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WIPP Horizon Free Field Fluid Transport Characteristics

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1. INTRODUCTION

The Waste Isolation Pilot Plant (WIPP), located in southeast New Mexico, is being developed by the Department of Energy to demonstrate the safe geologic disposal of radioactive waste generated by the defense programs of the United States. The WIPP disposal horizon is located approximately 650 meters below the ground surface in a bedded halite deposit.

A part of the WIPP research and development program is the Plugging and Sealing Program (PSP) conducted by Sandia National Laboratories (SNL). The PSP is an integrated program of modeling, laboratory testing, and *in situ* testing directed toward developing acceptable sealing technology for man-made WIPP penetrations (boreholes, shafts, and drifts) as required for the eventual decommissioning of the facility. The objective of sealing is to limit fluid migration in, through and out of the repository.

Flow through a sealed system is partially dependent on host rock permeability. Therefore the host rock flow characteristics are an important consideration in the development of sealing strategy and seal designs. Formation flow characteristics also determine the brine influx from the surrounding rock and affect the buildup and dissipation of natural and waste generated gases in the repository. As a result, the host rock flow characteristics are also required input parameters for repository performance assessment.

The work described here represents the first attempt to measure the free field brine transport characteristics of the host rock. The resulting data, which have been used to estimate the brine permeability, also suggest free field pore pressure values. Data were obtained from two boreholes. One borehole was located in a competent predominantly halite bed with the test region positioned approximately nine meters from the rib. A second borehole intersected Marker Bed 139, which is a one meter thick fractured predominantly anhydrite layer. For this second borehole, the test region was positioned approximately 12 meters from the invert/rib intersection.

This work represents a continuing effort by the PSP to understand fluid transport through possible man made seals and the horizon surrounding the WIPP facility horizon. A summary of related flow measurements obtained by the PSP prior to 1985 is given in References 1 and 2 where results of laboratory tests, gas flow tests performed from surface boreholes, and gas flow tests performed from boreholes drilled from the mined facility are presented. Results of preliminary gas flow and tracer tests performed to infer the gas permeability, fracture extent, and permeability change with time of the disturbed zone surrounding the mined openings are summarized in Reference 3. Reference 4 presents summarized results of the initial small scale seal performance tests.

This report is arranged as follows: A description of the tests provided in Section 2. Data obtained during these tests are described in Section 3. Analysis of these data and the associated uncertainties inherent in the data interpretation are presented in Section 4. Test results are given in Section 5. Conclusions are provided in Section 6.

2. TEST DESCRIPTION

The 10 cm diameter test boreholes are located approximately ten meters west of the Room-M/N1420-drift intersection shown on Figure 1. Horizontal boreholes DPH01 and DPH02, drilled from the north rib, are in a competent bed which is predominantly halite. Boreholes DPD01 and DPD02, are drilled at a 45° downward angle from the north-rib/invert intersection, and pass through Marker Bed 139. Figure 2 illustrates the DPH01 and DPD02 borehole test configurations. Note that in each borehole, the region extending from the bottom of the lower packer to the bottom of the hole constituted the test region.

Borehole DPH01 encompassed a 2.1 meter long, 19.5 liter volume test region. Borehole DPH02 possessed a 1.8 meter long, 16.7 liter volume test region. Borehole DPD02 had a 4.0 meter long, 36 liter test region volume. All installations used a 2.2 liter volume guard region. There were no tests performed in borehole DPD01.

The measurement system is shown in schematic form on Figure 3. This system was previously used to perform the Series A and B tests and is described in detail in Reference 5.

Tests were performed in the horizontal DPH01 borehole as follows. After completion on April 9, 1986, the borehole remained open until May 20, 1986. A dual packer system was then installed, the packers were inflated, the test region was pressurized with nitrogen to 2.1 MPa and was then shut in. The subsequent pressure decay was measured for approximately 20 hours after which the test region was vented to atmospheric pressure. Additional gas was then evacuated from the test and guard regions using a vacuum pump. During this evacuation the packers remained inflated. Both regions were then filled with brine and a brine flow test was initiated on May 22, 1986. This test continued for 240 days, after which brine was removed from the borehole and a second

Figure 1. Plan view of WIPP facility test area.

Figure 2. Illustration showing borehole DPH01 and DPD02 test configurations (no scale).

Figure 3. Schematic showing the test system.

Gas flow tests were performed for two reasons. One reason was to obtain data at 2.1 MPa for comparison with the 0.8 MPa gas flow test data described in Reference 2 in order to investigate potential threshold pressure effects. A second reason was to obtain additional gas flow data which could be compared to the brine flow test results. It was recognized that the preliminary gas flow test could affect the brine flow test response.

Tests were performed in borehole DPH02 as follows. After completion on April 8, 1986, the borehole remained open until a dual packer system was installed on May 21, 1986. A brine flow test was initiated on May 22, 1986 and continued for 240 days. There were no gas flow tests performed in this borehole.

Tests were performed in the downward slanting DPD02 borehole as follows. After completion on April 10, 1986 the borehole remained open until May 20, 1986. A dual packer system was then installed, and the test region was pressurized with nitrogen to 2.1 MPa and then shut-in. The subsequent pressure decay was measured for approximately 20 hours, after which the test region was vented to atmospheric pressure. Additional gas was then evacuated from the test and guard regions using a vacuum pump. Both regions were then filled with brine. During the brine fill an attempt was also made to continually remove any remaining gas in these regions through vent lines located below the packers. The brine flow test was initiated on May 22, 1986 and continued for 240 days. Brine was then removed from the borehole and a second 2.1 MPa, 20 hour, gas flow test was performed. This gas flow test was conducted on January 20, 1987. At no time during this testing period were the packers deflated.

3. DATA ACQUISITION

The complete suite of data obtained from the DPH01, DPH02, and DPD02 tests is included in Appendix A. A general description of these data will be provided in the following paragraphs using the DPH01 test results as an example.

During a gas or brine flow test, measurements are made of the test region pressure, the test region temperature, the guard region pressure, the test region packer pressure, and the guard region packer pressure. During a brine test, the brine supply pressure is also measured.

Data obtained during the May 20, 1986 gas flow test are shown on Figures 4 through 6. The total flow from the test region to the surrounding formation and guard region is determined from the Figure 4 pressure decay data. Flow to the guard region is calculated from the Figure 5 pressure rise data. The difference in these two flows is taken as that which enters the formation surrounding the test region. The test region pressure and the formation flow data are then used to estimate the formation permeability. Temperature changes can be important when testing with gas, hence the test region temperature is measured along with the test and guard region pressure. The test region temperature measured during the time over which the test region pressure in Figure 4 was obtained is presented in Figure 6. As expected, the gas temperature increases during pressurization of the test region. However, within a few hours the temperature decays to the ambient level where it remains for the duration of the test. In effect, the gas pressure decay tests are conducted under isothermal conditions. Note that the broken, straight line appearance of the curves, shown on Figures 5 and 6, is a result of the data sampling time interval selected. Selecting more discrete steps would result in a smoother appearing curve, but would not provide additional clarity for purposes of comparison with calculations.

Figure 4. Test region pressure history measured during the May 20, 1986 DPH01 gas flow test.

Figure 5. Guard region pressure history measured during the May 20, 1986 DPH01 gas flow test.

Figure 6. Test region temperature history measured during the May 20, 1986 DPH01 gas flow test.

Figure 7. Test region pressure history measured during the DPH01 brine flow test initiated on May 22, 1986.

Figure 8. Guard region pressure history measured during the DPH01 brine flow test initiated on May 22, 1986.

Figure 9. Test region packer pressure history measured during the DPH01 brine flow test initiated on May 22, 1986.

Selected data traces obtained during the DPH01 brine flow test are shown on Figures 7 through 9. A complete set of DPH01 brine flow data is included in Appendix A.

The brine flow tests were designed to measure flow to the formation assuming a 3.5 MPa test region pressure. The resulting data were to be used to estimate formation permeability.

Figure 7 shows the DPH01 test region pressure history. It can be seen that the pressure was maintained at the 3.4 MPa level for the first 13 days. However, during that time it became apparent, from results of periodic shut-in tests, that fluid was flowing from the formation into the borehole. After 13 days, the test region was therefore permanently shut-in. Following isolation of the test region, the pressure was seen to increase to 7.9 MPa after 211 days. At that time, the test region pressure was lowered to 3.0 MPa and the region was again shut-in until the test was terminated after 240 days. This latter short duration shut-in test was performed to confirm that flow was indeed entering the test region. Note that some of the pressure rise measured within the borehole may result from borehole closure as described in Section 5.

During a test, the guard region is always shut-in. For a test in which brine flows from the test region into the formation, the guard region pressure response can be used to determine flow past the test region packer. If, however, the brine flows from the formation into the borehole, the guard region primarily serves to make the test region response more one-dimensional by eliminating end effects. Assuming a uniform formation with flow into the borehole, the guard region pressure would be expected to increase faster than that of the test region because of its lower volume per unit length for this particular tool (i.e. presence of the packer mandrel).

The guard region pressure history shown on Figure 8 is consistent with the test region results shown on Figure 7. However, since it is known from the gas flow test that there is leakage past the test region packer, and since it cannot be determined whether there is leakage past the guard region packer, no firm conclusions can be made from the Figure 8 data.

The test region packer pressure history, which is very similar to that of the guard region packer, is shown on Figure 9. Both packer pressures were increased from 6.1 MPa to 8.5 MPa at the time the test region was shut-in. After 38 days (as shown on Figure 7), the test region pressure had increased to about 5.5 MPa. Thereafter, the packer and test region pressures increased congruently. With the inflatable packers used for these tests this behavior would be expected. It is important to note that once the test region, guard region, and packers have been shut-in any pressure increase seen within the system must result from flow into the borehole and/or borehole closure. Borehole closure results from halite creep resulting in a reduction of borehole volume with a concomitant pressure increase.

The rock temperature surrounding the WIPP facility is essentially constant. These long duration brine flow tests can therefore be considered to be conducted under isothermal conditions. Temperature data obtained during the DPH01, DPH02, and DPD02 tests are shown in Appendix A. The DPH02 and DPD02 temperature measurements indicate constant values until the temperature sensors malfunctioned after about 30 and 70 days for the DPD02 and DPH02 tests, respectively. The temperature sensor for the DPH01 test system malfunctioned from the beginning of the test. The most likely cause of this malfunction was a small brine leak into the connectors used to transmit the temperature sensor signal to the data logger.

4. DATA ANALYSIS AND EVALUATION

Data analysis methods are summarized in Section 4.1. Uncertainties inherent in these analyses and interpretations are addressed in the discussion presented in Section 4.2.

4.1 DATA ANALYSIS.

Short duration gas flow tests were performed to obtain order of magnitude permeability estimates for comparison with subsequent brine flow tests and previous gas flow tests. Permeability values were estimated from data obtained from these short duration tests using the simple one-dimensional steady-state radial flow equations described in Reference 5. These estimates assumed an unsaturated formation.

Formation permeability and pore pressure values were determined from the brine test data in an iterative manner using numerical solutions to the appropriate diffusion equations as described in Reference 5. In the analysis, the test region pressure history was calculated as a function of time using selected values for formation permeability, porosity, and pore pressure. When the calculated pressure history corresponded to the measured data, the assumed formation properties were taken as correct.

All brine test analyses assumed radial flow into the borehole from a completely brine saturated formation with a porosity of 0.001. For most calculations, the test region was assumed to be filled with brine having a 3.26×10^3 MPa bulk modulus. Some calculations were performed for the DPD02 tests which assumed a partially gas-filled test region. In those calculations the test region fluid compressibility was taken as that of the brine/gas mixture.

Borehole closure will, in the absence of flow, increase the test region pressure. These pressure changes are generally insignificant for a gas filled test region. However, for a brine flow test it may be necessary to consider closure

effects when estimating formation permeability from the measured test region pressure response.

Borehole closure effects have been considered in some of the analyses presented in this report. Closure rates were determined using the relation between closure, borehole radial stress, and far field stress, which is suggested in References 6 and 7. Results contained in these two references indicate that the change in borehole radius (R) with time may be described by

$$\frac{1}{R} \frac{dR}{dt} \approx -\alpha \left[\frac{P_o - P_h}{P_o - P_\infty} \right]^5 \quad (1)$$

where α , P_o , P_h and P_∞ represent the normalized closure rate, far field stress (assumed hydrostatic), internal radial stress applied to the borehole surface, and ambient pressure at the free surface of the drift, respectively. The normalized closure rate was taken as

$$\alpha = 20 \text{ microstrains/day.} \quad (2)$$

This rate was determined from measurements of drift closure provided in Reference 8. Note that 20 microstrains/day is approximately the same order as that measured by SNL (Reference 9, 10, 11) in 91 cm diameter boreholes.

4.2 DATA EVALUATION

The tests described in this report measured a pressure buildup with time which occurred when the test region shown on Figure 2 was shut-in or isolated. Two parameters were inferred from the resulting data. The asymptotic steady-state pressure value was taken as a measure of the local pore fluid pressure. This pore fluid pressure value was then used together with the time dependent

pressure response to estimate a formation permeability under the assumption that the connected pore space was completely saturated.

The major uncertainties in the interpreted data are not associated with the accuracy of the measurement system as has been discussed in Reference 5. Instead, major uncertainties are introduced by the assumptions which must be used to interpret the data.

The asymptotic steady-state pressure was assumed to represent the pore pressure. This should be correct, independent of formation saturation, provided the measurement system does not leak, and that the predominant pressure response occurred as a result of fluid migration rather than hole closure. If Equations (1) and (2) correctly represent borehole closure, then as will be shown in Section 5, the inferred pore pressure values are independent of these closure effects.

There was no evidence of either packer bypass flow or packer system leakage during the DPD02 test. There was also no evidence of packer system leakage during the DPH01 test. However, as previously discussed in Section 3, it cannot be determined whether there was flow past the DPH01 guard region packer. If such flow did occur, then the actual pore pressure would be higher than the stated value. For example, an approximate 0.5 cc/day leak from the guard region would lower the final measured steady-state asymptotic pressure from about 10 MPa to 8 MPa.

Determination of formation permeability is based upon the inferred pore pressure value and the measured test region time dependent pressure response. Uncertainties in the pore pressure therefore lead to uncertainties in the permeability value.

The various permeability values presented in this report values were determined assuming a fully saturated uniform porous formation and a brine filled or brine/gas filled test region. There is, at this time, no information available concerning the level of saturation or the validity of the uniform porous formation

(i.e. in contrast to a porous/fractured formation) assumption. The effect on the inferred permeability values of a brine/gas filled test region is considered in Section 5.

There are other effects which could influence the estimated permeability values such as threshold pressure effects, Klinkenberg effect on gas tests, and precipitation/dissolution effects. These are discussed in Reference 4.

5. TEST RESULTS

Test results are presented, compared to calculated pressure histories, and discussed in this section. Additional comparisons between measured and calculated results are presented in Appendix B. These additional results demonstrate the sensitivity of the calculated pressure responses to selected values for the formation permeability, the formation porosity, and the test region gas fraction.

It can be seen in Appendix B that the calculated pressure histories are quite insensitive to the low porosity values used for these studies, however they are quite sensitive to changes in the selected permeability and the test region gas fraction.

Zero time for the calculated pressure histories presented in this report is the date of hole completion. The holes were assumed to remain open during the approximate 44 day period prior to initiation of the brine flow tests. The effect of neglecting the open hole period on the calculated pressure histories is illustrated in Appendix B. The local pore pressure distribution changes during the open hole period as a result of flow into the borehole.

5.1 DPH01 TEST RESULTS

A comparison of the calculated and measured DPH01 test region pressure histories is shown on Figure 10. The calculated and measured histories are seen to compare favorably throughout the 199 day shut-in period assuming a formation permeability of 10^{-9} darcy, a porosity of 0.001, and a free field pore pressure of 8.2 MPa. Also shown are calculated pressure histories for assumed permeabilities of 10^{-8} and 10^{-10} . These graphically illustrate the sensitivity of the match between calculated and measured pressure histories.

There was little attempt made to calculationaly match the measured pressure increase which occurred following the test region vent at 212 days. As

Figure 10. Comparison of the measured DPH01 test region pressure history with that calculated assuming brine inflow but no borehole closure.

shown on Figure 10, the selected formation properties which match the 212 day history give a pressure recovery rate which is more rapid than that measured. This increased rate could be due to the presence of trapped gas within the borehole, or due to system compliance effects. These effects were not investigated during this work.

The test region pressure buildup, calculated to result from hole closure in the absence of flow, is shown on Figure 11. If the Equation (2) ambient pressure closure rate, and the Equation (1) closure rate sensitivity to pressure are correct, then in the absence of flow, borehole closure could force the DPH01 pressure to increase to about 6.1 MPa during the 199-day shut-in period.

A comparison of the measured test region pressure buildup with that calculated to occur as a result of brine inflow plus hole closure is shown on Figure 12. Calculated and measured results are seen to compare favorably assuming the same formation parameters used to obtain the Figure 10 results. In effect, borehole closure, as defined by Equations (1) and (2), does not influence the formation permeability or pore pressure values inferred from the DPH01 test data.

Figure 13 shows the calculated brine flow to an open 10 cm diameter hole assuming the formation properties shown on Figure 10. The flow is allowed to start immediately after hole completion. The inflow approaches an approximate rate of 10^{-2} cc/day per cm of hole length within a few days. This inflow compares favorably to the measured open hole inflow rate of Reference 12, obtained by a humidity monitoring technique, and the inflow rate of Reference 13 determined using a bailing technique.

Fluid was removed from the borehole DPH01 test and guard regions after the 199 day shut-in period. During the process of lowering the test region pressure from 7.9 MPa to 3.0 MPa and the guard region pressure from 7.7 MPa to 3.4 MPa, a total of 57 cc of fluid was removed from the test region while 41 cc of fluid was removed from the guard region. Assuming an absolutely stiff system, and a 3.26×10^3 MPa brine compressibility, It is estimated that 29 cc

Figure 11. Comparison of the measured DPH01 test region pressure history with that calculated assuming the pressure increase results only from hole closure.

Figure 12. Comparison of the measured DPH01 test region pressure history with that calculated assuming the pressure increase results from both brine inflow and hole closure effects.

Figure 13. Calculated brine flow to an open 10 cm diameter borehole from a saturated formation having an 8.2 MPa free field pore fluid pressure.

of fluid should be removed from the test region and 3 from the guard region to match the pressure decrease. During this removal procedure, the packer pressure was reduced by 2.0 MPa, hence there would be some associated packer deformation. However, packer deformation cannot account for the excess removed fluid.

One possible explanation for the disparity between the measured and anticipated fluid outflow revolves around the presence of a small amount of gas in the borehole. Recall that DPH01 is a horizontal borehole and that prior to filling the test and guard regions with brine, gas was evacuated from these regions using a vacuum pump. The vacuum pump may not, however, have been able to remove all of the gas contained in the test and guard regions. If, for example, only seven percent of the initial quantity of gas in the borehole remained in the borehole, this amount of air could account for the disparity between the calculated and measured brine removal volumes.

Short-duration, 2.1 MPa pressure, gas flow tests were conducted in borehole DPH01 both before and after performing a brine flow test. Analysis of the May 20, 1986 data shown on Figures 4 and 5 indicate that prior to performing the brine flow tests, gas would flow from the borehole into the surrounding formation at a rate consistent with a permeability of approximately 10^{-8} to 10^{-9} darcy. The January 20, 1987 2.1 MPa pressure gas flow test data shown on Figures 14 and 15 indicate no flow into the formation. This result was to be expected since the formation surrounding the borehole had been subject to a high pressure brine test. Note that the packers were set prior to the May 20, 1986 test and were not deflated until after the January 20, 1987 test.

Initially, the formation would accept gas driven at a 2.1 MPa borehole pressure. However, when the borehole was filled with brine and pressurized to 3.5 MPa, a pressure rise characteristic of potential brine inflow began to occur within 13 days after brine pressurization. The reasons for such disparate gas versus brine behavior are unknown at this time. This behavior could result because of threshold pressure effects, precipitation of solids in the flow channels,

Figure 14. Test region pressure history measured during the January 20, 1987 DPH01 gas flow test.

Figure 15. Guard region pressure measured during the January 20, 1987 DPH01 gas flow test.

flow channel plugging by tiny clay particles observed to be suspended in the brine, a locally unsaturated formation, or other means.

Analyses of the Figure 4 and 5 gas flow test results indicate that approximately two-thirds of the gas leaving the test region goes to the guard region due to packer bypass. This flow is rapid enough so that it can be expected that the test and guard region pressures may be similar during the long duration brine flow test.

5.2 DPD02 TEST RESULTS

A comparison of the calculated and measured DPD02 test region pressure histories is shown on Figure 16. The calculated and measured pressure histories are seen to compare favorably throughout the 144 day shut-in period for an assumed formation permeability of 3.0×10^{-9} darcy, a porosity of 0.001, and a free field pore pressure of 10.3 MPa.

The initial shut-in period shown on Figure 16 began six days after the hole was drilled. After the test region was pressurized with brine and shut-in, the test region pressure continued to increase to about 5.5 MPa after which it rapidly decayed as if the formation had fractured. This initial shut-in period was not considered in the calculated results.

At 212 days into the shut-in test, the test zone was vented and then shut-in. The test zone pressure exhibited the pressure rise shown on Figure 16. Little effort was expended to calculationaly match the measured pressure increase observed to occur following this test region vent. As can be seen on Figure 16, the materials properties yield a pressure recovery rate which is more rapid than that measured. In order to understand this lack of agreement, an effort was made to consider the influence of a partially gas filled test region on the pressure history after 212 days. These calculational results, which are discussed later, do provide a slightly better fit to the pressure recovery data.

The test region pressure buildup, which is calculated to result from hole closure in the absence of flow is shown on Figure 17. If the Equation (2)

Figure 16. Comparison of the measured DPD02 test region pressure history with that calculated assuming brine inflow but no borehole closure.

Figure 17. Comparison of the measured DPD02 test region pressure history with that calculated assuming the pressure increase results only from hole closure.

ambient pressure closure rate, and the Equation (1) closure rate sensitivity to pressure are correct, then as can be seen in Figure 17, borehole closure cannot account for the measured time-dependent pressure buildup observed in borehole DPD02. Note also that since this zone is largely anhydrite, borehole closure effects should be nonexistent.

A comparison of the measured test region pressure buildup with that calculated to occur as a result of brine inflow plus hole closure is shown on Figure 18. Calculated and measured results are seen to compare favorably assuming the same formation parameters used to obtain the Figure 16 results. Since these curves agree closely in both cases, borehole closure, as defined by Equations (1) and (2), does not influence the formation permeability or pore pressure values inferred from the DPD02 test data.

Figure 19 shows the calculated brine flow to an open 10 cm diameter hole assuming the same formation properties shown on Figure 16. The flow is allowed to start immediately after hole completion and is seen to approach an approximate rate of 1.2×10^{-2} cc/day per cm of hole length within a few days. This inflow compares favorably to the measured open hole inflow rate of Reference 12 obtained by a humidity monitoring technique and the inflow rate of Reference 13 determined using a bailing technique.

Fluid was removed from the borehole DPD02 test and guard regions after a shut-in period of 144 days. During the process of lowering the test region pressure from 9.7 MPa to 1.3 MPa a total of 870 cc of fluid was removed from the test region while 41 cc was removed from the guard region. It is estimated that 93 cc of fluid should have been removed from the test region assuming a stiff system, and a brine compressibility of 3.26×10^{-3} MPa. During this fluid removal procedure the test region packer pressure was dropped by 3.0 MPa. Although there would be some packer deformation associated with this pressure drop it is not sufficient to account for the excess fluid removed from the test region.

Figure 18. Comparison of the measured DPD02 test region pressure history with that calculated assuming the pressure increase results from both brine inflow and hole closure effects.

Figure 19. Calculated brine flow to an open 10 cm diameter borehole from a saturated formation having a 10.2 MPa free field pore fluid pressure.

Note that the packers were set prior to the May 20, 1986 test, and were not deflated until after completion of the brine flow test. At that time they were deflated in order to remove brine from the borehole. However, the packer system was not moved prior to the January 20, 1987 test.

A possible explanation for the source of this excess fluid lies in the observation that borehole DPD02 is slanted downward at a 45 degree angle. Prior to filling the test and guard regions of the borehole with brine, gas was evacuated from these regions using a vacuum pump. In addition, once the brine level reached the bottom of the packer, a vent line was opened and brine was circulated in order to attempt to remove any remaining gas. Unfortunately, the small amount of gas which may have remained in the borehole could not account for the disparity between the calculated and measured brine volumes removed. A more likely explanation is that some gas which was injected during the preliminary gas flow test remained in the connected formation void volume surrounding the borehole. The additional compressibility of this brine/gas system could then account for the excess brine removed from the test region. Note that the borehole/formation system would have to contain approximately 10^4 standard cubic centimeters of air or nitrogen to yield the observed volume of fluid removed.

A comparison of the measured test region pressure buildup with that calculated to occur assuming a partially gas filled borehole is shown on Figure 20. Calculated and measured values are seen to compare favorably assuming a formation permeability of 10^{-8} darcy, a porosity of 0.001, a free field pore pressure of 10.3 MPa, and the gas fractions shown on Figure 20. These gas fractions were determined from the brine removal data. For purposes of comparison the best fit obtained with a completely brine filled borehole required a formation permeability of 3×10^{-9} darcy.

Short duration 2.1 MPa pressure, gas flow tests were conducted in borehole DPD02 both before and after performing the brine flow test. Analysis of the May 20, 1986 data shown on Figure 21 indicate that prior to performing the brine flow test, gas would flow from the borehole to the surrounding

Figure 20. Comparison of the measured DPD02 test region pressure history with that calculated assuming brine inflow to a brine/gas filled borehole.

Figure 21. Test region pressure history measured during the June 20, 1986 DPD02 gas flow test.

Figure 22. Test region pressure history measured during the January 20, 1987 DPD02 gas flow test.

formation at a rate consistent with an approximate 4×10^{-7} darcy permeability. A connected formation void space greater than 2×10^4 cc would be required to accept the measured flow from the borehole. Analysis of the January 20, 1987, 2.1 MPa pressure gas flow test data shown on Figure 22 indicate no flow to the formation. This result was expected since the formation surrounding the borehole had been subject to the high pressure brine test.

Approximately 10^3 cc of brine were injected into the formation immediately prior to shut-in of the test region at 67 days as shown on Figure 20. This volume of brine is an order of magnitude less than the connected void volume inferred from the May 20, 1986 gas flow test. Unfortunately, the reasons why the formation would initially accept gas at a 2.1 MPa pressure but would not accept a comparable brine volume at 3.5 MPa remain unknown.

As shown in Appendix A there was negligible flow to the borehole DPD02 guard region during the gas flow tests. There was some guard region pressure buildup during the brine flow tests. However, the rate was small compared to either that of the test region or to the rates observed in borehole DPH01. Note that the borehole DPD02 test region intersected Marker Bed 139 while the guard region was located in competent salt.

5.3 DPH02 TEST RESULTS

A brine flow test was conducted in borehole DPH02. Unfortunately a small leak was found to exist in the test region pressure monitoring line at a connection located within the handling sub at an approximate 5 meter borehole depth. This leak was repaired but not retested after the test had progressed 96 days. Data obtained subsequent to this fix indicate the borehole DPH02 test region pressure did increase after shut-in. No attempt was made to determine pore pressure or formation permeability values from the DPH02 test data, since they were neither as extensive nor as unambiguous as those data obtained in DPD02. The data are presented in Appendix A.

6. CONCLUSIONS

Data obtained during the brine flow tests indicate that competent halite within the WIPP horizon exhibits an estimated formation pore pressure of 8.3 MPa. These data further indicate that the Marker Bed 139 region exhibits an estimated pore pressure of 10.3 MPa. Inherent in these estimated pore pressures is the assumption that hole closure does not occur at a rate which is significantly faster than 20 microstrains/day. It was also assumed there was no brine leakage from the test region along the borehole/packer interface or from the measurement system. If leakage did occur the actual pore pressure values would be higher than those presented above.

Formation permeability values were determined from the brine flow test shut-in pressure buildup data based on the above mentioned pore pressure values and the assumption that the host formation is completely brine saturated. Under these assumptions the data are consistent with a competent halite permeability of 10^{-9} darcy and a Marker Bed 139 region permeability of approximately 10^{-8} darcy. All data were consistent with a formation porosity of 0.001. Note, however, that these data are not particularly sensitive to the absolute porosity value and should not therefore be used to infer porosity.

Prior to performing the brine flow tests, short duration 2.1 MPa pressure gas flow tests were performed. During those tests the competent halite accepted flow at a rate consistent with a permeability of approximately 10^{-8} darcy. The Marker Bed 139 region accepted flow at a rate consistent with a permeability of approximately 4×10^{-7} darcy. These permeability values were inferred assuming an unsaturated formation possessing a porosity of 0.001. Subsequent to performing the brine flow tests, gas flow tests were performed. During these tests the formation would not accept gas driven at a test region pressure of 2.1 MPa.

Apparently those flow channels which enabled gas to flow out of the borehole at a 2.1 MPa test region pressure cannot be the same flow channels

through which brine entered the borehole since brine pressures approach free field values of 8.3 or 10.3 MPa. The reasons for the very different gas flow and brine flow test responses remain unknown.

Numerous explanations for the observed results exist. The simplest may be that either as a result of precipitation or possible plugging by fine particulates within the brine, the initial brine flow served to close the gas flow channels. Subsequent pressure buildup resulted from borehole closure and/or brine inflow which occurred at so low a rate that it could not be detected during the gas flow tests.

In summary, two brine flow tests were performed. While the data can be interpreted to yield free field pore fluid pressure and formation permeability values, the results are not conclusive. Additional confirmatory testing in other boreholes would be desirable. Specifically, borehole tests in which pressure buildup is measured along with borehole closure rate would provide strong confirmatory evidence for the interpretation of pressure buildup in terms of pore pressure.

REFERENCES

1. Peterson, E. W., Lagus, P. L., and Stormont, J. C., "Permeability Measurements at the Waste Isolation Pilot Plant (WIPP)", Proceedings of the Waste Management Symposium, Tucson, Arizona, 1986.
2. Peterson, E., Lagus, P., Brown, J., and Kie, K., "WIPP Horizon In-Situ Permeability Measurements", SAND 85-7166, Sandia National Laboratories, Albuquerque, New Mexico, 1985.
3. Stormont, J.C., Peterson, E. W., and Lagus, P. L., "Summary of and Observations About WIPP Facility Horizon Flow Measurements Through 1986", SAND 87-0176, Sandia National Laboratories, Albuquerque, New Mexico, 1985.
4. Peterson, E. W., Lagus, P. L., and Lie, K., "Fluid Flow Measurements of Test Series A and B for the Small Scale Seal Performance Tests", SSS-R-87-8424R1, S-CUBED, San Diego, California, 1987.
5. Peterson, E. W., and Lagus, P. L., "WIPP Horizon In-Situ Permeability Measurements, Permeability Test System", SSS-R-86-7461, S-CUBED, San Diego, California, 1987.
6. Chabannes, C. R., "An Evaluation of the Time-Dependent Behavior of Solution-Mined Cavities in Salt for the Storage of Natural Gas", M.S. Thesis, Department of Mining, Pennsylvania State University, State College PA, 1982.
7. Kelsall, P. C., et al., "Schematic Designs for Penetration Seals for a Reference Repository in Bedded Salt", ONWI-405, Battelle, Columbus, Ohio, 1982.

8. U.S. Department of Energy. Waste Isolation Pilot Plant Design Validation Final Report. DOE-WIPP-86-010, prepared by Bechtel National, October 1986.
9. Labreche, D., and Van Sambeek, L. L., "Evaluation of Test Series B of the Small-Scale Seal Performance Tests," SAND 87-7155, December 1987.
10. Stormont, J. C., and Howard, C. L., "Development, Implementation, and Early Results: Test Series C of the Small-Scale Seal Performance Tests," SAND 87-2203, November 1987.
11. Chakrabarti, S., Patrick, W. C., and Duplanic, N., "Digital Signal Processing of Data From Borehole Creep Closure," 28th US Symposium On Rock Mechanics, June 1987.
12. Nowak, E. J., "Interim Results Of Brine Transport Studies In The Waste Isolation Pilot Plant," SAND 87-0880, May 1987.
13. Nowak, E. J., "Preliminary Results Of Brine Migration Studies In The Waste Isolation Pilot Plant," SAND 86-0720, May 1986.

APPENDIX A MEASURED DATA

This Appendix contains plots of the measured field data used as a basis for the calculations and interpretations presented in the body of this report. These data were originally recorded on a Hewlett Packard Model 3056 Data Logger. A general description of these data is provided in Section 3.

The pressure acquisition system was calibrated in psi units. Note that 14.9 psi is equivalent to 0.1 MPa. and 1 psi equals 6.9×10^{-3} MPa.

Figure A-1. Test region pressure measured during the May 20, 1986 DPH01 gas flow test.

Figure A-2. Guard region pressure measured during the May 20, 1986 DPH01 gas flow test.

Figure A-3. Test region temperature measured during the May 20, 1986 DPH01 gas flow test.

Figure A-4. Test region pressure measured during the DPH01 brine flow test initiated on May 22, 1986.

Figure A-5. Guard region pressure measured during the DPH01 brine flow test initiated on May 22, 1986.

Figure A-6. Test region packer pressure measured during the DPH01 brine flow test initiated on May 22, 1986.

Figure A-7. Guard region packer pressure measured during the DPH01 brine flow test initiated on May 22, 1986.

Figure A-8. Test region temperature measured during the DPH01 brine flow test initiated on May 22, 1986.

Figure A-9. Brine supply pressure measured during the DPH01 brine flow test initiated on May 22, 1986.

Figure A-10. Test region pressure measured during the January 20, 1987 DPH01 gas flow test.

Figure A-11. Guard region pressure measured during the January 20, 1987 DPH01 gas flow test.

Figure A-12. Test region temperature measured during the January 20, 1987 DPH01 gas flow test.

Figure A-13. Test region pressure measured during the May 20, 1986 DPD02 gas flow test.

Figure A-14. Guard region pressure measured during the May 20, 1986 DPD02 gas flow test.

Figure A-15. Test region temperature measured during the May 20, 1986 DPD02 gas flow test.

Figure A-16. Test region pressure measured during the DPD02 brine flow test initiated on May 22, 1986.

Figure A-17. Guard region pressure measured during the DPD02 brine flow test initiated on May 22, 1986.

Figure A-18. Test region packer pressure measured during the DPD02 brine flow test initiated on May 22, 1986.

Figure A-19. Guard region packer pressure measured during the DPD02 brine flow test initiated on May 22, 1986.

Figure A-20. Test region temperature measured during the DPD02 brine flow test initiated on May 22, 1986.

Figure A-21. Brine supply pressure measured during the DPD02 brine flow test initiated on May 22, 1986.

Figure A-22. Test region pressure measured during the January 20, 1987 DPD02 gas flow test.

Figure A-23. Guard region pressure measured during the January 20, 1987 DPD02 gas flow test.

Figure A-24. Test region pressure measured during the DPH02 brine flow test initiated on May 22, 1986.

Figure A-25. Guard region pressure measured during the DPH02 brine flow test initiated on May 22, 1986.

Figure A-26. Test region packer pressure measured during the DPH02 brine flow test initiated on May 22, 1987.

Figure A-27. Guard region pressure measured during the DPH02 brine flow test initiated on May 22, 1987.

Figure A-28. Test region temperature measured during the DPH02 brine flow test initiated on May 22, 1987.

Figure A-29. Brine supply pressure measured during the DPH02 brine flow test initiated on May 22, 1987.

APPENDIX B

PARAMETER SENSITIVITY

This Appendix contains plots which compare the measured and calculated test region pressures histories. The sensitivity of the data interpretation to the selected formation permeability, and formation porosity, and test region gas volume can be determined by comparing these Figures.

The calculated pressure histories shown in this appendix do not consider borehole closure effects. The sensitivity of the data to borehole closure can be determined from Figures 10, 11 and 12 and Figures 16, 17 and 18.

With the exception of those pressure histories shown on Figures B-2 and B-8, the zero time for the calculations is either April 9 or 10, 1986. These are the respective dates on which each hole was completed. The holes were assumed to be open during an approximately 44 day period which preceded the May 22, 1986 date at which time the brine flow tests were initiated (i.e., zero time on the Figures).

The calculated DPH01 pressure histories assume a brine filled borehole. The effect of having a partially gas filled borehole is considered as noted on some of the DPD02 calculated pressure histories.

Figure B-1. Comparison of the measured DPH01 test region pressure with that calculated assuming brine inflow but no borehole closure.

Figure B-2. Comparison of the measured DPH01 test region pressure with that calculated assuming brine inflow but no borehole closure. (Compare with Figure B-1 to determine the effect, on the calculated results, of neglecting the approximate 44 day open hole period.)

Figure B-3. Comparison of the measured and calculated DPH01 test region pressures. (Compare with Figure B-1 to determine the effect of changing the permeability from 10^{-9} darcy to 10^{-8} darcy.)

Figure B-4. Comparison of the measured and calculated DPH01 test region pressures. (Compare with Figure B-1 to determine the effect of changing the permeability from 10^{-9} darcy to 10^{-10} darcy.)

Figure B-5. Comparison of the measured and calculated DPH01 test region pressures. (Compare with Figure B-1 to determine the effect of changing the porosity from 0.001 to 0.005.)

Figure B-6. Comparison of the measured and calculated DPH01 test region pressures. (Compare with Figure B-1 to determine the effect of changing the porosity from 0.001 to 0.0005.)

Figure B-7. Comparison of the measured DPD02 test region pressure history with that calculated assuming brine inflow but no borehole closure.

Figure B-8. Comparison of the measured DPD02 test region pressure history with that calculated assuming brine inflow but no borehole closure. (Compare with Figure B-7 to determine the effect, on the calculated results, of neglecting the approximate 44 day open hole period.)

Figure B-9. Comparison of the measured DPD02 test region pressure history with that calculated assuming brine inflow to a brine/gas filled borehole. (Compare with Figure B-7 to determine the effect of a partially gas filled test region.)

Figure B-10. Comparison of the measured and calculated DPD02 test region pressures. (Compare with Figure B-9 to determine the effect of changing the porosity from 0.001 to 0.005.)

Figure B-11. Comparison of the measured and calculated DPD02 test region pressures. (Compare with Figure B-9 to determine the effect of changing the porosity from 0.001 to 0.0005.)

Figure B-12. Comparison of the measured and calculated DPD02 test region pressures. (Compare with Figures B-7 and B-9 to determine the effect of a partially gas filled test region.)

Figure B-13. Comparison of the measured and calculated DPD02 test region pressures. (Compare with Figure B-12 to determine the effect of changing the permeability from 10^{-8} darcy to 10^{-7} darcy.)

Figure B-14. Comparison of the measured and calculated DPD02 test region pressures. (Compare with Figure B-12 to determine the effect of changing the permeability from 10^{-8} darcy to 10^{-9} darcy.)

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