ambient conditions (no stress) and that this data is adequate to describe two-phase conditions at stress.
- 5) The threshold pressures reported in SAND94-0472 are actually entry pressures (first gas bubble in to a 100% liquid saturated rock). The threshold pressures derived by curve fits to the data (as presented here) are the threshold pressure at the critical (residual) gas saturation. These threshold pressures are consistent with the Brooks and Corey and the vanGenuchten/Parker definition of threshold pressure.

Process:

Verified that Kaledagraph curve fits were working as required.

Curve fit steps:

1. Using Kaledagraph general curve fit routine, define the vG/P equation for mixed relative permeability (eqn 3 except Se' is defined as in eqn 2) and solve for all 4 variables (Alpha, Slr, Sgr, m) based upon Pc vs Saturation data.
2. Check the curve fit R2 and chisq. R2 > 0.99 and chisq < 10. (Also see if the curve fit looks adequate)
If they are OK— goto 3
If they are not OK— Eliminate data points (usually choose data with less than 40% saturation and one low sat. point) and goto 1.
3. Check for values with an error less than 12%. Use that (those) values in subsequent curve fits until you get a Slr and Sgr that has less than 10% error.
4. Put the Slr and Sgr determined in the previous steps into the mixed B/C curve fit (eqn 1) and fit the data.
5. Obtain v: 3 variables (Pt, Slr, lambda). If neither is negative, find the variable that has the least error and fix that variable
6. Determine the vG/P parameter m from lambda (eqn 4), and alpha from Pt, lambda, m (eqn 6).
7. Using eqn 1 define Pc data that fit the parameters determined for B/C and add the data to the graph.
8. Using eqn 3 define Pc data that fit the parameters determined for vG/P and add the data to the graph.
9. Curve fit the B/C generated data to check the software.
10. Curve fit the vG/P generated data to check the software.
11. Equate PCT_A to the value determined for Pt, and equate PCT_EXP to 0 (see eqn 7).

Capillary Pressure Model Params Calculation Sheet

Solution: The values found are provided in Table 1.

Each curve fit data and errors sheet are provided as indicated in Table 1.

No definitive data exists to recommend one set of characteristic curves over the other. However the data does show that either B/C or vG/P can be used to describe the data.

Figure 1 a, b, c, d, e, f show that there is possibly a relationship between Pt and Sgr (Fig. 1b)

Figure 2 shows box diagrams indicating that there are data that may be considered statistical outliers.

Figures 3, 4, 5 and 6 show the histograms and probability distribution for Pt, Slr, Sgr and lambda, respectively.

Figure 7 shows the curve for the mean values

Figures 8 though 13 are the curve fits for each specimen (including data)

Figure 14 shows the relationship between the Pt determined, the Davies equation and the entry pressures determined for the specimens.

Recommendations:

1. use 50% mixed B/C and 50% mixed vG/P characteristic curves (Pc and rel perm).
2. The mean value of Sgr is: Sgr=7.71%
3. The mean value of Pt is: Pt=0.54 MPa
4. The mean value of Slr is: Slr=8.36%
5. The mean value of lambda is: lambda= 0.644
6. The maximum Pc should be 100 Mpa (seems adequate to provide full data realization)
7. The initial brine saturation should be 100% (no evidence for anything else).
8. The Davies relationship ($P_t = 0.26 \cdot k^{-0.348}$) appears to be adequate in relating threshold pressure to permeability for the anhydrites. PCT_A=.26 Pa: PCT_EXP=-.348

TABLE 1. Capillary Pressure Curve Fit Values

TABLE 1. Summary Pressure Curve Fit Values										
Mercury Injection	Sample	Pt (MPa)	Slr (%)	Sgr (%)	Lambda	m	Alpha (1/MPa)	Pc Max (MPa)	Figure	Perm (m2)
	5	0.54132	7.262	11.032	0.655	0.3958	1.646	100	8	5.10E-19
	7	0.78	6.986	7.7729	0.66452	0.3992	1.141	100	9	9.50E-19
	11	0.45026	17.401	1.3981	0.55775	0.3580	2.010	100	10	1.80E-18
	13	0.75274	10.861	19.719	0.652	0.3947	1.184	100	11	1.60E-18
	21	0.32914	0.77846	2.5201	0.49053	0.3291	2.785	100	12	7.70E-19
	23	0.39724	6.8842	3.2177	0.84178	0.4570	2.201	100	13	1.30E-18
Statistics		Pt (MPa)	Slr (%)	Sgr(%)	Lambda					
Minimum		0.329	0.778	1.398	0.491	0.391591	1.648	100		
Maximum		0.780	17.401	19.719	0.842					
Sum		3.251	50.173	46.265	3.862					
Points		6	6	6	6					
Mean		0.5418	8.3621	7.7108	0.6436					
Median		0.4958	7.1240	5.4953	0.6536					
Std Deviation		0.1875	5.4908	7.0228	0.1189					
Variance		0.0351	30.1492	49.3195	0.0141					
Std Error		0.0765	2.2416	2.8670	0.0486					
Skewness		0.4327	0.5632	1.1346	0.6365					
Kurtosis		-1.8573	1.4753	0.5853	1.2579					

Capillary Pressure Model Params
Calculation Sheet

Verification of Software as per QAP 9-1:

1. Software used:

MicroMicrosoft Excel v. 4.0 and KaleidaGraph v. 3.0.3b2 on a PowerMacintosh with system 7.5.

2. All software is considered "off the shelf" and thus can be verified in use.

3. Kaleidagraph was verified by computing the characteristic curve values and then applying the appropriate curve fit. The R2 value of the curve fit should equal 1. (shown on each graph)

4. Hand calculations of equations for Excell. An audit of the worksheet is provided from page 20 through 37 at the end of this calc sheet which includes a map, formulae, and contents.

Figure 1a

Figure 1b

Figure 1c

Figure 1d

Figure 1e

Figure 1f

Figure 2. Box diagrams

Figure 3. Pt histogram and probability graphs

Figure 4. Slr histogram and probability graph

Figure 5. Sgr histogram and probability graphs

Figure 6. Lambda histogram and probability graphs

Figure 7. Mean values characteristic curves

Sample 5 Data 11:57:09 AM 12/14/95 vG/P

$$y = (1/m5)^{((((m0-m2)/(100-...))^{1/m6}-1)^{1-m6})}$$

	Value	Error
m2	7.262	1.2759
m3	11.637	0.65159
m5	1.0531	0.10894
m6	0.42977	0.027708
Chisq	0.41455	NA
R ²	0.99973	NA

$$y = (1/m5)^{((((m0-m2)/(100-...))^{1/m5}-1)^{1-m5})}$$

	Value	Error
m2	7.262	0.10451
m5	1.0531	0.028209
Chisq	0.41455	NA
R ²	0.99973	NA

B/C

$$y = m1/((m0-7.262)/(100-7.262))^{1/m1}$$

	Value	Error
m1	0.5413	0.06774
m4	0.65521	0.019205
Chisq	5.1848	NA
R ²	0.99657	NA

$$y = m1/((m0-7.262)/(100-7.262))^{1/m1}$$

	Value	Error
m1	0.54132	0.0061217
Chisq	5.1848	NA
R ²	0.99657	NA

vG/P: Validation of Software: m6 should =.3958

$$y = (1/1.646)^{((((m0-7.262)/(100-7.262))^{1/m6}-1)^{1-m6})}$$

	Value	Error
m6	0.3958	3.2804e-12
Chisq	8.4361e-13	NA
R ²	1	NA

B/C: Validation of Software: m4 should=.65521

$$y = .54132/((m0-7.262)/(100-7.262))^{1/m4}$$

	Value	Error
m4	0.65521	5.3358e-11
Chisq	1.6523e-11	NA
R ²	1	NA

General Curve Fit "vG/P 1"	$(1/m5)^{((((m0-m2)/(100-m2-m3))^{1/m6}-1)^{1-m6})}$
General Curve Fit "vG/P 2"	$(1/m5)^{((((m0-m2)/(100-m2-11.637))^{1/m6}-1)^{1-m6})}$
General Curve Fit "vG/P 3"	$(1/1.646)^{((((m0-7.262)/(100-7.262))^{1/m6}-1)^{1-m6})}$
General Curve Fit "Brooks/Corey"	$m1/((m0-7.262)/(100-7.262-11.637))^{1/m4}$
General Curve Fit "B/C2"	$m1/((m0-7.262)/(100-7.262-11.637))^{1/1.65521}$
General Curve Fit "B/C3"	$.54132/((m0-7.262)/(100-7.262-11.637))^{1/m4}$

Figure 8. Sample 5 curve fits

Sample_7.data 12:34:43 PM 12/14/95

vG/P

$$y = (1/m5)^{((((m0-m2)/(100-...))$$

	Value	Error
m2	8.8747	1.0607
m3	23.094	3.6823
m5	0.21275	0.055392
m6	0.561	0.049125
Chisq	333.41	NA
R ²	0.9745	NA

$$y = (1/m5)^{((((m0-m2)/(100-...))$$

	Value	Error
m2	6.986	0.22449
m3	7.7729	0.23324
m5	0.80499	0.065639
m6	0.42739	0.0086918
Chisq	0.6288	NA
R ²	0.99985	NA

$$y = m1/((m0-6.986)/(100-6.98...$$

	Value	Error
m1	0.78033	0.10006
m4	0.66452	0.020229
Chisq	12.383	NA
R ²	0.99712	NA

$$y = m1/((m0-6.986)/(100-6.98...$$

	Value	Error
m1	0.78032	0.0083466
Chisq	12.383	NA
R ²	0.99712	NA

vG/P: Validation of Software: m6 should =.3992

$$y = (1/1.141)^{((((m0-6.986)...$$

	Value	Error
m6	0.3992	1.3935e-10
Chisq	6.4558e-12	NA
R ²	1	NA

B/C: Validation of Software: m4 should=.66452

$$y = .78032/((m0-6.986)/(100-...$$

	Value	Error
m4	0.66452	2.3784e-10
Chisq	1.5711e-12	NA
R ²	1	NA

General Curve Fit "vG/P 1"
$(1/m5)^{((((m0-m2)/(100-m2-m3))^{(-1/m6)}-1)^{(1-m6))}$
General Curve Fit "vG/P 2"
$(1/1.141)^{((((m0-6.986)/(100-6.986))^{(-1/m6)}-1)^{(1-m6))}$
General Curve Fit "Brooks/Corey"
$m1/((m0-6.986)/(100-6.986-7.7729))^{(1/m4)}$
General Curve Fit "B/C2"
$m1/((m0-6.986)/(100-6.986-7.7729))^{(1/0.66452)}$
General Curve Fit "B/C3"
$.78032/((m0-6.986)/(100-6.986-7.7729))^{(1/m4)}$

Figure 9. Sample 7 curve fits

Sample 11 data 11:21:49 AM 12/5/95

vG/P

$$y = (1/m5)^{((((m0-m2)/(100-...))$$

	Value	Error
m2	17.608	3.7007
m3	-0.27798	25.642
m5	2.1116	2.7548
m6	0.35866	0.1025
Chisq	456.65	NA
R ²	0.96501	NA

$$y = (1/m5)^{((((m0-m2)/(100-...))$$

	Value	Error
m2	17.433	1.1487
m3	0.53421	1.7706
m5	1.5741	0.23392
m6	0.37659	0.022446
Chisq	0.61342	NA
R ²	0.9997	NA

$$y = (1/m5)^{((((m0-m2)/(100-...))$$

	Value	Error
m2	17.401	0.063272
m3	1.3932	0.51951
m5	1.5532	0.031652
Chisq	0.1582	NA
R ²	0.99992	NA

$$y = (1/1.5532)^{((((m0-17.40...))$$

	Value	Error
m3	1.3981	0.081404
Chisq	0.1582	NA
R ²	0.99992	NA

B/C

$$y = m1/((m0-17.401)/(100-17....$$

	Value	Error
m1	0.45026	0.042994
m4	0.55775	0.011568
Chisq	3.3113	NA
R ²	0.9984	NA

vG/P: Validation of Software: m6 should =.358

$$y = (1/2.01)^{((((m0-17.401)...$$

	Value	Error
m6	0.358	7.0637e-11
Chisq	1.1011e-12	NA
R ²	1	NA

B/C: Validation of Software: m4 should=0.55775

$$y = .45026/((m0-17.401)/(100-...)$$

	Value	Error
m4	0.55775	1.2818e-10
Chisq	5.3839e-13	NA
R ²	1	NA

General Curve Fit "vG/P 1"
$(1/m5)^{((((m0-m2)/(100-m2-m3))^{(-1/m6)}-1)^{(1-m6))}$
General Curve Fit "vG/P 2"
$(1/m5)^{((((m0-m2)/(100-m2-m3))^{(-1/37669)}-1)^{(1-37669))}$
General Curve Fit "vG/P 3"
$(1/1.5532)^{((((m0-17.401)/(100-17.401-m3))^{(-1/37669)}-1)^{(1-37669))}$
General Curve Fit "vG/P 4"
$(1/2.01)^{((((m0-17.401)/(100-17.401))^{(-1/m6)}-1)^{(1-m6))}$
General Curve Fit "Brooks/Corey"
$m1/((m0-17.401)/(100-17.401-1.3981))^{(1/m4)}$
General Curve Fit "B/C2"
$.45026/((m0-17.401)/(100-17.401-1.3981))^{(1/m4)}$

Figure 10. Sample 11 curve fits

Sample 13 data 9:29:46 AM 12/14/95

vG/P

$$y = (1/m5)^{((((m0-m2)/(100-...))}^{1/m6}) - 1)^{(1-m6)}$$

	Value	Error
m2	10.002	1.4335
m3	25.068	6.2913
m5	0.37471	0.1267
m6	0.45984	0.048036
Chisq	225.57	NA
R ²	0.98271	NA

$$y = (1/m5)^{((((m0-m2)/(100-...))}^{1/m6}) - 1)^{(1-m6)}$$

	Value	Error
m2	10.976	1.0028
m3	20.553	1.1045
m5	0.59574	0.062887
m6	0.44388	0.027805
Chisq	0.37516	NA
R ²	0.99991	NA

$$y = (1/m5)^{((((m0-m2)/(100-...))}^{1/m6}) - 1)^{(1-m6)}$$

	Value	Error
m2	10.861	0.079001
m3	19.719	0.94012
m5	0.61652	0.02239
Chisq	0.35013	NA
R ²	0.99992	NA

B/C

$$y = m1/((m0-10.861)/(100-10....))^{1/m4}$$

	Value	Error
m1	0.75275	0.10968
m4	0.65174	0.021272
Chisq	8.4475	NA
R ²	0.99799	NA

$$y = m1/((m0-10.861)/(100-10....))^{1/m4}$$

	Value	Error
m1	0.75274	0.0066906
Chisq	8.4475	NA
R ²	0.99799	NA

vG/P: Validation of Software: m6 should =.3946

$$y = (1/1.184)^{((((m0-10.861)...))^{1/m6}) - 1)^{(1-m6)}$$

	Value	Error
m6	0.3946	1.027e-10
Chisq	7.0805e-12	NA
R ²	1	NA

General Curve Fit "vG/P 1"
(1/m5)^{((((m0-m2)/(100-m2-m3))^{1/m6}) - 1)^{(1-m6))}
General Curve Fit "vG/P 2"
(1/m5)^{((((m0-m2)/(100-m2-m3))^{1/m6}) - 1)^{(1-m6))}
General Curve Fit "vG/P 3"
(1/1.184)^{((((m0-10.861)/(100-10.861))^{1/m6}) - 1)^{(1-m6))}
General Curve Fit "Brooks/Corey"
m1/((m0-10.861)/(100-10.861-19.719))^{1/m4}
General Curve Fit "B/C2"
m1/((m0-10.861)/(100-10.861-19.719))^{1/m4}
General Curve Fit "B/C3"
.75274/((m0-10.861)/(100-10.861-19.719))^{1/m4}

Figure 11. Sample 13 curve fits

Sample 21 Data 2:26:30 PM 12/5/95

$$y = (1/m5)^{((((m0-m2)/(100-...))}^{(1/m6)}-1)^{(1-m6))}$$

	Value	Error
m2	0.55551	3.472
m3	2.4469	25.431
m5	1.9078	1.8813
m6	0.35058	0.073591
Chisq	321.57	NA
R ²	0.97535	NA

$$y = (1/m5)^{((((m0-m2)/(100-...))}^{(1/m6)}-1)^{(1-m6))}$$

	Value	Error
m2	0.77834	1.5129
m3	2.5342	0.5038
m5	1.7947	0.16896
m6	0.35298	0.020812
Chisq	0.10557	NA
R ²	0.99997	NA

$$y = (1/m5)^{((((m0-m2)/(100-...))}^{(1/m6)}-1)^{(1-m6))}$$

	Value	Error
m2	0.7785	0.10544
m3	2.5199	0.47547
m5	1.7966	0.048236
Chisq	0.104	NA
R ²	0.99997	NA

$$y = (1/1.7966)^{((((m0-m2)/(...))}^{(1/1.7966)}-1)^{(1-1.7966))}$$

	Value	Error
m2	0.77846	0.034373
m3	2.52	0.40294
Chisq	0.104	NA
R ²	0.99997	NA

$$y = (1/1.7966)^{((((m0-.7784...))}^{(1/1.7966)}-1)^{(1-1.7966))}$$

	Value	Error
m3	2.5201	0.058376
Chisq	0.104	NA
R ²	0.99997	NA

$$y = m1/((m0-.77846)/(100-77...))$$

	Value	Error
m1	0.32913	0.038377
m4	0.49053	0.011018
Chisq	1.7003	NA
R ²	0.9995	NA

$$y = m1/((m0-.77846)/(100-77...))$$

	Value	Error
m1	0.32914	0.0014887
Chisq	1.7003	NA
R ²	0.9995	NA

General Curve Fit "vG/P 1"
$(1/m5)^{((((m0-m2)/(100-m2-m3))^{(1/m6)}-1)^{(1-m6))}$
General Curve Fit "vG/P 2"
$(1/m5)^{((((m0-m2)/(100-m2-m3))^{(1/1.35298)}-1)^{(1-1.35298))}$
General Curve Fit "vG/P 3"
$(1/1.7966)^{((((m0-m2)/(100-m2-m3))^{(1/1.35298)}-1)^{(1-1.35298))}$
General Curve Fit "vG/P 4"
$(1/1.7966)^{((((m0-.77846)/(100-.77846-m3))^{(1/1.35298)}-1)^{(1-1.35298))}$
General Curve Fit "vG/P 5"
$(1/2.785)^{((((m0-.77846)/(100-.77846-0))^{(1/m6)}-1)^{(1-m6))}$
General Curve Fit "Brooks/Corey"
$m1/((m0-.77846)/(100-.77846-2.5201))^{(1/m4)}$
General Curve Fit "B/C2"
$m1/((m0-.77846)/(100-.77846-2.5201))^{(1/49053)}$
General Curve Fit "B/C3"
$.32914/((m0-.77846)/(100-.77846-2.5201))^{(1/m4)}$

Figure 12. Sample 21 curve fits

Sample 23 data

$$y = (1/m5)^{((((m0-m2)/(100-...))$$

	Value	Error
m2	6.4023	2.2757
m3	-67.739	10248
m5	56.143	6370.3
m6	0.36158	0.20869
Chisq	881.58	NA
R ²	0.93256	NA

$$y = (1/m5)^{((((m0-m2)/(100-...))$$

	Value	Error
m2	6.8705	0.33304
m3	2.4815	0.26179
m5	1.7183	0.17424
m6	0.47663	0.01972
Chisq	0.36215	NA
R ²	0.99989	NA

$$y = (1/m5)^{((((m0-m2)/(100-...))$$

	Value	Error
m2	6.8732	0.038617
m3	2.4813	0.25583
m5	1.7222	0.05475
Chisq	0.36206	NA
R ²	0.99989	NA

$$y = (1/1.7222)^{((((m0-m2)/(100-...))$$

	Value	Error
m2	6.8842	0.016869
m3	3.2146	1.1258
Chisq	0.35812	NA
R ²	0.9999	NA

$$y = (1/1.7222)^{((((m0-6.884...))$$

	Value	Error
m3	3.2177	0.16467
Chisq	0.35812	NA
R ²	0.9999	NA

General Curve Fit "vG/P 1"

$$(1/m5)^{((((m0-m2)/(100-m2-m3))^{(1-1/m6)}-1)^{(1-m6))}$$

General Curve Fit "vG/P 2"

$$(1/m5)^{((((m0-m2)/(100-m2-m3))^{(1-1/47663)}-1)^{(1-1/47663))}$$

General Curve Fit "vG/P 3"

$$(1/1.7222)^{((((m0-m2)/(100-m2-m3))^{(1-1/47663)}-1)^{(1-1/47663))}$$

General Curve Fit "vG/P 4"

$$(1/1.7222)^{((((m0-6.8842)/(100-6.8842-m3))^{(1-1/47663)}-1)^{(1-1/47663))}$$

General Curve Fit "vG/P 5"

$$(1/2.201)^{((((m0-6.8842)/(100-6.8842))^{(1-1/m6)}-1)^{(1-m6))}$$

General Curve Fit "Brooks/Corey"

$$m1/((m0-6.8842)/(100-6.8842-3.2177))^{(1/m4)}$$

General Curve Fit "B/C2"

$$m1/((m0-6.8842)/(100-6.8842-3.2177))^{(1/0.84178)}$$

General Curve Fit "B/C3"

$$.39724/((m0-6.8842)/(100-6.8842-3.2177))^{(1/m4)}$$

B/C

$$y = m1/((m0-6.8842)/(100-6.8...))$$

	Value	Error
m1	0.39723	0.044994
m4	0.84178	0.019069
Chisq	2.6033	NA
R ²	0.99924	NA

$$y = m1/((m0-6.8842)/(100-6.8...))$$

	Value	Error
m1	0.39724	0.0021747
Chisq	2.6033	NA
R ²	0.99924	NA

Figure 13. Sample 23 curve fits

Figure 14. Permeability vs Threshold Pressure
Correlations found in SAND91-0893/3 page 2-13

Audit of Capillary Pressure Model Params

Worksheet Info

Document Info

Name	Capillary Pressure Model Params
Path	No changes made since last save
Protection	Dino:PA Parameters:2-Phase
Version	None
System	Microsoft Excel version 4.0
	Macintosh 7.50

Worksheet Info

Active Area	830 rows by 11 columns
	9,130 cells
Blanks	8,812 (96.5%)
Constants	259 (2.8%)
Numbers	48 (0.5%)
Text	211 (2.3%)
Logicals	0 (0.0%)
Errors	0 (0.0%)
Formulas	59 (0.6%)
Names	30 total
	16 normal
	14 hidden
Objects	24

Map of Capillary Pressure Model Params

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RECORD 3

General Correspondence

RECORD 4

Technical Review of Record Package

January 31, 1996

Technical Review of Record Package

SALADO PARAMETER PRINCIPAL INVESTIGATOR DOCUMENTATION PACKAGE FOR: ANHYDRITE TWO-PHASE PARAMETERS

Technical Review Status:

Scientific Notebooks:

Not Applicable X ; Incomplete ; Complete
(Give Date) (Give Date)

Interpretive Analyses:

Not Applicable ; Incomplete ; Complete December 21, 1995
(Give Date) (Give Date)

Routine Calculations:

Capillary Pressure Model Parameters Calc. Sheet Incomplete ; Complete December 21, 1995
(Give Date) (Give Date)

Qualification Status:

Data: Used WIPP Observational Data

Not Applicable ; Incomplete 1/31/96; Complete
(Give Date) (Give Date)

NOTES:

Data must be technically reviewed and forwarded to SWCF (TLCF-1/31/96)

Codes

Microsoft Excell; Incomplete ; Complete 12/21/95 (in use verification)
(Give Date) (Give Date)

KaleidaGraph; Incomplete ; Complete 12/21/95 (in use verification)
(Give Date) (Give Date)

PARAMETER QUALIFIED: Incomplete: 1/31/96; Complete:
(Give Date) (Give Date)

RECORD 5

Roadmap to Supporting Documentation

January 31, 1996

RAODMAP FOR
SALADO PARAMETER PRINCIPAL INVESTIGATOR DOCUMENTATION PACKAGE FOR:
ANHYDRITE TWO-PHASE PARAMETERS

RECORD 6

Memo to PA Parameter Task Leader

Sandia National Laboratories

Albuquerque, New Mexico 87185-1341

date: January 31, 1996
to: PA Parameter Task Leader

from: Tracy L. Christian-Frear, MS-1324 (6115)

subject: SALADO PARAMETER PRINCIPAL INVESTIGATOR DOCUMENTATION
PACKAGE FOR: ANHYDRITE TWO-PHASE PARAMETERS

The attached record contains the anhydrite two-phase values for the capillary and relative permeability models, the residual gas and brine saturation, the initial brine saturation, pore size distribution parameter and the threshold pressure.

The title of the records package is: SALADO PARAMETER PRINCIPAL
INVESTIGATOR DOCUMENTATION PACKAGE FOR: ANHYDRITE TWO-
PHASE PARAMETERS

The SWCF is: SWCF-A:WBS 1.2.07.1:PDD:QA:SALADO:PKG 10:Anh 2-Phase
Parameters

The WPO is: 30643

The deficiencies in the parameter documentation are:
Data must be technically reviewed and forwarded to SWCF

Please call me at 848-0704 if you have any questions.

Attachment:

SALADO DATA/PARAMETERS : ANHYDRITE TWO-PHASE PARAMETERS

Appendix F.
Memorandum: S.W. Webb to P. Vaughn, August 29, 1995

The following information is provided as Appendix F of this document.

Appendix F

Memorandum: S.W. Webb to P. Vaughn, August 29, 1995.

Errata Sheet

The two citations in Appendix F:

Davies, SAND90-3246 on p. F-3 and

Davies (1991) on p. F-4

refer to the same report. A copy is on file in SWCF as WPO#26169.

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: August 29, 1995

to: P. Vaughn, MS-1328 (6749)

from:
S.W. Webb, MS-1324 (6115)

subject: Mixed Brooks and Corey Two-Phase Characteristic Curves

The mixed Brooks and Corey two-phase characteristic curves have been used in SPM-2 calculations and will be recommended for future studies including the compliance application. The mixed Brooks and Corey model uses two definitions of the effective saturation to reflect the different saturation ranges for the relative permeabilities of the wetting and nonwetting phases. However, the approach used in SPM-2 was inconsistent with the definition of threshold pressure used in the Davies' correlation (Davies, SAND90-3246), partially due to the use of displacement pressure instead of threshold pressure in the original specification. The correct form of the mixed Brooks and Corey curves consistent with Davies' threshold pressure definition is summarized below.

In the mixed Brooks and Corey model, two separate effective saturations are used which are defined as

$$S_e = \frac{S - S_r}{1 - S_r} \quad (1)$$

$$S'_e = \frac{S - S_r}{S_c - S_r} \quad (2)$$

where

- S_e = effective saturation
- S = wetting phase saturation
- S_r = wetting phase residual saturation
- S_c = critical gas saturation = $1 - S_{r,nw}$
- $S_{r,nw}$ = nonwetting phase residual saturation.

S_e is the original Brooks and Corey definition while S'_e is a modified definition.

The capillary pressure relationship is

$$S_e' = \left(\frac{P_t}{P_c} \right)^\lambda \quad (3)$$

or

$$P_c = \frac{P_t}{S_e'^{1/\lambda}} \quad (4)$$

where P_t and P_c are the threshold pressure and the capillary pressure, respectively, and λ is the pore-size distribution parameter.

The wetting phase relative permeability expression is given by

$$k_{r,w} = S_e'^{(2+3\lambda)/\lambda} \quad (5)$$

while the nonwetting phase relationship is

$$k_{r,nw} = (1 - S_e')^2 (1 - S_e'^{(2+3\lambda)/\lambda}) \quad (6)$$

Therefore, consistent with Davies (1991), the threshold pressure is the capillary pressure when the saturation is equal to the critical gas saturation (S_c), or when S_e' equals 1.0.

If there are any questions, please contact me.

cc:

MS-1324 P.B. Davies (6115)

MS-1324 A.R. Lappin (6115)

MS-1324 T.L. Christian-Frear (6115)

MS-1328 D.R. Anderson (6749)

MS-1341 K.W. Larson (6747)

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Director, RW-30
Office of Program Mgmt. & Integ.
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Forrestal Building
Washington, DC 20585

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Yucca Mountain Site Characterization Office
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P.O. Box 30307
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1324	6115	C. Boney
1324	6115	R. L. Beauheim
1324	6115	S. W. Webb
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1322	6121	J. R. Tillerson
1328	6849	D. R. Anderson
1328	6848	H. N. Jow
1335	6801	M. Chu
1335	6801	S. M. Howarth (15)
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1395	6821	M. Marietta
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