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IN-SITU LEACHING STUDIES OF URANIUM ORES

-- PHASE V

David C. Grant
Principal Investigator

National Mine Health & Safety Academy
National Mine Health & Safety Academy
Learning Resource Center
RESERVE COPY

Prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

by

Westinghouse R&D Center
1310 Beulah Road
Pittsburgh, Pennsylvania 15235

Phase V Final Report
May, 1980
Contract H0262004



Westinghouse R&D Center
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The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines or of the U. S. Government.

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16. Abstract (Limit: 200 words) A laboratory technique for simulating in-situ uranium mining was developed and used to determine the effects of leaching variables on permeability, uranium recovery, leach solution interaction with the ore-aquifer environment, and post-leach chemical leakage. In particular, ammonium bicarbonate, the commonly-used leach solution, was examined in great detail. Agitation leach tests were conducted to examine the effect on ammonium sorption and desorption of clay content, solution and clay ammonium levels, pH, and the type and concentration of other anions and cations in solution. Initial column tests were performed to determine the degree of ore-aquifer interaction that could be expected for various leach solutions; sulfuric acid, and ammonium, sodium, and potassium bicarbonates. Subsequent tests examined various methods to restore the ores by lowering the post-leach chemical leakage. The restoration tests examined the use of reducing agents (e.g., ammonium bisulfite, sodium bisulfite, and sodium sulfite), ore blocking and stabilizing agents (e.g., sodium silicate, aluminum chloride, and magnesium-calcium salts).			
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*and ammonium displacement agents (e.g., aluminum chloride and lanthanum chloride-sulfate).

FOREWARD

This report was prepared by Westinghouse Research and Development Center, Pittsburgh, Pennsylvania 15235 under USBM Contract No. H0262004. The contract was initiated under the Bureau of Mines Metallurgy Program. It was administered under the technical direction of Metallurgy with Mr. D. C. Seidel and Mr. Ivan Nichols acting as the Technical Project Officers. Mr. William Case was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period January 1979 to May 1980. This report was submitted by the author in May 1980.

Invention disclosures based on work presented in this report have been submitted to the Department of Interior, Bureau of Mines. The invention disclosures are related to the following areas:

1. "Chemical and Physical Restoration of Ammoniated Ores Using Sodium Sulfite and Sodium Bisulfite".
2. "Use of Calcium, Magnesium, and/or Sodium Salts to Prevent Ammonium Contamination and Permeability Damage During Ammonium Bicarbonate Leaching of Uranium Ores".
3. "In-Situ Leaching of Uranium Using Potassium Bicarbonate-Carbonate".
4. "Restoration of Leached Ores Using Aluminum Chloride".
5. "Reduction of Post-Leach Leakage and the Stabilization of Permeability Using Sodium Silicate".
6. "Ammonium Removal from Ammonium Bicarbonate Leached Ores Using Sodium Silicate Plus Sodium and/or Calcium Salts".

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SUMMARY

In-situ uranium mining is a process for recovering uranium from relatively small or low-grade ore bodies, which cannot be economically mined by conventional techniques. The process involves passing a lixiviant and oxidant solution through the uranium containing ore body. As the solution progresses through the ore body, the uranium is oxidized from the plus four to the soluble plus six state. The uranium-laden solution is removed from the ore body, and the uranium recovered in a plant on the surface. A laboratory technique for simulating this underground process was developed and used to determine the effects of leaching variables on the permeability, uranium recovery, and ore-aquifer environment, for ores from Texas and Wyoming. Ammonium bicarbonate is the commonly-used leach solution, and as such, was studied in the greatest detail.

In order to complete the total number of tests planned for this phase of the program, it was determined that additional Wyoming ore would likely be required. The new ore obtained was processed and chemically characterized in a manner similar to the old ores. Even though the ore was obtained from the same mining site as the old Wyoming ore and processed in a similar manner, it differed significantly from the old Wyoming ore in particle size distribution, and uranium content and distribution. This led to significant differences between the two ores in permeability, uranium recovery, and ion leakage.

Agitation leach tests were performed to develop a better understanding of the process of ammonium sorption and desorption from ores. The tests provided information on the rate and degree of ore and groundwater ammoniation, which occurs during and after ammonium bicarbonate leaching. The tests showed that ammonium sorption and

desorption occurred relatively rapidly, and were a function of clay content, solution and clay ammonium levels, pH, and the type and concentration of other cations in solution. The oxidant, pressure, and anions in solution (sulfate or chloride) did not significantly influence ammonium sorption or desorption. Using, in part, the information gained from these experiments, column tests were performed to obtain information on the ore-aquifer restoration effort required for in-situ uranium leaching with various leach solutions: sodium bicarbonate, potassium bicarbonate, sulfuric acid, and, in particular, ammonium bicarbonate.

Baseline column tests determined the degree of ore-aquifer contamination that could be expected for the various leach solutions. Subsequent tests examined various methods to restore the ores by lowering the post-leach chemical leakage. The restoration tests examined the use of reducing agents, ore blocking and stabilizing agents, and ammonium displacement agents. The results showed that reducing agents (ammonium bisulfite, sodium bisulfite, or sodium sulfite) can restore permeability, and cause a decrease in chemical leakage. The use of aluminum chloride prior to ammonium bicarbonate leach and the use of sodium silicate during leach were found to reduce permeability damage, but did not affect ammonium sorption and could lower uranium recovery. The addition of magnesium and/or calcium salts to an ammonium bicarbonate leach solution were shown to substantially reduce ammonium sorption and thus reduce post-leach desorption into groundwater. Certain post-leach ammonium displacement solutions (e.g., aluminum chloride, sodium silicate-sodium chloride, or sodium bisulfite) were capable of relatively rapidly removing ammonium from leached ores, which resulted in a significant reduction in ammonium leakage into subsequent groundwater flow. The post-leach use of aluminum chloride, sodium silicate, or lanthanum chloride (sulfate), was also found to reduce the leakage levels of other contaminants (e.g., uranium, selenium, and bicarbonate).

The information obtained from these simulation tests provide for a better understanding of the leaching process. The data indicates what factors likely influence permeability, uranium recovery, the interaction of the leach with the ore-aquifer environment, and the restoration of the ore body. Using this information, conditions can perhaps be chosen to optimize leaching, particularly with ammonium bicarbonate, in terms of permeability, uranium recovery, and environment effects.

1. INTRODUCTION

In-situ leaching is an important method for the recovery of uranium from small or low grade ore deposits because capital and operating costs are relatively low, environmental disturbance is minimal, and the sandstone host is amenable to the leaching technique. The process involves injecting a leach solution into the ore body and recovering the leached uranium from the solution in an above ground plant. The two types of leaches used are a bicarbonate-carbonate solution⁽¹⁾ and sulfuric acid.⁽²⁾ Before the uranium can be dissolved by the leach solution, the uranium must be oxidized to its soluble plus six state. Dissolved oxygen and peroxide are the oxidants commonly used with the bicarbonate-carbonate leach, while peroxide, magnesium dioxide, and ferric iron are used with the acid leach. To improve and to provide a better understanding of the leaching process, a method was needed to study both the chemical and physical phenomena occurring in ore bodies during in-situ leaching.

The major objective of this program has been to develop and demonstrate equipment and a methodology for examining the effects of various operating variables on uranium extraction. The first three phases of this program served to develop and validate a laboratory technique.⁽³⁾ The Texas and Wyoming ores used in this study were examined initially to determine their mineralogical (e.g., uranium, iron, carbonate, etc.) and physical (e.g., particle size distribution, moisture content, etc.) characteristics. Simulation systems using 13-foot long columns for ore packings were then designed and constructed. A packing method was developed for each ore sample which consistently yielded an acceptable water permeability. Experiments were then conducted using leach reagents such as ammonium bicarbonate, potassium bicarbonate, sodium bicarbonate, and sulfuric acid, and two oxidants--hydrogen peroxide and dissolved

oxygen. The tests provided baseline data on uranium recovery and recovery rates and on the permeability changes in an ore bed. In addition, qualitative inferences were made on the chemical and physical phenomena which occur underground. These experiments also demonstrated the desirability of performing agitation leach scoping studies prior to committing an experiment to the columns.

Phase IV was designed to more closely model the in-situ mining practice.⁽⁴⁾ High pressure leaching and a closed cycle process were studied. The closed cycle process is one in which the uranium is removed from the leach solution; the leach solution is then fortified and recirculated. These studies modeled more closely the process practiced in the field. A variety of leachant and oxidant combinations were examined to further validate the model and add to the store of in-situ mining information. Also examined were the effect of reducing the column diameter and length, and of operating the column in a vertical rather than horizontal position. These tests demonstrated the desirability of using the larger diameter (4 in vs. 2 in) and longer columns (12 ft vs. 8 ft) in a horizontal position. In addition, studies were performed to assess the restoration requirement associated with in-situ uranium mining. This preliminary work, which examined ion leakage and permeability changes during a brief post-leach water flow, demonstrated the complexity of the in-situ mining restoration. While providing direction for proceeding to potentially more efficient and effective restoration processes, this work also demonstrated the need for longer duration restoration experiments.

Phase V of the program, described in this report, examined the restoration aspects of in-situ uranium mining. The specific objective was to develop an improved understanding of the equilibrium and kinetic relationships needed to predict the restoration responses of ore bodies that have been leached with various lixiviants. The environmental effects examined were the type and amount of elements dissolved and mobilized with a leach solution, and the interaction of leach solution with the ore body.

One important ore-leach interaction examined in each of the bicarbonate tests was the sorption of the leach reagent cation onto the ore body and the leakage of these sorbed cations into post leach groundwater. Often uranium ore bodies, such as the one tested here, contain cation-exchanging clay fractions. These clays usually carry a net negative charge which is balanced by the sorption of cations. As the mining solution comes in contact with these clays, cations in solution exchange with those on the clay. These sorbed cations can later equilibrate with the naturally occurring cations in groundwater as the water comes in contact with the exchanged clay. Depending on the pre-mining groundwater quality in the ore aquifer, the resulting equilibrated water may require restoration. Ammonium bicarbonate, the reagent most often used commercially, was used in a majority of the tests performed.

The work performed in this phase consisted of the following tasks:

1. Ore acquisition and characterization.
2. Agitation leach tests.
3. Column simulation leach tests.

In order to complete the desired number of tests, it was determined that additional ore may be required. New ore was therefore processed and characterized.

Agitation leach tests were performed to obtain a better understanding of the process of ammonium sorption onto and desorption from ores. The tests provided information on the rate and degree of ore and groundwater interaction by ammonium, and how this potential problem can be approached.

The column studies examined a variety of lixiviants under several different operating conditions. The tests were used to develop baseline data on the kinetic and equilibrium relationships of post-leach restoration operations, and to investigate the effect of variables, such as restoration solution type, concentration, and duration.

2. CONCLUSIONS

2.1 AGITATION LEACH EXPERIMENTS

1. Ammonium sorption and desorption occurs rapidly with equilibrium being very nearly reached within 2 hours after solution-ore contact.
2. Ammonium sorption onto an ore increases with increasing ore-clay content and increasing ammonium solution levels, and decreases as the ammonium fraction of the cationic strength of the feed decreases.
3. The ability of ammonium to sorb onto an ore is dependent upon the cations initially occupying the exchange sites. A higher ammonium sorption will likely occur if sodium is present on the ore rather than the divalent calcium. Calcium typically has a greater affinity for the ore.
4. Ammonium desorption into a given solution decreases with increasing ore-clay content and decreasing ammonium content on the clay.
5. The ability of common groundwater cations to prevent ammonium sorption is of the following order: $Mg^{++} > Ca^{++} > K^+ > Na^+$. That is, the presence of Mg^{++} (at a given cationic strength) in solution will prevent the greatest amount of ammonium from exchanging onto the ore. The magnitude of the ammonium sorption decreases with increasing cationic strength of the added groundwater cation.
6. The ability of common groundwater cations to remove ammonium from ores is of the following order: $Mg^{++} \sim Ca^{++} > Na^+$. The amount of ammonium removed increases with increasing cationic strength.

7. The oxidant (peroxide and dissolved oxygen), pressure changes (1 and 6 atm), and the anion present (sulfate or chloride) do not significantly influence ammonium sorption or desorption.
8. The higher the cationic strength of a given solution, the greater its ability to remove ammonium. The use of trivalent cation solutions (e.g., AlCl_3) are thus very effective at removing ammonium from clays.
9. The ammonium sorption and desorption characteristics observed in the batch agitation tests can be used to predict the ammonium response in column tests. The results of agitation tests have shown good agreement with those obtained in column tests performed under the same conditions.

2.2 COLUMN LEACH TESTS

1. Permeability decline during leaching decreases with decreasing leach oxygen content, at a given ore bed pressure and with increasing ionic strength of the solution.
2. Using a feed that contains oxygen at a concentration greater than the oxygen level that will remain in solution at the pressure of the ore bed, can cause substantial permeability damage.
3. Permeability decline during leaching can reduce the uranium recovery rate.
4. In the experimental systems used, uranium recovery during bicarbonate leaching is reaction and/or mass transfer constrained, and is thus affected by flow rate, or leach solution residence time in the ore bed.
5. Sodium bicarbonate leach solutions can cause much greater permeability damage than ammonium, or potassium, bicarbonate leach solutions. Sodium solutions, in general, seem to have an adverse effect on permeability.

6. Ammonium and potassium bicarbonate leach solutions have very similar leach characteristics, in terms of uranium recovery, permeability, cation sorption during leach, and post-leach ion leakage.
7. If potassium leakage into groundwater has a higher permissible level than ammonium, its use could require significantly less post-leach restoration. Ammonium removal is likely needed after ammonium bicarbonate leaching to obtain the relatively low ammonium solution levels presently being required by governmental agencies.
8. Ion leakage after sulfuric acid leaching can differ significantly from that after bicarbonate leaching. For the Wyoming ore tested, vanadium, iron, and hydrogen ion concentrations remained high after acid leaching, while selenium, uranium, and bicarbonate were high after the bicarbonate leaches.
9. Increasing uranium recovery during the leach reduces the subsequent post-leach uranium leakage into groundwater.
10. Permeability can be improved rapidly in an ore field that has been leached with ammonium bicarbonate and dissolved oxygen (or peroxide) by the injection of a reducing agent; ammonium or sodium bisulfite (or sulfite). The reducing agent likely restores permeability that has been damaged by oxygen gas blockage.
11. Reducing agents, ammonium bisulfite, sodium bisulfite, and sodium sulfite, have the ability to reduce uranium and bicarbonate leakage when used after bicarbonate leaching. The bisulfites also reduce selenium leakage.
12. The use of the reducing agent, sodium bisulfite, after sulfuric acid leaching has the ability to lower the leakage levels of uranium, selenium, arsenic, vanadium, and iron. The solubilities of these chemicals is much lower in their reduced state than when in their oxidized state.

13. The use of 3.0 g/l aluminum chloride prior to an ammonium bicarbonate-peroxide leach reduces the permeability damage that would normally occur, but may cause a slight reduction in uranium recovery.
14. The use of 1.0 g/l sodium silicate during an ammonium bicarbonate-peroxide (or dissolved oxygen) leach can reduce permeability damage, but also reduces uranium recovery by about 20% if used for the entire leach duration. The sodium silicate does not have an adverse effect on recovery if only used for the first 3 to 5 pore volumes of leach.
15. The addition of 1.0 g/l magnesium sulfate and/or calcium chloride to a 1.0 g/l ammonium bicarbonate leach improves permeability and uranium recovery, reduces ammonium sorption during leach by over 50%, and lowers post-leach ammonium leakage into groundwater. The increased cationic strength of the solution by the magnesium or calcium addition is the cause of these benefits.
16. The use of 3.0 g/l aluminum chloride after leaching with 1.0 g/l ammonium bicarbonate-saturated oxygen (45 psig) rapidly improved permeability, reduced uranium and selenium leakage, and in 9 pore volumes removed over 90% of the ammonium sorbed during leaching which resulted in a post-restoration ammonium groundwater leakage of less than 5 mg/l.
17. After leaching with ammonium bicarbonate-saturated oxygen, the use of lanthanum salts at concentrations of 1.0 and 3.0 g/l improves permeability and reduces uranium leakage.
18. The use of 1.0 g/l sodium silicate after an ammonium bicarbonate-peroxide (or saturated oxygen) leach may improve permeability slightly, while reducing uranium leakage to levels less than 1 mg/l.

19. The use of high pH sodium silicate solutions containing additional salts (e.g., sodium chloride) results in improved ammonium removal from ores that have been leached with ammonium bicarbonate.

3. RECOMMENDATIONS

In the numerous tests conducted thus far in this program, factors have been identified which quite likely influence permeability, uranium recovery, chemical interaction of the ore during leaching (e.g., ammonium sorption), and post-leach ion leakage. A logical extension of this work is to now obtain a more quantitative understanding of these factors. That is, to tie the factors together so that leaching and restoration can be quantitatively examined and more effectively optimized. Permeability, uranium recovery, and the environmental effects are interrelated, and all must be understood to effectively deal with any one of them. It is thus considered extremely important that models be developed for the following:

1. Permeability
2. Uranium recovery
3. Ammonium sorption and desorption
4. Ion leakage
5. Chemical restoration

After completing the model development, it would be useful to exercise the models on a new ore. The objective would be to determine how well the models predict the leaching and restoration characteristics of the new ore. Also, having determined with the models and from previous test data what leaching parameters are important and how these parameters can be adjusted to optimize conditions, leaching experiments should be performed under those conditions that have been deemed to be the most desirable. Column tests should thus be performed in order to determine if the following can be reasonably done:

1. Predict leaching response of new ore.
2. Optimize leach conditions.

4. ORE ACQUISITION AND CHARACTERIZATION

In order to complete the total number of tests planned for this phase of the program, it was determined that additional Wyoming ore would be required. Rather than investigating an ore from a different mine site, it was deemed desirable to obtain the ore from the same mining site that the Wyoming ore in Phase I was obtained. It was hoped that the new ore would have leaching characteristics similar to the old ore, so that tests performed on either ore could be compared based solely on differences in the leaching operating conditions (e.g., type of leachant). The new ore was processed and chemically characterized in a manner similar to the old ore.⁽³⁾

4.1 ORE ACQUISITION AND PREPARATION

The Wyoming ore sample was acquired from the pit of the Shirley Basin Mine of Utah International. The 1.5 tons of ore were placed in drums and shipped to the Colorado School of Mines Research Institute (CSMRI) for size reduction, blending, and chemical analysis.

At CSMRI, the 1.5 ton sample was spread over the floor and partially dried. The sample was then screened at 10 mesh. The plus 10 mesh product was then crushed using a jaw crusher-hammer mill in closed circuit with a vibrating screen fitted with a 10 mesh screen deck. A head sample of the minus 10 mesh product was obtained using an automatic sample cutter. This 150-200 lb head sample was blended by coning and quartering, then split into two halves. One half was shipped to the U.S. Bureau of Mines in Salt Lake City, Utah. Two 2,000 gram portions were split from the second half; one portion for screen size analysis, and one for chemical analysis.

The 1.5 tons of minus 10 mesh product was blended using a small front end loader, and bagged in 50 pound lots using double lined

plastic bags. These bagged samples were placed in seven 55 gallon drums and then shipped to the Westinghouse Research and Development Center in Pittsburgh, Pennsylvania.

The new ore received from CSMRI was not as dry as the ore received in the earlier phase of the program. The new ore had a moisture content of about 6% compared to 2% for the old ore. The ore was so moist that each 50 pound bag of ore required 48 hours of air drying before the ore could be packed in the column using the ore packing method developed in Phase I of this program. It is likely that CSMRI did not air dry the new ore as long as the old ore, thus causing the moisture content differences.

4.2 ORE CHARACTERIZATION

A dry screen analysis, down to 325 mesh, was made of the minus 10 mesh head sample. Although the ore received at the R&D Center had a high moisture content, CSMRI stated the ore used in the screen analysis was dry. The results of the particle size distribution for this ore (Wyoming II) and for the previously obtained ore (Wyoming I) are given in Table 4.1 and shown graphically in Figure 4.1. The size distribution for the two ores differs slightly. The Wyoming I ore has a greater percentage (50% vs. 37%) of large particles (+28 to -10 mesh). The Wyoming II ore has a greater percentage (44% vs. 33%) of medium particles (+100 to -28 mesh), and a slightly higher fraction (19% vs. 17%) of small particles (-100 mesh).

It is known that particle size distribution affects the permeability and the kinetics of the leaching process. The differences in the particle size distribution between the two ores may therefore result in differences in their leaching and permeability characteristics. The greater amount of smaller particles is likely to result in a lower permeability for the new Wyoming ore.

It was also found in the earlier phases of this program that a wide particle size distribution generally results in a more compact packing.

TABLE 4.1

Summary of the Screen Size Analysis
Results of the New and Old Wyoming Ores

(Tyler)	Mesh	Wyoming I* Dry Wt. %	Wyoming II° Dry Wt. %
- 10	+ 14	9.3	8.7
- 14	+ 20	25.1	15.1
- 20	+ 28	16.0	13.0
- 28	+ 35	9.6	12.8
- 35	+ 48	8.4	13.4
- 48	+ 65	7.7	10.1
- 65	+100	7.4	7.9
-100	+150	5.0	4.5
-150	+200	4.0	3.4
-200	+270	1.9	1.2
-270	+325	0.7	1.4
-325		4.9	8.5

* Obtained from Shirley Basin on April 12, 1976.

° Obtained from Shirley Basin on December 8, 1978.

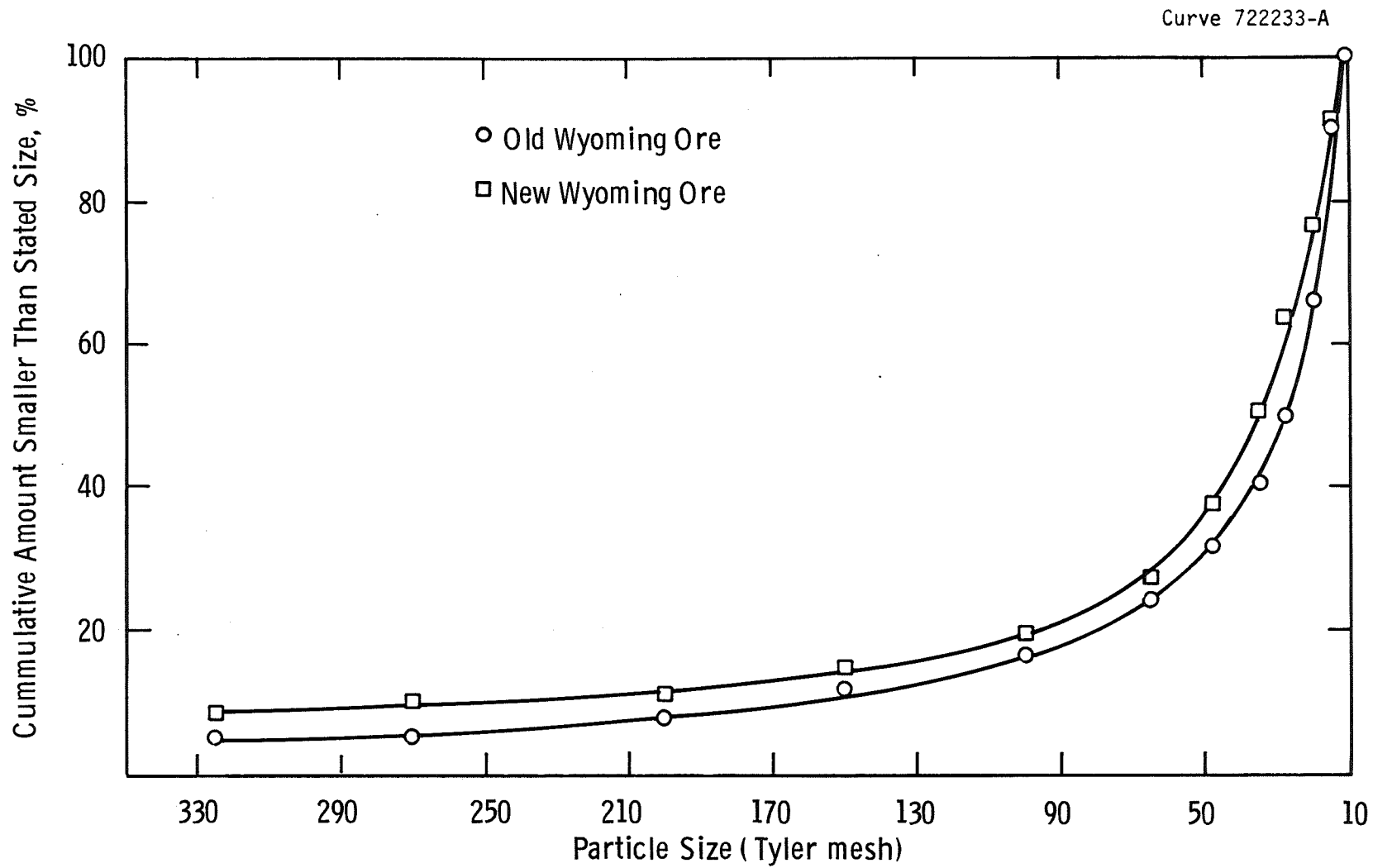


Fig. 4. 1 — Particle size distribution for new and old Wyoming ores.

Insufficient bed compaction results in an instability of the ore bed permeability leading to channelling or even a complete packing breakdown. The distribution of the new ore, like the old ore, should be sufficiently wide to result in a compact packing.

The chemical analyses performed on the Wyoming I and Wyoming II ores for uranium, calcium, molybdenum, iron, vanadium, sulfates, carbonates, total sulfur, and chlorides are given in Table 4.2. The most significant difference between the two ores is the much lower uranium content of the new ore. The uranium distribution for the two ores is given in Table 4.3. It is known that the uranium distribution in the ore affects the chemical behavior of the packing. The uranium in smaller particles should be more accessible to the leach solution than that in larger particles. Because of the greater resistance to mass transfer in the large particles and due to the likely less accessibility of the uranium, a greater distribution of uranium in the larger particles will exhibit a longer tailing on the depletion front rather than a well-defined breakthrough. The greater distribution of uranium in the smaller particles of Wyoming II could therefore result in a more rapid and greater percentage recovery than that obtained with Wyoming I under similar leach conditions.

Because of the physical (particle size distribution) and chemical (uranium concentration and distribution) differences between the new and old ore, it was decided to use the old ore in as many of the tests in this phase as possible. Previous tests done on this ore could be compared more reasonably with tests done on the same ore in this phase. Tests performed on the new ore did show variations due to ore differences rather than to the changes in operating conditions.

TABLE 4.2

Summary of the Chemical Analysis
for the New and Old Wyoming Ores

Chemical	Wyoming I Wt. %	Wyoming II Wt. %
U_3O_8	0.105	0.046
CaO	1.12	0.63
MoO_3	0.001	<0.001
Fe (total)	0.94	1.36
V_2O_5	0.014	0.001
SO_4	0.005	0.06
CO_3	1.09	<0.3
S (total)	0.33	0.40
Cl	--	<0.05

TABLE 4.3

 U_3O_8 Distribution in New and Old

Wyoming Ores

Screen Product (Tyler) Mesh	Wyoming I		Wyoming II	
	U_3O_8 wt. %	Percent Distribution U_3O_8	U_3O_8 wt. %	Percent Distribution U_3O_8
Feed (analyzed)	0.091		0.046	
Feed (calculated)	0.089	100	0.047	100
+20	0.048	18.6	0.020	10.2
-20 +48	0.071	27.2	0.037	31.0
-48 +65			0.043	9.3
-65 +100	0.152	54.2	0.050	8.5
-100			0.101	41.0

5. AGITATION LEACH TESTS

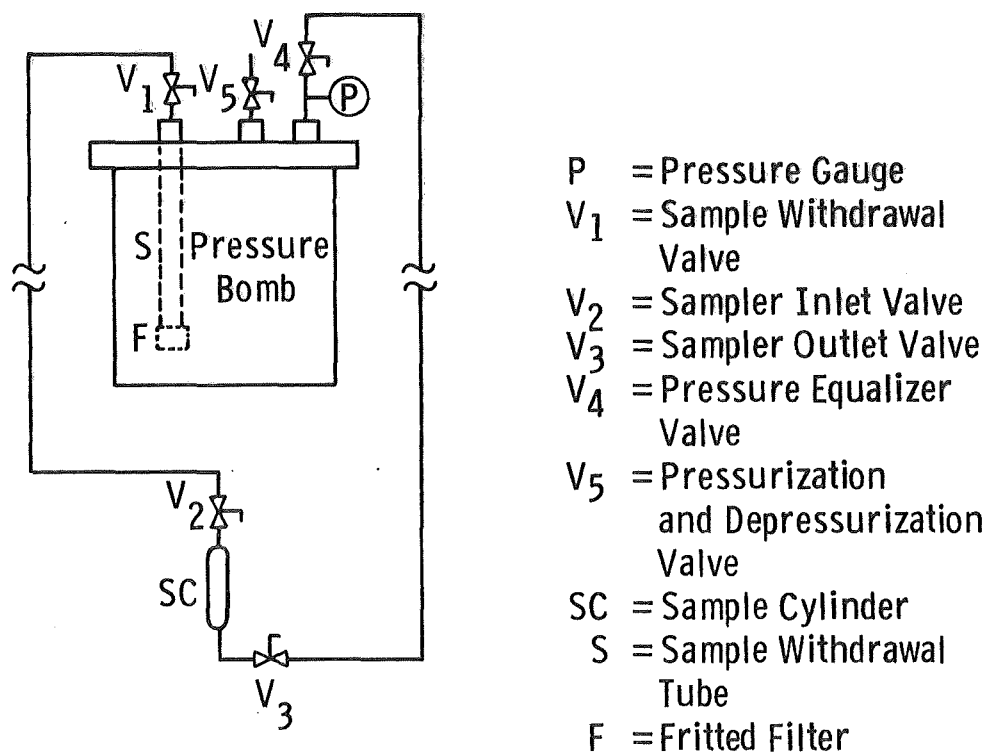
The objective of the agitation leach tests was to develop a better understanding of the process of ammonium sorption and desorption from ores. These tests provide information on the rate and degree of ore and groundwater ammoniation. The test results obtained are used as guidelines for the column simulation leach tests performed later in the program.

The agitation leach tests sought to determine the equilibrium between ammonium in solution and ammonium on the ore under various conditions. Thus the tests should be performed at the temperature and pressure conditions of the actual underground ore body. However, column studies carried out in Phase IV of this program showed no significant difference in ammonium sorption characteristics when performed at high or low pressures. Initial agitation leach tests were performed at high (6 atm) and low (1 atm) pressures to make certain that no significant difference did exist. All additional tests were done at low pressure.

Ammonium bicarbonate was used as the ammoniating agent in all of the tests. Although no difference in ammoniation could be noted between peroxide and dissolved oxygen in column tests performed in Phase IV, initial tests were performed using peroxide, dissolved oxygen, or no oxidant to make certain that no differences did exist. All future tests requiring oxidant used only peroxide, because it can be used at low pressures.

5.1 EXPERIMENTAL METHOD

The agitation leach tests were conducted using 100 g of dry ore and 300 ml of solution. The high pressure leach experiments were carried out in the Carpenter 20 alloy steel vessels obtained in Phase IV.⁽⁴⁾ The vessels, shown schematically in Figure 5.1, are rated for operation



Sampling Procedure:

- Purge and Pressurize Sample Cylinder with Nitrogen
- Connect Sample Cylinder to Pressure Bomb as Shown
- Open Valves V₁, V₂, V₃, and V₄
- Fill Sample Cylinder
- Shut all Valves and Separate the Sample for Transfer

Fig. 5.1 – Schematic diagram of high pressure agitation leach bomb and sampling equipment

up to 2000 psig and are equipped with a valve for pressurizing and depressurizing, a valve for solution sampling, and a pressure gauge. In tests requiring peroxide as the oxidant, the leach vessels were pressurized with 6 atm of nitrogen. In those tests where dissolved oxygen was desired, the vessels were pressurized with 6 atm of oxygen. The vessels were designed to allow sampling of the solution phase without depressurizing the vessel. This was done to prevent the loss of oxygen and the decomposition of peroxide that would result if the vessel depressurized. During sampling, the sampling valve was opened and the solution flowed by pressure from the pressurized bomb to the unpressurized sample bottle. A fritted filter located in the vessel at the end of the solution withdrawal tube prevented any significant ore loss during sampling. The mixture of ore and solution were well agitated during testing using a variable speed shaker table.

The low pressure agitation leach tests were carried out in stoppered 500 ml Erlenmeyer flasks at ambient pressure and temperature. The low pressure tests were agitated using a wrist action variable speed shaker. Sampling was accomplished by decanting off the desired amount of solution, after allowing the ore to settle by stopping the agitation.

A majority of the tests (both high and low pressure) were of 24 hour duration. Samples, when noted for a given series of tests, were taken at 2, 6, and 24 hours. The sample solutions were taken in 30 ml glass bottles, which were completely filled with solution to hopefully prevent any ammonia loss to the air. Certain tests were conducted for 72 hours, with samples taken at 24, 48, and 72 hours. These tests were done to determine any effects of long-term contact time.

At the end of each test, the ore was separated from the solution by filtration or by centrifuging. Centrifuging the samples was often required because of slow filtration rates. The ore was then washed with 300 ml of a 80-20 methanol-water mixture, which was used to prevent the removal of any sorbed ammonium from the ore. The dry weight of ore residue and its ammonium content were determined for each test. The

ammonium content and volumes of all solutions were measured to obtain an ammonium material balance on each test.

The analysis of the solution for ammonium was done using Kjeldahl distillation. The ammonium content of the ore was estimated by solubilizing the sample and analyzing the resultant solution using Kjeldahl distillation.

5.2 AGITATION TEST RESULTS

5.2.1 Series I - Ammonium Sorption Equilibrium and Kinetics

The objective of this series of tests was to examine the ammonium sorption kinetics and equilibrium as a function of the ammonium bicarbonate feed concentration, the oxidant, and the pressure. The ammonium bicarbonate concentrations used were 1.0, 2.0, and 3.0 g/l. The tests examined the effect of 0.5 g/l peroxide, 6 atm oxygen, and no oxidant. Test duration was 24 hours, with samples taken for analysis at 2, 6, and 24 hours. Spot check tests were also done with samples taken at 24, 48 and 72 hour retention times. The tests employed the -28 mesh Wyoming and Texas ore samples acquired in the Phase I of the study.

The results of the tests are presented in Table 5.1 for Wyoming ore and in Table 5.2 for Texas ore. The tables list an ammonium ore concentration based on solution analyses, which was used to check the analysis on the final ore residue (which is also listed in the tables). The ore ammonium concentration based on solution analyses was determined by measuring the decrease in the ammonium feed concentration, which was also analyzed. The ammonium lost from solution was assumed to be due to sorption by the ore. Ammonia gas could also have been lost to the air during agitation; however, the typically good agreement ($\pm 10\%$) between the ore ammonium levels determined by changes in solution levels and the final ore analysis indicates that ammonia lost to the air was very small.

TABLE 5.1

Ammonium Sorption Equilibrium and Kinetics

Wyoming Ore

Test No.	Test Conditions				[NH ₄ ⁺] mg/ℓ sol. at t ₁ *	[NH ₄ ⁺] mg/ℓ sol. at t ₂ *	[NH ₄ ⁺] mg/ℓ sol at t ₃ *	Final [NH ₄ ⁺] ore	
	Pressure, atm	NH ₄ HCO ₃ g/ℓ	H ₂ O ₂ g/ℓ	O ₂ atm				Sol. • mg/g	Ore ⁺
1	6	1.0	0.5	--	122	109	104	0.38	0.38
2	6	1.0	--	6	118	105	102	0.38	0.39
3	6	2.0	0.5	--	234	234	225	0.62	0.77
4	6	2.0	--	6	230	227	221	0.64	0.66
5	6	3.0	0.5	--	395	386	351	0.90	1.09
6	6	3.0	--	6	377	369	348	0.91	0.84
7	1	1.0	0.5	--	114	110	100	0.39	0.38
8	1	2.0	0.5	--	253	241	222	0.69	0.70
9	1	3.0	0.5	--	394	384	354	0.98	0.98
10	1	1.0	No oxidant		115	117	111	0.38	0.31
11	1	2.0	No oxidant		249	240	219	0.63	0.65
12	1	3.0	No oxidant		387	380	354	1.01	1.06
13	1	2.0	0.5	--	248	230	213	0.72	0.75
14	1	2.0	No oxidant		240	227	213	0.72	0.71

* For tests 1 - 12, t₁ = 2 hr., t₂ = 6 hr., and t₃ = 24 hr.
 For tests 13 & 14, t₁ = 24 hr., t₂ = 48 hr., and t₃ = 72 hr.

• - NH₄⁺ ore level based on changes in
 NH₄⁺ solution concentration.

+ - NH₄ ore level based on final
 analysis of ore.

TABLE 5.2

Ammonium Sorption Equilibrium and Kinetics
Texas Ore

Test No.	Test Conditions				$[\text{NH}_4^+]$ mg/l sol. at t_1^*	$[\text{NH}_4^+]$ mg/l sol. at t_2^*	$[\text{NH}_4^+]$ mg/l sol. at t_3^*	Final $[\text{NH}_4^+]$ ore	
	Pressure, atm	NH_4HCO_3 g/l	H_2O_2 g/l	O_2 atm				mg/g Sol.	Ore
1	6	1.0	0.5	--	147	138	116	0.32	0.31
2	6	1.0	--	6	152	134	116	0.32	0.26
3	6	2.0	0.5	--	279	257	247	0.64	0.59
4	6	2.0	--	6	293	254	241	0.65	0.59
5	6	3.0	0.5	--	446	412	385	0.75	0.80
6	6	3.0	--	6	445	407	383	0.76	0.80
7	1	1.0	0.5	--	146	142	114	0.33	0.35
8	1	2.0	0.5	--	298	267	247	0.65	0.61
9	1	3.0	0.5	--	461	426	385	0.86	0.82
10	1	1.0	No Oxidant		140	130	106	0.35	0.33
11	1	2.0	No Oxidant		279	265	225	0.69	0.62
12	1	3.0	No Oxidant		432	407	373	0.90	0.79
13	1	2.0	0.5	--	256	248	235	0.70	0.64
14	1	2.0	No Oxidant		245	239	238	0.70	0.64

*For tests 1-12, $t_1=2$ hr., $t_2=6$ hr., and $t_3=24$ hr.

For tests 13 & 14, $t_1=24$ hr., $t_2=48$ hr., and $t_3=48$ hr.

The results indicate that most of the ammonium sorption is relatively rapid. About 80 to 90% of the total sorption that will occur in 24 hours takes place within 2 hours. A relatively slow sorption occurs over the remainder of the test. The rate of sorption decreases because as the NH_4^+ content of the ore increases, there is less of a driving force for the NH_4^+ to go from the solution to the ore. Also, perhaps the latter slow sorption is because the NH_4^+ must reach less accessible exchange sites on the clay, and thus diffusion within ore particles becomes important. The long duration tests for Wyoming ore indicate that approximately 10% more ammonium will be sorbed as the contact time is extended from 24 to 72 hours. The 24 and 72 hour tests performed under similar conditions (Test Nos. 3 and 13, and 11 and 14) had very nearly identical final ammonium ore and solution contents.

Ammonium sorption rate and the ammonium equilibrium ore concentration were shown to increase with increasing ammonium feed concentration. Because the ammoniation is thought to be a stoichiometric reaction and would, therefore, be governed by the laws of mass action, this concentration effect was expected. The ammonium ore equilibrium values as a function of ammonium solution concentrations are shown in Figure 5.2. Each point plotted is the arithmetic average of all final data values (listed in tables) collected for a given NH_4HCO_3 feed level. The results show that for a given equilibrium ammonium solution level, the ammonium content of Texas ore was below that of Wyoming ore. This is likely due, in part, to the fact that Texas ore has a lower clay content than Wyoming ore (6.9 wt% vs. 9.1 wt%). The clay portion of the ore is known to be involved in the ammonium exchange process.⁽⁵⁾ Therefore, by decreasing the amount of clay, the number of exchange sites is decreased and thus the amount of ammonium that can be taken up by the ore.

Although the effect of clay content on ammonium sorption is dealt with in much greater detail in Section 5.4, its effect can also be seen

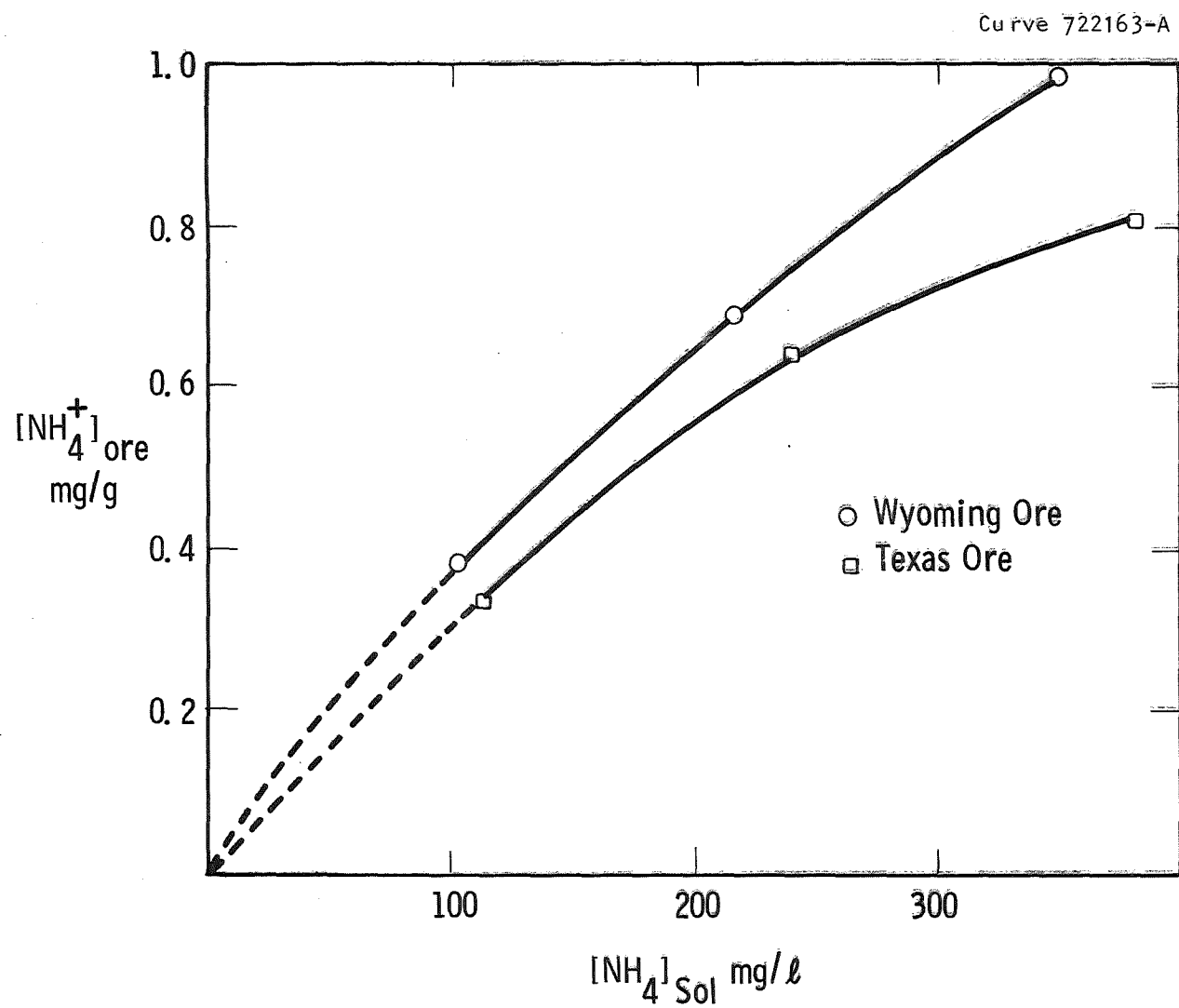


Fig.5. 2-Ammonium ore sorption as a function of ammonium solution concentration

by examining the data obtained here. The ratio of the ammonium concentration on the clay to the ammonium concentration in solution, given in Table 5.3, is shown to be very similar for the two ores at a given ammonium solution level. This is in contrast to the differing values given in Table 5.3, for the ratio of ammonium concentration on the ore to the ammonium concentration in solution for the two ores. The results thus indicate that ammonium sorption is a function of the ore clay content.

Further examination of the results indicates that the ammonium clay-solution ratio decreases with increasing ammonium exchange onto the clay, and that the ratio is higher for the Texas ore, particularly at the ammonium solution level of 220 mg/l. These findings can perhaps be explained by the relative amounts of sodium and calcium occupying the ore exchange sites initially. Given in Table 5.4 are the results of agitation tests performed on 100 g samples of each ore with 300 ml of 4.0 g/l ammonium chloride to determine the initial cation content of the ores. The large excess of ammonium used (75 meq/l) was considered sufficient to displace a majority of the cations initially occupying the exchange sites on each ore's clays. As the results show, sodium occupies a much greater percentage of the exchange sites on Texas ore than on Wyoming ore. The exchange of the monovalent ammonium will more readily occur with the monovalent sodium than with the divalent calcium.⁽⁶⁾ That is, the ammonium will exchange with the sodium first and to a larger degree. At the lowest ammonium feed level (225 mg/l) in the Series I tests, ammonium is likely exchanging with mainly the sodium on both ores, which results in a similar ammonium clay/solution ratio. At the middle ammonium feed level (450 mg/l), much of the ammonium is likely still exchanging the sodium on the Texas ore, but is now exchanging with calcium on the Wyoming ore, which gives a lower ammonium clay/solution ratio for the Wyoming ore. As the ammonium feed level is increased to its highest feed level (675 mg/l), the additional ammonium exchange is now occurring with calcium for both ores, which produces similar ammonium clay/solution ratios. The decrease in the ammonium clay/solution ratio with increasing ammonium feed concentration is likely due to the switch in ammonium exchange from displacing sodium to displacing calcium.

TABLE 5.3

Ammonium Sorption Concentration on the Ore and Clay
As a Function of the Ammonium Solution Concentration

Ore Type (% clay)	$[\text{NH}_4^+]_{\text{sol}}$ mg/l	$[\text{NH}_4^+]_{\text{ore}}$ mg/g	$[\text{NH}_4^+]_{\text{clay}}$ mg/g	$\frac{[\text{NH}_4^+]_{\text{ore}}}{[\text{NH}_4^+]_{\text{sol}}}$	$\frac{[\text{NH}_4^+]_{\text{clay}}}{[\text{NH}_4^+]_{\text{sol}}}$
Wyoming (9.1%)	104	0.38	4.2	0.0037	0.040
Texas (6.9%)	113	0.33	4.8	0.0029	0.042
Wyoming (9.1%)	219	0.67	7.4	0.0031	0.034
Texas (6.9%)	239	0.67	9.7	0.0028	0.041
Wyoming (9.1%)	352	0.95	10.4	0.0027	0.030
Texas (6.9%)	382	0.82	11.9	0.0021	0.031

TABLE 5.4

Cations Present on the Clay Exchange Sites
Of Wyoming and Texas Ores Prior to Leaching

Ore	Ca ⁺⁺ meq/l	Na ⁺ meq/l	Fraction of Exchange Sites Occupied by Na ⁺⁺ [Na ⁺⁺ /(Ca ⁺⁺ + Na ⁺)]
Wyoming	366	9	0.024
Texas	226	66	0.226

The test results in this series of tests also indicated that ammonium sorption was not a function of the presence of dissolved oxygen or peroxide, nor of pressure. For ease of experimentation, all future tests were thus done at atmospheric pressure and without an oxidant.

5.2.2 Series II - Effect of Ionic Strength and Species on Ammonium Sorption

The objective of this series of tests was to examine the effect of ionic species and concentrations on ammonium sorption. In actual field leaching, site groundwater is used to make up the leach solution; therefore, it is necessary to know what effect the presence of the groundwater ions have on ammonium sorption. The ions used (Na^+ , Ca^{++} , Mg^{++} , and K^+) are the type commonly found in the groundwaters of Wyoming and Texas. The effect of the anion present ($\text{SO}_4^{=}$, HCO_3^- , and Cl^-) was also examined in these tests.

Because no pressure or oxidant effect was found in Series I, the tests were carried out at atmospheric pressure with no oxidant. The tests used -28 mesh Wyoming ore acquired in Phase I of the program.⁽³⁾ In all of the tests, 1.0 g/l NH_4HCO_3 was used. The test duration was 24 hours for the experiments, with samples taken at 2, 6, and 24 hours. Each sample was analyzed for ammonium. Ammonium equilibrium and sorption kinetics were determined as a function of the initial ionic strength and species.

The results of the tests are presented in Table 5.5. As the table shows, the ammonium ore concentration values based on solution analyses are in good agreement ($\pm 10\%$) with a majority of the ammonium levels determined by final ore analysis. Only in several of the sodium tests and in the potassium test were there significant discrepancies. The solution analyses indicated a greater ammonium uptake than the ore analyses. The reason for this discrepancy is not known.

The results obtained show that ammonium sorption decreases when other cationic species are added to the ammonium feed solution. In

TABLE 5.5

Effect of Cationic Strength and Species on Ammonium Sorption of Wyoming Ore

Test No.	Ionic Species and Concentration in the 1.0 g/l NH_4HCO_3 Feed	$[\text{NH}_4^+]$ mg/l sol. at t_1^*	$[\text{NH}_4^+]$ mg/l sol. at t_2^*	$[\text{NH}_4^+]$ mg/l sol. at t_3^*	Final $[\text{NH}_4^+]_{\text{ore}}$ mg/g	
					Sol.	Ore
1	0.5 g/l Na_2SO_4	113	99	92	0.36	0.26
2	1.0 g/l Na_2SO_4	117	115	104	0.33	0.31
3	2.0 g/l Na_2SO_4	122	115	110	0.31	0.32
4	1.0 g/l NaHCO_3	108	104	92	0.36	0.29
5	1.0 g/l NaCl	106	104	101	0.32	0.32
6	1.0 g/l CaSO_4	153	151	139	0.20	0.22
7	1.0 g/l MgSO_4	164	158	157	0.16	0.18
8	0.33 g/l Na_2SO_4 , 0.33 g/l NaHCO_3 0.33 g/l NaCl	108	103	86	0.36	0.29
9	0.5 g/l Na_2SO_4 , 0.5 g/l CaSO_4	144	142	137	0.21	0.21
10	0.5 g/l NaHCO_3 , 0.5 g/l CaSO_4	146	140	131	0.23	0.22
11	0.5 g/l NaCl , 0.5 g/l CaSO_4	144	140	139	0.21	0.20
12	0.5 g/l CaSO_4 , 0.5 g/l MgSO_4	155	148	155	0.17	0.18
13	0.5 g/l NaCl , 0.5 g/l MgSO_4	146	140	131	0.23	0.21
14	0.5 g/l NaHCO_3 , 0.5 g/l MgSO_4	140	144	144	0.20	0.22
15	0.5 g/l Na_2SO_4 , 0.5 g/l MgSO_4	149	148	142	0.20	0.18
16	1.0 g/l KCl	124	124	115	0.28	0.23
17	1.0 g/l NaCl	113	97	97	0.35	0.29
18	2.0 g/l Na_2SO_4	113	106	92	0.39	0.29

* - For tests 1-16, $t_1 = 2$ hr., $t_2 = 6$ hr., and $t_3 = 24$ hr.

* - For tests 17-18, $t_1 = 24$ hr., $t_2 = 48$ hr., and $t_3 = 72$ hr.

the Series I agitation leach tests, 1.0 g/l ammonium bicarbonate feed with no other cations present produced the following ammonium equilibrium: 102 mg of NH_4^+ /l, 0.38 mg of NH_4^+ /g of ore. Compared with that equilibrium, the results obtained here show that the presence of other cations in this same ammonium feed solution reduces the level of ammonium sorption. The results indicate that the ammonium sorption is a function of the type of cations in solution, but does not seem to be a significant function of the anions examined ($\text{SO}_4^{=}$, HCO_3^- , and Cl^-).

In Table 5.6 the effect of cationic strength and the cationic milliequivalent concentration on ammonium sorption is examined. The data seems to indicate that the ammonium sorption is more directly related to the cationic strength.

In Figure 5.3 ammonium sorption concentration on the clay is plotted as a function of the ammonium fraction of the total solution feed cationic strength. The results show that for a given cation, (Mg, Ca, K, or Na) ammonium sorption level on the clay decreases as the cationic strength of the cations is increased or the ammonium fraction of the cationic strength is decreased. The figure shows that the addition of sodium alone was the least effective of the cations examined. The one test using potassium (Test 16) showed it to be more effective at reducing ammonium sorption than sodium, but not as effective as magnesium or calcium. The use of magnesium and calcium alone at similar cationic strengths (Tests 6 and 7), indicates that magnesium was more effective. Although there is some scatter in the other magnesium and calcium test results, likely caused in part by the addition of the less effective sodium, these tests also showed the greater ability of magnesium to reduce ammonium sorption. The relationship between ammonium sorption and the cationic strength of a given cation could perhaps have been better identified by using only one of the cations (magnesium or calcium) at various concentrations as was done with sodium.

TABLE 5.6
Effect of Cationic Strength and Milliequivalent Cation Concentration
On Ammonium Sorption Onto Clay

Test No.	Chemical Added To 1.0 g/l NH_4HCO_3 Leach	Total Cationic* Strength of Feed	NH_4^+ Fraction Of Cationic Strength in Feed	Total Cation Milliequivalent Concn. in Feed	NH_4^+ Fraction of Milliequivalent Cation Concn. in Feed	$[\text{NH}_4^+]$ on Clay mg/g
1	0.5 g/l Na_2SO_4	1.97×10^{-2}	0.64	19.7	0.64	3.96
2	1.0 g/l Na_2SO_4	2.67×10^{-2}	0.48	26.8	0.48	3.63
3	2.0 g/l Na_2SO_4	4.07×10^{-2}	0.31	40.9	0.31	3.41
4	1.0 g/l NaHCO_3	2.46×10^{-2}	0.52	25.0	0.52	3.96
5	1.0 g/l NaCl	2.98×10^{-2}	0.43	29.8	0.43	3.52
6	1.0 g/l CaSO_4	4.21×10^{-2}	0.30	27.4	0.46	2.20
7	1.0 g/l MgSO_4	4.63×10^{-2}	0.27	29.3	0.43	1.76
8	0.33 g/l Na_2SO_4 , 0.33 g/l NaHCO_3 , 0.33 g/l NaCl	3.05×10^{-2}	0.42	27.0	0.47	3.96
53 9	0.5 g/l Na_2SO_4 , 0.5 g/l CaSO_4	3.44×10^{-2}	0.37	27.1	0.47	2.31
10	0.5 g/l NaHCO_3 , 0.5 g/l CaSO_4	3.34×10^{-2}	0.38	26.2	0.48	2.53
11	0.5 g/l NaCl , 0.5 g/l CaSO_4	4.14×10^{-2}	0.31	28.5	0.44	2.31
12	0.5 g/l CaSO_4 , 0.5 g/l MgSO_4	4.42×10^{-2}	0.29	28.4	0.45	1.87
13	0.5 g/l NaCl , 0.5 g/l MgSO_4	4.35×10^{-2}	0.29	29.6	0.43	2.53
14	0.5 g/l NaHCO_3 , 0.5 g/l MgSO_4	3.55×10^{-2}	0.36	27.2	0.47	2.20
15	0.5 g/l Na_2SO_4 , 0.5 g/l MgSO_4	3.65×10^{-2}	0.35	27.4	0.46	2.20
16	1.0 g/l KCl	2.61×10^{-2}	0.49	26.1	0.49	3.08

* Cationic Strength = $\sum m_i z_i^2$, where m_i = molality of ith cation
 z_i = charge of ith cation

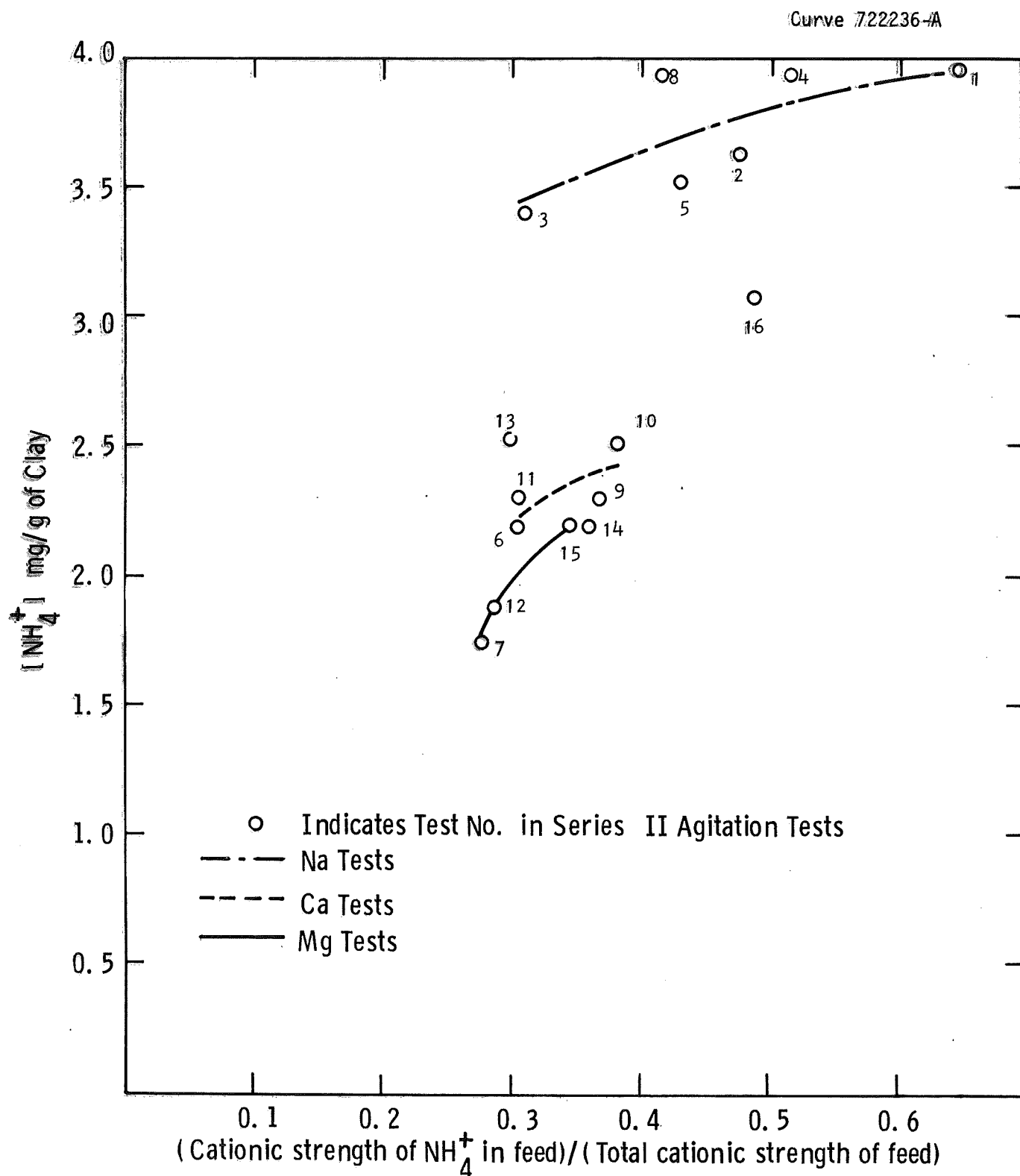


Fig. 5. 3 — Ammonium sorption onto Wyoming ore as a function of the NH_4^+ fraction of the total cationic strength of the feed solution

Thus, the results show that the ability of the cations to prevent ammonium sorption onto the Wyoming ore was shown to be of the following order: $Mg^{++} > Ca^{++} > K^+ > Na^+$. That is, for a given cationic strength magnesium seemed to prevent the greatest amount of ammonium from exchanging onto the ore. Using mixtures of cations and changing the anion did not seem to significantly alter the effect of a given cation. Ammonium sorption was thus shown to be a function of the other cations in solution.

5.2.3 Series III - Effect of Ore Clay Content on Ammonium Sorption

The objective of this series of agitation leach tests was to study the effect of the ore clay content on ammonium sorption. Clay is known to be the fraction of ore involved in the ammonium sorption process.⁽⁵⁾ It is thus desirable to know how a change in clay content affects ammonia sorption. By knowing the effect of clay content, one can better estimate the degree of ammonium sorption that is likely to occur with an ore having a given clay content.

The tests were performed at ambient temperature and pressure using the -28 mesh Wyoming and Texas ores acquired during Phase I of the program.⁽³⁾ The clay added to the ore was a Montmorillonite clay standard. The 100 g of ore-clay sample was agitated with 300 ml of 2.0 g/l ammonium bicarbonate for 24 hours.

The test conditions and results are presented in Table 5.7. The results show that ammonium sorption did increase with increasing clay content of the ore. It is reasonable that ammonium sorption should increase with clay content. Clay is that fraction of the ore onto which ammonium is sorbed. It is likely that the concentration of ammonium on the clay (meq of NH_4^+ /g of clay), rather than the ammonium level on the ore (meq of NH_4^+ /g of ore), determines the equilibrium ammonium solution level. The following discussion will hopefully show this more clearly.

TABLE 5.7

Effect of Ore Clay Content on Ammonium Sorption

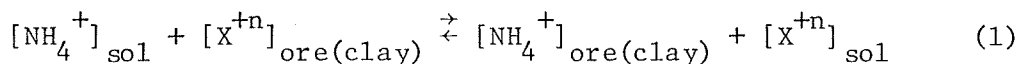
Test No.	Ore Type	Wt. of Ore g	Wt. of Clay Added g	Total Clay Wt. %	Final $[\text{NH}_4^+]$ sol mg/l	Final $[\text{NH}_4^+]$ mg/g of ore	Final $[\text{NH}_4^+]$ mg/g of clay	$\frac{[\text{NH}_4^+]_{\text{clay}}}{[\text{NH}_4^+]_{\text{sol}}}$
1	Wyo	100	0	9.1	247	0.636	6.99	0.028
2	Wyo	95	5	13.6	221	0.714	5.25	0.024
3	Wyo	90	10	18.2	185	0.822	4.52	0.024
4	Wyo	85	15	22.7	164	0.885	3.90	0.024
5	Tex	100	0	6.9	245	0.648	9.39	0.038
6	Tex	95	5	11.6	205	0.768	6.62	0.032
7	Tex	90	10	16.2	189	0.816	5.04	0.027
8	Tex	85	15	20.9	167	0.882	4.22	0.025

Test Conditions

Ammonium feed level: 450 mg/l

Contact time: 24 hours

It is assumed that the exchange reaction can be represented by the following:



where X is a cation (Na^+ , Ca^{++}) of charge n initially present on the ore. The equilibrium relation would then be as follows:

$$K_{\text{eq}} = \frac{[\text{NH}_4^+]_{\text{ore(clay)}} [\text{X}^{+n}]_{\text{sol}}^n}{[\text{NH}_4^+]_{\text{sol}} [\text{X}^{+n}]_{\text{ore(clay)}}^n} \quad (2)$$

where K_{eq} is the equilibrium constant. Examination of the data in Table 5.7 shows the ammonium concentration on the ore ($[\text{NH}_4^+]_{\text{ore}}$) increases with decreasing ammonium solution level ($[\text{NH}_4^+]_{\text{sol}}$). Note also that the concentration of the other cations on the ore ($[\text{X}^{+n}]_{\text{ore}}$) would also decrease, while the solution concentration of these cations ($[\text{X}^{+n}]_{\text{sol}}$) would go up. As equation (2) shows, this would give a continually increasing K_{eq} , not a constant value. However, Table 5.7 shows that the ammonium concentration on the clay ($[\text{NH}_4^+]_{\text{clay}}$) decreases with decreasing ammonium solution concentration. The ratio $[\text{NH}_4^+]_{\text{clay}}/[\text{NH}_4^+]_{\text{sol}}$ is relatively constant, thus tending to give a constant K_{eq} . It therefore appears that the ammonium concentration on the clay fraction is that which helps to determine the equilibrium ammonium solution level.

The results also indicate that the Wyoming and Texas ore of the same clay content do not have the same ammonium sorption equilibrium at the lower clay contents. This is likely the result of differences in other ore characteristics. For example, Texas ore is more acidic than Wyoming ore. As the following reaction indicates, essentially all of the ammonia would exist as ammonium in acidic conditions: $\text{NH}_3 + \text{H}^+ \rightleftharpoons \text{NH}_4^+$. This could result in higher ammonium exchange because

of higher ammonium solution levels. The results do show that Texas ore does have a slightly higher ammonium sorption for a given clay content. Also, as pointed out in Section 5.2.1, (Table 5.4), there are different relative amounts of cations (sodium and calcium) initially present on the clay, which leads to a different ammonium sorption. Ammonium will displace sodium more readily than it will displace calcium. The higher sodium level on the Texas clay results in the higher ammonium clay/solution ratio for the lower clay contents. However, as more clay is added, the ammonium clay/solution ratio for the two ores becomes more nearly equal. This is reasonable because the clay added to both ores is identical thus the exchange which occurs on this clay should be very similar for both ores.

5.2.4 Series IV - Ammonium Desorption Equilibrium and Kinetics

This series of tests examined the ammonium desorption kinetics and equilibrium from an ore by groundwater as a function of the ammonium level on the ore and as a function of the cationic strength and species in the groundwater. These tests provided information on the degree and rate of ammonium ion leakage that can be expected from an ore into groundwaters of differing composition. How this leakage varies with the initial ore ammonium content will provide input as to what level the ammonium on the ore must be in order to obtain acceptable ammonium leakage levels for various ionic strength groundwaters. Different mining sites have different ores and groundwaters and will thus have different ammonium leakage levels.

Because these tests require ore ammoniated to different degrees, large, 2000 g, batches of -28 mesh Wyoming ore were ammoniated using various concentrations of ammonium bicarbonate. From the Series I agitation tests, estimates were made as to what feed concentration was necessary to ammoniate the ore to the desired degrees: approximately 0.5 mg, 0.75 mg, and 1.0 mg of NH_4^+ /g of ore. Large batches of ore were ammoniated to ensure that the initial ammonium ore content was the same in those tests where only the groundwater was varied. After

ammoniation, the ore was blended to ensure the uniformity of each sample used from that batch.

The test results are given in Table 5.8. The results indicate that a majority (80 to 90%) of the ammonium removal occurs within two hours. The effects of the solution cationic strength and the initial ammonium ore level on ammonium desorption are shown in Figure 5.4. The data shows that at a given initial ammonium ore level ammonium desorption increases with increasing cationic strength of the solution, and at a given solution cationic strength, ammonium desorption increases with increasing initial ammonium content of the ore. The desorption curves in Figure 5.4 show, however, that ammonium desorption is not directly proportional to either the cationic strength or to the ammonium ore levels in the concentration ranges examined here. That is, doubling the cationic strength (or the ammonium ore level) does not double the ammonium desorption.

At all of the initial ammonium ore levels, sodium seemed to produce a lower ammonium desorption than magnesium or calcium at similar cationic strengths. Magnesium and calcium at the same cationic strength resulted in very similar ammonium desorption levels. The results also seem to indicate that sulfate and chloride compounds at the same cationic strength have similar ammonium removal responses, while bicarbonate salts have a lower removal.

In summary, the results indicate that groundwaters containing calcium and/or magnesium will result in higher ammonium leakage levels than groundwaters containing sodium. In addition, the higher the cation concentration of the groundwater, the greater the resulting ammonium leakage. Also, the lower the initial ammonium ion concentration on the ore, the smaller the ammonium groundwater leakage. Thus, the magnitude of ammonium leakage can be reduced by removing ammonium from the ore. The level to which the ammonium concentration on the ore must be reduced before an acceptable ammonium leakage level is obtained is dependent upon the groundwater composition. Groundwaters, having low cationic concentrations and/or sodium as the principle cation, will

TABLE 5.8

AMMONIUM DESORPTION EQUILIBRIUM AND KINETICS

Test No.	Initial NH_4^+ Ore Content mg/g	Initial Solution Composition (Cationic Strength)	$[\text{NH}_4^+]$ mg/l (meq/l) Sol. at 2 Hours	$[\text{NH}_4^+]$ mg/l (meq/l) Sol. at 24 Hours	Final % NH_4^+ Desorbed
1	0.40	0.5 g/l CaSO_4 (1.47×10^{-2})	63 (3.5)	61 (3.4)	45.4
2	0.40	1.0 g/l CaSO_4 (2.94×10^{-2})	81 (4.5)	79 (4.4)	58.5
3	0.40	2.0 g/l CaSO_4 (5.88×10^{-2})	95 (5.3)	92 (5.1)	68.6
4	0.40	1.0 g/l MgSO_4 (3.36×10^{-2})	86 (4.8)	77 (4.3)	57.8
5	0.40	1.0 g/l Na_2SO_4 (1.40×10^{-2})	58 (3.2)	58 (3.2)	43.0
6	0.40	1.0 g/l NaCl (1.70×10^{-2})	67 (3.7)	58 (3.2)	43.7
7	0.40	1.0 g/l NaHCO_3 (1.19×10^{-2})	41 (2.3)	38 (2.1)	28.6
8	0.40	0.33 g/l CaSO_4 , 0.33 g/l NaCl 0.33 g/l NaHCO_3 (1.92×10^{-2})	50 (2.8)	49 (2.7)	36.3
9	0.86	0.5 g/l CaSO_4 (1.47×10^{-2})	107 (5.9)	110 (6.1)	38.0
10	0.86	1.0 g/l CaSO_4 (2.94×10^{-2})	121 (6.7)	120 (6.7)	41.7

TABLE 5.8
(Continued)

Test No.	Initial NH_4^+ Ore Content mg/g	Initial Solution Composition (Cationic Strength)	$[\text{NH}_4^+]$ mg/l (meq/l) Sol. at 2 Hours	$[\text{NH}_4^+]$ mg/l (meq/l) Sol. at 24 Hours	Final % NH_4^+ Desorbed
11	0.86	2.0 g/l CaSO_4 (5.88×10^{-2})	160 (8.9)	165 (9.2)	57.0
12	0.86	1.0 g/l MgSO_4 (3.36×10^{-2})	121 (6.7)	121 (6.7)	42.0
13	0.86	1.0 g/l Na_2SO_4 (1.40×10^{-2})	79 (4.4)	81 (4.5)	28.0
14	0.86	1.0 g/l NaCl (1.70×10^{-2})	68 (3.8)	90 (5.0)	30.1
15	0.86	1.0 g/l NaHCO_3 (1.19×10^{-2})	32 (1.8)	41 (2.3)	13.8
16	0.86	0.5 g/l CaSO_4 , 0.5 g/l MgSO_4 (3.15×10^{-2})	110 (6.1)	110 (6.1)	38.2
17	0.86	0.5 g/l CaSO_4 , 0.5 g/l Na_2SO_4 (2.17×10^{-2})	83 (4.6)	99 (5.5)	33.5
18	0.86	0.5 g/l CaSO_4 , 0.5 g/l NaCl (2.32×10^{-2})	68 (3.8)	88 (4.9)	29.4
19	0.86	0.5 g/l CaSO_4 , 0.5 g/l NaHCO_3 (2.07×10^{-2})	58 (3.2)	70 (3.9)	23.7
20	0.86	0.33 g/l CaSO_4 , 0.33 g/l NaCl, 0.33 g/l NaHCO_3 (1.92×10^{-2})	59 (3.3)	72 (4.0)	24.3

TABLE 5.8
(Continued)

Test No.	Initial NH_4^+ Ore Content mg/g	Initial Solution Composition (Cationic Strength)	$[\text{NH}_4^+]$ mg/l (meq/l) Sol. at 2 Hours	$[\text{NH}_4^+]$ mg/l (meq/l) Sol. at 24 Hours	Final % NH_4^+ Desorption
21	1.06	0.5 g/l CaSO_4 (1.47×10^{-2})	111 (6.2)	130 (7.2)	35.7
22	1.06	1.0 g/l CaSO_4 (2.94×10^{-2})	189 (10.5)	158 (8.8)	45.8
23	1.06	2.0 g/l CaSO_4 (5.88×10^{-2})	146 (8.1)	189 (10.5)	51.5
24	1.06	1.0 g/l MgSO_4 (3.36×10^{-2})	165 (9.2)	156 (8.7)	44.3
25	1.06	1.0 g/l Na_2SO_4 (1.40×10^{-2})	89 (4.9)	---	25.1
26	1.06	1.0 g/l NaCl (1.70×10^{-2})	93 (5.2)	---	26.2
27	1.06	1.0 g/l NaHCO_3 (1.19×10^{-2})	54 (3.0)	59 (3.3)	16.4
28	1.06	0.33 g/l CaSO_4 , 0.33 g/l NaCl , 0.33 g/l NaHCO_3 (1.92×10^{-2})	74 (4.1)	87 (4.8)	24.0

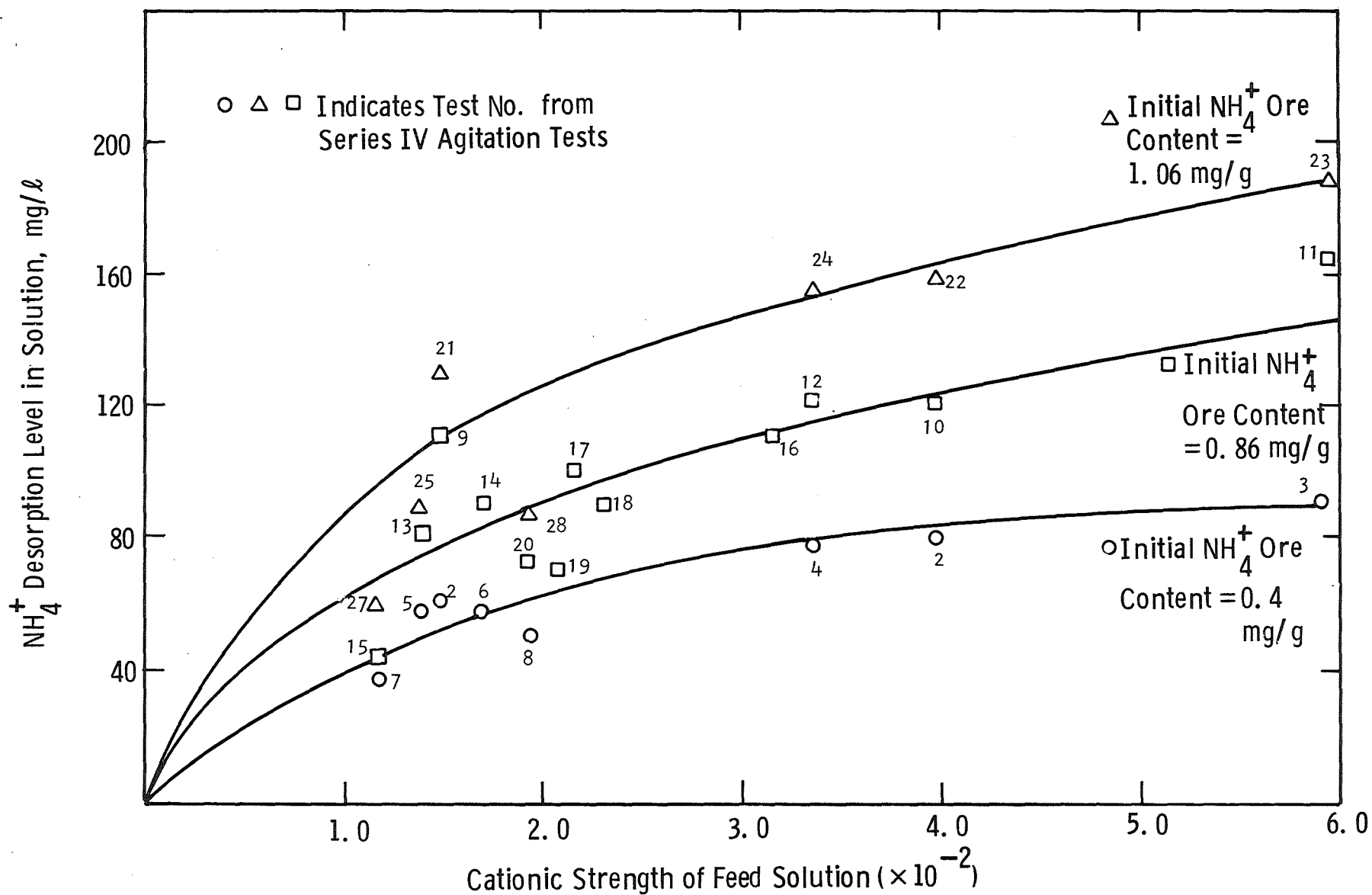


Fig. 5.4 — Ammonium desorption into ground water as a function of cationic strength of the solution and initial ammonium ore content.

allow relatively high ammonium levels to be left on the ore. An area with a groundwater having higher cation concentrations and/or calcium (magnesium) as its principle cation, will require greater restoration of the ore.

5.2.5 Series V - Ammonium Blocking Agents

This series of tests examined the use of chemicals which, because of their size and/or high charge density, could potentially prevent ammonium contamination of the ore and/or the groundwater. Large chemical agents, which can be sorbed onto the ore, could cover exchange sites, thus effectively "blocking" the ore from ammonium contamination. High charge density cations would likely be readily exchanged onto the ore, but would not be easily displaced by ammonium. Again, the ore would be blocked from ammonium exchange. These same, or similar, agents may also prevent the ammonium from leaving ores already ammoniated, thus preventing contamination of the groundwater.

These tests examined the use of such agents before and after leaching with ammonium bicarbonate (1.0 g/ℓ) and peroxide (0.5 g/ℓ). Simulated groundwaters of low and high ionic strength were contacted with the ores after leaching and blocking to examine the stability and effectiveness of the "blocking" agent.

The tests were done at 1 atm using Wyoming - 28 mesh ore samples acquired during the Phase I studies. In each test, 50 g of ore was contacted with 150 ml of solution for 24 hours. After each contact, the solution-ore mixture was centrifuged. The solution was decanted, volumetrically measured, and sampled. The ore was then contacted with 150 ml of the next solution. The blocking agent contact solution and all solutions that followed that contact were analyzed for the blocking agent. The leach contact solution and all solutions that followed that contact were analyzed for ammonium. All solutions were analyzed for uranium. The tests provided information on the degree of blocking accomplished, the effect on uranium recovery, and the stability of the agent.

The results of the tests are given in Tables 5.9 through 5.12. The agents examined were scandium chloride, quaternary amine, aluminum hydroxy-chloride and lead citrate. As the results show, none of these agents, when used before the ammonium bicarbonate contact, significantly reduced ammonium sorption. Also, the agents did not remove significant amounts of ammonium, nor did they seem to reduce ammonium desorption into groundwater. The agents thus failed to accomplish their desired effect.

It should be noted that Al and Pb may have precipitated after contacting the ore. This is indicated by the fact that these cations are absent from all product solutions. If these cations had exchanged onto the ore, one would expect that at least some Al or Pb exchange into solution would have occurred during subsequent solution contacts.

5.2.6 Series VI - Ammonium Displacement Solutions

This series of tests examined the use of chemicals that would remove ammonium from ores. Restoration solutions were studied which contained cations that were known to have the ability to exchange for ammonium and that would not be easily removed from the ore into the groundwater. Highly charged cations were used because generally the higher the charge, the greater the exchange and the more tightly held the cation. Different anion species were used because anions are known to have an effect on cation exchange.⁽⁶⁾ Also, different cation and anion solutions were examined to provide alternate solutions in the event that a restoration solution, which appeared superior in agitation leach tests, failed to perform adequately in column studies. Each restoration solution was tested at several concentrations to determine perhaps an optimum concentration.

The -28 mesh Wyoming ore used in this series was first ammoniated in a large batch (~ 2000 g) using 2 liters of 8.0 g/l NH_4HCO_3 . A large batch of ore was ammoniated to ensure that the initial ammonium content of the ore ($1.15 \text{ mg NH}_4^+/\text{g ore}$) was the same in all tests. After ammoniation, the ore was blended to ensure the uniformity of

TABLE 5.9

Series V - Ammonium Blocking Agent, $\text{Pb}_3(\text{C}_6\text{H}_5\text{O}_7)_2$

Test-Contact No. No.	Solution	$[\text{NH}_4^+]_{\text{sol}}$	$[\text{NH}_4^+]_{\text{ore}}$	$[\text{U}]_{\text{sol}}$	Additional % U Removed	[Blocking Cation] mg/l
		mg/l	mg/g	mg/l		
1 - 1	1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2	56	0.46	57	17.1	-
1 - 2	1.0 g/l $\text{Pb}_3(\text{C}_6\text{H}_5\text{O}_7)_2$	22	0.41	14	1.6	Pb < 1
1 - 3	*Texas Grd. H_2O	21	0.35	8	2.0	Pb < 1
2 - 1	1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2	56	0.46	57	17.1	-
2 - 2	1.0 g/l $\text{Pb}_3(\text{C}_6\text{H}_5\text{O}_7)_2$	23	0.41	14	2.1	Pb < 1
2 - 3	^o Wyo. Grd. H_2O	15	0.37	27	8.8	Pb < 1
3 - 1	1.0 g/l $\text{Pb}_3(\text{C}_6\text{H}_5\text{O}_7)_2$	-	-	41	12.3	Pb < 1
3 - 2	1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2	43	0.55	55	16.9	Pb < 1
3 - 3	Texas Grd. H_2O	39	0.43	17	3.4	Pb < 1
4 - 1	1.0 g/l $\text{Pb}_3(\text{C}_6\text{H}_5\text{O}_7)_2$	-	-	41	12.3	Pb < 1
4 - 2	1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2	52	0.55	45	13.7	Pb < 1
4 - 3	Wyo. Grd. H_2O	24	0.49	24	6.0	Pb < 1

* - Texas Grd. H_2O Composition: Ca^{++} - 260 mg/l, Na^+ - 550 mg/l

^o - Wyo. Grd. H_2O Composition: Ca^{++} - 60 mg/l, Na^+ - 180 mg/l

TABLE 5.10

Series V - Ammonium Blocking Agent, $\text{Al}(\text{OH})_2\text{Cl}$

Test-Contact No. No.	Solution	$[\text{NH}_4^+]_{\text{sol}}$ mg/l	$[\text{NH}_4^+]_{\text{ore}}$ mg/g	$[\text{U}]_{\text{sol}}$ mg/l	Additional % U Removed	[Blocking Cation] mg/l
1 - 1	1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2	32	0.53	13	3.9	-
1 - 2	0.5 g/l $\text{Al}(\text{OH})_2\text{Cl}$	20	0.48	8	2.0	$\text{Al} < 0.5$
1 - 3	*Texas Grd. H_2O	18	0.43	10	3.2	$\text{Al} < 0.5$
2 - 1	1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2	37	0.52	13	3.9	-
2 - 2	0.5 g/l $\text{Al}(\text{OH})_2\text{Cl}$	32	0.43	8.5	2.2	$\text{Al} < 0.5$
2 - 3	°Wyo. Grd. H_2O	16	0.39	15	5.0	$\text{Al} < 0.5$
3 - 1	0.5 g/l $\text{Al}(\text{OH})_2\text{Cl}$	-	-	-	-	$\text{Al} < 0.5$
3 - 2	1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2	32	0.51	16	6.1	$\text{Al} < 0.5$
3 - 3	*Texas Grd. H_2O	29	0.43	15	4.4	$\text{Al} < 0.5$
4 - 1	0.5 g/l $\text{Al}(\text{OH})_2\text{Cl}$	-	-	-	-	$\text{Al} < 0.5$
4 - 2	1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2	47	0.45	20	7.6	$\text{Al} < 0.5$
4 - 3	°Wyo. Grd. H_2O	16	0.42	21	6.4	$\text{Al} < 0.5$

* - Texas Grd. H_2O Composition: Ca^{++} - 260 mg/l, Na^+ - 550 mg/l
 ° - Wyo. Grd. H_2O Composition: Ca^{++} - 60 mg/l, Na^+ - 180 mg/l

TABLE 5.11

Series V - Ammonium Blocking Agent, Quaternary Amine

Test-Contact No. No.	Solution	$[\text{NH}_4^+]_{\text{sol}}$ mg/l	$[\text{NH}_4^+]_{\text{ore}}$ mg/g	$[\text{U}]_{\text{sol}}$ mg/l	Additional % U Removed
1 - 1	1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2	45	0.50	79	23.7
1 - 2	• 0.75 g/l Quat. Amine	20	0.45	21	3.5
1 - 3	*Texas Grd. H_2O	20	0.39	27	8.5
2 - 1	1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2	48	0.49	67	20.1
2 - 2	0.75 g/l Quat. Amine	17	0.45	11	0.6
2 - 3	°Wyo. Grd. H_2O	18	0.40	28	9.2
3 - 1	0.75 g/l Quat. Amine	-	-	<3	0
3 - 2	1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2	50	0.45	19	6.7
3 - 3	Texas Grd. H_2O	36	0.35	14	3.9
4 - 1	0.75 g/l Quat. Amine	-	-	48	14.4
4 - 2	1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2	43	0.48	65	20.2
4 - 3	Wyo. Grd. H_2O	31	0.39	33	8.4

• - Quat. Amine - obtained from Baroid Petroleum Services

* - Texas Grd. H_2O Composition: Ca^{++} - 260 mg/l, Na^+ - 550 mg/l

° - Wyo. Grd. H_2O Composition: Ca^{++} - 60 mg/l, Na^+ - 180 mg/l

TABLE 5.12

Series V - Ammonium Blocking Agent, ScCl_3

Test-Contact		Solution	$[\text{NH}_4^+]_{\text{sol}}$	$[\text{NH}_4^+]_{\text{ore}}$	$[\text{U}]_{\text{sol}}$	Additional % U Removed	[Blocking Cation] mg/l
No.	No.		mg/l	mg/g	mg/l		
1 - 1		1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2	52	0.47	75	22.5	-
1 - 2		0.1 g/l ScCl_3	21	0.42	20	3.1	<0.2
1 - 3		*Texas Grd. H_2O	23	0.35	13	3.5	0.7
2 - 1		1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2	58	0.46	69	20.7	-
2 - 2		0.1 g/l ScCl_3	24	0.40	19	3.1	<0.2
2 - 3		^o Wyo. Grd. H_2O	18	0.35	32	10.3	<0.2
3 - 1		0.1 g/l ScCl_3	-	-	37	11.1	0.4
3 - 2		1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2	50	0.54	48	14.8	<0.2
3 - 3		Texas Grd. H_2O	35	0.51	17	3.4	0.7
4 - 1		0.1 g/l ScCl_3	-	-	45	13.5	0.3
4 - 2		1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O	46	0.56	62	19.3	0.2
4 - 3		Wyo. Grd. H_2O	26	0.49	33	8.5	<0.2

* - Texas Grd. H_2O Composition: Ca^{++} - 260 mg/l, Na^+ - 550 mg/l.

^o - Wyo. Grd. H_2O Composition: Ca^{++} - 60 mg/l, Na^+ - 180 mg/l.

each sample. Each test was of 24 hour duration. After completion of the test, the solution was analyzed for ammonium.

The results of the tests are presented in Table 5.13. The results show that, of the reducing agents tested (NaHSO_3 , Na_2SO_3 , and ZnSO_3), NaHSO_3 appears to have the greatest ability to remove ammonium. ZnSO_3 showed solubility problems. All the trivalent ions tested (Al, La, and Sc) indicated an ability to remove significant amounts of ammonium.

The ability of the solutions to remove ammonium is examined in Figure 5.5 as a function of the restoration solution's cationic strength. The cationic strength of the restoration solution corresponds well with its ability to remove ammonium. The high cationic strength of the aluminum chloride solution produces a relatively high ammonium removal. Of the reducing agents tested, (sodium bisulfite, sodium sulfite, and zinc sulfite), sodium bisulfite showed the greatest ability to remove ammonium at a given cationic strength. The acidity of this solution may have aided its ability. The relatively poor ability of zinc sulfite was likely due to the low solubility of this compound.

The results thus show that the higher the cationic strength of the solution, the more rapidly ammonium will be removed from an ore. Ammonium restoration should thus be attempted using a high cationic strength solution.

5.3 DISCUSSION OF AGITATION LEACH TESTS

The data obtained from the agitation leach tests showed the relative importance, and provided for a better understanding, of the factors influencing ammonium sorption and desorption. The information seems to support the assumption that the ammonium exchange can reasonably be described by the laws of mass action. That is, the exchange reaction can be represented by the following:

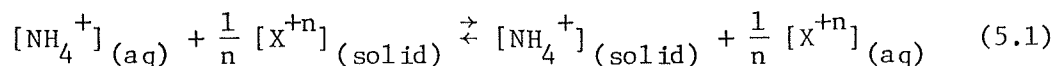


TABLE 5.13

Ammonium Displacement Solutions

Test No.	Restoration Solution	Cation Feed Conc. mg/l (Cat. Strength)	NH ₄ ⁺ Removed mg/l	% NH ₄ ⁺ Removed
1	1.0 g/l Na ₂ SO ₃	365 mg/l (1.6 x 10 ⁻²)	90	24.8%
2	2.0 g/l Na ₂ SO ₃	730 mg/l (3.2 x 10 ⁻²)	120	33.0%
3	1.0 g/l NaHSO ₃	221 mg/l (1.9 x 10 ⁻²) *	160	44.0%
4	2.0 g/l NaHSO ₃	442 mg/l (3.8 x 10 ⁻²)	193	53.1%
5	1.8 g/l AlCl ₃	336 mg/l (11.2 x 10 ⁻²)	232	63.9%
6	2.7 g/l AlCl ₃	548 mg/l (18.3 x 10 ⁻²)	266	73.2%
7	3.6 g/l AlCl ₃	732 mg/l (24.4 x 10 ⁻²)	275	75.7%
8	0.5 g/l LaCl ₃	283 mg/l (1.8 x 10 ⁻²)	87	23.7%
9	1.0 g/l LaCl ₃	566 mg/l (3.7 x 10 ⁻²)	140	38.5%
10	1.5 g/l LaCl ₃	849 mg/l (5.5 x 10 ⁻²)	170	46.8%
11	1.0 g/l La ₂ (SO ₄) ₃	491 mg/l (3.2 x 10 ⁻²)	140	38.5%
12	1.5 g/l La ₂ (SO ₄) ₃	737 mg/l (4.8 x 10 ⁻²)	170	46.8%
13	2.0 g/l La ₂ (SO ₄) ₃	982 mg/l (6.4 x 10 ⁻²)	189	52.0%
14	0.1 g/l ScCl ₃	30 mg/l (0.6 x 10 ⁻²)	99	27.2%
15	0.1 g/l ZnSO ₃	45 mg/l (0.3 x 10 ⁻²)	79	21.7%

* Includes H⁺

TABLE 5.13 (Cont'd)
Ammonium Displacement Solutions

Test No.	Restoration Solution	Cation Feed Conc. mg/l (Cat. Strength)	NH ₄ ⁺ Removed mg/l	% NH ₄ ⁺ Removed
16	0.25 g/l ZnSO ₃	113 mg/l (0.7 x 10 ⁻²)	81	22.3%
17	0.50 g/l ZnSO ₃	226 mg/l (1.4 x 10 ⁻²)	72	19.8%

Initial NH₄⁺ ore content: 1.15 mg NH₄⁺/g ore

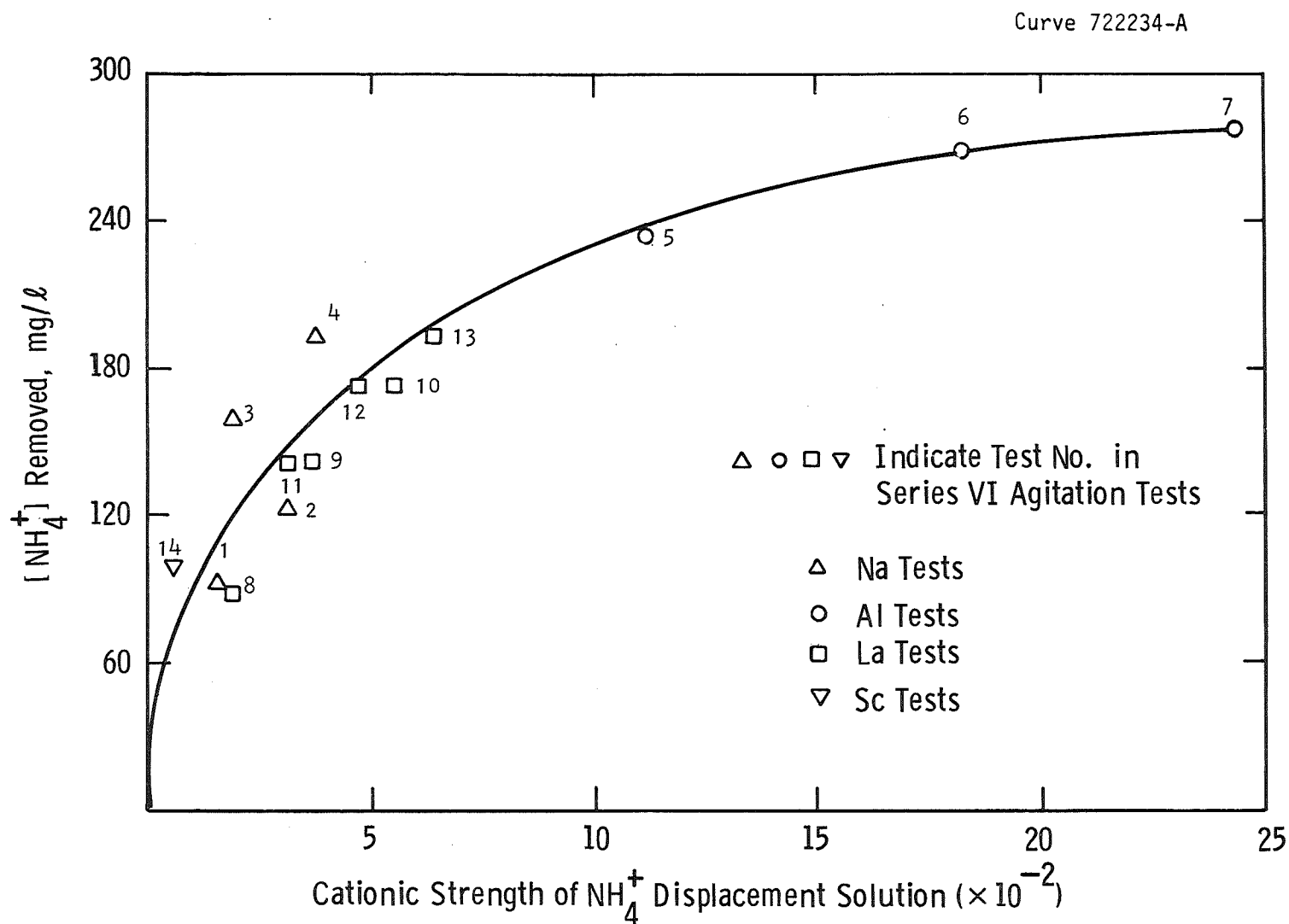


Fig. 5.5 — Ability of solutions to remove ammonium from Wyoming ore as a function of their cationic strength.

where X is a cation (Na^+ , Ca^{++} , Mg^{++} , etc.) of charge n. The mass action equilibrium is as follows:

$$K_{\text{eq}} = \frac{[\text{NH}_4^+]_{(\text{solid})} [\text{X}^{+n}]_{(\text{aq})}^{1/n}}{[\text{NH}_4^+]_{(\text{aq})} [\text{X}^{+n}]_{(\text{solid})}^{1/n}} \quad (5.2)$$

where K_{eq} is an equilibrium constant. The activity coefficients for all the cations have been taken to be unity. The desorption reaction and equilibrium are just the reverse of 5.1 and inverse of 5.2, respectively. The test data showed that the exchange reaction (both sorption and desorption) is relatively rapid, with a vast majority (> 90%) of the exchange occurring within 6 hours. Thus, it is reasonable that the equilibrium relation, rather than the kinetic relation, can be used to describe accurately the process.

The data obtained during the various sets of tests indicated that the following factors likely influenced ammonium sorption equilibrium:

1. Ammonium feed concentration,
2. Type and cationic strength of other cations (Mg, Ca, K, and Na) in solution, and
3. Ore characteristics (pH, cations initially present on clay, and clay content).

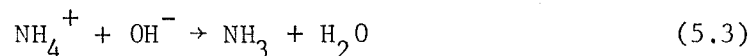
Ammonium desorption was shown to be influenced by the following:

1. Ammonium concentration on clay, and
2. Cationic strength of solution.

By examining equation (5.1), one can see that the mass action equilibrium is in agreement with the fact that these factors influence ammonium sorption. Increasing the ammonium feed concentration should cause an increase in equilibrium ammonium level on the clay. It should be noted, however, that once complete ammonium saturation of the clay

has occurred, then no further ammonium exchange will occur even with increasing ammonium feed concentration. The mass action equilibrium thus only applies until saturation has been obtained or nearly obtained. The influence of other cations on the sorption and desorption of ammonium can also be seen from the equilibrium equation. The fact that different cations, both on the ore and in solution, have a different effect is the result of the charge, n , of the cation and the differing equilibrium constants, (K_{eq}), for each cation involved. Based on the tests performed, the affinity of the various cations for the clay is as follows: $Mg^{++} > Ca^{++} > K^+ > Na^+$. For example, in terms of ammonium sorption, the presence of magnesium in solution results in a lower ammonium clay/solution ratio than when the same equivalent concentration of sodium is put into solution.

The fact that ore characteristics effect ammonium sorption may not be readily apparent, but their affect can also be seen by examining the equilibrium relation. First, the ore clay content affects the equilibrium ammonium values because clay is that portion of the ore involved in the exchange process. An increase in the clay content increases the number of exchange sites and thus the amount of other cations initially present. More ammonium will now have to exchange to occupy the same proportion of exchange sites. That is, with an increase in clay content, more exchange is now required to obtain the same ratio of ammonium on the clay to the other exchangeable cations on the clay (see eq. 5.2). The pH maintained by an ore body likely affects ammonium sorption and desorption because it influences the ammonium concentration in solution. As pH increases, the following reaction occurs:



The conversion of ammonium to the unionized ammonia reduces the amount of ammonium available to exchange.

The data obtained during the tests also indicated that the following did not influence ammonium sorption and desorption:

1. Oxidant type (peroxide or dissolved O_2)
2. Pressure (1 or 6 atm)
3. Anions ($SO_4^{=}$ and Cl^-)

The oxidant, pressure, and the anions would not be expected to influence the ammonium equilibrium unless these factors affected the ammonium or the other cation concentrations. In the ammonium desorption studies, the presence of bicarbonate in solution seemed to reduce the ammonium desorption (see Section 5.2.4). The bicarbonate may have tied up or caused precipitation of cations (Mg and Ca) thus effectively reducing the concentration of cations available to exchange. It should also be noted that the presence of hydroxide, as shown above, would also likely influence the ammonium equilibrium.

The agitation test findings provided some extremely useful information on ammoniation in the following areas:

1. Evaluating potential ammonium problems.
2. Minimizing the ammonium problems.
3. Restoring ammoniated ore bodies.

First, by examining the characteristics of the ore (e.g., clay content, cations present on clay, ore pH, etc.) and the leach to be used (ammonium and other cation concentrations, etc.), the degree of ammonium sorption likely to occur during leach can be estimated reasonably. Examination of the groundwater characteristics would then lead to an estimation of the subsequent ammonium leakage into groundwater.

From the test results, it has been shown that ammoniation during leach can be substantially reduced by adding magnesium and/or calcium salts to the ammonium leach solution. The reduced ammonium ore level will result in lower ammonium leakage into groundwater. The pretreatment of the ore with scandium chloride, quaternary amine, aluminum-hydroxy-chloride, or lead citrate was found to be ineffective in reducing ammoniation.

The results also indicated that the ammonium leakage from an ore at a given ammonium level into a groundwater can likely be estimated from the ammonium ore level and the cationic strength of the groundwater. Thus, by knowing the ammonium ore level after leaching, and the ammonium ore level that will result in an acceptable ammonium groundwater leakage, the amount of ammonium that must be removed after leaching can be determined. The test results showed that high cationic strength solutions (aluminum chloride, scandium chloride, lanthanum solutions, and sodium bisulfite) were effective at removing ammonium.

Thus, the rate and degree of ore and groundwater contamination by ammonium during a given ammonium leach can be reasonably determined. By knowing what factors do, or do not, influence ammonium sorption and desorption, the ammonium problem can be evaluated, minimized and restored in a more quantitative manner. The validity and usefulness of these findings were supported by the results of many of the following column tests, which examined the use and applications of chemicals deemed desirable in these agitation tests.

6. COLUMN SIMULATION LEACH TESTS

Column simulation tests were conducted to develop baseline data on the kinetic and equilibrium relationships of the post-leach restoration operations, and to investigate the effect of variables such as changes in restoration solution flow rates, reducing agents, clay blocking agents, and cation displacing agents. Phases I through IV of the program developed a laboratory simulation technique for in-situ leaching and studied the effect of various variables on permeability and uranium extraction. This phase of the study examined the applicability of this simulation technique for examining the environmental aspects of the chemical leaches.

The Phase IV program, which in a limited manner attempted to estimate the magnitude of the environmental leaching effects, showed that significant levels of chemical leakage occurred during post-leach groundwater flow. This phase of the program examined, in much greater detail, the effects of various leaches on the ore body and the groundwater. Based, in part, on the agitation leach test results, restoration techniques were selected and developed.

6.1 SIMULATION TEST EXPERIMENTAL SYSTEM AND METHOD

In order to study restoration it is necessary that the ore first be leached using the same procedure of the earlier phases. Each test thus required an initial deionized water flow period to ensure the correct permeability and packing stability, then a chemical leach period, and finally a groundwater and/or a restoration flow period. The tests were conducted in the feed systems and columns designed and constructed in Phases I - IV.^(3,4)

The in-situ simulation system used in the column leach testing is shown schematically in Figure 6.1. The system consists of a pressurized

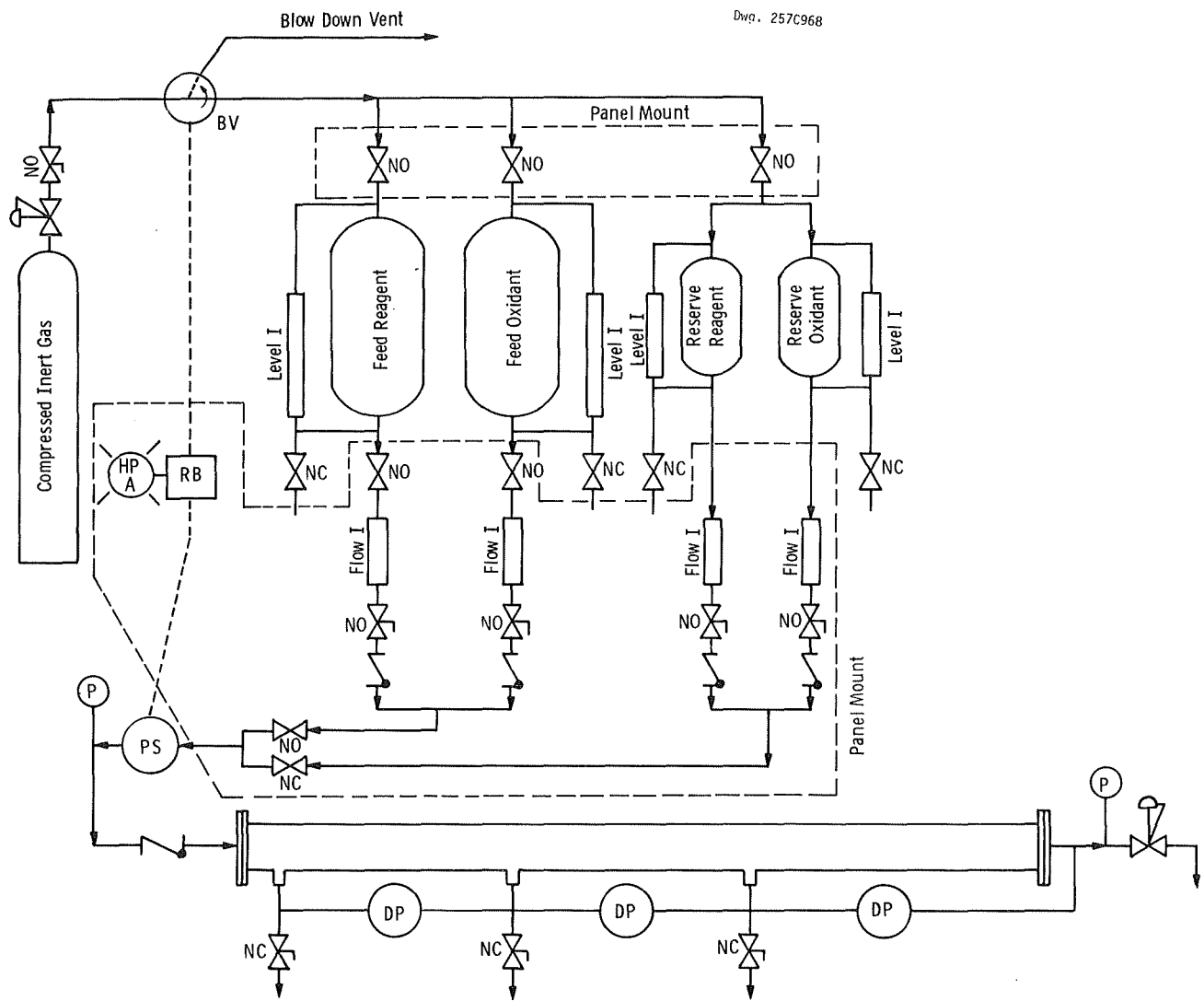


FIG. 6.1 - SCHEMATIC DIAGRAM OF LOW PRESSURE FEED SYSTEM

feed section from which the leach solution is fed through flow metering and monitoring devices. The system is mechanically simple and reliable. The two main feed tanks are 16 gallon Type 316 stainless steel, certified for a maximum allowable working pressure of 120 psig. Two tanks are required in order to allow the separation of the oxidant and leach feeds so that the oxidant dosage may be controlled and, in particular when using hydrogen peroxide, to avoid premature oxidant decomposition in the feed tank.

Pressurizing a solution with gas does increase the dissolved gas content of the solution. When saturation of the solution with the pressurizing gas (nitrogen) is not desirable (e.g., during deionized or groundwater flow or when using peroxide as the oxidant), a replaceable impermeable rubber membrane was placed in the feed tank to separate the gas and solution phases, and thus prevent an increase in the dissolved gas content of the solutions. Saturating the feed with gas would cause undesirable, and unnecessary, gas nucleation in the ore bed as the solution came into contact with the lower pressure column. In those tests using dissolved oxygen as the oxidant in the leach solution, the rubber bladder was removed, and the solution pressurized with oxygen. A pump was used to recirculate and thus agitate the solution in the tank to make certain that the feed was saturated with oxygen. The oxygen level of the solution is limited by the partial pressure of the oxygen in the tank and the Henry's law constant for oxygen in the solution. Oxygen saturation levels in bicarbonate solutions as a function of the oxygen gas pressure are shown in Figure 6.2.⁽⁷⁾ The oxygen concentration of the solution entering the ore bed can be controlled by pressurizing the leach solution with oxygen or an oxygen-nitrogen mixture so that the partial pressure of oxygen in the tank produces the desired oxygen level in solution. The oxygen level can also be controlled by saturating the leach solution with oxygen in one of the feed tanks and mixing this in correct proportion with unoxxygenated leach solution contained in the other primary feed tank, which has the rubber bladder.

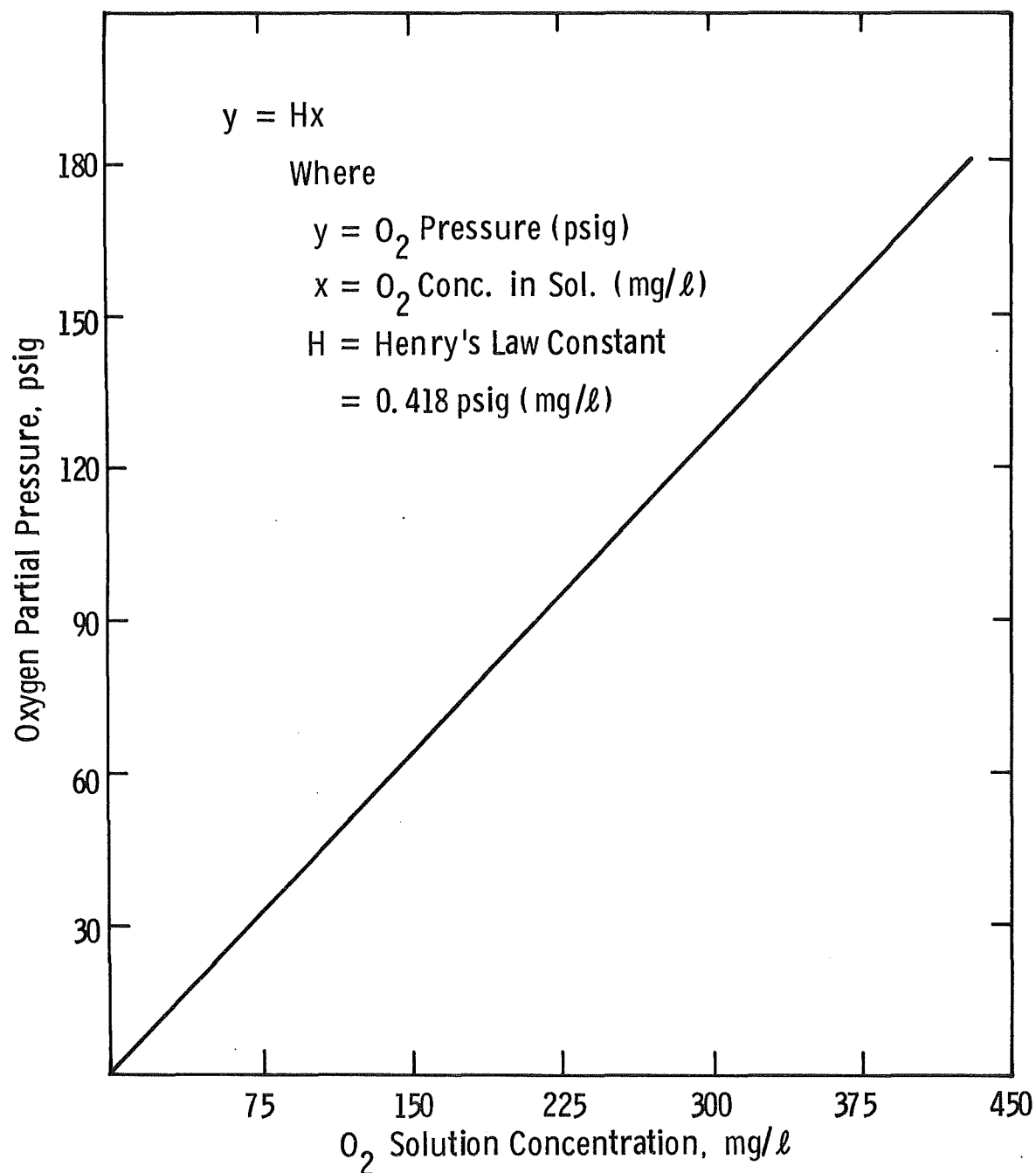


Fig.6.2—Oxygen solubility in ammonium carbonate/bicarbonate solutions as a function of oxygen partial pressure⁽⁷⁾

Most of the tests were conducted in 4 in. diameter, 13 ft. long columns. The first 10 inches was filled with highly permeable sand, which gave a uniform flow distribution of leach solution prior to contacting the ore. The sand was followed by about 12 feet of the ore sample for leaching, and then 5 inches of the sand. In a majority of the leach tests, glass columns were used. The glass columns, shown schematically in Figure 6.3, consist of two 3-ft. sections, a 3.5-ft. section, and three 14-in. (4x1 in.) tees. The glass, rated for a maximum allowable working pressure of 50 psig, allows visual inspection of the ore bed during testing. To monitor and obtain solution samples from the ore packing during the test, tee sections are located between each of the three sections. The tee sections allow insertion of pressure taps, specific ion electrodes, and permit sample withdrawal. Differential pressure gauges are connected between sections in order to determine the pressure drop for each section. Concentration profiles across the column can be obtained from solution samples collected. An overall view of a typical glass-column assembly used during the tests is shown in Figure 6.4.

In some of the tests, a high pressure Type 316 stainless steel column, rated for 120 psig, was used. The dimensions of this column were the same as the glass column. The high pressure column, shown in Figure 6.5, offers the advantage of performing tests at much higher pressures, which more closely resembles the actual field conditions. Also, the frequent spacing (every 13 inches) of the sample ports allowed more accurate determination of where concentration and permeability changes were occurring.

The 12-foot ore bed packing length was used in tests in which the leaching solution was a carbonate lixiviant, while an 8-foot ore bed length was used in the acidic leaching tests. Previous test results had indicated that carbonate leaching was reaction or mass transfer constrained and thus required at least a 12-foot ore bed. Acid leaching was found to be equilibrium constrained and thus the solution residence time in an 8-foot bed was likely sufficient. Using the same volumetric

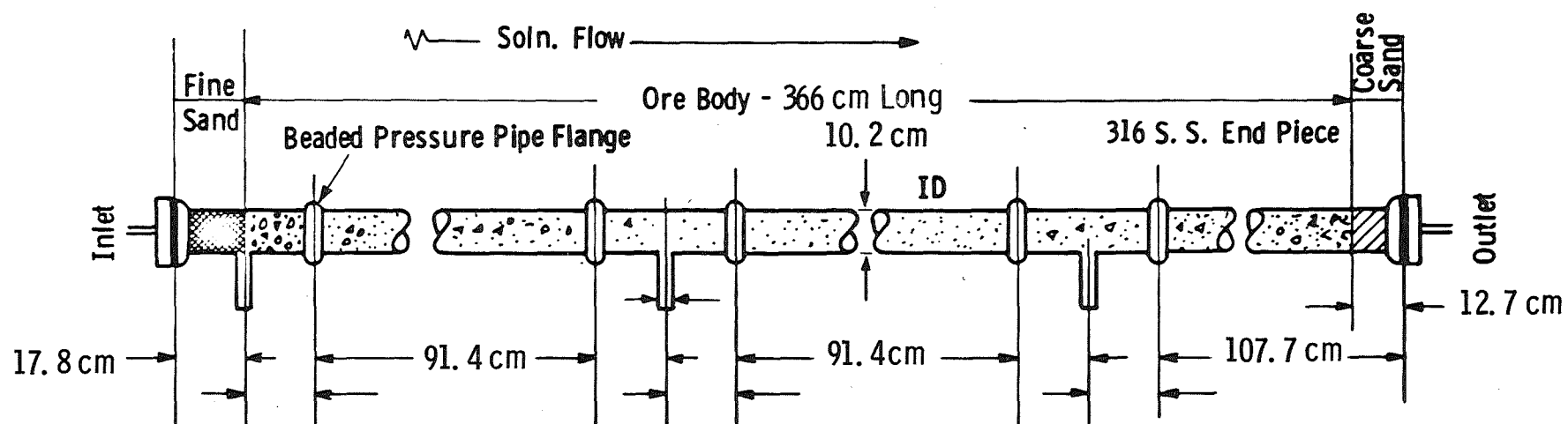


Fig. 2 – Low pressure glass column for insitu tests

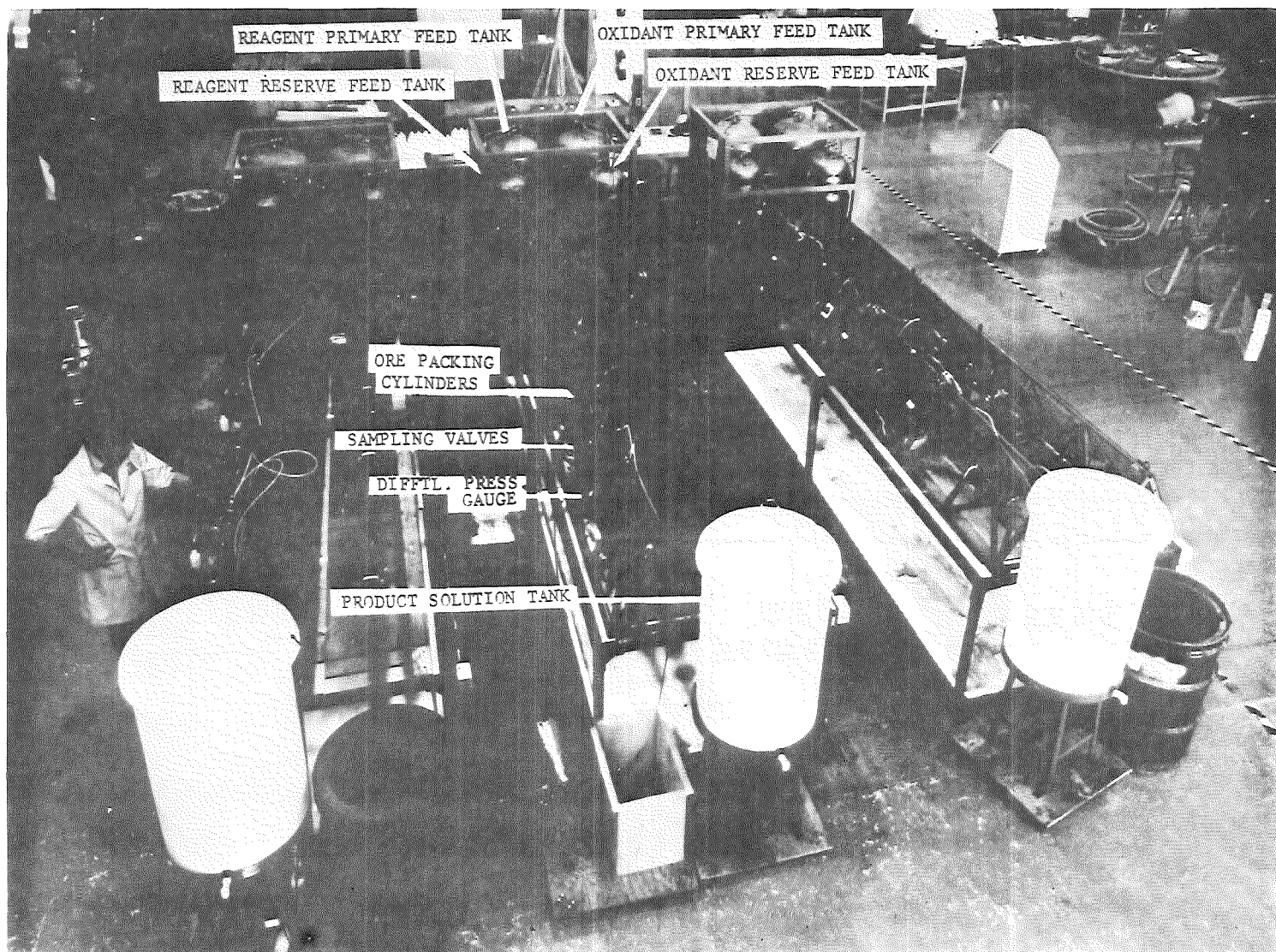


FIG. 6.4 - In-Situ Leach Simulation Systems

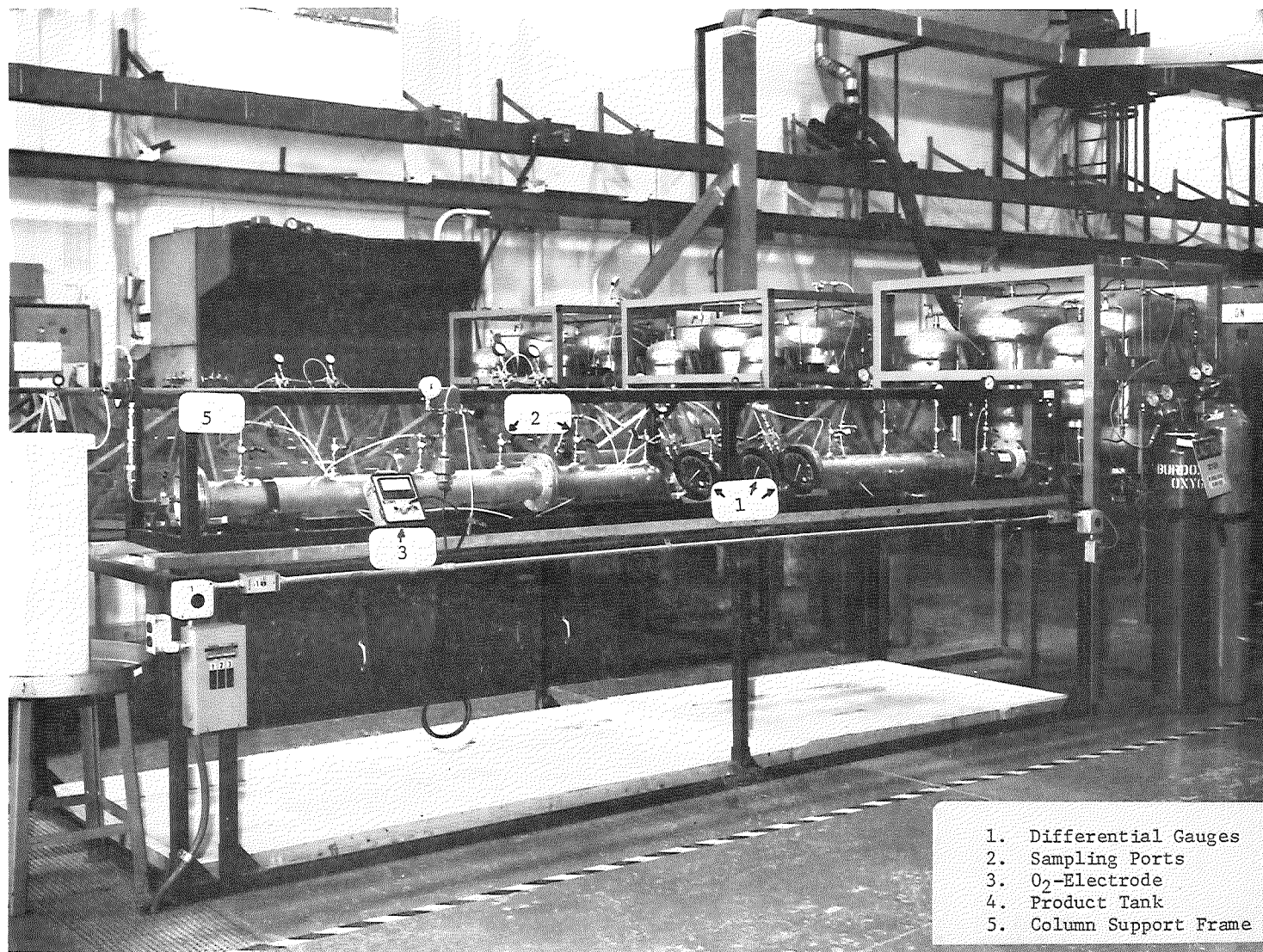


FIG. 6.5 - High Pressure Stainless Steel Column in Operation

flow rate with the 8-foot column, the same number of solution pore volumes could be passed through the ore in a shorter period of time. The test duration was thus significantly shortened.

The columns were packed using a method developed in Phase I of the program⁽³⁾ and detailed in Appendix A. After packing, each ore bed was inspected for voids or faults before accepting the column for testing. For each packing, the length and weight of each section (inlet sand, ore, and outlet sand) were measured and recorded. A summary of the ore packing parameters for each test conducted is given in Table 6.1.

Each column test started with a 150 hour deionized water flow period (100 hours for 8-foot column) to ensure correct permeability and packing stability. During this initial flow period, the ore was slowly wetted (about 5 ml/min) in order to allow it to consolidate. After approximately 24 hours, the flow was gradually increased during the next 24 hours until the desired rate of 10 ml/min was obtained.

After the permeability and stability of the packing was found acceptable, the chemical leach solution was introduced. A packing was acceptable if the permeability was within the range of 0.5 to 3.0 darcy, and if no cracks or ore compactions occurred. The reagent flow was carried out for a minimum of 750 hours (500 hours for the 8-foot column). Previous testing had shown that this was sufficiently long to characterize the leaching response. The leach solution flow was initially kept at 10 ml/min. However, as permeability dropped, the flow was constrained by the maximum allowable operating pressure; 45 psig for the glass columns and 120 psig for the steel column.

Following the leach solution, restoration solution and/or groundwater was passed through the ore bed. Restoration solution choice was based, in part, on the results of the agitation leach tests. During this portion of the test, at least 10 pore volumes of solution were collected in order to get a reasonable estimate of the environmental effects.

TABLE 6.1

Summary of Leach Simulation Test Ore Packing Conditions

Test No.	Ore Type	Inlet Sand		Ore Section Packing			Ore Wt. g	Outlet Sand		Dry Ore Packing, Kg/l	Ore Pore Volume, l	System Void Volume, l
		Length, In.	Weight, g	Front Length, In.	Middle Length, In.	End Length, In.		Length, In.	Weight, g			
62	Wyo	10.0	3400	46.88	50.00	44.38	49,779	5.25	1670	1.71	9.4	10.7
63	Wyo	10.0	3400	46.75	50.13	44.25	49,912	5.00	1600	1.72	9.3	10.6
64	Tex	10.0	3400	46.75	--	52.38	30,073	5.00	1607	1.47	7.5	8.8
65	Wyo	10.0	3400	47.00	50.25	44.25	49,689	5.00	1600	1.71	9.5	10.8
66	New Wyo	10.0	3400	47.00	50.25	44.25	46,336	5.00	1600	1.59	10.4	11.7
67	Wyo	10.0	3400	35.50	52.00	52.00	48,551	5.00	1732	1.67	10.0	11.3
68	Tex	10.0	3400	46.38	--	52.50	29,922	5.00	1637	1.47	7.6	8.9
69	Wyo	10.0	3400	47.13	--	52.25	34,568	5.00	1698	1.69	6.8	8.1
70	Wyo	10.0	3400	47.38	50.25	44.38	49,274	5.00	1628	1.69	9.7	11.0
71	Wyo	10.0	3400	47.00	--	52.00	34,776	5.00	1675	1.71	6.6	7.9
72	Wyo	10.0	3400	47.00	50.13	44.13	49,109	5.00	1615	1.69	9.7	11.0
73	Wyo	10.0	3400	47.00	50.25	44.00	49,480	5.00	1630	1.70	9.5	10.8
74	Wyo	10.0	3400	47.00	50.13	44.38	49,487	5.00	1552	1.70	9.6	10.9
75	Wyo	10.0	3400	35.50	52.00	52.00	48,627	5.00	1680	1.69	9.5	10.9
76	Wyo	10.0	3400	47.25	50.00	44.38	48,962	5.00	1653	1.68	9.8	11.1
77	Wyo	10.0	3400	47.25	50.00	44.38	49,100	5.00	1607	1.68	9.8	11.1
78	Wyo	10.0	3400	47.00	50.00	44.13	48,228	5.00	1603	1.66	10.0	11.3
79	Wyo	10.0	3400	47.50	50.00	44.25	48,514	5.00	1623	1.66	10.0	11.3
80	Wyo	10.0	3400	47.13	50.25	44.38	48,317	5.00	1539	1.66	10.1	11.4
81	Wyo	10.0	3400	47.38	50.25	44.50	48,105	5.00	1570	1.64	10.2	11.5

At the conclusion of the test, the packed column was disconnected from the feed system and drained vertically for at least 48 hours. After draining, the column was placed horizontally for approximately 48 hours to allow the remaining moisture to distribute uniformly. The system was then disassembled to obtain post-leach residue samples.

A typical schedule for the sampling and monitoring of each test was as follows:

1. The pressure profile along the length of the packing was recorded every six hours.
2. All flow rates were recorded every six hours, and any required flow adjustments were made at this time.
3. Prior to leach, ore samples were taken from each ore bag used in the packing and three samples (ore from the middle of each section) of the post-leach residue were collected. Uranium content of the leached and unleached ore and the ammonium content, when applicable, of the post-leach residue were determined.
4. All visual changes were recorded every six hours.
5. The product solution cumulative volume was measured every six hours. A 500 ml solution sample was collected approximately every 48 hours.
6. Solution profile samples along the length of the column were collected in those tests where it was deemed necessary. The 50 ml samples were taken approximately every 48 hours.
7. A 500 ml sample of each solution feed to the packing was taken whenever a feed was changed.

It should be noted that the sampling schedule did vary. During initial water flow and chemical leach which have been previously studied, the samples were not taken as frequently. However, during restoration

flow, sampling was more frequent because how rapidly changes would occur was not known to any great degree. Profile sampling was done in several tests to study ammonium sorption and desorption characteristics and to study oxygen utilization during leaching.

In order to minimize the number of analyses, some of the product leach solution samples were blended in their respective volume ratio. These blended samples were then analyzed for the uranium content and, when desired, the principle leach anion (e.g., HCO_3^- or $\text{SO}_4^{=}$). Certain leach product samples were also analyzed for the principle leach cation (e.g., NH_4^+ , K^+ , or Na^+) in order to determine cation sorption characteristics during a given bicarbonate leach. During the post-leach solution flows, the product samples were analyzed for contaminant ions that were of environmental concern and that were thought to likely mobilize following a given leach. The pH of the product solution samples were also recorded. In order to determine a uranium balance on each system, all ore samples used to pack the ore bed and the three post-leach residue samples from each test were analyzed for uranium. The uranium input and output (solution and ore) were thus measured for each test.

The analysis of the solutions for uranium was carried out using differential pulse polarography. The uranium content of the ore was estimated by solubilizing the uranium in a shattered sample using nitric acid and subsequently analyzing the solubilized uranium using differential pulse polarography. The solution ammonium and the ore ammonium after solubilization were analyzed using Kjeldahl distillation. The oxygen analysis was done using a high pressure oxygen probe.

The pressure and flow rate measurements taken were used to determine the permeability of each of the three ore bed sections. The division of the ore packing was based on the location of the sample and pressure ports. The correlation (Darcy equation) used in the calculation of permeability is given by

$$\frac{1}{\alpha} = 6.223 \times 10^{-1} \frac{\mu \cdot V' \cdot L'}{\Delta P' \cdot A}$$

where:

$1/\alpha$ = darcy (by definition)

μ = solution viscosity, centipoise

V' = solution volumetric flow, ml/min

L' = packing length, inches

$\Delta P'$ = pressure differential across the ore bed section, psi

A = cross-sectional packing area, cm²

Thus, for a given ore section length and cross-sectional area, and assuming a solution viscosity of 1.0 cp, the permeability could be determined for a given flow rate and pressure drop.

In the following sections, the column leach tests performed are presented and discussed. Typically, for each test, illustrations for permeability changes, concentration variations, and uranium recovery are presented. The figures are designed to illustrate the physical and chemical changes occurring during the leaching process and during the post-leach solution flows. The permeability curves are only selected operating points during the course of the test. That is, not all of the data points are displayed. Complete pressure drops across the ore bed sections, volumetric flow rates, and estimated permeabilities observed during each test are presented in their entirety in Appendix B. The pH, uranium recovery, concentration variations, and ion leakage data have also been tabulated for each test. A summary of the chemical operating conditions used in each of the tests is given in Table 6.2.

6.2 COLUMN LEACH SIMULATION TEST RESULTS

6.2.1 Baseline Experiments

This set of tests was designed to determine the degree of ore-aquifer changes that could be expected for various leaches. These tests were a direct extension of the preliminary ion leakage studies done in Phase IV of this program.⁽⁴⁾ The post-leach groundwater in the tests performed here were operated for a longer period of time, and the groundwater was alternately started and stopped for periods of time

TABLE 6.2
Summary of In-Situ Simulation Leach Data

Test No.	Ore Type	Pre-Leach Solution				Leach Solution				Post-Leach Solutions				Total Initial Uranium Content, g	Total Final Uranium Content, g	% Uranium Recovery	
		Composition	Average Flow Rate ml/min	Total Vol Collected, l	Total Ore Pore Volumes	Composition	Average Flow Rate ml/min	Total Vol Collected, l	Total Ore Pore Volumes	Composition	Average Flow Rate ml/min	Total Vol Collected, l	Total Ore Pore Volumes			Ore*	Sol*
62	Wyo	Deionized H ₂ O	8.2	69.6	7.4	1.0 g/t NH ₄ HCO ₃ -sat'd O ₂ at 45 psig	7.9	364.3	38.8	Wyo. Grd. H ₂ O	3.5	70.6	7.5	48.9	6.3	86.7	73.7
63	Wyo	Deionized H ₂ O	5.5	45.4	4.9	2.0 g/t NaHCO ₃ -sat'd O ₂ at 45 psig	3.6	162.4	17.4	Wyo. Grd. H ₂ O	4.1	120.6	12.9	48.0	6.0	87.5	77.4
64	Tex	Deionized H ₂ O	6.8	37.6	5.0	H ₂ SO ₄ , pH = 1.0	2.7	83.4	11.1	Texas Grd. H ₂ O	4.2	83.6	11.2	18.0	0.8	95.4	72.6
65	Wyo	Deionized H ₂ O	4.3	38.3	4.0	1.0 g/t KHCO ₃ -sat'd O ₂ at 45 psig	8.9	409.0	43.1	Wyo. Grd. H ₂ O	2.2	82.0	8.6	47.0	6.2	86.8	72.3
66	New Wyo	Deionized H ₂ O	8.2	93.2	9.0	1.0 g/t NH ₄ HCO ₃ -0.5 g/t H ₂ O ₂	3.0	137.0	13.2	Wyo. Grd. H ₂ O	2.3	90.2	8.7	25.7	5.4	78.9	59.3
67	Wyo	Deionized H ₂ O	7.4	85.4	8.5	1.0 g/t NH ₄ HCO ₃ -sat'd O ₂ at 120 psig	9.7	416.8	41.3	1) 1.0 g/t Na ₂ SO ₃ 2) Wyo. Grd. H ₂ O 3) 1.0 g/t Na ₂ SO ₃ 4) Wyo. Grd. H ₂ O	6.6 2.4 2.0 2.0	50.1 43.4 14.4 25.1	5.0 4.3 1.4 2.5	46.1	5.5	88.0	71.0
68	Tex	Deionized H ₂ O	6.3	47.3	6.2	H ₂ SO ₄ , pH = 1.0	1.1	52.4	6.7	1) 1.0 g/t NaHSO ₃ (pH=2) 2) 1.0 g/t NaHSO ₃ (pH=3.4) 3) Tex. Grd. H ₂ O	0.5 2.8 3.1	8.0 36.4 39.3	1.1 4.8 5.2	18.6	0.45	97.6	71.9
69	Wyo	Deionized H ₂ O	7.5	77.8	11.4	H ₂ SO ₄ , pH = 1.0	8.1	219.9	32.3	Wyo. Grd. H ₂ O	0.8	67.9	10.0	34.2	0.52	98.5	76.7
70	Wyo	Deionized H ₂ O	8.9	77.0	7.9	1) 1.0 g/t NH ₄ HCO ₃ -0.5 g/t H ₂ O ₂ 2) 1.0 g/t NH ₄ HSO ₃ 3) 1.0 g/t NH ₄ HCO ₃ -0.5 g/t H ₂ O ₂ 4) 1.0 g/t NH ₄ HSO ₃ 5) 1.0 g/t NH ₄ HCO ₃ -0.25 g/t H ₂ O ₂	6.7 9.2 4.5 8.0 5.7	56.0 14.4 44.8 12.0 130.6	5.8 1.5 4.6 1.2 13.5	1) 1.0 g/t NH ₄ HSO ₃ 2) Wyo. Grd. H ₂ O 3) 1.0 g/t NH ₄ HSO ₃ 4) Wyo. Grd. H ₂ O	9.8 6.8 7.0 7.1	45.7 85.9 50.1 30.6	4.7 8.9 5.2 3.2	48.0	6.4	86.7	67.9
71	Wyo	Deionized H ₂ O	6.7	60.5	9.2	H ₂ SO ₄ , pH = 1.0	6.8	204.4	31.0	1) 2.0 g/t NaHSO ₃ (pH=2) 2) Wyo. Grd. H ₂ O 3) 2.0 g/t NaHSO ₃ (pH=3.4) 4) Wyo. Grd. H ₂ O	3.3 2.8 3.1 2.2	57.2 35.4 54.9 41.0	8.7 5.4 8.3 6.2	34.5	0.52	98.5	72.7
72	Wyo	Deionized H ₂ O	7.5	65.2	6.7	1) 1.0 g/t NH ₄ HCO ₃ -0.5 g/t CaCl ₂ -0.5 g/t MgSO ₄ -sat'd O ₂ at 45 psig 2) Same leach -0.5 g/t H ₂ O ₂	8.1 8.6	141.8 237.0	14.6 24.4	1) Wyo. Grd. H ₂ O 2) 1.0 g/t NaHSO ₃ 3) Wyo. Grd. H ₂ O	7.0 5.8 4.4	60.4 82.3 45.1	6.2 8.5 4.6	47.8	4.8	90.1	70.3

* - Recovery based on ore analysis before and after leaching
 * - Recovery based on product solution analysis
 o - Average flow rate during actual flow periods

TABLE 6.1 (Cont'd)

Test No.	Ore Type	Pre-Leach Solution			Leach Solution			Post-Leach Solutions			Total Initial Uranium Content, g	Total Final Uranium Content, g	Σ Uranium Recovery				
		Composition	Average Flow Rate ml/min	Total Vol Collected, l	Total Ore Pore Volumes	Composition	Average Flow Rate ml/min	Total Vol Collected, l	Total Ore Pore Volumes	Composition			Average Flow Rate ml/min	Total Vol Collected, l	Total Ore Pore Volumes	Ore*	Sol.
73	Wyo	Deionized H ₂ O	8.4	75.8	8.0	1.0 g/l NH ₄ HCO ₃ -1.0 g/l Na ₂ SiO ₃ -0.5 g/l H ₂ O ₂	8.1	370.4	39.0	1) Wyo. Grd. H ₂ O 2) 2.0 g/l NaHSO ₃ 3) Wyo. Grd. H ₂ O	7.5 6.3 3.2	43.1 74.3 45.4	4.5 7.8 4.8	50.0	12.2	75.6	53.4
74	Wyo	Deionized H ₂ O	7.8	78.8	8.2	1.0 g/l NH ₄ HCO ₃ -sat'd O ₂ at 45 psig	7.0	348.1	36.3	1) 3.0 g/l AlCl ₃ 2) Wyo. Grd. H ₂ O	6.4 4.3	94.3 48.3	9.8 5.0	47.9	4.5	90.6	72.3
75	Wyo	Deionized H ₂ O	8.3	95.9	10.1	1.0 g/l NH ₄ HCO ₃ -sat'd O ₂ at 45 psig	9.3	455.1	47.9	1) 0.5 g/l LaCl ₃ -0.5 g/l La ₂ (SO ₄) ₃ 2) Wyo. Grd. H ₂ O	6.0 4.7	94.8 100.8	10.0 10.6	49.0	4.7	90.4	66.6
76	Wyo	Deionized H ₂ O	4.5	51.7	5.3	1) 1.0 g/l NH ₄ HCO ₃ -1.0 g/l Na ₂ SiO ₃ -sat'd O ₂ at 45 psig 2) 1.0 g/l NH ₄ HCO ₃ -sat'd O ₂ at 45 psig	10.1 7.7	25.4 346.6	2.6 35.4	1) 1.0 g/l Na ₂ SiO ₃ 2) Wyo. Grd. H ₂ O	5.5 3.9	127.8 105.9	13.0 10.8	49.6	6.2	87.5	66.3
77	Wyo	1) Deionized H ₂ O 2) 3.0 g/l AlCl ₃	6.9 5.0	76.8 43.5	7.8 4.5	1.0 g/l NH ₄ HCO ₃ -0.5 g/l H ₂ O ₂	8.3	360.7	36.8	None	-	-	-	48.3	8.7	82.0	62.8
78	Wyo	Deionized H ₂ O	7.2	69.6	7.0	1.0 g/l NH ₄ HCO ₃ -sat'd O ₂ at 45 psig	7.9	380.3	38.0	Wyo. Grd. H ₂ O	4.1	275.4	27.5	50.2	5.0	90.1	66.8
79	Wyo	Deionized H ₂ O	7.4	74.7	7.5	1.0 g/l NH ₄ HCO ₃ -1.0 g/l Na ₂ SiO ₃ -sat'd O ₂ at 25 psig	10.0	473.3	47.3	Wyo. Grd. H ₂ O	4.8	108.7	10.9	47.7	5.5	88.5	70.5
80	Wyo	Deionized H ₂ O	5.3	53.9	5.3	1.0 g/l NH ₄ HCO ₃ -sat'd O ₂ at 45 psig	8.3	380.2	37.6	1) 3.0 g/l NaHSO ₃ 2) Wyo. Grd. H ₂ O	4.0 3.5	98.6 56.0	9.8 5.5	45.0			74.0
81	Wyo	Deionized H ₂ O	5.7	74.1	7.3	1.0 g/l NH ₄ HCO ₃ -0.5 g/l H ₂ O ₂	4.8	227.3	22.3	1) 3.0 g/l LaCl ₃ -LaSO ₄ 2) 1.0 g/l Na ₂ SiO ₃ -2.0 g/l NaCl 3) Wyo. Grd. H ₂ O	4.3 4.4	37.3 57.5	3.7 5.6	50.3			61.3

* - Recovery based on ore analysis before and after leaching
 • - Recovery based on product solution analysis
 • - Average flow rate during actual flow periods

to make certain that the ore and groundwater were in equilibrium. If large concentration changes occurred after the flow had restarted, this would indicate that equilibrium was not achieved during the groundwater flow, and thus, that higher levels of chemical leakage could be reached. Actual aquifer flow is very slow (0.5 to 15 ft/year), so equilibrium would be reached in the field. Sudden peaks in chemical concentrations after restarting the stopped groundwater would indicate a need to slow down the groundwater in order to better correlate the simulated test data with the actual field.

6.2.1.1 Leaching of Wyoming Ore Using 1.0 g/l NH_4HCO_3 Saturated with Oxygen at 45 psig Followed by Groundwater, Test 62

This test was designed to study the potential chemical leakage into groundwater following leaching with 1.0 g/l NH_4HCO_3 saturated with oxygen at 45 psig. The test ran for a total of 1601.1 hours. It started with 163.0 hours of deionized water, was followed by 767.0 hours of chemical leach, and concluded with 671.1 hours of groundwater. The simulated Wyoming groundwater flow sequence was as follows: 103.0 hours flow, 168.0 hours no-flow, 168.0 hours flow, 167.0 hours no-flow, and 60.2 hours flow. The last groundwater flow period was shortened due to a development of a crack and subsequent leak in the front glass section. The cause of this breakage was not known.

The permeability variations experienced during this test are shown in Figure 6.6. The permeabilities of the three ore sections were in the range of 0.75 to 1.1 darcy at the end of the deionized water flow period. Within 120 hours after chemical injection, the permeability of the front section dropped from about 1.1 to about 0.20 darcy. The front section permeability then showed a more gradual decline, reaching 0.1 darcy after 300 hours of chemical leach and 0.05 darcy at the conclusion of the leach period (760 hours). The permeabilities of the middle section and end section were approximately 0.5 and 1.1 darcy, respectively, during most of the chemical leach. After groundwater injection, the front section permeability dropped to between 0.02 and 0.03 darcy, while the middle section permeability slowly dropped to less than 0.15

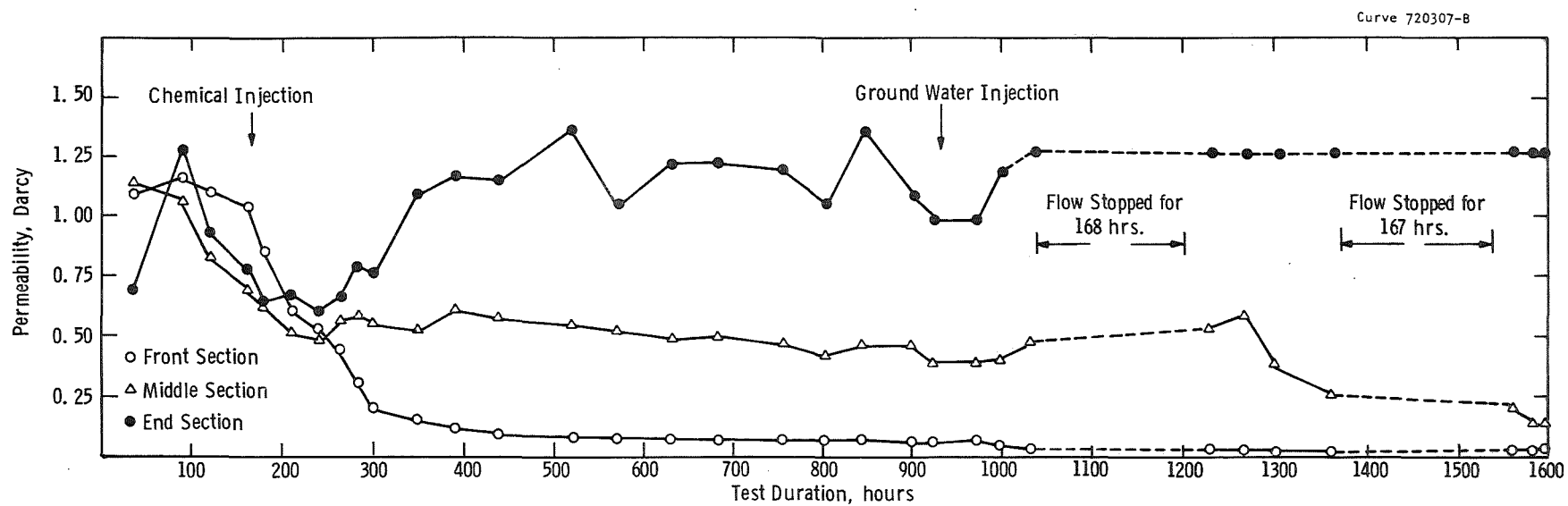


Fig. 6.6 — Permeability variations observed during leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 saturated with oxygen at 45 psig, Test 62.

darcy. The permeability would increase slightly after restarting the groundwater feed after a no-flow period but would then drop back down again.

The permeability experienced in the front section during the leaching period was higher than that obtained in a previous test using 1.0 g/l NH_4HCO_3 leach with 0.5 g/l peroxide (Test 18).⁽³⁾ The front section permeability in that test was about 0.05 darcy after 300 hours of leach and less than 0.02 darcy after 750 hours. The greater permeability damage that occurs in the peroxide test is believed caused by oxygen blockage which results from the large excess of oxygen produced by the rapid decomposition of peroxide. The dissolved oxygen content (~ 110 mg/l) used in this test is not as great as that produced by the peroxide (~ 250 mg/l) and thus did not cause nearly the degree of permeability damage. However, the front section permeability obtained in this test was not as good as that obtained in a similar test (1.0 g/l NH_4HCO_3 saturated O_2 at 45 psig) performed in an earlier study. In that test (Test 43), the permeability remained above 0.2 darcy for the first 300 hours of chemical leach.⁽⁴⁾ The higher permeability obtained in that test was possibly due to the fact that the oxidant was periodically shut off for short periods of time. As well as reducing the total oxygen input, the unoxidized leach could have possibly redissolved some of the oxygen gas existing in the ore bed. The lower oxygen blockage resulted in higher permeability. Permeability damage thus appears to be reduced with decreasing oxygen content.

The gradual decline in permeability experienced during leaching in this test is attributed to the ammoniation of clays, which results in clay swelling, dissociation, and dispersion. Further decline in permeability during the groundwater flow is likely caused by an increase in the clay movement due to the low ionic strength of the groundwater. Restarting groundwater flow seems to initially cause a reopening of the pores. Perhaps the ore clay particles are moved slightly due to

initial impact of the solution. However, the permeability then drops as the flow rate declines and the particles reorient themselves and again block the pores.

A summary of the chemical data obtained during this test is tabulated in Table 6.3. The pH of product leach solutions were in the 7 to 8.2 range. The uranium, bicarbonate and ammonium variations experienced during the test are shown in Figure 6.7. The bicarbonate and uranium variations followed similar trends. As the bicarbonate concentration dropped during deionized water flow, so did the uranium concentration. After chemical injection, the uranium concentration increased with the increase in bicarbonate concentration. The ammonium level was less than 9 mg/l for the first 115 liters (12.2 pore volumes) of leach. The ammonium concentration then continually increased, reaching a final value of 170 mg/l which was less than the expected feed concentration (220 mg/l). A total of 50 g of ammonium (or 0.056 meq of ammonium/g of ore) was picked up by the ore in the 364 liters (or 39 pore volumes) of leach. This is approximately the same amount of ammonium sorbed in the previously performed 1.0 g/l ammonium bicarbonate tests.^(3,4)

The ammonium concentration profiles along the length of the ore column at various times during leach are shown in Figure 6.8. As expected, the results show that the ammonium solution level decreases as the solution progresses through the ore bed, indicating the ammonium sorption is occurring in all three ore sections. The profiles show that the magnitude, or percentage, of an ammonium concentration decline in a given ore section decreases with time, thus showing the rate and degree of ammonium sorption is decreasing with time. For example, in the middle section at a leach time of 167 hours, the ammonium concentration dropped from 142 to 34 mg/l; a decline of 108 mg/l or 76%. However, at a leach time of 218 hours, the ammonium concentration in this section only dropped from 164 to 86 mg/l; a decline of 78 mg/l or 48%. This concentration decline becomes progressively smaller with time which results in ammonium equilibrium between the ore and the feed concentration

TABLE 6.3

Summary of Data Obtained During Leaching of Wyoming Ore Using 1.0 g/l NH_4HCO_3
Saturated with O_2 at 45 psig, Test 62

Duration, Hrs	Product Solution vol, l	Σ Vol, l	Σ Ore Pore Volumes (1 PV = 9.4 l)	pH	NH_4^+ mg/l	HCO_3^- mg/l	Uranium mg/l	% Uranium Recovery
90.0	22.9	22.9	2.4	6.10	--	665	399	18.67%
163.0	46.7	69.6	7.4	6.98	--	145	36	21.10%
213.0	30.6	100.2	10.7	6.94	--	510	235	36.80%
258.0	25.9	126.1	13.4	7.14	--	--	--	--
330.0	40.8	166.9	17.7	7.38	--	665	114	52.34%
381.0	28.2	195.1	20.8	7.62	9	--	--	--
426.0	25.6	220.7	23.5	7.60	--	465	51	57.94%
474.0	24.3	245.0	26.1	7.82	79	--	--	--
522.0	23.0	268.0	28.5	7.90	106	--	--	--
594.0	30.9	298.9	31.8	7.95	113	--	--	--
642.0	19.9	318.8	33.9	7.81	130	415	30	63.96%
690.6	19.2	338.0	36.0	7.85	--	--	--	--
762.0	30.0	368.0	39.1	7.98	148	630	--	--
810.0	20.3	388.3	41.3	7.89	--	--	--	--
858.0	20.0	408.3	43.4	8.08	--	--	--	--
930.0	25.6	433.9	46.2	8.21	164	700	17	67.95%
961.5	12.4	446.3	47.5	8.09	171	--	10	68.21%
1032.0	20.5	466.8	49.6	8.16	173	410	8.3	71.68%
1266.0	13.2	480.0	51.1	8.18	193	--	26.0	72.39%
1369.0	14.3	494.3	52.6	8.27	153	380	19.0	72.94%
1601.1	10.2	504.5	53.7	8.24	140	420	16.0	73.27%

Times of Solution Injection: (1) NH_4HCO_3 - saturated O_2 - 163 hours
(2) Wyo. Ground Water - 930 hours

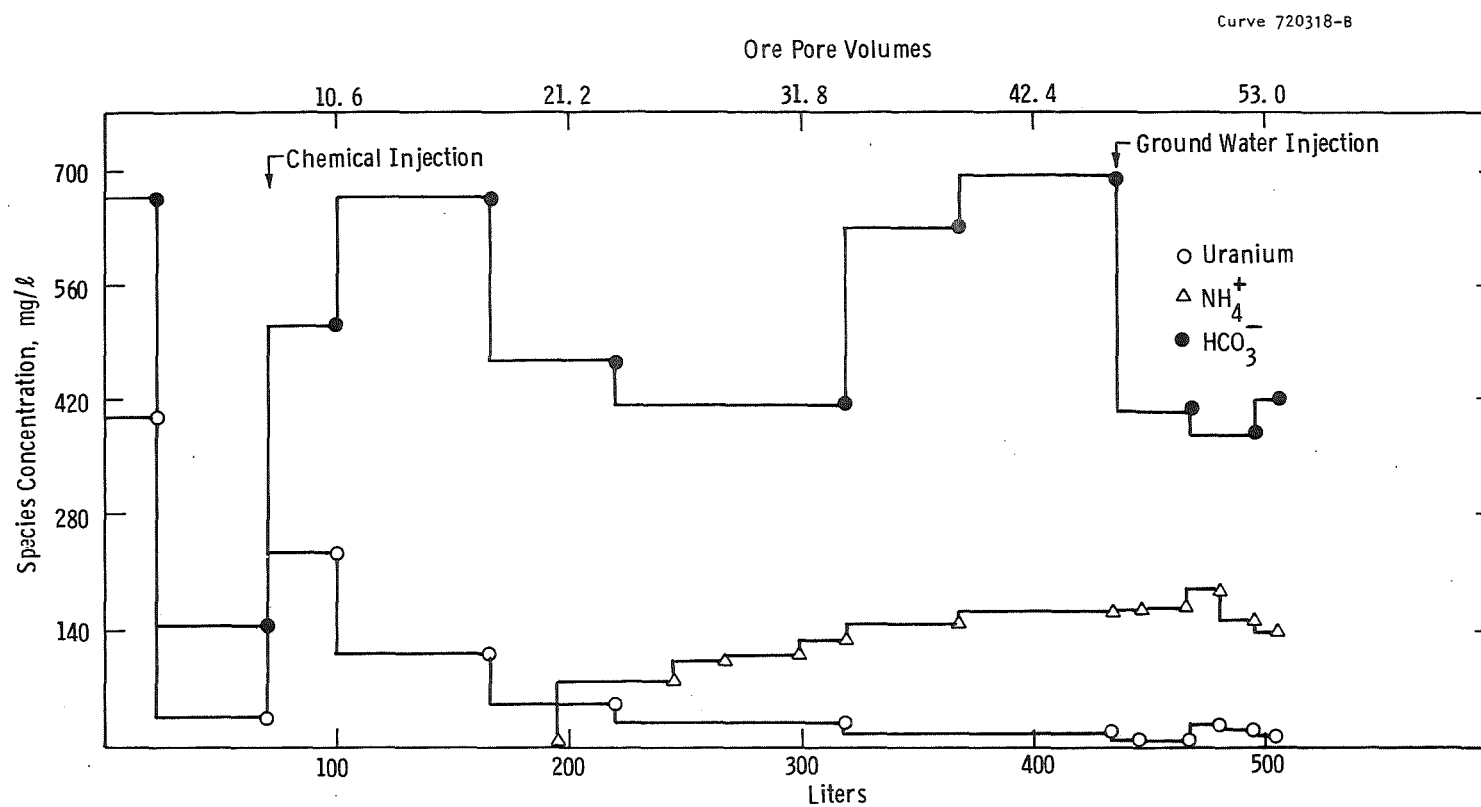


Fig. 6.7 — Concentration variations experienced during leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 saturated with O_2 at 45 psig, Test 62.

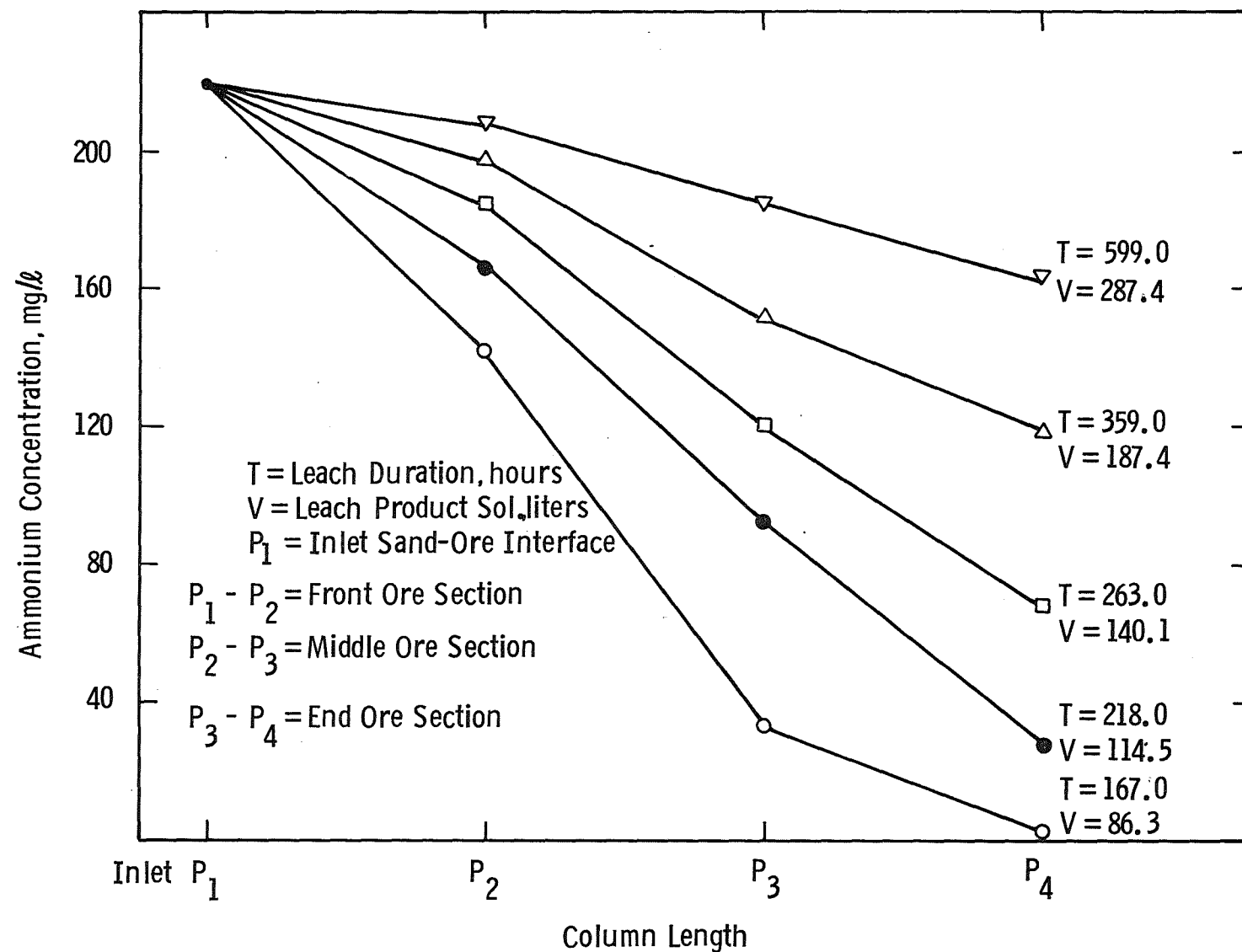


Fig. 6.8 – Ammonium concentration profiles along the length of the column during leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 saturated with O_2 (45 psig), Test 62

(220 mg/l) to be reached very slowly. This is shown by the fact that even after 600 hours (or 290 liters) of leach, the ammonium level (208 mg/l) leaving the front section is still slightly less than the feed concentration. Ammonium sorption is thus still occurring in this section. This continual decline in the ammoniation rate results in the very gradual complete ammonium breakthrough in the ore bed.

The uranium recovery rate observed during this test is shown in Figure 6.9. The total recovery was 73.3% based on solution uranium analyses. Approximately 22% of the uranium was removed during the water flow period. In the first 10 pore volumes (95 liters) of actual solution leach collected,* approximately 32% of the uranium was recovered. The recovery rate and the total recovery was less than that obtained in the test (Test 43) previously performed under essentially identical conditions.⁽⁴⁾ In that test, 37% of the uranium was recovered in the first 10 pore volumes of leach, and a total recovery of 85.2% was obtained. As noted before, the permeability was better in Test 43 which may have permitted greater uranium accessibility and thus better recovery. Also, the flow rate was slightly less in that test (7.1 vs. 7.9 ml/min), thus allowing more time for the uranium to be leached. The results have indicated that alkaline leaching is reaction rate or mass transfer constrained, thus an increase in leaching time should improve the uranium heads grade and the total recovery obtainable in a given volume of solution.^(3,4)

The results of the post-leach ion leakage study using simulated groundwater are presented in Table 6.4. Chloride, radium, thorium, arsenic, molybdenum, vanadium, iron, and magnesium were all at relatively low levels within 4 pore volumes of groundwater. Sulfate dropped to within the background groundwater level after 6.5 pore volumes. Selenium, which has an EPA drinking water standard of 10 ppb,⁽⁸⁾ was

*The first system void volume of solution (10.7 l) collected after the injection of leach solution is residual deionized H₂O, and is thus not taken to be actual leach solution (see Appendix C).

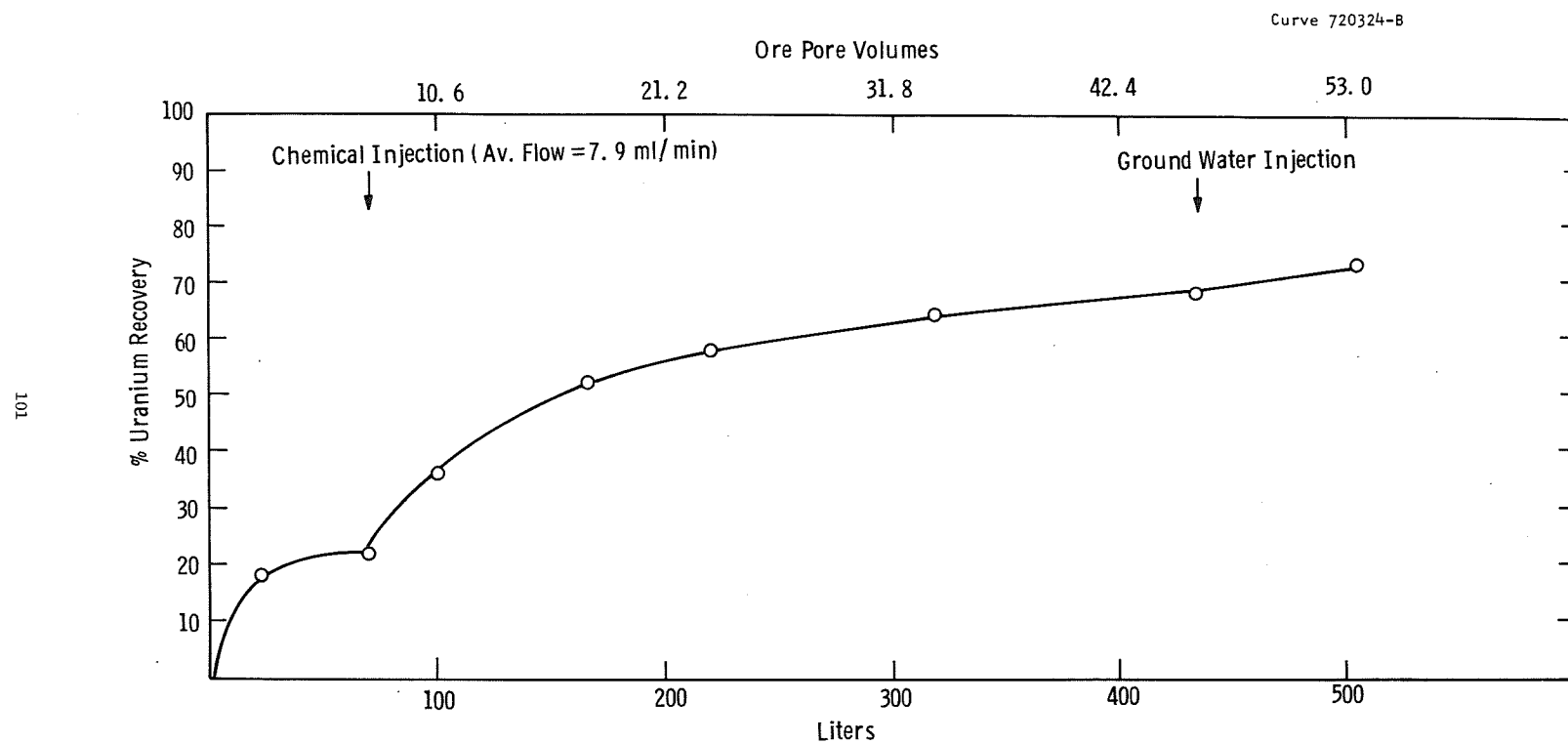


Fig. 6.9—Uranium recovery rate observed during leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 saturated in oxygen at 45 psig, Test 62.

TABLE 6.4

Ion Leakage From Wyoming Ore Residue After Leaching With
1.0 g/l NH_4HCO_3 Saturated With O_2 At 45 psig, Test 62

No.	Duration hrs.	Vol. l	Σ Vol. l	Σ Ore Pore Volumes	pH	U mg/l	NH_4^+ mg/l	HCO_3^- mg/l	$\text{SO}_4^{=}$ mg/l	Cl^- mg/l	Ra pC/ml	Th pC/ml	Se mg/l	As mg/l	Mo mg/l	V mg/l	Fe mg/l	Mg mg/l
Feed	930.0	--	--	--		0	0	320	190	65	0	0	0	0	0	0	0	0
1	961.5	12.4	12.4	1.3	8.09	10	171	--	50	15	0.5	0.2	0.20	0.005	<0.2	<0.5	<0.1	6.0
2	1032.0	20.5	32.9	3.5	8.16	8.3	173	410	210	60	--	--	0.14	0.0036	<0.2	<0.5	<0.1	6.3
3	1266.0	13.2	46.1	4.9	8.18	26.0	193	--	320	60	--	--	0.12	0.0024	<0.2	<0.5	<0.1	7.6
4	1369.0	14.3	60.4	6.4	8.27	19.0	153	380	150	--	--	--	--	--	--	--	--	--
5	1601.1	10.2	70.6	7.5	8.24	16.0	140	420	150	--	--	--	--	--	--	--	--	--

still at an unacceptable level (120 ppb) after about 5 pore volumes. Significant uranium (16 mg/l), ammonium (140 mg/l), and bicarbonate (420 mg/l) leakage was still occurring after 7.5 pore volumes of groundwater. The high bicarbonate likely helps the solubilization, and subsequent leakage, of the uranium. The ammonium leakage is likely the result of cations (Na^+ and Ca^{++}) in the groundwater exchanging with the ammonium that had been sorbed onto the ore's clay during leaching. The total meq (10.7 meq/l) of cations in the groundwater was sufficient to cause the observed ammonium leakage (7.8 to 10.7 meq/l). The Series IV agitation tests predict an ammonium desorption level of about 130 mg/l for this cationic strength groundwater (1.9×10^{-2}) and the final ammonium ore level of about 1 mg/g of ore. This shows good agreement between the agitation and column tests. Restarting the groundwater after the flow had been stopped for about a week did not seem to affect the levels of chemical leakage. Equilibrium was thus essentially reached between the ore and the groundwater at the flow rate used (3.5 ml/min).

Analysis of the ore after leaching showed that the front, middle, and end ore sections had ammonium levels of 0.77, 0.72, and 0.58 mg of ammonium/g of ore, respectively. As was indicated by the solution ammonium profiles (Figure 6.8), ammonium sorption occurs initially to the greatest extent in the front of the ore bed. Based on ammonium solution concentrations during leach and post-leach, the average ammonium ore level after testing should have been 0.78 mg/g of ore. This is in fair agreement (+12%) with the average of the post-test ore ammonium analyses (0.69 mg/g).

6.2.1.2 Leaching of Wyoming Ore Using 1.0 g/l NH_4HCO_3 Saturated With Oxygen at 45 psig Followed by Groundwater, Test 78

This test is essentially the same as Test 62. Those test conditions were duplicated in order to determine if the leach data and, especially, the post-leach leakage data were reproducible. In this test, the groundwater flow was extended beyond that of Test 62 in order to

determine the long-term leakage levels. The post-leach groundwater flow of Test 62 was shortened due to column breakage. This test ran for a total of 2089.0 hours. This included 162.0 hours of deionized water, 799.0 hours of leach, and 1128.0 hours of groundwater.

The permeability variations experienced during this test are shown in Figure 6.10. By the conclusion of the deionized water flow period, the permeabilities of the front, middle, and end sections were approximately 2.0, 1.7, and 3.0, respectively. The front section permeability dropped to about 0.9 darcy within 120 hours after chemical injection, to about 0.3 darcy after 300 hours of leach, and to about 0.1 darcy after 500 leach hours. The front section permeability seemed to level off at about 0.05 darcy by the conclusion of the leach. The permeability decline was more gradual than in Test 62, but the final permeability was the same. After groundwater injection, the front section permeability stayed between 0.04 and 0.05 darcy. The middle section, however, dropped significantly from about 1.0 to 0.1 darcy. This decline in the middle section also occurred in Test 62. Unlike Test 62, there was also a permeability decline in the end section. Perhaps the permeability damaging effects of clay dissociation and dispersion occur in the end sections after long flow durations of the low ionic strength groundwater. Initially, the groundwater likely dissolves ore material as it passes through the ore bed. Thus, it is of relatively high ionic strength by the time it passes through the end section of the ore. As more solution passes through the ore bed, however, less material is available to come into solution and the ionic strength remains low. Clay dissociation and dispersion then occur as this low ionic strength solution passes through the end sections of the ore bed.

The chemical data collected during this test is given in Table 6.5. The pH variations and concentrations variations, shown in Figure 6.11, were typical of the previous 1.0 g/l ammonium bicarbonate leaches (Test 62). The ammonium concentration was 2 mg/l or less for the first 90.1 liters of leach. The ammonium level then gradually increased, reaching a final value of 175 mg/l, which was still less than the

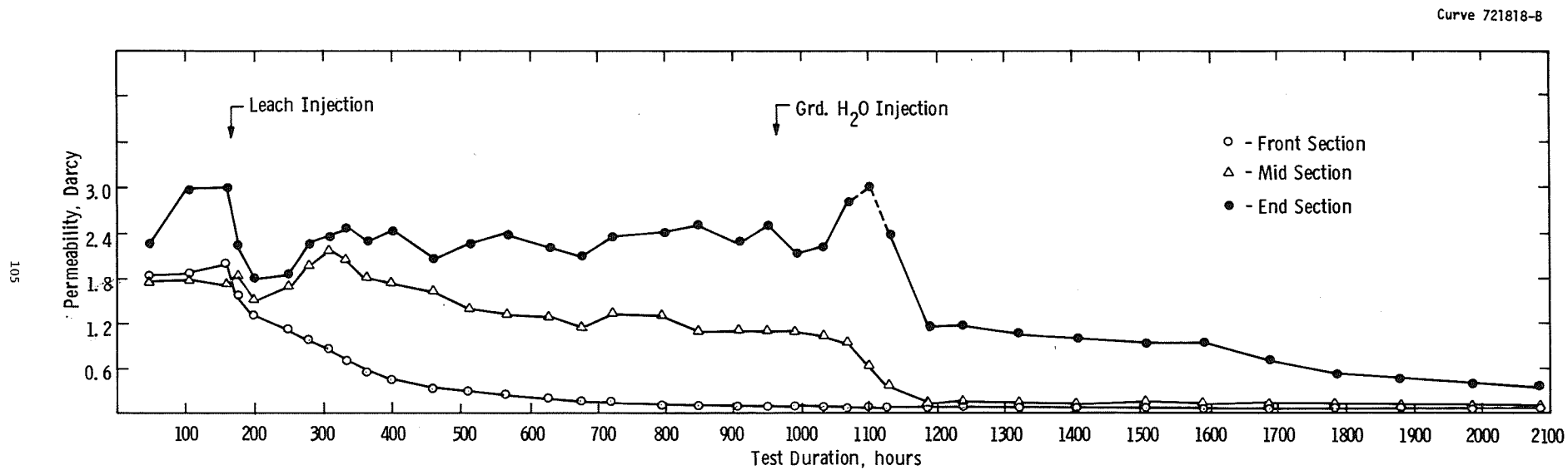


Fig. 6.10 — Permeability variations experienced during leaching of Wyoming ore with 1.0 g/l NH_4HCO_3 sat'd O_2 (45 psig), followed by ground water, Test 78

TABLE 6.5

Summary of Data Obtained During Leaching of Wyoming Ore
 With 1.0 g/l NH_4HCO_3 -Saturated O_2 (45 psig), Followed by Ground Water, Test 78

Duration, Hrs.	Product Solution, Vol., l	Σ Vol., l	Σ Ore Pore Volumes (1PV=10.0l)	pH	NH_4^+ mg/l	Uranium mg/l	% Uranium Recovery
114.0	43.2	43.2	4.3	6.60	---	238	20.5
162.0	26.4	69.6	7.0	7.28	---	23	21.7
216.0	29.2	98.8	9.9	7.07	---	198	33.2
282.0	34.4	133.2	13.3	7.05	---	246	50.1
354.0	37.8	171.0	17.1	7.58	2	---	---
451.0	46.9	217.9	21.8	7.83	41	58	59.9
523.0	37.0	254.9	25.5	7.92	100	---	---
619.0	47.8	302.7	30.3	7.93	129	16	62.6
715.0	45.4	348.1	34.8	8.09	147	---	---
811.0	47.2	395.3	39.5	8.12	165	---	---
910.0	37.8	433.1	43.3	8.18	---	---	---
961.0	16.8	449.9	45.0	8.27	175	8.9	65.2
1003.0	17.8	467.7	46.8	7.94	188	6.2	65.4
1054.0	17.8	485.5	48.6	8.00	188	3.9	65.5
1123.0	17.5	503.0	50.3	8.15	186	4.7	65.7
1177.0	14.3	517.3	51.7	8.16	158	4.6	65.9
1246.0	16.4	533.7	53.4	8.18	142	4.0	66.0
1315.0	16.0	549.7	55.0	8.28	---	---	---
1414.0	18.7	568.4	56.8	8.30	101	3.5	66.3
1489.0	17.6	586.0	58.6	8.22	---	---	---
1561.0	17.0	603.0	60.3	8.26	81	2.8	66.5
1633.0	16.1	619.1	61.9	8.09	---	---	---
1699.0	18.1	637.2	63.7	8.28	69	1.8	66.6
1750.0	13.3	650.5	65.1	8.31	---	---	---
1843.0	21.9	672.4	67.2	8.35	61	1.5	66.7
1918.0	15.9	688.3	68.8	7.92	---	---	---
2011.0	19.8	708.1	70.8	7.97	53	1.5	66.8
2089.0	17.2	725.3	72.5	8.21	---	---	---

Times of Solution Injection: 1. $\text{NH}_4\text{HCO}_3\text{-O}_2$ - 162.0 hours

2. Wyo. Grd. H_2O - 961.0 hours

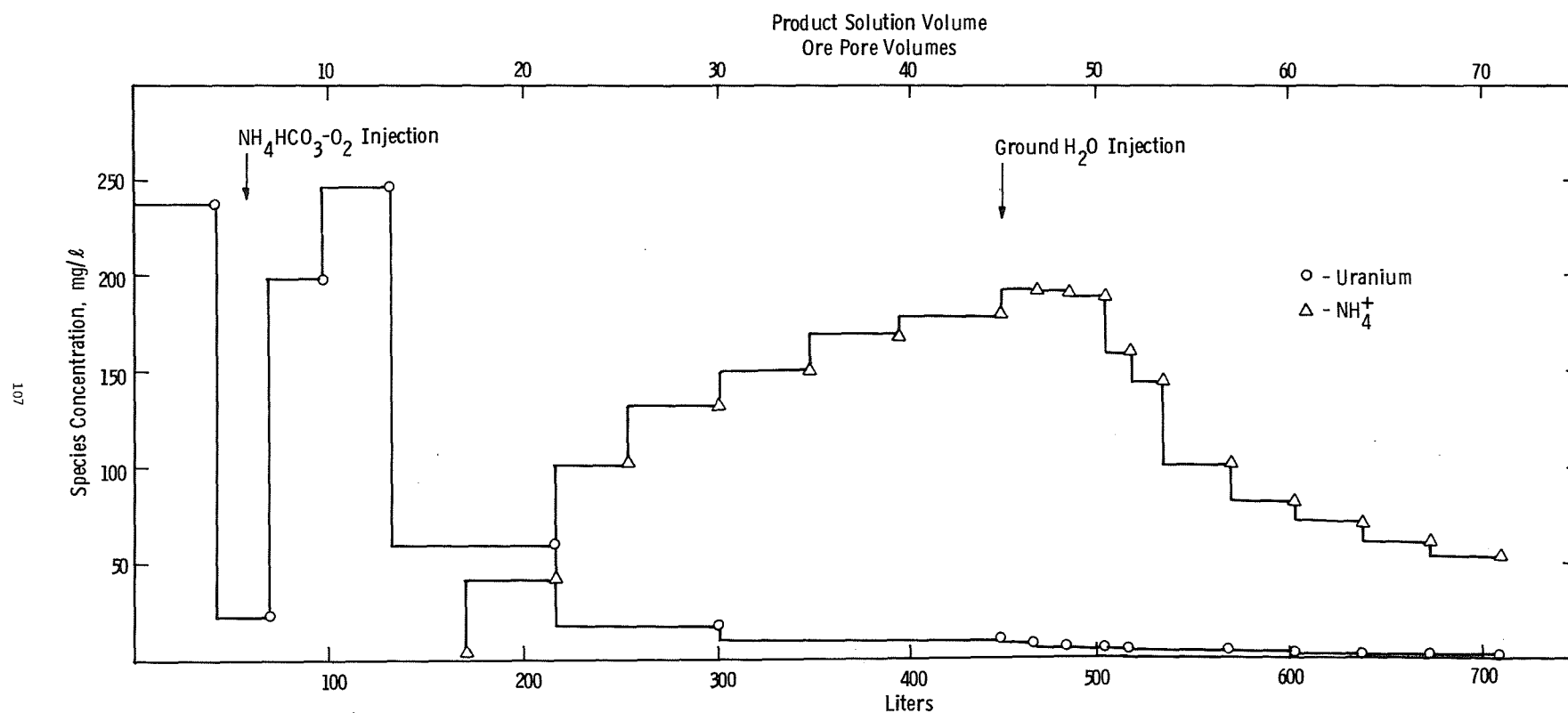


Fig. 6.11 — Concentration variations experienced during the leaching of Wyoming ore with 1.0 g/l NH_4HCO_3 saturated O_2 (45 psig) followed by ground water, Test 78

expected feed concentration of 200 mg/ℓ. In the 380.3 liters (38.0 pore volumes) of leach, a total of 45.8 g of ammonium was sorbed by the ore. This ammonium sorption level on the ore (0.053 meq of NH_4^+ /g of ore) is approximately the same as that obtained in Test 62.

The uranium recovery rate observed during this test, shown in Figure 6.12, is essentially identical to that obtained in Test 62. Approximately 22% of the uranium was removed during the deionized water flow period. In the first 10 pore volumes (100 liters) of actual leach solution collected, about 32% of the uranium was recovered. The total recovery by the conclusion of leach was about 65%. The leach flow rate in this test was the same (7.9 mL/min) as that used in Test 62, thus giving the same leach residence time.

The results of the post-leach ion leakage into ground water are given in Table 6.6. Again, the results were similar to those obtained in Test 62. Iron, molybdenum, and vanadium presented no leakage problems; while significant ammonium, selenium, and uranium leakages did occur. The initial uranium leakage (4-5 mg/ℓ) was not as high as in Test 62 (16-20 mg/ℓ). The reason for the lower leakage in this test was not known. The uranium level remained above 2 mg/ℓ for about 15 pore volumes of groundwater. The ammonium concentration was above 100 mg/ℓ for about the first 12 pore volumes, and did not drop below 60 mg/ℓ until about 25 pore volumes were passed through the ore. The selenium level remained at 130 ppb or above during the entire groundwater flow, and showed no real indication of dropping below this.

This test showed that the leach test data obtained using this in-situ leaching simulation system is reproducible. The permeability, uranium recovery, and post-leach ion leakage data obtained in this test reasonably duplicated the results obtained earlier in a column test performed under identical leach conditions. This test was also valuable in that it pointed out the likely need for post-leach restoration. The leakage of uranium, ammonium, and selenium were shown to persist for long

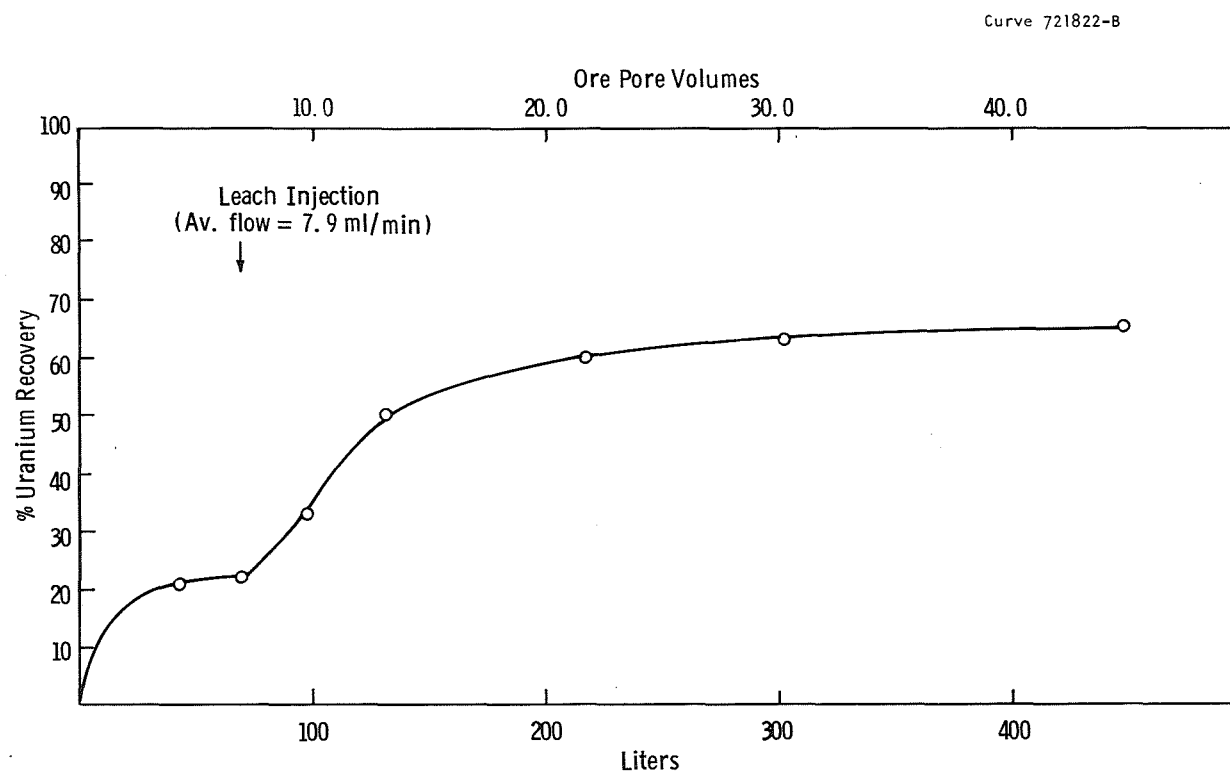


Fig. 6.12 — Uranium recovery rate observed during leaching of Wyoming ore with 1.0 g/l NH_4HCO_3 saturated O_2 (45 psig), Test 78.

TABLE 6.6

Ion Leakage From Wyoming Ore After Leaching
 With 1.0 g/l NH_4HCO_3 -Saturated O_2 (45 psig), Test 78

No.	Duration, Hrs.	Vol., ℓ	Σ Vol., ℓ	Σ Ore Pore Volumes	pH	U mg/ℓ	NH_4^+ mg/ℓ	Se mg/ℓ	Fe mg/ℓ	Mo mg/ℓ	V mg/ℓ
Wyo. Grd. H ₂ O Feed	961.0	---	---	---		---	---	---	---	---	---
1	1003.0	17.8	17.8	1.8	7.94	6.2	188	0.18	<0.5	<0.5	<1
2	1054.0	17.8	35.6	3.6	8.00	3.9	188	0.14	<0.5	<0.5	<1
3	1123.0	17.5	53.1	5.3	8.15	4.7	186	0.14	<0.5	<0.5	<1
4	1177.0	14.3	67.4	6.7	8.16	4.6	158	0.15	---	---	---
5	1246.0	16.4	83.8	8.4	8.18	4.0	142	0.13	---	---	---
6	1315.0	16.0	99.8	10.0	8.28	---	---	---	---	---	---
7	1414.0	18.7	118.5	11.9	8.30	3.5	101	0.17	---	---	---
8	1489.0	17.6	136.1	13.6	8.22	---	---	---	---	---	---
9	1561.0	17.0	153.1	15.3	8.26	2.8	81	0.16	---	---	---
10	1633.0	16.1	169.2	16.9	8.09	---	---	---	---	---	---
11	1699.0	18.1	187.3	18.7	8.28	1.8	69	0.17	---	---	---
12	1750.0	13.3	200.6	20.1	8.31	---	---	---	---	---	---
13	1843.0	21.9	222.5	22.3	8.35	1.5	61	0.17	---	---	---
14	1918.0	15.9	238.4	23.8	7.92	---	---	---	---	---	---
15	2011.0	19.8	258.2	25.8	7.97	1.5	53	0.13	---	---	---
16	2089.0	17.2	275.4	27.5	8.21	---	---	---	---	---	---

durations if no restoration was attempted. Therefore, in order to obtain acceptable leakage levels in a reasonable amount of time, some post-ammonium bicarbonate leach restoration of the ore is likely necessary.

6.2.1.3 Leaching of Wyoming Ore Using 2.0 g/l NaHCO_3 Saturated With Oxygen at 45 psig Followed by Groundwater, Test 63

The purpose of this test was to examine the possible groundwater chemical leakage following a sodium bicarbonate leach. The effect of changing the principle cation of the bicarbonate leach could thus be studied. Sodium, an ion commonly found in groundwater, would have a higher acceptable groundwater baseline level than ammonium. This test also examined the effect of using dissolved oxygen as the oxidant with sodium bicarbonate. A similar leach test (Test 37) had been previously performed using peroxide as the oxidant.⁽⁴⁾

This test ran for a total of 1800 hours. This included a 168-hour initial deionized water flow, a 762.2-hour leach, and a 869.8-hour groundwater period. The groundwater period consisted of the following flow sequence: 101.8 hours of flow, 70 hours of no-flow, 164 hours of flow, 168 hours of no-flow, 96 hours of flow, 144 hours of no-flow, and finally, 126 hours of flow.

The permeability variations experienced during the test are shown in Figure 6.13. At the conclusion of the deionized water flow period, the permeability of all three sections was in the range 0.7 to 0.9 darcy. After chemical injection, the permeabilities of all sections initially dropped. The permeability of the middle section stayed at about 0.5 darcy, while the end section typically stayed between 0.5 and 0.8 darcy. The front section permeability dropped from 0.88 darcy to less than 0.06 darcy within 120 hours of chemical leach. The front section permeability then gradually declined to less than 0.02 darcy at the conclusion of the leach period. The permeability experienced here was slightly higher than that experienced with the previous sodium test using 0.5 g/l peroxide (Test 37). In that test, permeability

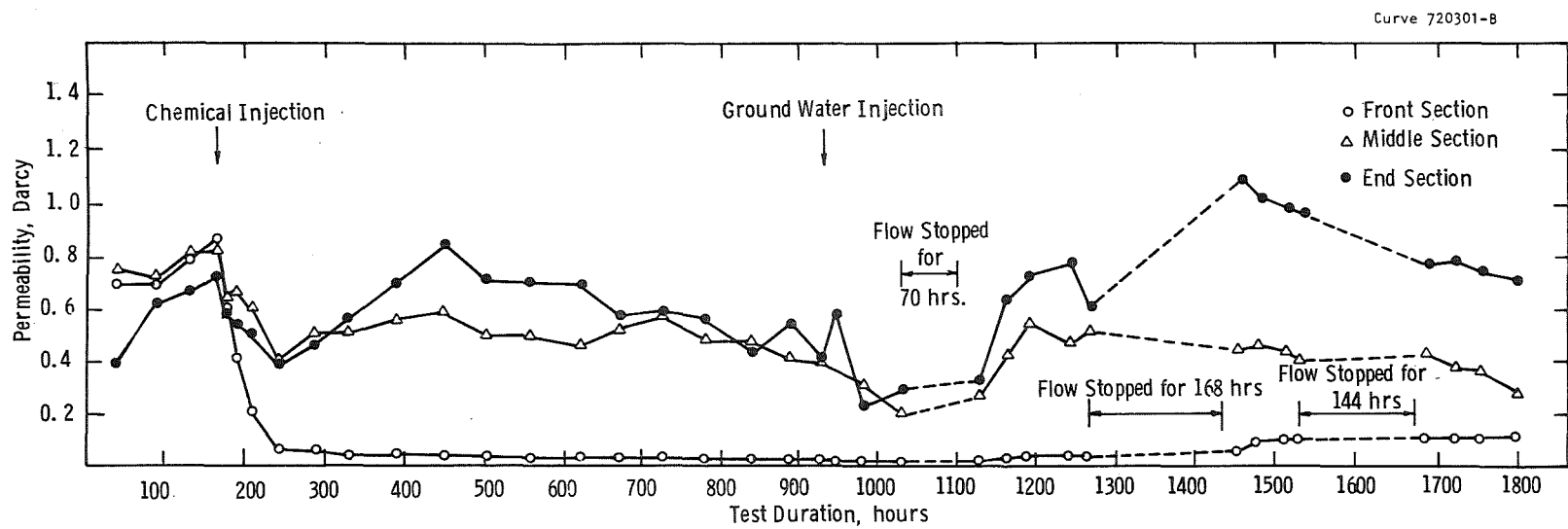


Fig. 6.13 - Permeability variations observed during leaching of Wyoming ore using 2.0 g/l NaHCO_3 saturated with O_2 at 45 psig, Test 63.

dropped to less than 0.04 darcy after 150 hours of leach, and was less than 0.01 darcy at the termination of the leach. The higher permeability experienced in this test is attributed to less oxygen blockage resulting from the dissolved oxygen feed (~ 110 ppm) compared to that resulting from the peroxide feed (~ 235 ppm of O_2).

The front section permeability was significantly lower than that obtained with the ammonium bicarbonate test (Test 62), in which permeability was about 0.2 darcy after 120 hours of leach, and 0.05 darcy at the conclusion of the leach. It is believed that the greater permeability damage that occurs during sodium leach is the result of the sodium exchanging onto the ore's clay. Sodium substituted clays may cause greater clay swelling, dispersion, and dissociation than ammonium (or potassium) substituted clays.⁽¹⁷⁾ These clay interactions have a substantial adverse effect on permeability by blocking or reducing the pores in the ore bed.

During groundwater flow, permeability showed a rapid decline. The front section permeability dropped to less than 0.005 darcy after the first 40 hours of groundwater. The low ionic strength of the groundwater likely caused an increase in clay dispersion and dissociation. The groundwater flow was stopped after 100 hours in the hope of restoring some of the permeability. Restarting the flow after 70 hours produced a significant increase in permeability (from 0.005 to about 0.02 darcy). Each subsequent stopping and restarting of feed also caused an increase in permeability. The permeability was about 0.1 darcy during the final groundwater flow. The impact of restarting the groundwater flow may cause ore particles (e.g., dispersed clay particles) to reorient thus reopening pores. Also, the no-flow period may have sufficient time for the oxygen blocking the pores to dissolve in the residual groundwater thus causing a reopening of the pores for subsequent flow.

The chemical data collected during this test is given in Table 6.7. The pH's of the product solution were typical of bicarbonate leaches;

Table 6.7

Summary of Data Obtained During Leaching of Wyoming Ore
Using 2.0 g/l NaHCO_3 Saturated With O_2
at 45 psig, Test 63

Duration hrs.	Product Solution Vol., l	Σ Vol. l	Σ Ore Pore Volumes (1 pv = 9.3 l)	pH	Na^+ mg/l	HCO_3^- mg/l	Uranium mg/l	% Uranium Recovery
90	15.8	15.8	1.7	6.44	--	1000	612	20.16%
168	29.6	45.4	4.9	7.18	--	195	63	24.05%
213	26.8	72.2	7.7	6.98	8.2	905	327	42.32%
258	19.3	91.5	9.8	7.16	195	--	--	--
330	20.9	112.4	12.0	7.27	313	1220	180	57.41%
381	12.1	124.5	13.3	7.62	--	--	--	--
450	14.7	139.2	14.9	7.80	397	--	--	--
522	12.9	152.1	16.3	8.04	--	--	--	--
594	10.9	163.0	17.5	7.89	419	1250	122	70.28%
666	11.1	174.1	18.7	8.03	--	--	--	--
762	13.9	188.0	20.2	8.05	425	1185	--	--
834	9.5	197.5	21.2	8.21	450	1200	--	--
930.2	10.3	207.8	22.3	8.44	437	1210	47	74.67%
1170.0	11.6	219.4	23.5	8.38	463	1135	52	75.79%
1266.0	16.8	236.2	25.3	8.59	282	440	18	76.42%
1482.0	19.9	256.1	27.4	8.30	244	335	12	76.92%
1530.0	23.9	280.0	30.0	8.28	214	230	3.6	77.10%
1722.3	20.4	300.4	32.2	8.23	227	250	4	77.27%
1800.0	28.0	328.4	35.2	8.40	234	240	3	77.44%

Times of Solution Injection: (1) NaHCO_3 - O_2 - 168 hrs. (Na^+ - 500 mg/l, HCO_3^- - 1385 mg/l)

(2) Wyoming Groundwater - 930.2 hrs.

pH 7 to 8.4. The bicarbonate, sodium, and uranium concentrations are shown in Figure 6.14. The uranium and bicarbonate variations followed trends typical of past bicarbonate leaches. The sodium level in the product seemed to fairly rapidly reach the feed concentration. This indicates that, unlike ammonium in Test 62, sodium exchange onto the ore's clay was relatively small. This is, in part, due to the fact that sodium is already present on the ore's clay, and thus the concentration driving force is low for the leach sodium ions to move to the clay exchange sites and exchange with other cations (e.g., Ca^{++}) present on the clay. Also, sodium has been found to have a lower exchange ability than ammonium or potassium. In this 2.0 g/l NaHCO_3 test, only 0.03 meq of sodium was sorbed per g of ore. This is much lower than the 0.056 meq of ammonium per g of ore obtained using only 1.0 g/l NH_4HCO_3 leach (Test 62). Also, unlike ammonium, the sodium level in the product did reach that of the feed thus indicating that no further exchange was occurring.

The uranium recovery rate observed during this test is given in Figure 6.15. An overall recovery of 77.4% was obtained. During the initial water flow period, approximately 24% of the uranium was recovered. In the first 93 liters (or 10 ore pore volumes) of actual leach solution collected, approximately 42% of the uranium was recovered. In a previously performed test (Test 37) using 2.0 g/l NaHCO_3 with 0.5 g/l H_2O_2 , only 34% of the uranium was recovered in 97 liters (or 10 pore volumes) of leach.⁽⁴⁾ As was noted before, the previous test's permeability was much lower than this test. The lower permeability perhaps resulted in less uranium accessibility and thus a lower uranium recovery.

The uranium recovery obtained in this sodium test was also significantly better than the uranium recovery obtained with the NH_4HCO_3 leach (Test 62). In the NH_4HCO_3 test, 32% of the uranium was recovered in the first 10 pore volumes (94 liters) of leach. The better recovery with NaHCO_3 is attributed to the much slower flow rate (3.6 vs. 7.9 ml/min) and thus greater leaching residence time obtained

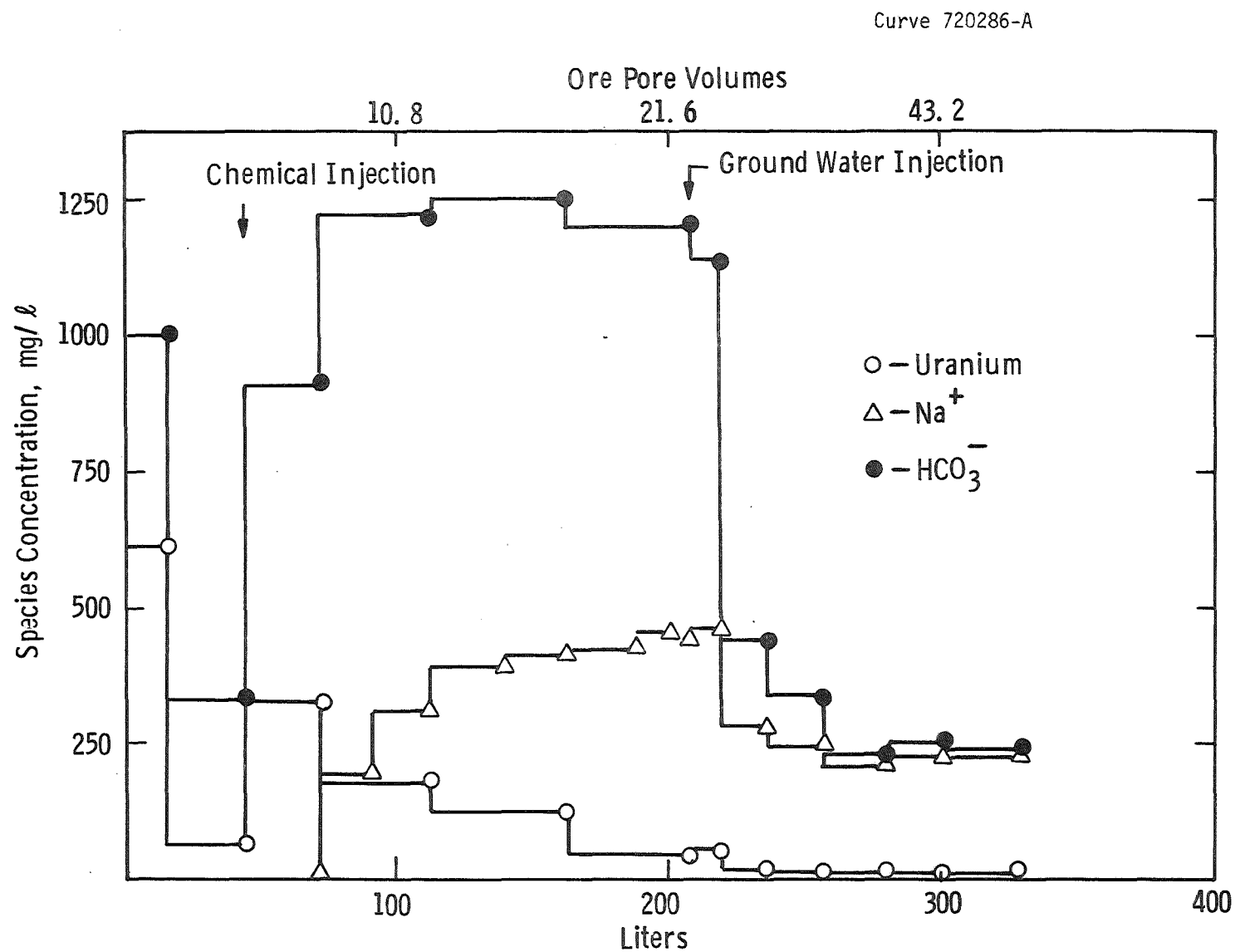


Fig. 6. 14— Concentration variations experienced during leaching of Wyoming ore using 2.0 g/l NaHCO₃ saturated with O₂ at 45 psig, Test 63.

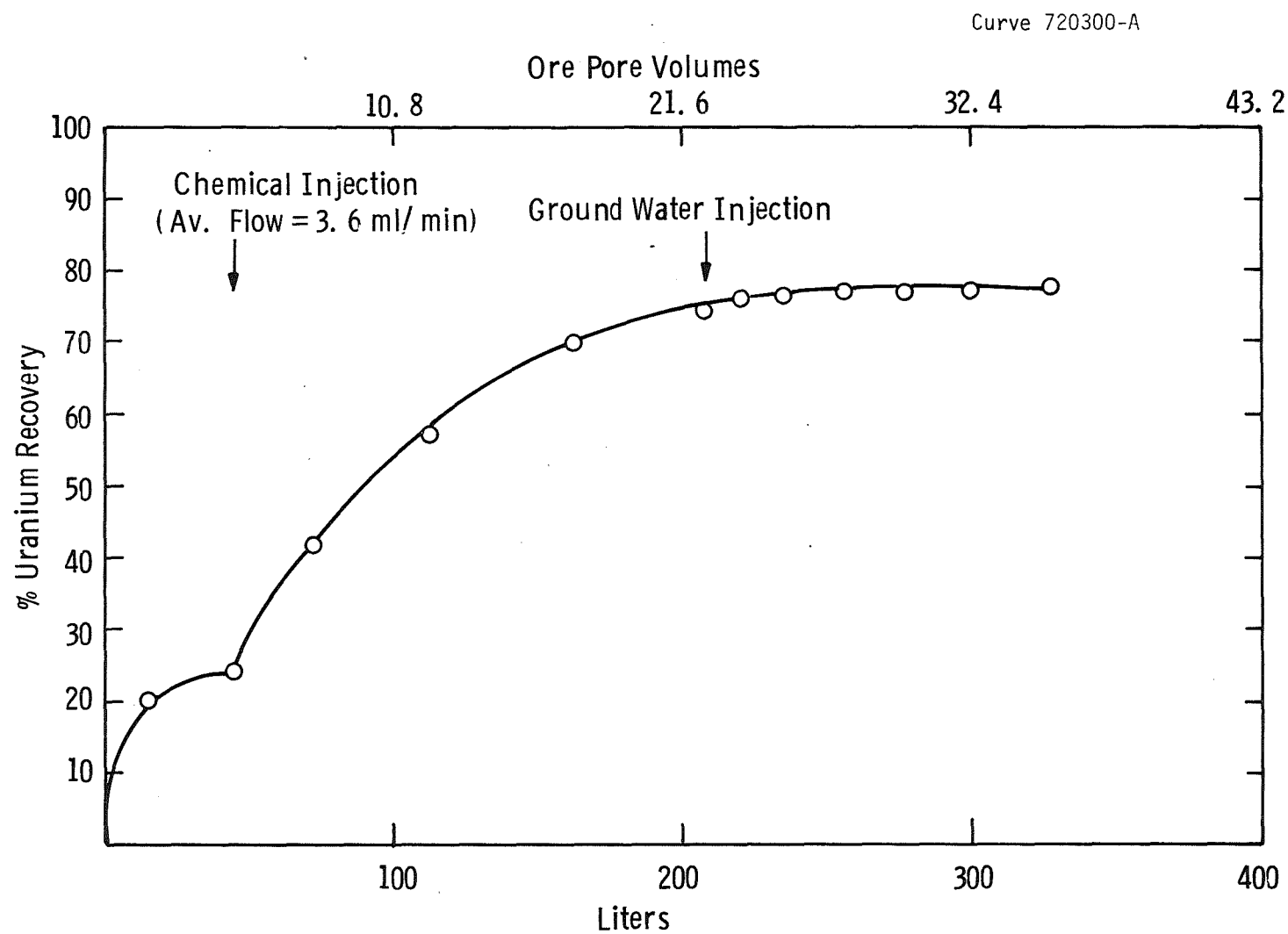


Fig. 6. 15—Uranium recovery rate observed during leaching of Wyoming ore using 2.0 g/l NaHCO_3 saturated in oxygen at 45 psig, Test 63.

in that test. Column test results have indicated that bicarbonate leaches are reaction and/or mass transfer controlled; therefore, increased leaching time should cause greater recovery. However, if the increased leaching time (slower flow rate) is due to significant permeability damage, then greater recovery may not necessarily result. As noted above, permeability damage can result in less uranium accessibility and thus a lower uranium recovery.

The results of post-leach chemical leakage into simulated Wyoming groundwater are presented in Table 6.8. Uranium, sodium, and selenium are significantly above the background groundwater levels. As has been true of the other bicarbonate leaches (Tests 62 and 65), the selenium seems to have been mobilized to a level above the EPA drinking water standard. The uranium leakage (3 to 4 mg/l) after 7 pore volumes of groundwater is significantly lower than that observed in the other bicarbonate leaches (10-20 mg of U/l in Tests 62 and 65). This may, in part, be due to the fact that the leakage of bicarbonate, which can solubilize the uranium, is also lower than in the previous tests. The sodium level is only 20 to 40 mg/l above the groundwater concentration. The low sodium sorption during leaching and the high sodium content of the groundwater accounts for the relatively low sodium leakage. Again, stopping the groundwater flow did not seem to affect the contaminant leakage levels, thus indicating that equilibrium had essentially been reached at this groundwater flow rate (4.1 ml/min).

6.2.1.4 Leaching Wyoming Ore Using 1.0 g/l KHCO_3 Saturated With Oxygen at 45 psig, Test 65

This test was performed in order to examine the potential chemical leakage into groundwater following a KHCO_3 leach. To determine the effect of the leach cation, this test could be compared to tests using NaHCO_3 (Test 63) and NH_4HCO_3 (Test 62) which were performed under similar conditions. This test also allowed a comparison to again be made between dissolved oxygen and peroxide, which had been used in an earlier test with KHCO_3 (Test 45).⁽⁴⁾

TABLE 6.8

Ion Leakage From Wyoming Ore Residue After Leaching With
2.0 g/l NaHCO_3 Saturated With O_2 at 45 psig, Test 63

No.	Duration hrs.	Vol. l	Σ Vol. l	Ore Pore Volumes	pH	U mg/l	Na^+ mg/l	HCO_3^- mg/l	$\text{SO}_4^{=}$ mg/l	Cl^- mg/l	Ra pC/l	Th pC/l	Se mg/l	As mg/l	Mo mg/l	V mg/l	Fe mg/l	Mg mg/l
Feed	930.2	--	--	--		0	192	320	190	65	0	0	0	0	0	0	0	0
1	1170.0	11.6	11.6	1.2	8.38	52	463	1135	130	10	0.3	0.4	0.56	0.005	<0.2	<0.5	<0.1	5.2
2	1266.0	16.8	28.4	3.0	8.59	18	282	440	245	65	--	--	0.32	0.004	<0.2	<0.5	<0.1	2.3
3	1482.0	19.9	48.3	5.2	8.30	12	244	335	215	80	--	--	0.27	0.0035	<0.2	<0.5	<0.1	1.8
4	1530.0	23.9	72.2	7.7	8.28	3.6	214	230	150	75	--	--	--	--	--	--	--	--
5	1722.3	20.4	92.6	9.9	8.23	4	227	250	175	--	--	--	--	--	--	--	--	--
6	1800.0	28.0	120.6	12.9	8.40	3	234	240	150	--	--	--	--	--	--	--	--	--

This test had a total duration of 1896.0 hours. It consisted of a 168.0-hour deionized water flow, a 768.0-hour leach and a 960.0-hour groundwater period. The groundwater sequence was as follows: 66.0 hours flow, 168.0 hours no-flow, 168.0 hours flow, 168.0 hours no-flow, and 390.0 hours of flow.

The permeability variations observed during this test are shown graphically in Figure 6.16. The permeabilities of all three sections were in the range 1.1 to 1.5 darcy at the beginning of chemical leaching. Within 150 hours after chemical injection, the permeability of the front section dropped from about 1.1 darcy to 0.2 darcy. The front section permeability stayed between 0.07 and 0.11 darcy for the remainder of the chemical leach. Upon the introduction of groundwater, the front section permeability continually dropped, reaching a final level of less than 0.007 darcy.

The front section permeability experienced during this test was very similar to that obtained in a previous test using 2.0 g/l KHCO_3 leach with 0.5 g/l H_2O_2 (Test 45). In that test, the front section permeability was about 0.2 darcy after 150 hours of leach, and 0.08 darcy at the conclusion of the leaching period. Although the adverse effects on permeability of oxygen blockage in the dissolved oxygen test should not have been as severe as in the peroxide test, the peroxide test used a higher concentration of KHCO_3 which would benefit permeability. The higher ionic strength leach is believed to prevent clay dissociation and dispersion, which are causes of pore blockage. Thus, the benefit to permeability of using dissolved oxygen in place of peroxide in this test seemed to be offset by the adverse effect of reducing the ionic strength of the leach.

Oxygen profiles, shown in Figure 6.17, taken along the length of the column indicate that oxygen blockage is a likely cause for permeability damage, even when dissolved oxygen is used. The profiles indicate that the majority (65 to 85%) of the oxygen is removed from solution by the beginning of the middle ore section. If the oxygen were being

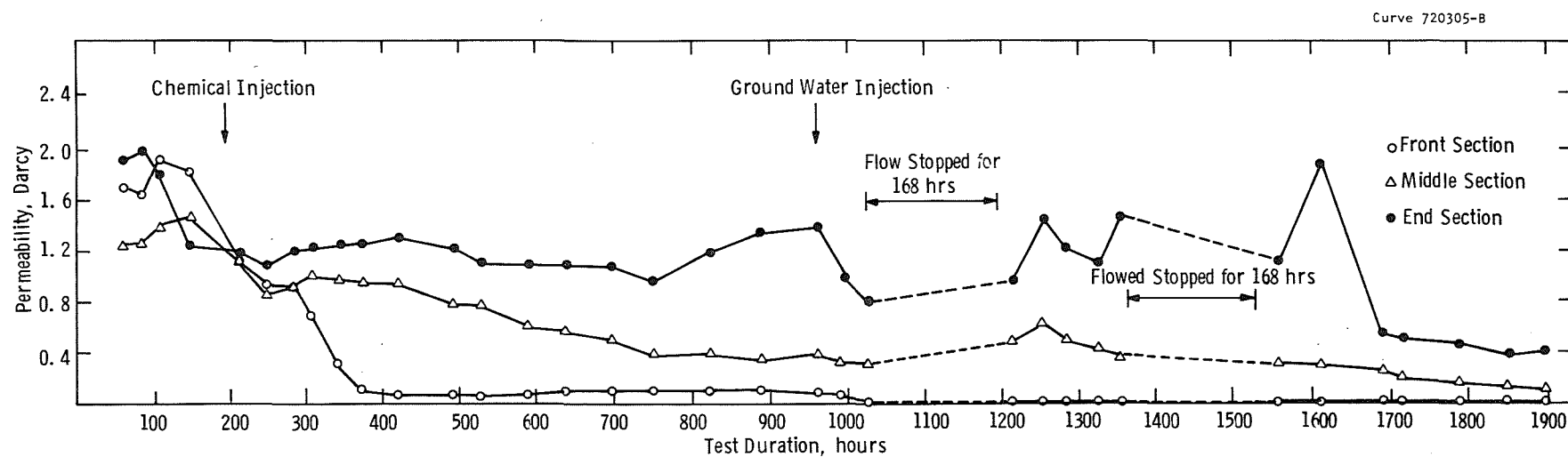


Fig. 6.16 - Permeability variations observed during leaching of Wyoming ore using 1.0 g/l KHCO_3 saturated with oxygen at 45 psig, Test 65.

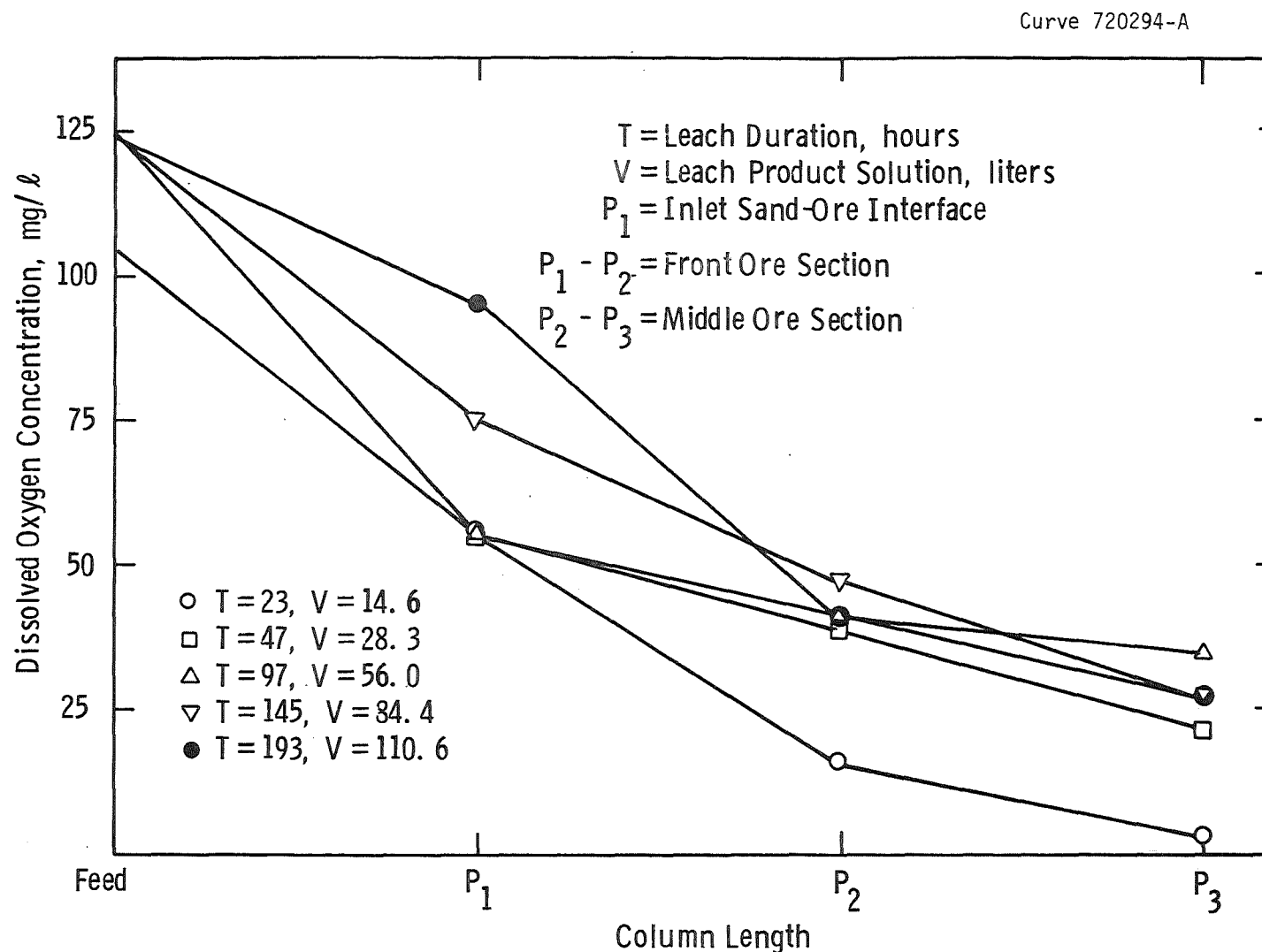


Fig. 6.17 – Dissolved oxygen concentration profiles along the length of the column, during leaching of Wyoming ore using 1.0 g/l KHCO_3 saturated with O_2 (45 psig), Test 65.

consumed by the ore (i.e., by oxidation reactions), then the oxygen would be expected to drop in the middle section similar to the front section, which it does not. Much of the drop in the solution oxygen concentration in the front section is thus likely the result of gas bubbling out of solution as the feed comes into contact with the lower pressure ore bed. The results also show that as the pressure builds up in the front section due to the decrease in permeability, higher oxygen concentrations are maintained in solution. The oxygen is thus likely released further down the column causing permeability damage there.

The permeability variations obtained in this test were similar to the ammonium bicarbonate leach results (Test 62), and were better than the sodium bicarbonate leach results (Test 63). The improvement over sodium bicarbonate are attributed to the adverse effects on permeability of the swelling and dispersion of Na^+ -substituted clays. K^+ -substituted clays must have characteristics similar to NH_4^+ -substituted clays.

The chemical data collected during the test is given in Table 6.9. The concentration variations are shown graphically in Figure 6.18. The uranium and bicarbonate concentration variations were typical of past bicarbonate leach tests. The potassium concentration variations indicated that, like ammonium, potassium was being picked up by the ore during leaching. In the 409 liters (43 pore volumes) of leach, a total of 101 g of potassium (or 0.053 meq of potassium/g of ore) were removed from solution. This is approximately the same number of cation milliequivalents picked up by the ore during the ammonium bicarbonate leach (Test 62).

The total uranium recovery obtained during this test was 72% based on uranium solution analyses. The uranium recovery rate observed is shown graphically in Figure 6.19. During chemical leach, approximately 33% of the uranium was recovered in the first 10 pore volumes (95 liters). This is very similar to the recovery rate obtained in the previously performed 2.0 g/l potassium bicarbonate test (Test 45). Thus,

TABLE 6.9

Summary of Data Obtained During Leaching of Wyoming Ore Using 1.0 g/l KHCO_3
with O_2 at 45 psig, Test 65

Duration, Hrs	Product Solution vol, l	Σ Vol, l	Σ Ore Pore Volumes (1 PV = 9.5 l)	pH	K^+ mg/l	HCO_3^- mg/l	Uranium mg/l	% Uranium Recovery
114.0	23.7	23.7	2.5	6.16	--	710	459	23.1%
192.0	14.6	38.3	4.0	6.34	--	195	87	25.8%
237.0	26.4	64.7	6.8	6.77	9	365	192	36.6%
282.0	26.5	91.2	9.6	6.72	9	--	--	--
330.0	28.5	119.7	12.6	6.97	10	465	163	55.7%
378.0	26.2	145.9	15.4	7.38	11	--	--	--
450.0	27.7	173.6	18.3	7.44	10	--	--	--
498.0	23.0	196.6	20.7	7.55	14	500	49	63.7%
546.0	21.4	218.0	22.9	7.70	56	--	--	--
618.0	40.3	258.3	27.2	7.81	141	--	--	--
666.0	28.2	286.5	30.2	8.14	--	--	--	--
714.0	28.8	315.3	33.2	7.81	226	530	17	68.0%
793.0	44.5	359.8	37.9	7.96	--	--	--	--
840.0	24.8	384.6	40.5	7.82	266	--	--	--
888.0	27.8	412.4	43.4	8.00	--	--	--	--
960.0	34.9	447.3	47.1	7.99	281	570	8	70.2%
978.0	12.2	459.5	48.4	8.22	299	520	7	70.4%
1026.0	16.0	475.5	50.1	8.07	330	310	5.3	70.6%
1248.0	10.7	486.2	51.2	8.10	358	380	18	71.0%
1361.3	15.3	501.5	52.8	8.22	330	350	15	71.5%
1649.3	12.0	513.5	54.1	8.22	323	370	17	71.9%
1919.3	15.8	529.3	55.7	8.58	288	340	12	72.3%

Times of Solution Injection: (1) $\text{KHCO}_3 - \text{O}_2$ - 192 hours

(2) Wyo. Ground Water - 960 hours

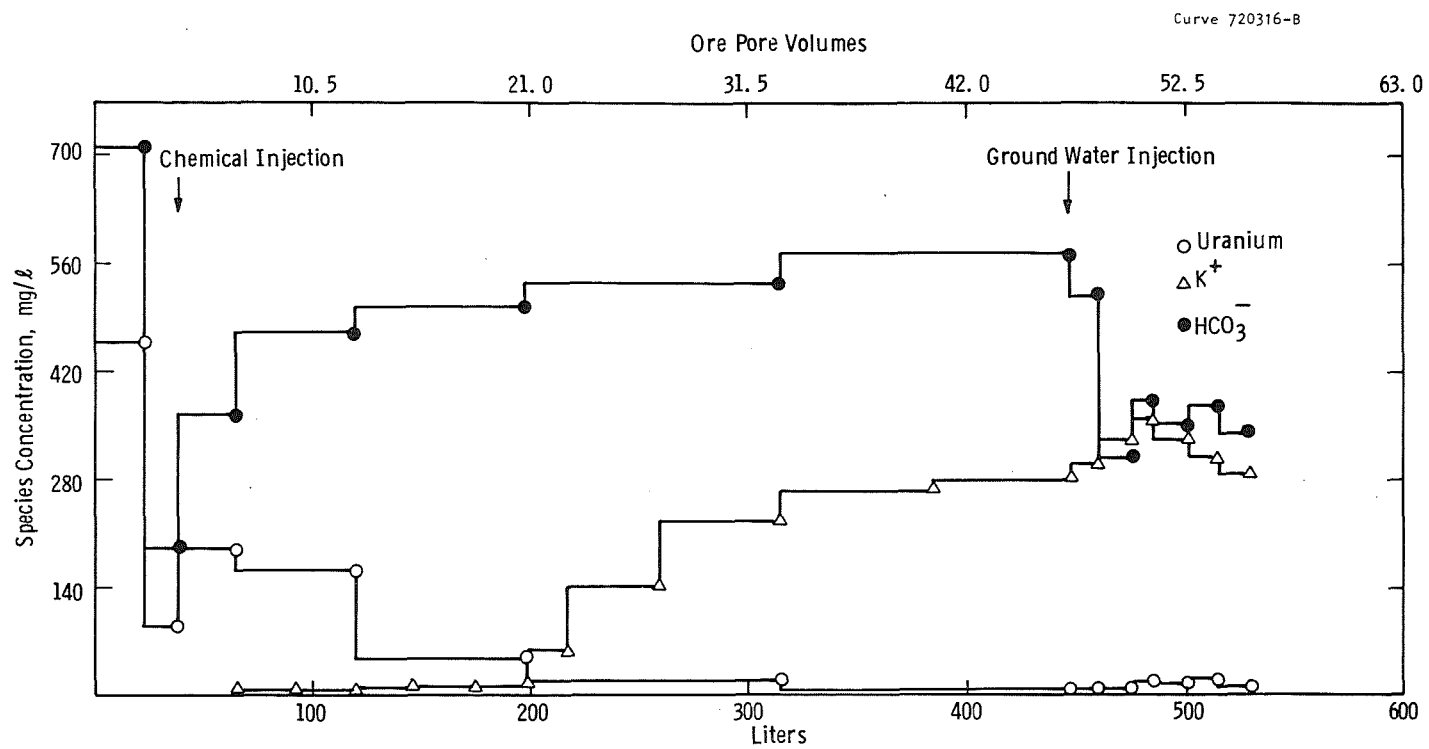


Fig. 6. 18— Concentration variations experienced during leaching of Wyoming ore using 1.0 g/l KHCO_3 saturated in oxygen at 45 psig, Test 65.

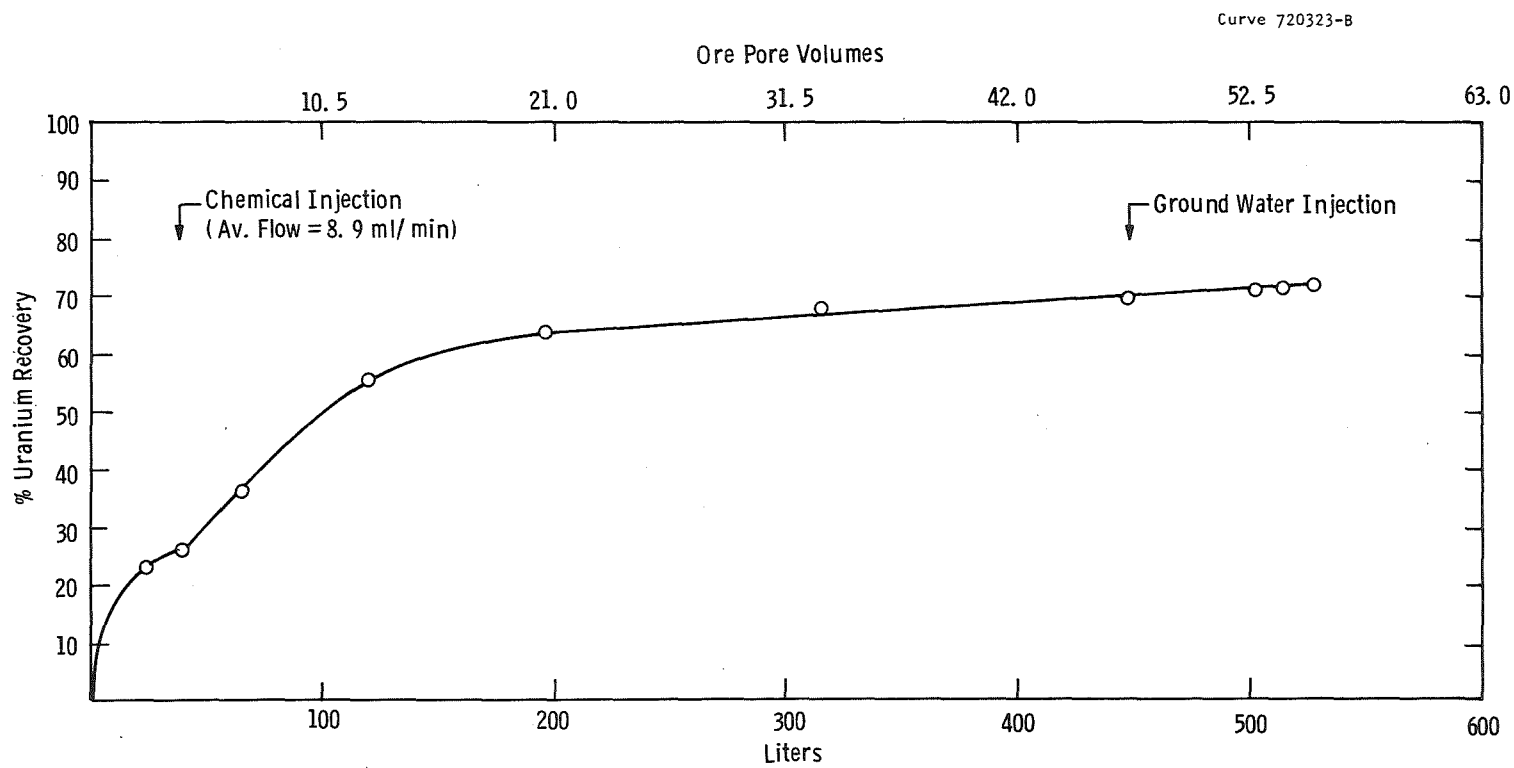


Fig. 6. 19—Uranium recovery rate observed during leaching of Wyoming ore using 1.0 g/l KHCO_3 saturated in oxygen at 45 psig, Test 65.

increasing the potassium bicarbonate concentration from 1.0 to 2.0 g/l does not seem to benefit uranium recovery. The uranium recovery obtained here also compared favorably to that obtained with 1.0 g/l ammonium bicarbonate (Test 62) where 32% of the uranium was removed in 10 pore volumes.

The ion leakage into groundwater following 1.0 g/l KHCO_3 leach is presented in Table 6.10. The results are nearly identical to that obtained with NH_4HCO_3 leach. Of all the ions examined, only uranium, potassium, and selenium were significantly above the groundwater background concentrations. Uranium and selenium were both above acceptable standards. Like ammonium, the high potassium concentrations (9.2 to 7.4 meq/l) were the result of cations (10.7 meq/l) in the groundwater exchanging with the potassium sorbed onto the ore's clay during leaching. Again, stopping the groundwater flow did not seem to affect the levels of chemical leakage.

6.2.1.5 Leaching of New Wyoming Ore Using 1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2 , Test 66

This test was performed in order to obtain baseline data on the leaching and restoration characteristics of the new ore obtained from Wyoming. The test also allowed comparisons to be made between the new and old Wyoming ore. The test ran for a total of 1961.0 hours. This included 213.0 hours of deionized water, 765.0 hours of leach, and 983.0 hours of simulated groundwater. The groundwater flow followed the following sequence: 192.0 hours flow, 168.0 hours no-flow, 264.0 hours flow, 167.0 hours no-flow, and finally, 192.0 hours flow.

The permeability variations experienced during this test are shown graphically in Figure 6.20. The permeability of the front section during deionized water flow was abnormally high (2.0 to 3.0 darcy). Upon chemical injection, the permeability rapidly declined. Within 120 hours after chemical injection, the front section was less than 0.05 darcy. It continually declined, reaching approximately 0.02 darcy after about 300 hours of leach and less than 0.01 darcy after 750 hours

TABLE 6.10

Ion Leakage From Wyoming Ore Residue After Leaching With
1.0 g/l KHCO_3 Saturated With O_2 at 45 psig, Test 65

No.	Duration hrs.	Vol. l	Σ Vol. l	Ore Pore Volumes	pH	U mg/l	K^+ mg/l	HCO_3^- mg/l	$\text{SO}_4^{=}$ mg/l	Cl^- mg/l	Ra pC/l	Th pC/l	Se mg/l	As mg/l	Mo mg/l	V mg/l	Fe mg/l	Mg mg/l
Feed	960.0	--	--	--			0	320	190	65	0	0	0	0	0	0	0	0
1	978.0	12.2	12.2	1.3	8.22	7	299	520	170	17	2.0	2.5	0.24	0.003	<0.2	<0.5	<0.1	3.6
2	1026.0	16.0	28.2	3.0	8.07	5.3	330	310	230	290	--	--	0.16	0.0024	<0.2	<0.5	<0.1	4.9
3	1248.0	10.7	38.9	4.1	8.10	18.0	358	380	210	70	--	--	0.14	0.0018	<0.2	<0.5	<0.1	5.8
4	1361.3	15.3	54.2	5.7	8.22	15.0	330	350	200	50	--	--	--	--	--	--	--	--
5	1649.3	12.0	66.2	7.0	8.22	17.0	323	370	200	--	--	--	--	--	--	--	--	--
6	1919.3	15.8	82.0	8.6	8.58	12.0	288	340	200	--	--	--	--	--	--	--	--	--

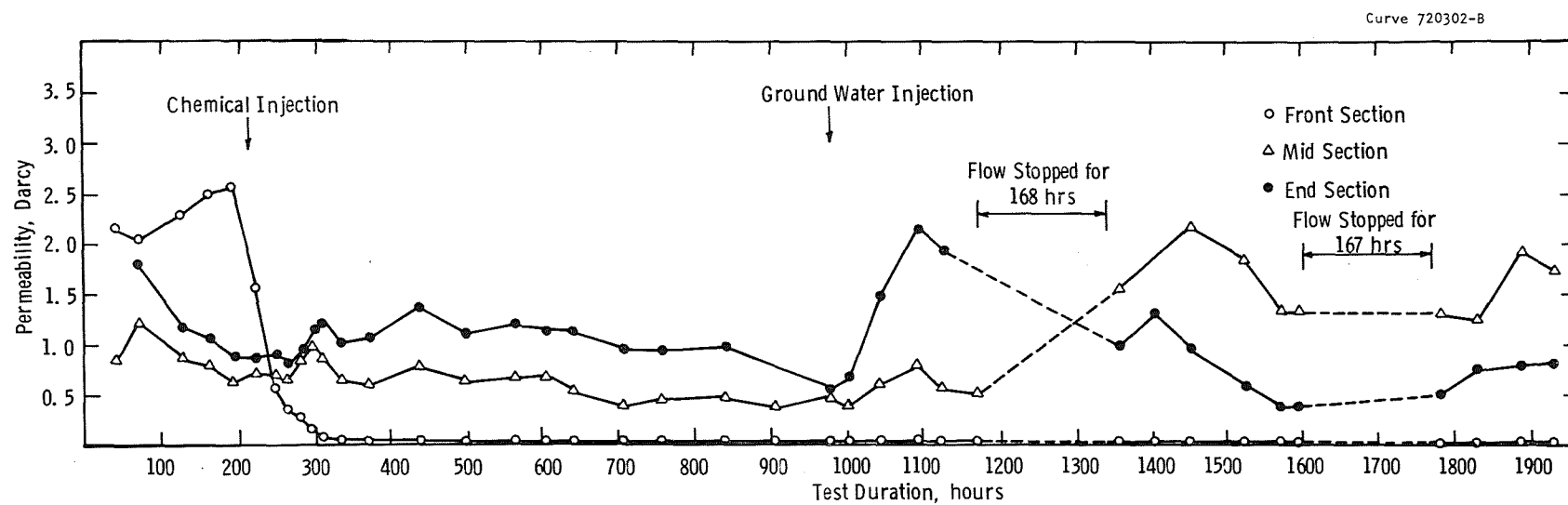


Fig. 6. 20- Permeability variations observed during leaching of new Wyoming ore using $1.0 \text{ g/l NH}_4\text{HCO}_3 - 0.5 \text{ g/l H}_2\text{O}_2$, Test 66.

of leach. This permeability decline was much more severe than in the 1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O test performed on the old Wyoming ore (Test No. 18).⁽³⁾ The front section permeability in that test was about 0.05 darcy after 300 hours of leach, and slightly less than 0.02 darcy after 750 hours. The post-leach groundwater flow seemed to restore some of the permeability in the new Wyoming ore; however, the front section permeability rose only slightly above 0.04 darcy.

The packing density obtained with the new Wyoming ore (1.59 g/ml) was much less than that typically obtained with the old Wyoming ore (1.7 g/ml), even though the same packing technique was used on both ores. This was likely the result of the differences in particle size distributions between the two ores (see Section 4.2). The lower density may have been the cause of the high permeability in the front section during the initial deionized water flow period. Also, the low density may have resulted in the compression, and subsequent collapse, of the front ore section during leach. The front section showed signs of compression and collapse during the first 100 hours of leach. The first 2 to 3 inches of ore did eventually collapse during the leach. This ore bed failure may have caused the very low permeability. All future tests using the new Wyoming ore should use a refined packing technique. Each batch of ore packed into the column should be smaller in size and should be tamped more times in order to obtain a higher density packing.

A summary of the chemical data collected during this test is given in Table 6.11. The pH variations obtained were similar to those obtained with bicarbonate leaches on the old Wyoming ore; pH 7.4 to 8.3. The uranium, bicarbonate, and ammonium variations experienced during the test are shown in Figure 6.21. The uranium and bicarbonate changes were typical of past bicarbonate leaches. The ammonium never broke through the ore bed during leaching. The ammonium level in the product never exceeded 2 mg/l during leach. In the 137 liters (13 pore volumes) of leach, 0.034 meq of ammonium was sorbed per g of ore. This is much less than the 0.056 meq of ammonium/g of ore obtained in a previous 1.0 g/l ammonium bicarbonate leach test with old Wyoming

TABLE 6.11

Summary of Data Obtained During Leaching of New Wyoming Ore Using
 $1.0 \text{ g/l NH}_4\text{HCO}_3 - 0.5 \text{ g/l H}_2\text{O}_2$, Test 66

Duration, Hrs	Product Solution Vol, l	Σ Vol, l	Σ Ore Pore Volumes (LPV = 10.4 l)	pH	NH_4^+ mg/l	HCO_3^- mg/l	Uranium mg/l	% Uranium Recovery
90	30.6	30.6	2.9	7.39	--	390	124	14.78
138	27.9	58.5	5.6	7.95	--	--	--	--
186	23.4	81.9	7.9	8.04	--	--	--	--
213	11.3	93.2	9.0	8.27	--	90	4.5	15.88
258	18.0	111.2	10.7	8.22	--	180	44	18.98
306	26.7	137.9	13.3	7.81	--	730	129	32.38
354	14.0	151.9	14.6	7.64	--	--	--	--
426	18.0	169.9	16.4	7.60	2	--	--	--
490	11.7	181.6	17.5	7.47	--	590	74	44.98
618	20.0	201.6	19.4	7.68	<2	--	--	--
718	8.8	210.4	20.3	7.54	--	--	--	--
864	11.9	222.3	21.4	7.69	<2	--	--	--
978	7.9	230.2	22.2	7.75	<2	510	50	54.44
1056	12.1	242.3	23.3	7.30	<2	380	36	56.14
1170	11.9	254.2	24.5	7.58	24	280	19	57.02
1458	13.5	267.7	25.8	7.73	2	240	24	58.28
1602	15.4	283.1	27.3	7.85	45	280	8.8	58.81
1865	15.6	298.7	28.8	7.37	58	390	5.6	59.15
1961	21.7	320.4	30.9	7.79	23	290	2	59.32

Times of Solution Injection: (1) $\text{NH}_4\text{HCO}_3 - \text{H}_2\text{O}_2$ - 213.0 hrs

(2) Wyo. Ground Water - 978.0 hrs

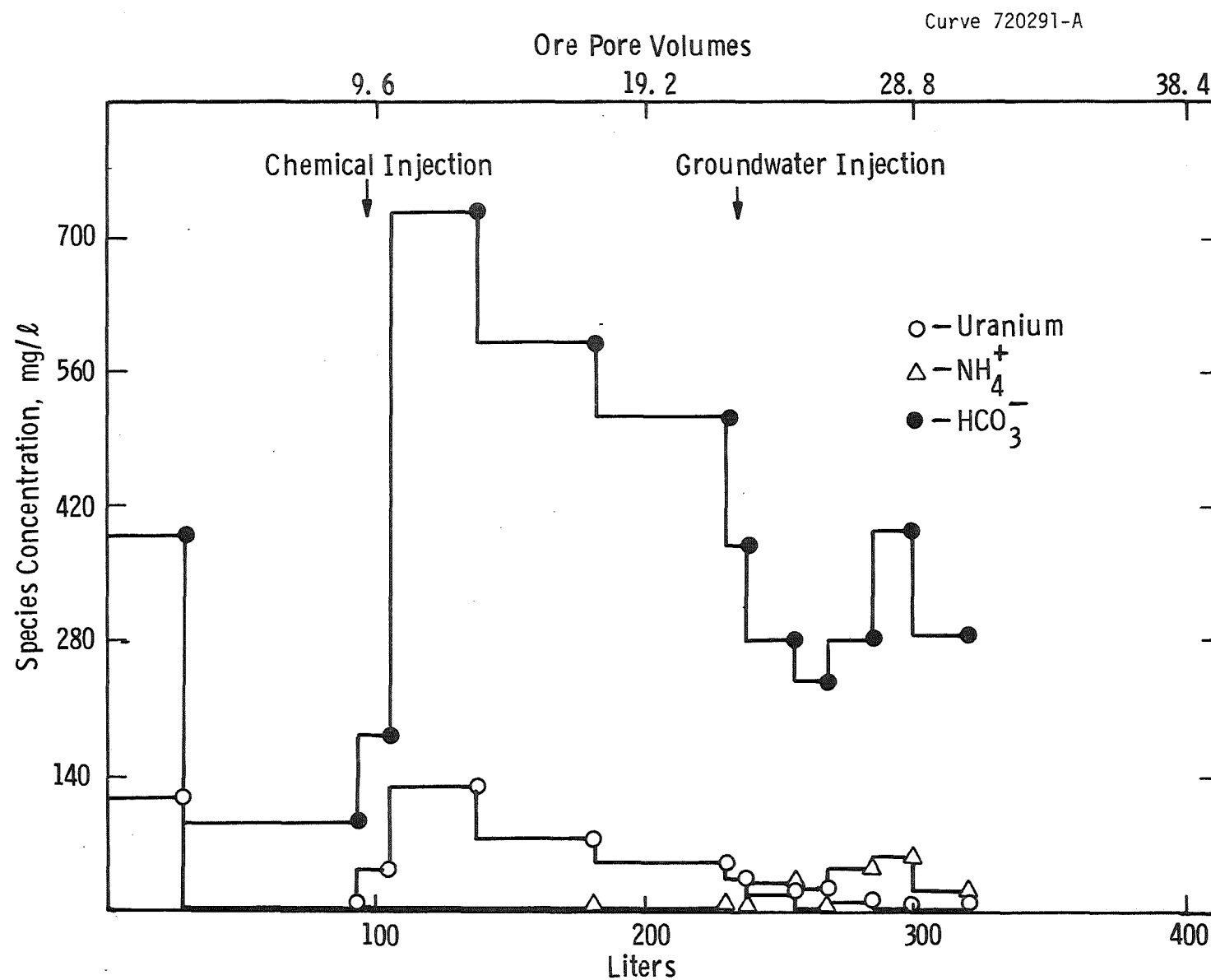


Fig. 6. 21 - Concentration variations experienced during leaching of new Wyoming ore using 1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2 , Test 66.

ore (Test 62). However, in that test a much greater volume of leach was passed through the ore bed due to better permeability. In the first 13 pore volumes of leach in that test (Test 62), 0.03 meq of ammonium was sorbed per g of ore, which is only slightly less than that obtained in this test. The much slower flow rate (great residence time) obtained in this test likely provided sufficient time for more complete ammonium exchange to occur, which would account for the slight difference in ammonium sorption between the two tests. The new and old Wyoming ores thus have similar ammonium sorption characteristics.

The uranium recovery rate observed during this test is shown graphically in Figure 6.22. During deionized water flow, only 16% of the uranium was recovered, which is less than the typical 20 to 25% recovered from the old Wyoming ore. In the first 10 pore volumes (104 liters) of leach, approximately 35% of the uranium was recovered. This recovery rate was slightly higher than that obtained with ammonium bicarbonate leaches on old Wyoming ore (Test 62). This was likely the result of the much slower flow rate (3.0 ml/min vs. 7.9 ml/min in Test 62) used in this test. The greater residence time resulted in a better recovery rate. However, the total recovery at the end of leach (750 hours) was only about 55% which is significantly less than that obtained from the old Wyoming ore (68% in Test 62) using the same leach. The difference in total recovery is likely due to the fact that a much smaller volume of solution (13 pore volumes) was passed through the ore during the leaching period in this test. This was because of the very low flow rate which resulted from the poor ore permeability. In 13 pore volumes of leach in Test 62, a total recovery of about 55% was obtained, which is the same as that obtained with the new Wyoming ore. However, it should be noted that the significantly higher leach residence time in the new Wyoming ore test should have resulted in a higher recovery. Perhaps the significantly greater permeability decline that occurred in this test resulted in a reduction in uranium accessibility. Any benefit to uranium recovery by the increased residence time was thus eventually cancelled by reduced uranium accessibility.

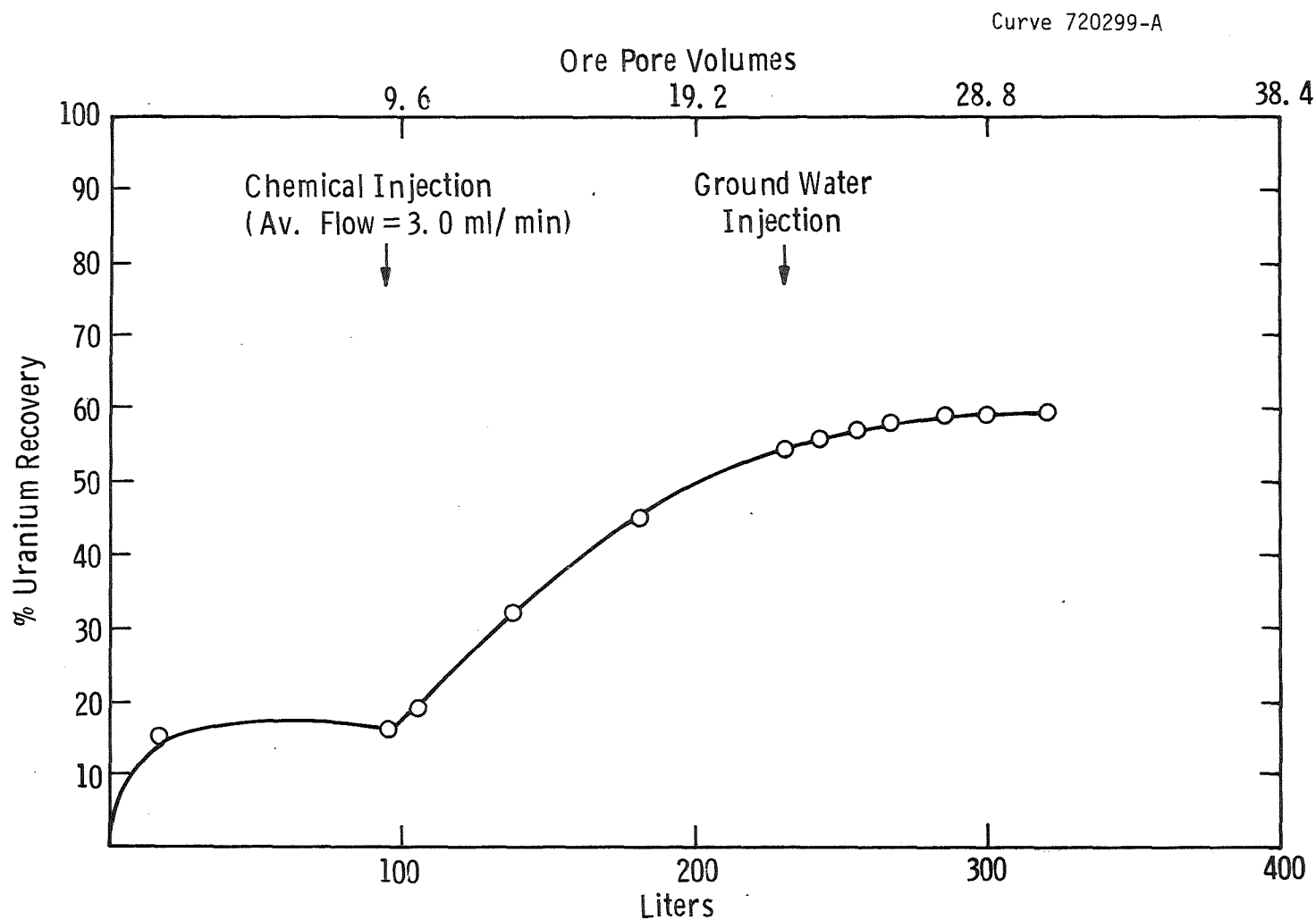


Fig. 6. 22 - Uranium recovery rate observed during leaching of new Wyoming ore using $1.0 \text{ g/l NH}_4\text{HCO}_3 - 0.5 \text{ g/l H}_2\text{O}_2$, Test 66.

The results of the chemical leakage into post-leach Wyoming groundwater are given in Table 6.12. As with old Wyoming ore, the sulfate, chloride, arsenic, molybdenum, vanadium, and iron were all at relatively low levels. Bicarbonate was within the background level of groundwater within 2 pore volumes. The magnesium level was greater than the previous old Wyoming ore tests (20-30 mg/l compared to 6-7 mg/l), but did not appear excessive. Like old Wyoming ore, uranium, ammonium, and selenium were all at levels significantly above the background values. However, the levels were less than that obtained with old Wyoming ore. Selenium was at 22 ppb after about 4 pore volumes, which although was significantly less than the 120 ppb obtained with old Wyoming ore, it was still above 10 ppb EPA drinking standard. Uranium (2-6 mg/l) and ammonium (20-60 mg/l) leakages were still above the background level after 8 pore volumes of groundwater. The ammonium leakage was much lower than that obtained with old Wyoming ore (Test 62 - 140 mg of ammonium/l) because so much less ammonium was put on the ore during leaching. The Series IV agitation tests predict an ammonium desorption level of about 70 mg/l for this cationic strength groundwater (1.9×10^{-2}) and for this ammonium ore level (0.61 mg/g of ore). Again, there is good agreement between the agitation and column ammonium test results.

6.2.1.6 Leaching of Texas Ore Using Sulfuric Acid of pH = 1.0 Followed by Simulated Groundwater, Test 64

This test was performed in order to determine the degree of chemical leakage into groundwater after leaching Texas ore. Because previous tests on Texas ore (Tests 29 and 44),^(3,4) had indicated that alkaline leach was not effective in leaching the uranium from Texas ore, the baseline leakage test was performed on Texas ore using acid leach. The purpose of this test was to examine what chemical species could potentially be mobilized during acid leaching and later enter the groundwater.

The ore bed length used in this test was only 8 foot compared to the typical 12 foot length. Previous acid leach tests (Tests 28 and 51)^(3,4) had indicated the uranium recovery was equilibrium constrained.

TABLE 6.12

Ion Leakage From Wyoming Ore Residue After Leaching With
1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2 , Test 66

No.	Duration, hrs	Vol, l	Σ Vol, l	Σ Ore Pore Volumes	pH	U mg/l	NH_4^+ mg/l	HCO_3^- mg/l	$\text{SO}_4^{=}$ mg/l	Cl^- mg/l	Ra pC/l	Th pC/l	Se mg/l	As mg/l	Mo mg/l	V mg/l	Fe mg/l	Mg mg/l
Feed	978.0	--	--	--	--	0	0	300	190	65	0	0	0	0	0	0	0	0
1	1056.0	12.1	12.1	1.2	7.30	36	<2	380	70	14	0.3	<0.15	0.03	0.002	<0.2	<0.5	<0.1	24.8
2	1170.0	11.9	24.0	2.3	7.58	19	24	280	215	65	--	--	0.028	0.0017	<0.2	<0.5	<0.1	29.0
3	1458.0	13.5	37.5	3.6	7.73	24	2	240	235	65	--	--	0.022	0.0018	<0.2	<0.5	<0.1	29.0
4	1602.0	15.4	52.9	5.1	7.85	8.8	45	280	175	--	--	--	--	--	--	--	--	--
5	1865.0	15.6	68.5	6.6	7.37	5.6	58	390	125	--	--	--	--	--	--	--	--	--
6	1961.0	21.7	90.2	8.7	7.79	2	23	290	175	--	--	--	--	--	--	--	--	--

It was hoped that this reduction in ore bed length, while maintaining the same volumetric solution rate (thus reducing solution-ore contact time), would still allow sufficient time for equilibrium to be reached in the system. The duration of a test could be substantially reduced if an 8-foot column can be used successfully. That is, for a given flow rate, the same number of ore pore volumes could be passed through the smaller bed in much less time. This test had a total duration of 1272 hours, which included a 114-hour deionized water period, a 510.5-hour leach period, and a 647.5-hour groundwater period. The groundwater period had the following flow sequence: 115 hours of flow, 167.5 hours of no-flow, 78 hours of flow, 168 hours of no-flow, and finally, 96 hours of flow.

The permeability variations observed during this test are shown in Figure 6.23. The ore bed, because of its 8-foot length, was divided into only two sections. During the initial water flow period, the permeability of the ore bed was in the range of 0.25 and 0.45 darcy. Upon chemical injection, the permeability of both sections dropped rapidly. After 50 hours of acid leach, the permeability of the front section dropped from about 0.45 to less than 0.05 darcy. A gradual decrease in both sections was observed over the remainder of the leach. The permeability of the front section was about 0.02 darcy at the conclusion of the leach period. The permeability behavior observed during leaching is similar to that observed during simulation Test 28 which was performed under these same conditions.⁽³⁾

After groundwater injection, the permeability improved. It went from 0.02 to 0.045 darcy in the front section. During a given groundwater flow period the permeability was relatively stable. However, when the groundwater was restarted after a non-flow period, there was an increase in permeability. The permeability of the front section jumped from 0.045 to 0.10 after the first non-flow period and from 0.093 to 0.120 after the second non-flow period.

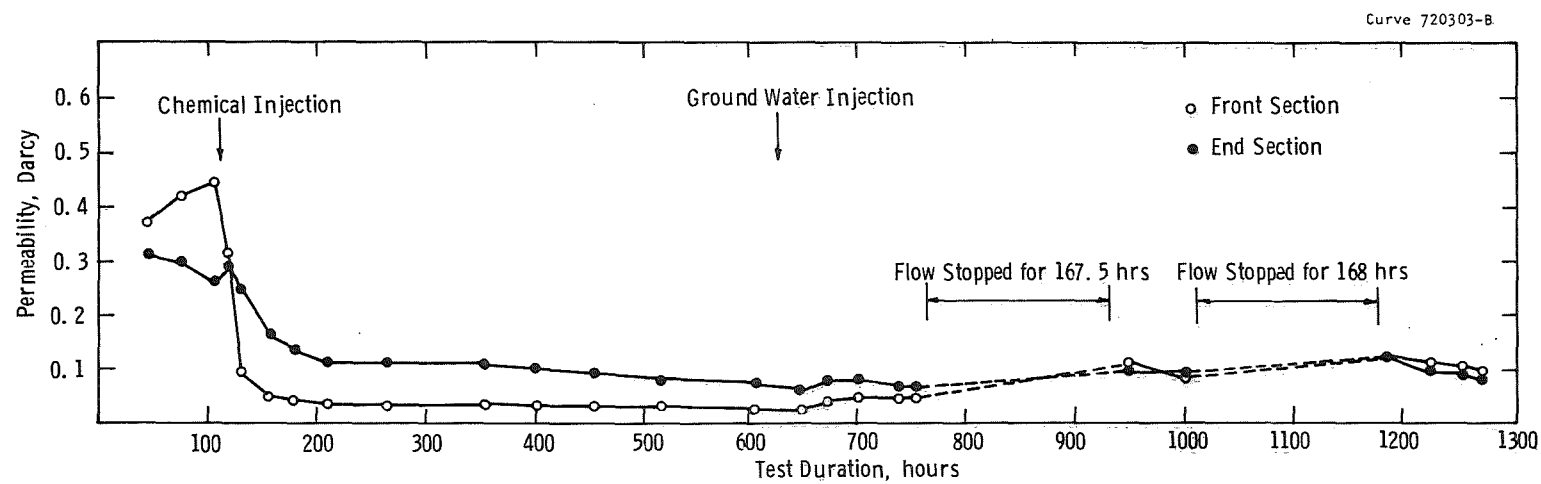


Fig. 6.23 - Permeability variations observed during leaching of Texas ore in 8-foot long column using sulfuric acid of pH = 1.0, Test 64.

It is believed that the large initial decrease in the permeability was caused by carbon dioxide liberation due to the reaction of acid with the carbonates in the ore. The carbon dioxide then caused gas blockage of the ore bed. The more gradual decrease during acid leach could possibly be due to chemical precipitation (e.g., gypsum) and to changes in the bed parameters (e.g., fines fraction, particle shape, etc.) due to the acid dissolution of the ore. The increase in permeability with groundwater is probably due to (a) the dissolution of the carbon dioxide gas formed during acid flow, and (b) the fact that the damaging effects of acid leach were no longer occurring. The improvement in permeability following a stoppage in groundwater flow may have been due to the initial impact of feed flow after the no-flow period. Ore particles were perhaps reoriented in the front section by the feed pulse, causing pores to open up. Also, the no-flow period may have given sufficient time for the carbon dioxide gas to dissolve into the groundwater remaining in the ore bed. When the feed was restarted, previously gas blocked pores were now available for flow and thus permeability was improved.

The chemical data collected during this test is tabulated in Table 6.13. The increase in uranium following acid injection seemed to occur with the sulfate and pH breakthrough. The pH breakthrough is believed to have been delayed by the ore carbonate neutralization of the acid. The uranium and sulfate concentration variations experienced during the test are shown in Figure 6.24. The uranium dropped rapidly after peaking and showed minimal tailing. The sulfate level was above 10.0 g/l during most of the leach.

The uranium recovery rate observed during this test is shown in Figure 6.25. As has been true of past Texas ore tests (Tests 28 and 51), the uranium recovery during the deionized water flow was extremely high; 43.6%. This large recovery may be the result of ore preoxidation, or perhaps the mobilization of ore sulfates and oxidizing agents (Fe^{3+}) by the deionized water flow. As in the earlier acid leach tests of Texas ore, there was not an immediate increase in uranium

TABLE 6.13

Summary of Data Obtained During Leaching of Texas Ore in 8-Foot Column
Using Sulfuric Acid of pH = 1.0, Test 64

Duration, Hrs	Product Solution Vol, ℓ	Σ Vol, ℓ	Σ Ore Pore Volumes (PV = 7.5 ℓ)	pH	SO ₄ ⁼ mg/ ℓ	Uranium mg/ ℓ	% Uranium Recovery
114.0	37.6	37.6	5.0	3.33	3,800	209	43.56%
168.0	19.3	56.9	7.6	3.78	2,200	23	46.02%
213.0	9.0	65.9	8.8	2.51	--	--	--
258.0	7.6	73.5	9.8	1.70	6,900	179	62.49%
330.0	10.8	84.3	11.2	1.54	--	--	--
381.0	7.5	91.8	12.2	1.52	11,000	39	66.45%
450.0	9.7	101.5	13.5	1.38	--	--	--
522.0	9.0	110.5	14.7	1.20	--	--	--
594.0	7.6	118.1	15.7	1.17	15,000	32	71.11%
666.0	7.9	126.0	16.8	1.14	14,000	17	71.86%
762.0	16.8	142.8	19.0	1.35	6,400	4	72.23%
961.5	11.4	154.2	20.6	1.79	2,900	3.3	72.44%
1032.0	14.2	168.4	22.5	2.12	2,100	0.86	72.51%
1220.0	16.4	184.8	24.6	2.37	1,400	0.36	72.54%
1272.0	16.9	201.7	26.9	2.63	800	<0.10	72.55%

Times of Solution Injection: (1) H₂SO₄ - 114 hours

(2) Tex. Ground Water - 624.5 hours

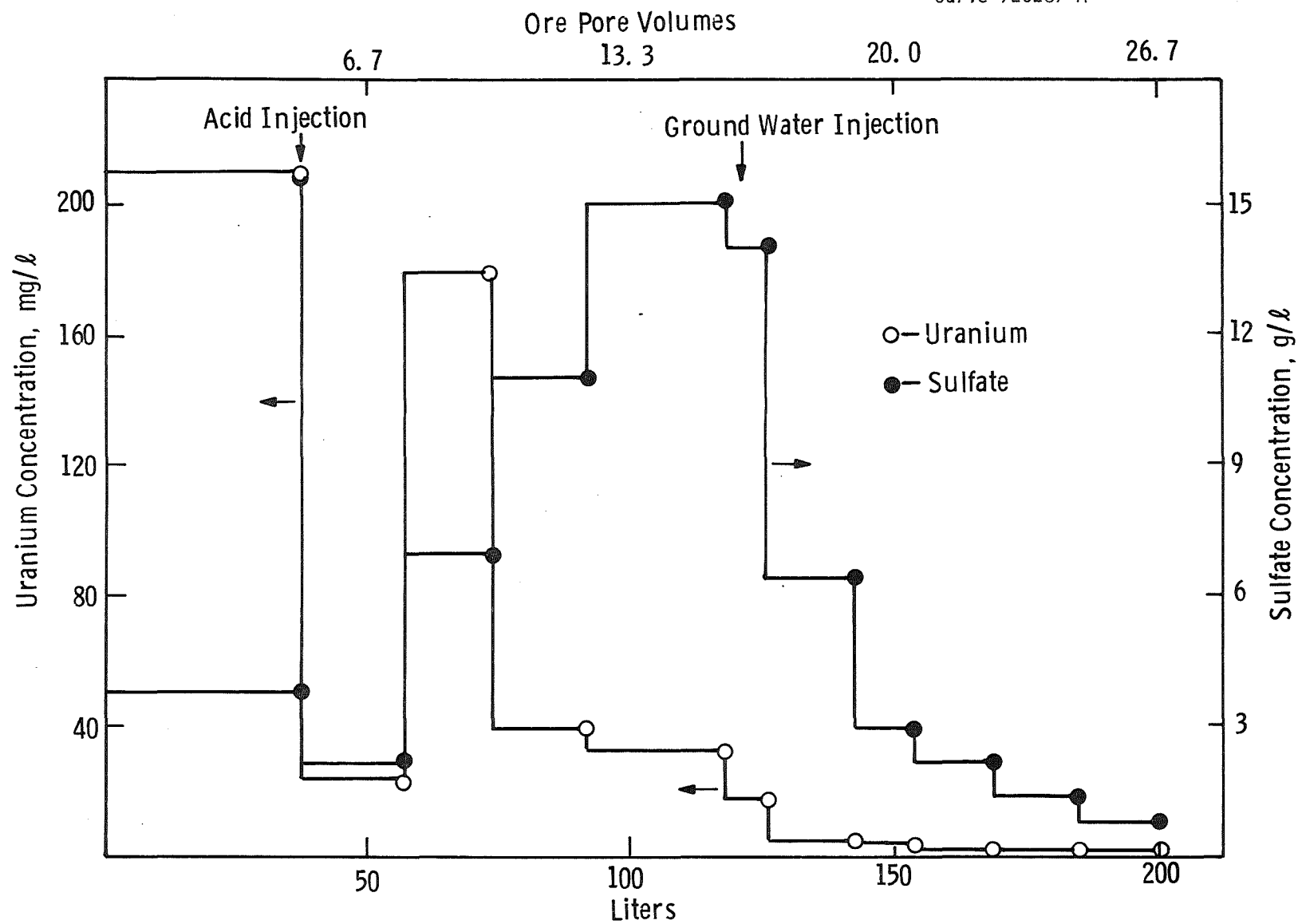


Fig. 6. 24—Concentration variations experienced during leaching of Texas ore using sulfuric acid of pH = 1. 0, Test 64.

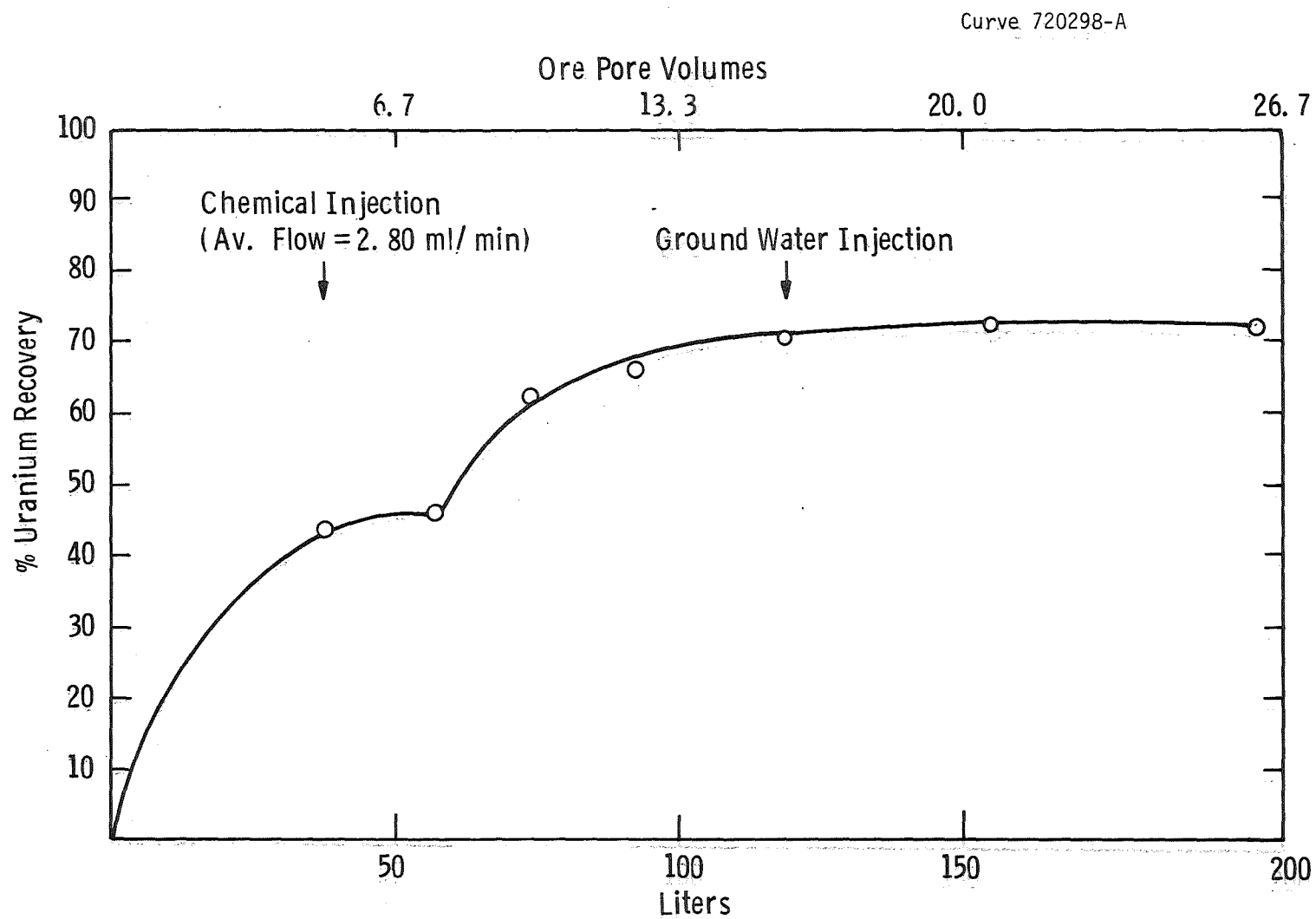


Fig. 6. 25 - Uranium recovery rate observed during leaching of Texas ore using sulfuric acid of pH = 1. 0, Test 64.

recovery after acid injection. The uranium increase did not occur until approximately 3 ore pore volumes (22.5 liters) were collected. Although the first 8.8 liters collected (the void volume of the system) is likely residual deionized H_2O , the uranium increase did not occur until over 20 liters (3 ore pore volumes) of solution were collected. (See Appendix C for determination of ore pore volume and system void volume). As indicated in the earlier tests, the uranium breakthrough coincides with the pH breakthrough, which is delayed due to the neutralization of the acid by the ore.

In this test, 23% of the uranium was recovered in the first 7.2 ore pore volumes (53.4 liters) collected after acid injection. In the earlier test (Test 28) performed with a 12-foot ore bed under identical leach conditions, 30% of the uranium was recovered in the first 7 ore pore volumes (79 liters) collected after injection. The faster uranium recovery (per liter collected) obtained in the earlier test can be attributed to slower flow rate (1.2 mL/min vs. 2.8 mL/min), and the longer ore bed (12 feet vs. 8 feet), and thus the longer residence time used in that test. Unlike the earlier test in which the uranium recovery appeared equilibrium constrained, the uranium recovery rate in this test seemed to be kinetically constrained. The total uranium recovery in this test was 72.6% based on solution analyses, which compares favorably with the total recovery (75.9%) obtained in the earlier test.

A summary of the post-leach ion leakage data obtained using simulated Texas groundwater is given in Table 6.14. The results indicate that the acid leach produced initially high levels of uranium, sulfate, selenium, arsenic, and iron in the post-leach groundwater. However, the uranium dropped to less than 1 mg/L within 7 pore volumes of groundwater, and sulfate level fell below the background groundwater concentration within 11 pore volumes. The arsenic (0.47 mg/L) and selenium (0.14 mg/L) were both above the EPA drinking standards of 0.05 and 0.01 mg/L, respectively.⁽⁸⁾ The iron level seemed to level off at about 150 mg/L, which was much greater than the initial groundwater content (~ 20 mg/L), and the EPA drinking standard of 0.3 mg/L.⁽⁹⁾

TABLE 6.14

Ion Leakage From Wyoming Ore Residue After Leaching With
 H_2SO_4 of pH = 1.0
 Test 64

No.	Duration hrs.	Vol. l	Σ Vol. l	Σ Ore Pore Volumes	pH	U mg/l	$\text{SO}_4^{=}$ mg/l	Cl^- mg/l	Ra pC/l	Th pC/l	Se mg/l	As mg/l	Mo mg/l	V mg/l	Fe mg/l	Mg mg/l
Feed*	624.5	--	--	--		0	1,070	670	0	0	0	0	0	0	0	0
1	666.0	7.9	7.9	1.1	1.14	17	14,000	4	0.3	<.15	0.51	2.0	3.8	0.5	420	20.8
2	762.0	16.8	24.7	3.3	1.35	4	6,400	650	--	--	0.27	0.98	1.0	<0.5	154	7.8
3	961.5	11.4	36.1	4.8	1.79	3.3	2,900	670	--	--	0.14	0.47	0.6	<0.5	135	7.7
4	1032.0	14.2	50.3	6.7	2.12	0.86	2,100	--	--	--	--	--	--	--	140	--
5	1220.0	16.4	66.7	8.9	2.37	0.36	1,400	--	--	--	--	--	--	--	190	--
6	1272.0	16.9	83.6	11.2	2.63	<0.10	800	--	--	--	--	--	--	--	150	--

*Contains 264 mg/l Ca^{++} and 545 mg/l Na^+ .

6.2.1.7 Leaching of Wyoming Ore Using Sulfuric Acid of pH = 1.0,
Followed by Groundwater, Test 69

This test was designed to study the chemical leakage into groundwater from Wyoming ore that had been leached with sulfuric acid. The leakage data could be compared to that obtained with Wyoming ore using bicarbonate leaches (Tests 62, 63, and 65). Differences in the post-leach restoration requirements between an alkaline and an acid leached ore could thus be estimated. The data obtained could also be compared to that obtained after leaching Texas ore with sulfuric acid. The effect of the type of ores on chemical leakage could, therefore, be examined.

The test was run for 2208.0 hours. This included 174.0 hours of deionized water, 454.0 hours of leach, and a 1580.0 hour groundwater period. The post-leach groundwater had the following flow sequence: 218.0 hours of flow, 162.0 hours of no-flow, and 1200.0 hours of flow. The flow was stopped to make certain that the groundwater was in equilibrium with the ore.

The permeability variations experienced during this test are shown in Figure 6.26. The 8-foot ore bed section was divided into two sections. At the end of the deionized water flow period, the permeabilities of the front and end sections were 1.3 and 1.7 darcy, respectively. The front section permeability fell to about 0.3 darcy by about 120 hours of acid leach. There was then a more gradual decline, reaching 0.1 darcy by about 300 hours of leach, and a relatively stable 0.05 darcy at the conclusion of the leach. The end section dropped to about 0.6 darcy after about 100 hours of leach and stayed approximately at this level for the remainder of the leach. These permeability changes were very similar to those experienced in a previous sulfuric acid (pH = 1.0) leach of Wyoming ore (Test 21).⁽³⁾

The rapid decrease in the front section permeability during leach is believed caused by carbon dioxide blockage of the ore bed. The

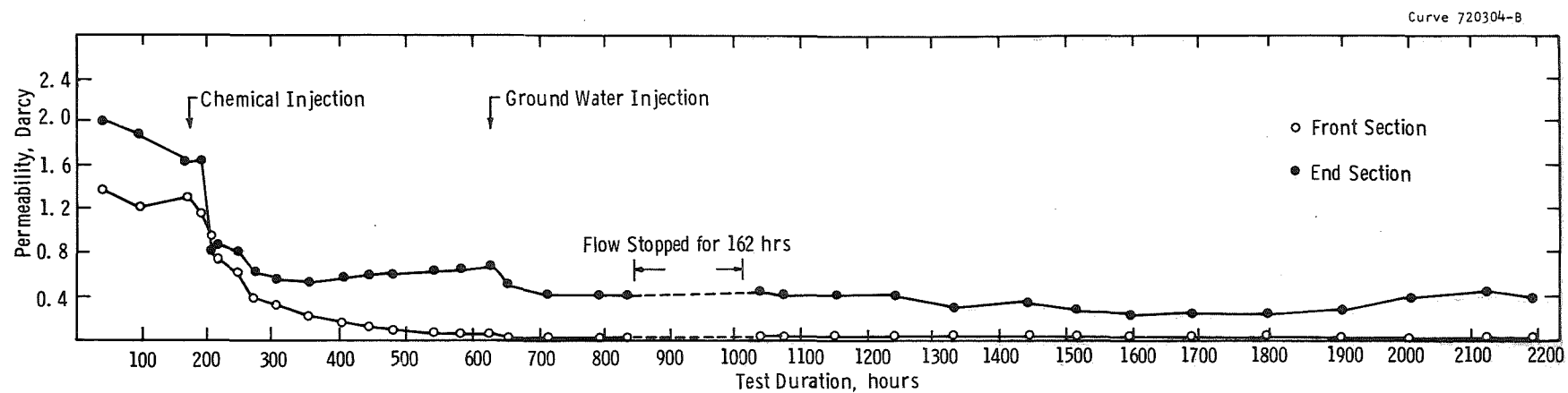


Fig. 6. 26- Permeability variations experienced during leaching of Wyoming ore with sulfuric acid of pH = 1. 0 followed by ground water, Test 69

carbon dioxide gas is formed by the reaction of sulfuric acid with the carbonates in the ore. The more gradual decline is possibly the result of gypsum precipitation, the formation of fines, and other acidic reactions with the ore.

After groundwater injection, the front section permeability dropped almost immediately from 0.05 to 0.0075 darcy. There was then a more gradual decline to 0.005 darcy. Restarting the flow after a week of no-flow, caused an initial increase in the front section permeability to 0.008 darcy. The permeability then very gradually declined to about 0.004 darcy. The front section permeability stayed between 0.004 and 0.008 darcy for the remainder of the groundwater flow. The end section permeability dropped to about 0.4 darcy after acid injection and remained at approximately this level for the duration of the groundwater flow.

The drop in the front section permeability during groundwater flow was believed caused by clay dispersion and dissociation which results from the low ionic strength of the groundwater. Clay swelling, which occurs when sodium from the groundwater exchanges onto the ore, may also add to this initial permeability decline and to the latter more gradual drop.

The chemical data collected during the test is presented in Table 6.15. The pH dropped to less than 1.8 within 6 pore volumes of leach, to less than 1.1 within 14 pore volumes, and to 1.0 after 25 pore volumes. Ore carbonate neutralization likely prolonged the complete pH breakthrough. The concentration variations experienced during the test are shown in Figure 6.27. The initial uranium response coincided with the sulfate level. During the deionized water flow, the uranium concentration dropped as the sulfate level declined. After acid injection and thus an increase in sulfate, the uranium level immediately increased. After peaking, the uranium concentration then rapidly declined showing a minimum tailing effect.

The uranium recovery rate observed during this test is shown in Figure 6.28. In the initial water flow period, approximately 21% of

TABLE 6.15

Summary of Data Obtained During Leaching of Wyoming Ore Using H_2SO_4 , pH = 1.0, Test 69

Duration, Hrs.	Product Solution Vol, ℓ	Σ Vol, ℓ	Σ Ore Pore Volume pH (1PV=6.8 ℓ)	pH	SO_4 mg/ ℓ	Uranium mg/ ℓ	% U Recovery
72.0	28.2	28.2	4.1	6.00	1,900	220	18.2%
168.0	46.7	74.9	11.0	6.71	100	19	20.8%
222.0	26.8	101.7	15.0	6.09	1,800	229	38.7%
264.0	24.7	126.4	18.6	1.78	6,000	438	70.4%
336.0	40.0	166.4	24.5	1.22	-	-	-
408.0	37.0	203.4	29.9	1.08	10,000	25	76.0%
457.0	24.9	228.3	33.6	1.04	-	-	-
528.0	33.4	261.7	38.5	1.01	-	-	-
582.0	21.0	282.7	41.6	1.01	-	-	-
628.0	15.0	297.7	43.8	1.00	11,000	2	76.6%
846.0	10.1	307.8	45.3	1.29	9,000	2	76.7%
1206.0	9.9	317.7	46.7	2.39	330	<0.1	76.7%
1466.6	10.3	328.0	48.2	2.71	-	-	76.7%
1848.0	10.8	338.8	49.8	2.67	195	<0.1	76.7%
2094.0	10.9	359.7	52.9	2.80	195	<0.1	76.7%
2208.0	5.9	365.6	53.8	-	170	<0.1	76.7%

Times of Solution Injection: (1) H_2SO_4 - 174 hrs.

(2) Ground H_2O - 628 hrs.

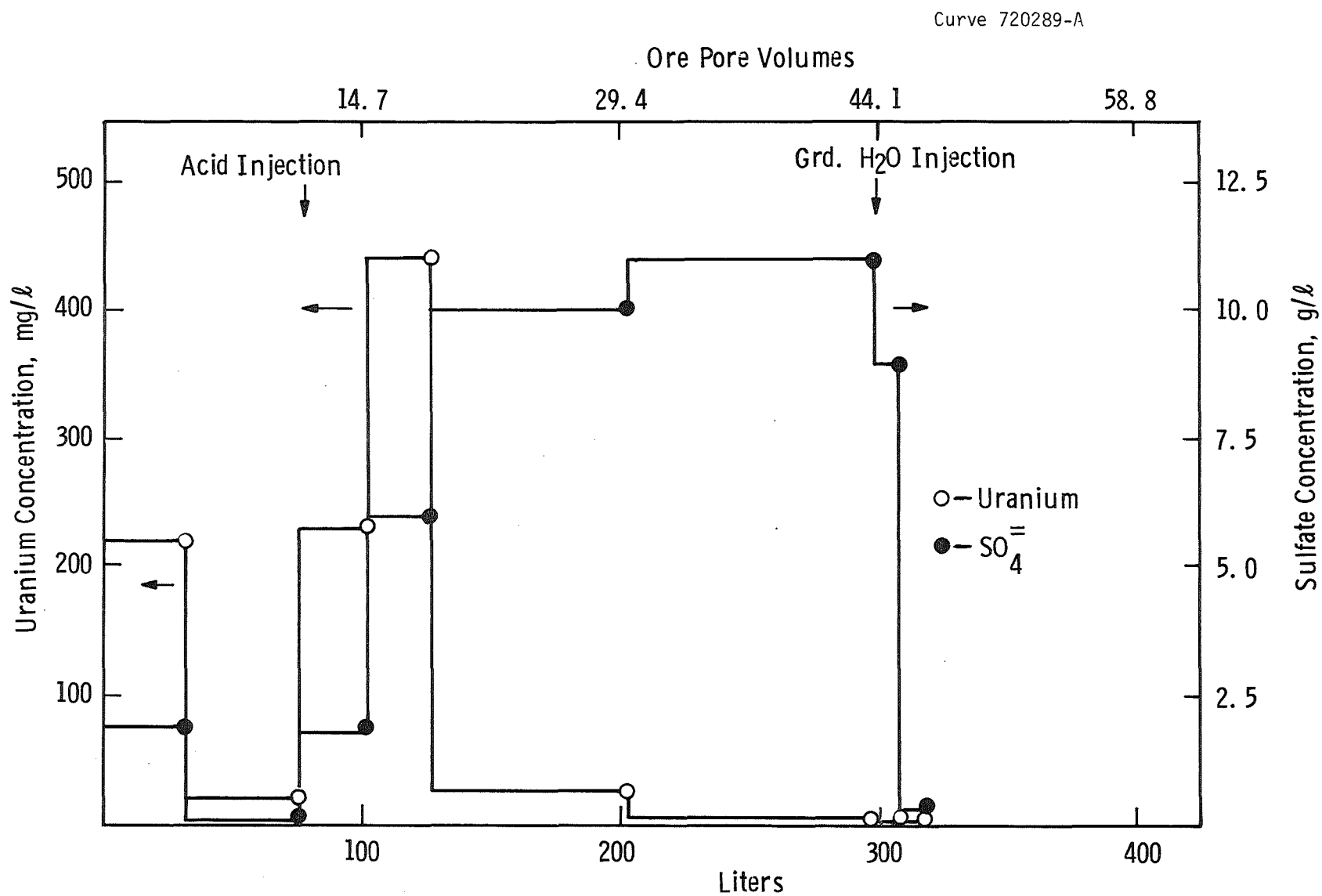


Fig. 6.27 – Concentration variations experienced during leaching of Wyoming ore using H₂SO₄ of pH = 1.0, Test 69.

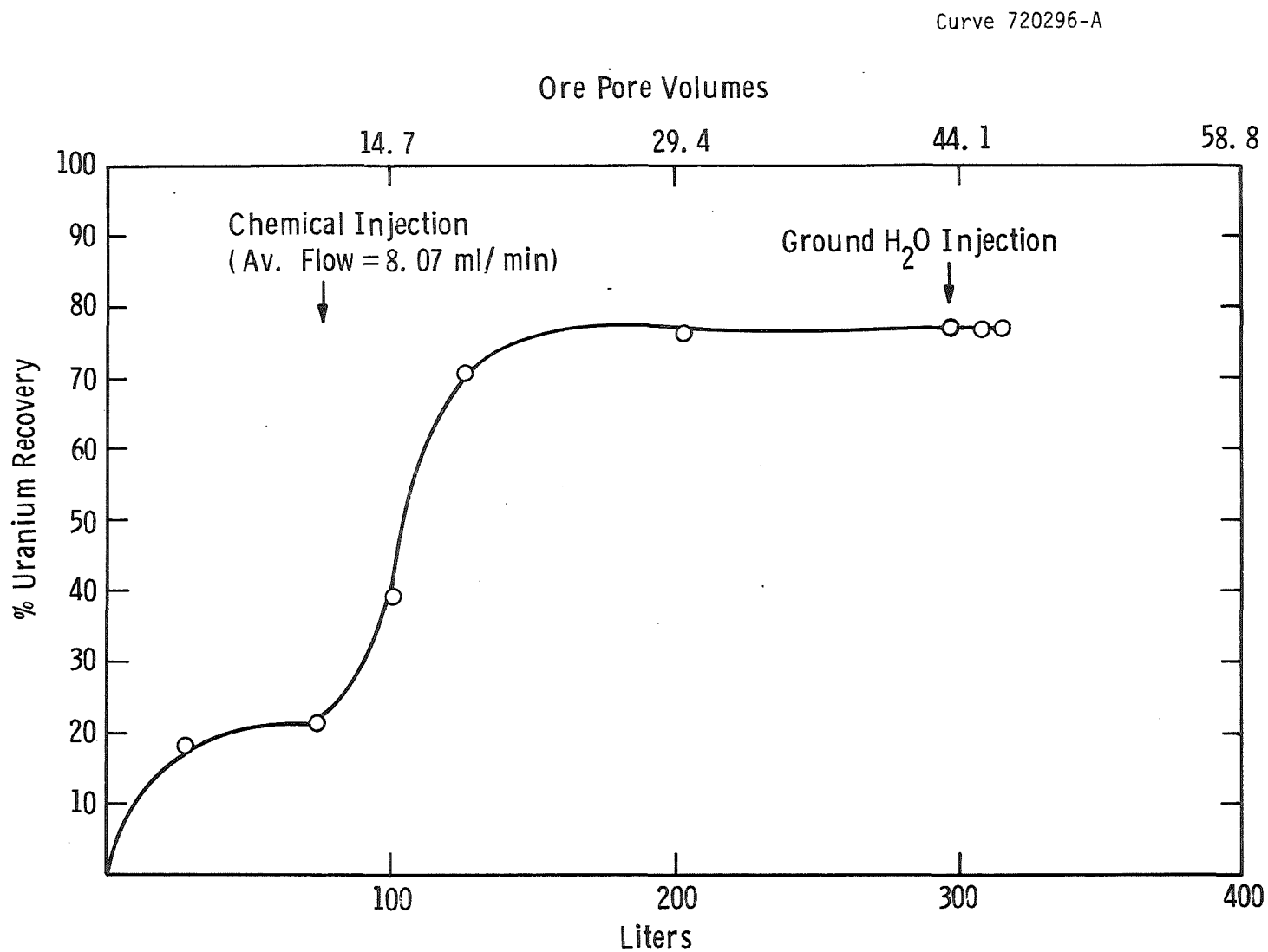


Fig. 6. 28—Uranium recovery rate observed during leaching of Wyoming ore using H₂SO₄ of pH = 1.0, Test 69.

the uranium was leached. As the response curve shows, after acid injection the uranium was rapidly removed. In the first 6 pore volumes (40.8 liters), about 50% of the uranium was recovered. This is slightly less than that obtained in a previous test (Test 21) performed under the same conditions. In that test, 55% of the uranium was recovered in the first 6 pore volumes of acid. The difference is perhaps the result of the longer ore bed (12 ft vs. 8 ft) used in that test (Test 21) with essentially the same solution flow rate (8 ml/min). The shorter solution residence time of this test (Test 69) resulted in a leaching system that was now kinetically constrained rather than equilibrium constrained. Longer residence times are likely to be used in the field, thus longer column tests more accurately simulate what is likely to occur.

The ion leakage that resulted during the post-leach groundwater flow is given in Table 6.16. Of the chemicals examined, only vanadium appeared to remain at excessive levels (≈ 130 mg/l), which were significantly higher than the EPA water quality for irrigation (10 mg/l).⁽⁹⁾ The uranium level dropped to less than 0.1 mg/l within 2 pore volumes of groundwater. The iron concentration (≈ 30 mg/l) obtained was significantly less than that (≈ 150 mg/l) obtained after acid leaching Texas ore (Test 64), but greater than that (< 0.1 mg/l) obtained after bicarbonate leaching of Wyoming ore and the EPA drinking water standard of 0.3 mg/l. Selenium, which was found to be excessive after bicarbonate leaching of Wyoming ore, and the acid leaching of Texas ore, and arsenic, which was high after the acid leaching of Texas ore, were both below the EPA drinking standards in this test after about 5 pore volumes of groundwater. Like the previous leaching tests, molybdenum seemed to present no post-leach leakage problem. Sulfate dropped to the background groundwater level (190 mg/l) after about 5 pore volumes, and was thus not at a long lasting problem.

TABLE 6.16

ION LEAKAGE FROM WYOMING ORE AFTER LEACHING WITH H_2SO_4 of pH = 1.0, TEST 69

No.	Duration, Hrs.	Vol., ℓ	Σ Vol., ℓ	Σ Ore Pore Volumes	pH	U mg/ℓ	$SO_4^{=}$ mg/ℓ	Se mg/ℓ	As mg/ℓ	Mo mg/ℓ	V mg/ℓ	Fe mg/ℓ
Feed	628.0	---	---	---	8.0	0	190	0	0	0	0	0
1	846.0	10.1	10.1	1.5	1.29	2	9,000	0.052	0.016	< 0.2	1075	210
2	1206.0	9.9	20.0	2.9	2.39	< 0.1	330	0.012	0.007	< 0.2	206	42.4
3	1466.6	10.3	30.3	4.5	2.71	---	---	0.006	0.005	< 0.2	180	36.9
4	1848.0	10.8	41.1	6.0	2.67	< 0.1	195	0.003	0.004	< 0.2	131	26.8
5	2094.0	10.9	52.0	7.6	2.80	< 0.1	195	---	---	---	---	---
6	2208.0	5.9	77.9	11.5	---	< 0.1	170	---	---	---	---	---

6.2.2 Reducing Agent Tests

This set of column tests was designed specifically to examine the use of reducing agents to restore leached ore beds. A test performed in Phase IV of this program (Test 48) had shown that the use of the reducing agent, ammonium bisulfite, significantly increased permeability and lowered uranium leakage in a column of Wyoming ore that had been leached with ammonium bicarbonate.⁽⁴⁾ The tests performed here provided information on different reducing agents and their effect after other leaches and on Texas ore. Groundwater was passed through after the post-leach use of the reducing agent to examine the changes in ion leakage.

6.2.2.1 Leaching of Wyoming Ore Using 1.0 g/l NH_4HCO_3 + (0.25 - 0.5) g/l H_2O_2 , Followed by 1.0 g/l NH_4HSO_3 , then Releach, Test 70

This test was performed to evaluate the effect of periodically using ammonium bisulfite to improve permeability during leaching with ammonium bicarbonate. Previous test work (Test 48) had indicated that ammonium bisulfite could drastically improve the permeability of an ammonium bicarbonate-peroxide leached ore body.⁽⁴⁾ The reducing agent is believed to lower the amount of oxygen gas binding in the ore. Improving the permeability allows one to maintain a higher leach flow rate at a lower feed pressure. In addition, opening pores by reducing the gas blockage may result in greater uranium accessibility. The reducing agent was also used at the end of the leaching period to examine its effect on post-leach chemical leakage. The test was 1362.0 hours in duration. There was a 144.0-hour deionized water flow period, a 738.0-hour leaching period, and a 480.0-hour post-leach period. The leaching period consisted of the following flow sequence; 139.0 hours NH_4HCO_3 - 0.5 g/l H_2O_2 , 26.0 hours NH_4HSO_3 , 167.0 hours releach, 25.0 hours reducing agent, and 381.0 hours NH_4HCO_3 - 0.25 g/l H_2O_2 . In the final leach portion of this period, the peroxide concentration was reduced from 0.5 to 0.25 g/l to determine what effect this

had on permeability and uranium leaching. The post-leach period flow sequence was 78 hours of NH_4HSO_3 , 210 hours of groundwater, 120 hours of NH_4HSO_3 , and finally, 72 hours of groundwater. The repetition of the reducing agent-groundwater flows was done to determine the effect of additional reducing agent on chemical leakage.

The permeability variations experienced during this test are shown in Figure 6.29. At the conclusion of the deionized water flow, the permeability of the front section was approximately 0.7 darcy. Upon the injection of 1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2 , the permeability dropped to 0.04 darcy after 140 hours of leach. The injection of 1.0 g/l NH_4HSO_3 caused the permeability to rise to 0.53 darcy after 13 hours, and to 0.81 darcy after 23 hours of the reducing agent. Within 50 hours after reinjection of the leach, the permeability dropped back to 0.04 darcy. The permeability then gradually declined reaching 0.03 darcy. Upon reinjection of the NH_4HSO_3 , the permeability rose to 0.4 darcy within 20 hours. The reinjection of the leach at the lower H_2O_2 level (0.25 g/l) did not cause as severe a reduction in permeability as the higher H_2O_2 level (0.5 g/l). The permeability dropped to 0.07 darcy within 50 hours of releach, and to 0.05 darcy within 120 hours. The permeability remained between 0.04 and 0.05 darcy for the remainder of the leach.

The first post-leach NH_4HSO_3 flow increased permeability to between 0.4 and 0.5 darcy. Groundwater injection caused a drop in permeability to about 0.09 darcy. Reinjection of the post-leach NH_4HSO_3 increased permeability to only about 0.1 darcy. In the final groundwater flow, permeability declined to about 0.07 darcy.

These results reaffirm the belief that oxygen gas blockage is a major cause of permeability damage. The oxygen blockage results from the large excess of oxygen produced by the rapid decomposition of peroxide. These results show that if the peroxide concentration is lowered, the rate of the permeability decline is significantly reduced. Also, the results show that the permeability damage incurred during

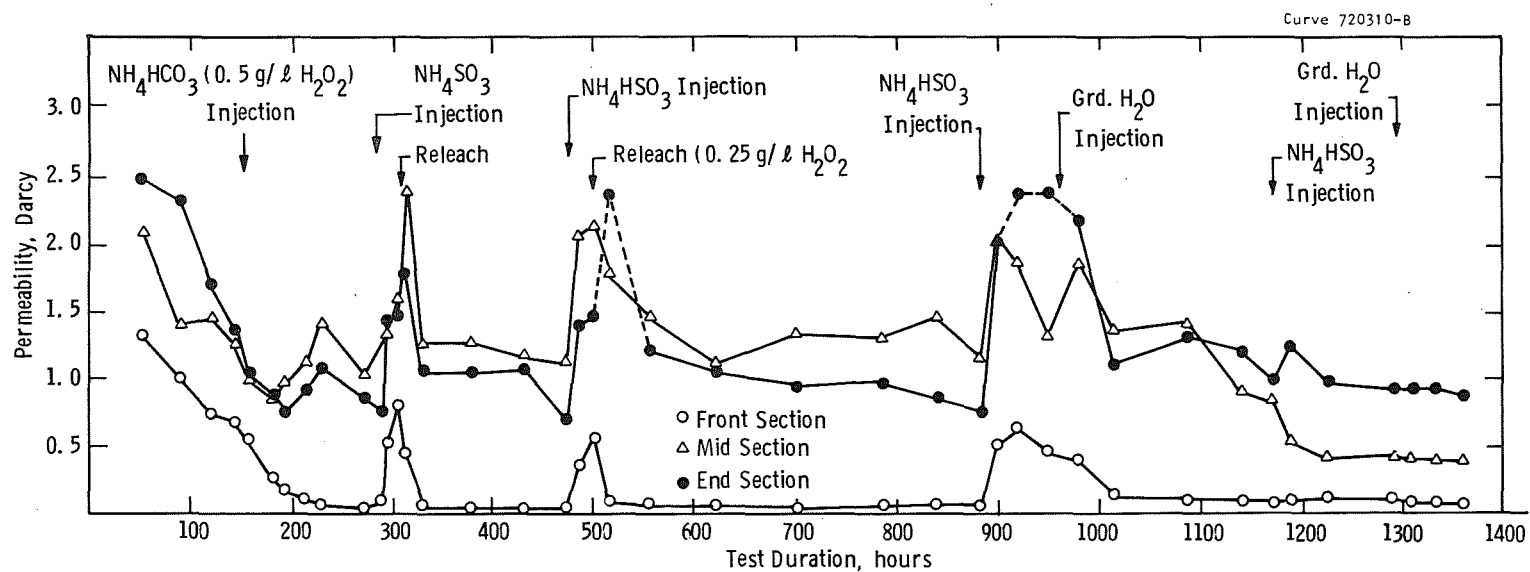


Fig. 6. 29—Permeability variations experienced during leaching of Wyoming ore with 1.0 g/l NH_4HCO_3 + (0.25–0.5 g/l) H_2O_2 , followed by 1.0 g/l NH_4HSO_3 then release, Test 70.

leaching can be overcome with the injection of ammonium bisulfite. The reducing agent is thought to react with and redissolve the oxygen blocking the ore bed. It rapidly reduces gas blockage and improves permeability. This agent may thus serve to restore permeability in ore beds having been damaged during leaching with solutions containing peroxide or dissolved oxygen.

The decrease in permeability caused by the groundwater flow is believed to be caused by clay particle deflocculation and subsequent migration which tend to block the pores of the ore. The low ionic strength of the groundwater can cause this deflocculation.⁽¹⁷⁾ Also, sodium in the groundwater exchanging onto the clay could have resulted in swelling and thus a reduction in the pore size. The ammonium bisulfite following the groundwater did not greatly improve the permeability, thus indicating that the damage was, in fact, caused by a mechanism different from that which occurred during the leaching portion of the test.

It should be noted that although the permeability did drop during the post-leach groundwater flow, the permeability was still much better than that obtained in previous tests. In Test 62, the permeability of the ammonium bicarbonate leached ore bed was as low as 0.02 darcy during the post-leach groundwater flow. Thus, the use of the reducing agent at the end of leaching period does seem to maintain a higher permeability for any subsequent restoration solutions that may be required.

The chemical data obtained during this test is listed in Table 6.17. The product leach solution pH variations (pH 6.9-7.9) were lower than previous bicarbonate leaches (e.g., pH = 8.2). The periodic use of ammonium bisulfite (pH = 3.0) likely resulted in the lower product pH's. During the post-leach ammonium bisulfite flow, the pH dropped to below 3.5. The ammonium, uranium, and bicarbonate concentration variations are shown in Figure 6.30. The use of ammonium bisulfite seemed to cause significant reductions in the bicarbonate level (720 to 240 mg/l),

TABLE 6.17

Summary of Data Obtained During Leaching of Wyoming Ore Using 1.0 g/l NH_4HCO_3 + (0.25 - 0.5 g/l) H_2O_2
 Followed by 1.0 g/l NH_4HSO_3 Then Releach, Test 70

Duration Hrs.	Product Solution Vol, l	Σ Vol, l	Σ Ore Pore pH Volumes (1 PV = 9.7)	pH	NH_4^+ mg/l	HCO_3^- mg/l	Uranium mg/l	% Uranium Recovery
66.2	29.0	29.0	3.0	6.11	--	--	309	18.7%
144.0	48.0	77.0	7.9	6.90	--	--	34	22.1%
192.0	23.3	100.3	10.3	7.05	--	350	177	30.6%
235.0	19.7	120.0	12.4	6.94	--	--	--	--
283.0	13.0	133.0	13.7	6.89	--	720	286	50.1%
309.0	14.4	147.4	15.2	7.03	2	--	112	53.5%
336.0	11.5	158.9	16.4	6.83	--	240	61	54.9%
405.0	18.4	177.3	18.3	6.81	3	--	--	--
474.0	14.9	192.2	19.8	7.22	14	470	59	59.0%
501.0	12.0	204.2	21.1	7.25	--	600	51	60.3%
552.2	25.7	229.9	23.7	7.00	71	310	22	61.5%
618.0	26.1	256.0	26.4	7.41	--	--	--	--
690.0	20.9	276.9	28.5	7.70	124	--	--	--
786.0	29.9	306.8	31.6	7.68	--	--	--	--
882.0	28.0	334.8	34.5	7.76	145	690	23	66.5%
909.0	15.9	350.7	36.2	7.93	157	600	11	66.9%
960.0	29.8	380.5	39.2	4.74	196	270	5	67.2%
1001.9	15.5	396.0	40.8	3.40	208	80	2.6	67.3%
1050.0	13.3	409.3	42.2	7.40	168	240	2.6	67.3%
1078.0	11.0	420.3	43.3	7.58	182	270	2.4	67.4%
1128.0	28.6	448.9	46.3	7.55	--	--	--	--
1170.0	17.5	466.4	48.1	7.93	--	--	--	--
1218.0	25.8	492.2	50.7	7.82	--	--	2.3	67.7%
1290.0	24.3	516.5	53.2	7.13	--	--	1.7	67.8%
1320.0	13.8	530.3	54.7	6.79	--	--	1.5	67.9%
1362.0	16.8	547.1	56.4	7.11	--	--	1.2	67.9%

Times of Solution Injections: (1) 1.0 g/l NH_4HCO_3 + (0.25 - 0.5 g/l) H_2O_2 - 144 hrs., 309 hrs., 501
 (2) 1.0 g/l NH_4HSO_3 - 283 hrs., 476 hrs., 882 hrs., 1170 hrs.
 (3) Wyo. Grd. H_2O - 960 hrs., 1290 hrs.

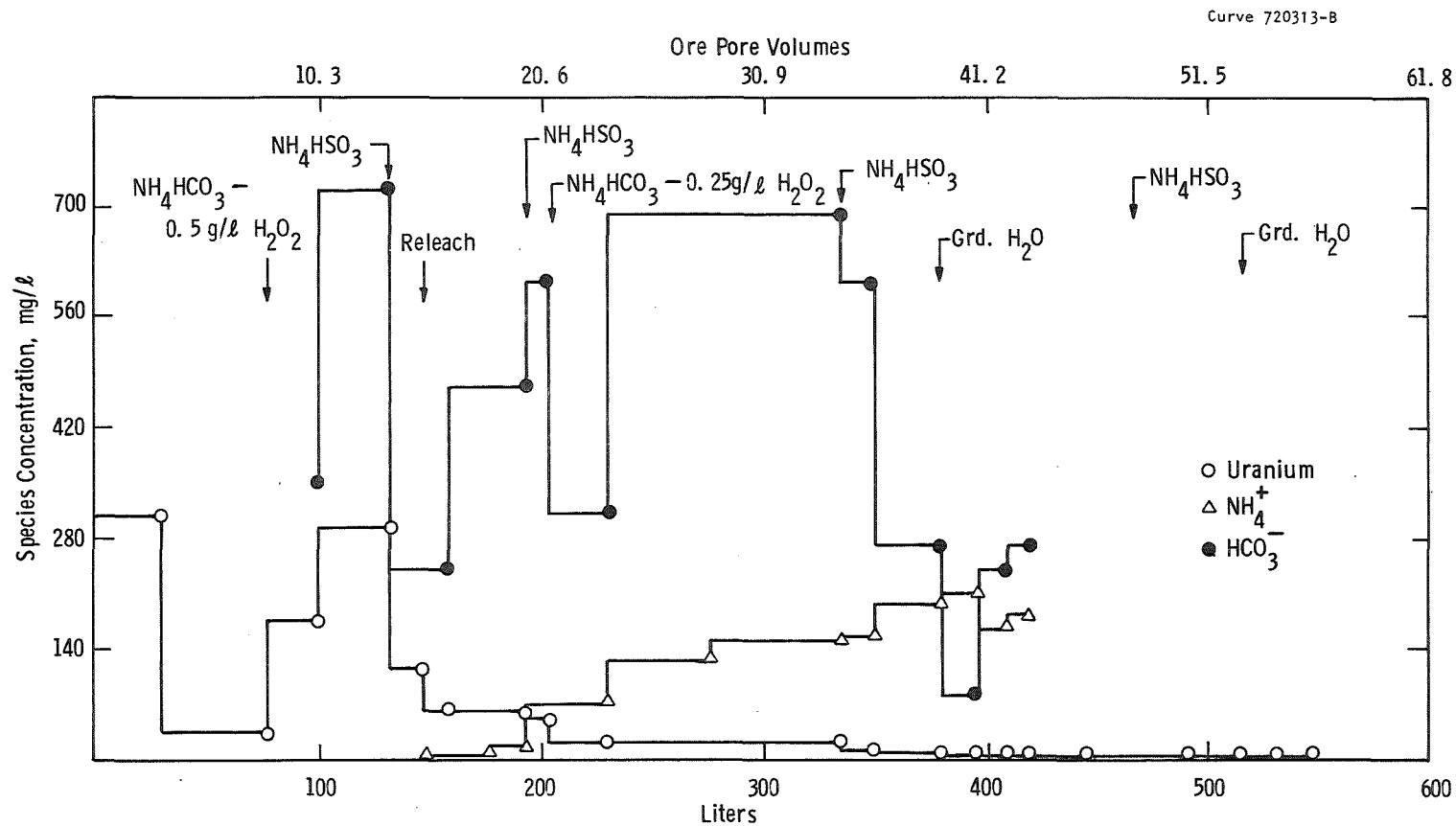


Fig. 6.30 - Concentration variations experienced during leaching of Wyoming ore using 1.0 g/l NH₄HCO₃ + (0.25 - 0.5 g/l) H₂O₂ followed by 1.0 g/l NH₄HSO₃ then release, Test 70.

but not to an extent to affect the uranium recovery rate. The sulfate formed during the oxidation of the sulfite may have helped to prevent a reduction in the uranium recovery rate. The uranium variations were typical of previous bicarbonate leaches. The ammonium level was less than 5 mg/l for the first 89 liters (9.3 pore volumes) of leach. The ammonium concentration then gradually increased, reaching a final value during leach of 145 mg/l. This final value was still significantly below the feed ammonium level (220 mg/l), thus indicating that ammonium exchange onto the ore was still occurring. In the 258 liters (26.6 pore volumes) of leach (including the first two short durations of NH_4HSO_3), there was a total of 38.7 g of ammonium sorbed by the ore (or 0.046 meq of ammonium/g of ore). This is approximately the same ammonium loading obtained in previous 1.0 g/l ammonium bicarbonate leaches (e.g., Test 62 - 0.046 meq of ammonium/g of ore after 26.6 pore volumes of leach). The use of ammonium bisulfite therefore did not affect ammonium sorption.

The uranium recovery rate observed during this test is shown in Figure 6.31. In the first 10 ore pore volumes of solution (including ammonium bisulfite) collected after the chemical leach breakthrough, 36% of the uranium was recovered. This is better than the 32% recovered in the first 10 pore volumes of the ammonium bicarbonate leach in Test 62. The higher recovery was possibly due to the improved permeability resulting from the ammonium bisulfite. The reduced oxygen blockage perhaps resulted in improved uranium accessibility and thus a faster initial uranium recovery. Reducing the peroxide level from 0.5 to 0.25 g/l after the second contact with ammonium bisulfite seemed to have no effect on uranium recovery. Thus, the higher peroxide level (0.5 g/l) does not seem to benefit uranium recovery, and does have an adverse effect on permeability.

The chemical leakage data collected during the post-leach solution flows is given in Table 6.18. After about the first 5 pore volumes of ammonium bisulfite, the uranium concentration fell to less than

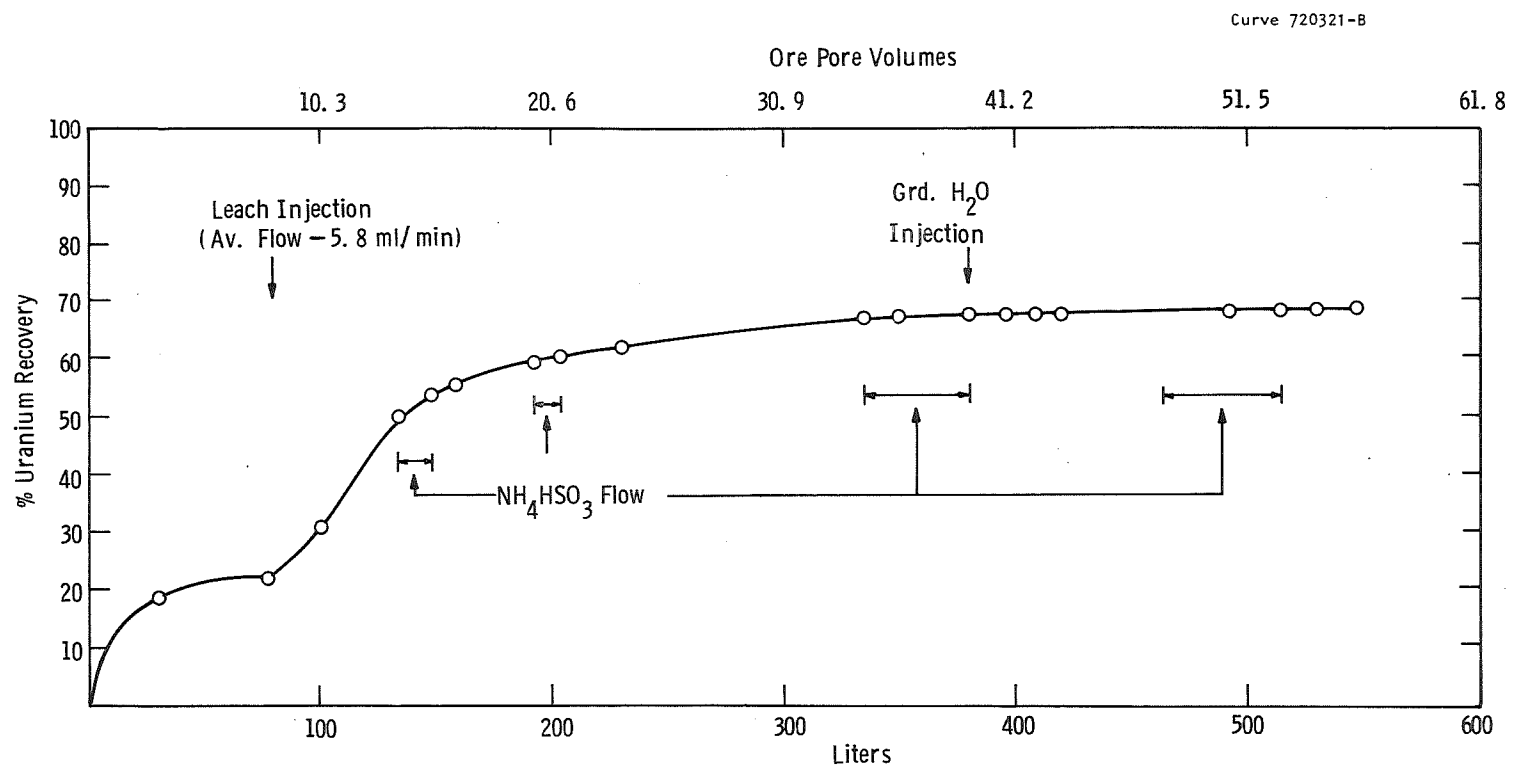


Fig. 6. 31 - Uranium recovery rate observed during leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2 , followed by 1.0 g/l NH_4HSO_3 then re-leach, Test 70.

TABLE 6.18

Ion Leakage From Wyoming Ore After Leaching With
1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2 , Test 70

Feed	Duration, hrs	Vol., ℓ	ΣVol., ℓ	ΣOre Pore Volumes	pH	NH_4^+ mg/ℓ	HCO_3 mg/ℓ	SO_4 mg/ℓ	U mg/ℓ	Se mg/ℓ
1.0g/ℓ NH_4HSO_3	882.0	-	-	-	7.8	145	690	-	23	-
	909.0	15.9	15.9	1.6	7.9	157	600	160	11	0.19
Wyo Grd. H_2O	960.0	29.8	45.7	4.7	4.7	196	270	600	5	0.52
	1001.9	15.5	61.2	6.3	3.4	208	80	650	2.6	0.20
	1050.0	13.3	74.5	7.7	7.4	168	240	260	2.6	0.38
	1078.0	11.0	85.5	8.8	7.6	182	270	160	2.4	0.17
	1128.0	28.6	114.1	11.8	7.6	-	-	-	-	0.09
1.0g/ℓ NH_4HSO_3	1170.0	17.5	131.6	13.6	7.9	-	-	-	-	0.10
	1218.0	25.8	157.4	16.2	7.8	-	-	-	2.3	-
Wyo Grd. H_2O	1290.0	24.3	181.7	18.7	7.1	-	-	-	1.7	-
	1320.0	13.8	195.5	20.2	6.8	-	-	-	1.5	-
	1362.0	16.8	212.3	21.9	7.1	-	-	-	1.2	-

3 mg/ℓ. During the subsequent groundwater flow, the uranium level remained at between 2 and 3 ppm. In the final groundwater flow, the uranium level was only slightly above 1 ppm. The results thus seem to indicate that extremely low uranium levels (< 1 mg/ℓ) can be obtained with the passage of sufficient ammonium bisulfite (~ 10 pore volumes).

The bicarbonate level, which fell after the addition of the ammonium bisulfite, increased during the groundwater flow but did not go above the background groundwater level (320 mg/ℓ). The ammonium bisulfite caused the sulfate level to increase significantly. However, the sulfate concentration did fall to the background level after about 3 pore volumes of groundwater.

The selenium level initially increased following the injection of the reducing agent, but then began to decrease. The selenium level was, however, still very much higher than the EPA drinking standard of 10 ppb after 3 pore volumes of groundwater. Perhaps greater amounts of the reducing agent (or a different reducing agent) would lower the selenium level.

6.2.2.2 High Pressure Leaching of Wyoming Ore Using 1.0 g/ℓ NH_4HCO_3 Saturated with Oxygen at 120 psig, Followed by 1.0 g/ℓ Na_2SO_3 , Test 67

This test was designed to study the effect of a reducing agent (Na_2SO_3) on the groundwater leakage of ions following an ammonium bicarbonate leach. The ion leakage that results can be compared to that obtained with groundwater following a similar leach test using no post-leach reducing agent (Test 62). The test had a 192-hour initial deionized water flow period, followed by 713.5 hours of chemical leach. The post-leach portion of the test consisted of the following flow sequence: 126.5 hours of Na_2SO_3 , 311.0 hours of groundwater, 120.0 hours of Na_2SO_3 , and 210.0 hours of groundwater. The test lasted a total of 1673.0 hours.

The permeability variations experienced during this test are illustrated in Figure 6.32. During the leach portion of the test, the

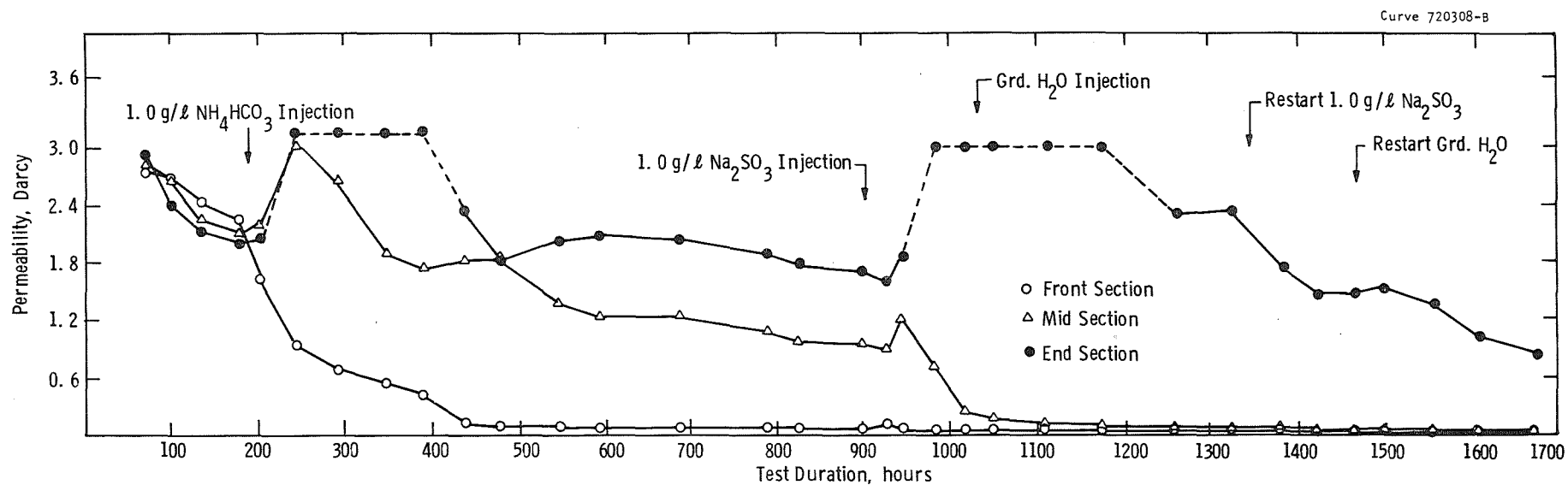


Fig 6.32-Permeability variations observed during high pressure leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 saturated with O_2 at 120 psig, followed by 1.0 g/l Na_2SO_3 . Test 67.

feed tank was pressurized to 120 psig with oxygen, and the outlet pressure was maintained by a back pressure regulator at 50 psig for most of the run. At the end of the deionized water flow period, the permeabilities of the front, middle, and end sections of the ore bed were in the range of 1.9 to 2.3 darcy. After chemical injection, the front section permeability dropped from 2.2 to about 0.6 darcy after 120 hours of leach, and to about 0.07 darcy within 300 hours of leach. The permeability then gradually declined to slightly less than 0.05 darcy by the end of the leaching period. The middle and end section permeabilities were approximately 1.0 and 1.8, respectively, at the conclusion of the leaching period. The permeability variations were similar to the baseline ammonium bicarbonate leach tests (Tests 62 and 78).

The permeability damage experienced in the front section during leach was likely, in part, the result of oxygen blockage. The leach, saturated with oxygen at 120 psig (≈ 285 ppm O_2), releases the oxygen as it comes into contact with the ore bed, which is at a much lower pressure (≈ 50 psig). The permeability variations in the front section are shown in more detail in Figure 6.33. These changes within the front section can best be explained by first examining the oxygen profiles taken along the column at various times in the test (Figure 6.34). The oxygen profiles show that during leaching the large oxygen decreases occur in the first 39 inches of the ore bed (by SP_3). This corresponds with the location of the poorest permeability in the front section (Figure 6.33). The results also show that the permeability continually declines further down the column as the pressure in the front portion of the column increases, thus causing the oxygen to be released from solution further down the column.

The permeability of all three sections of the ore bed increased immediately following the injection of sodium sulfite. The permeability of the front section went from about 0.05 darcy to 0.09 darcy. The increase in permeability is likely the result of the reducing agent

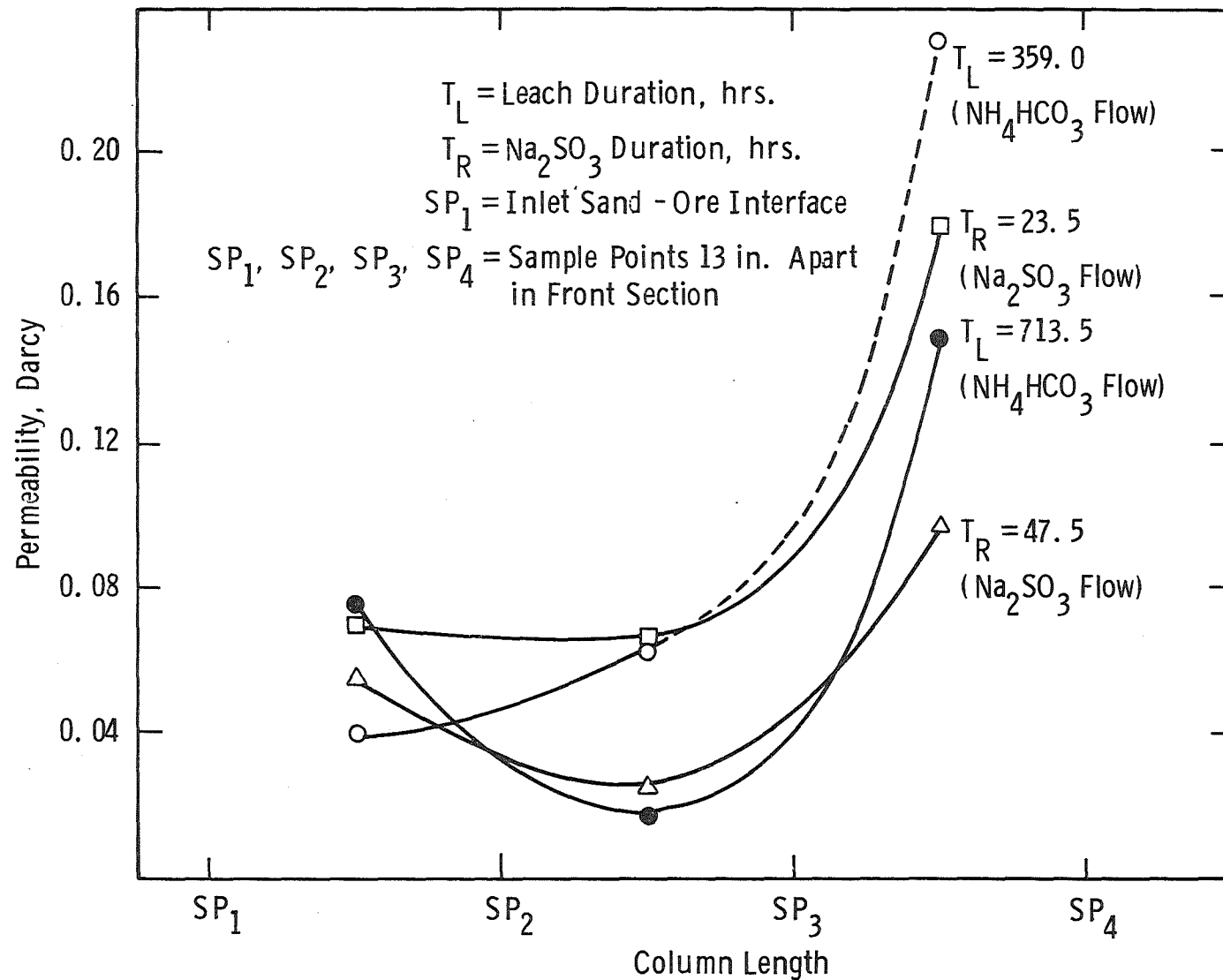


Fig. 6.33 - Permeability variations within front section of high pressure $\text{NH}_4\text{HCO}_3 - \text{O}_2$ leach test on Wyoming ore, Test 67.

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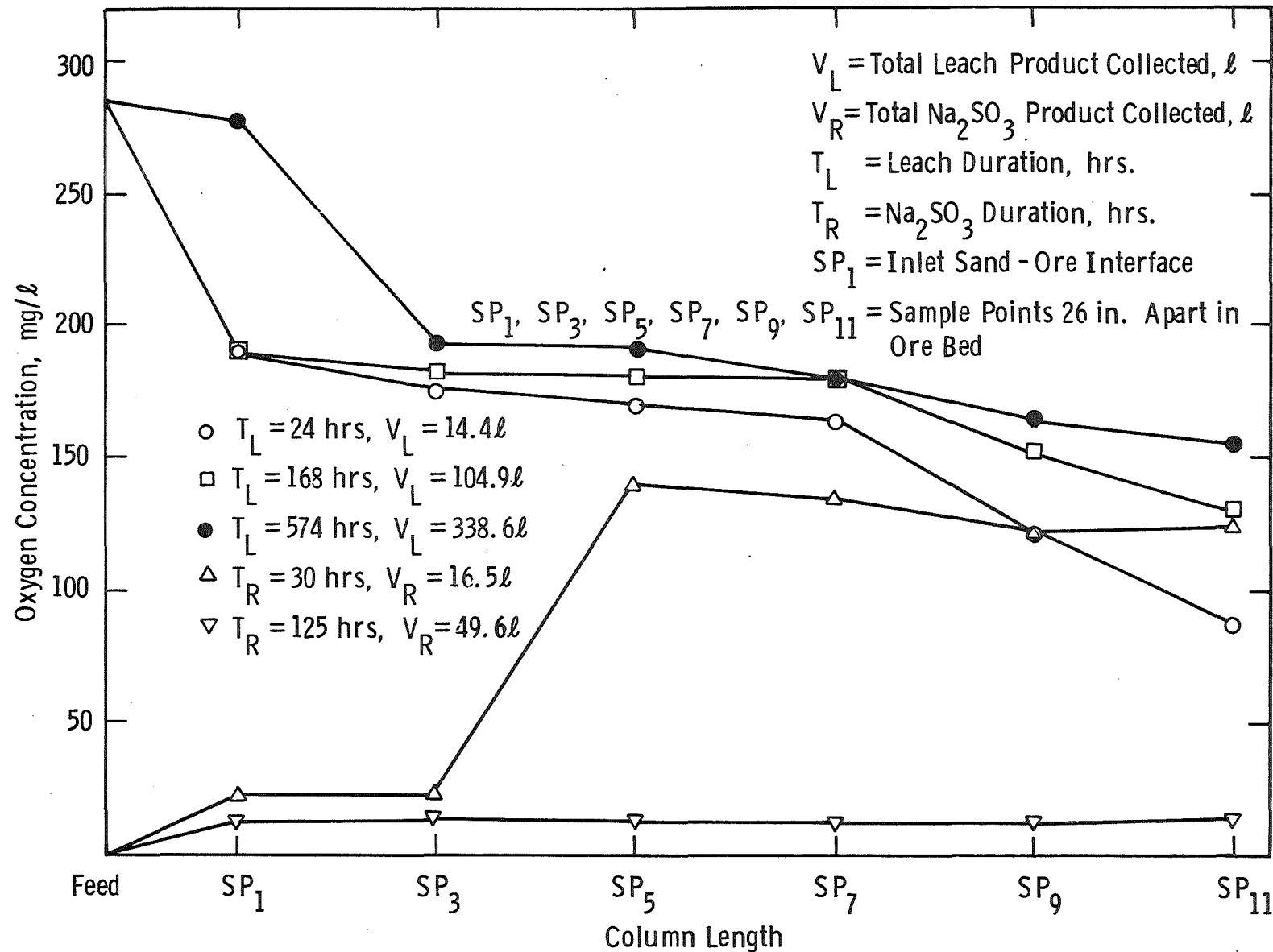


Fig. 6.34 - Oxygen concentration profiles along the length of the high pressure column during leaching of Wyoming using 1.0 g/l NH_4HCO_3 saturated with O_2 (120 psig), followed by 1.0 g/l Na_2SO_3 , Test 67

reacting with, and thus redissolving, the oxygen that has come out of solution. Gas blockage is thus reduced, and permeability improved. Figure 6.34 shows that the oxygen concentration in solution is greatly lowered following the injection of the reducing agent.

However, following the initial increase with the reducing agent the permeability then declined. The front section dropped to about 0.02 darcy, while the middle section dropped from 1.2 to 0.2 darcy. This decrease is believed to be caused by the exchange of sodium ions in solution for the ammonium on the ore's clay. Sodium substituted clays result in clay swelling, dissociation, and dispersion, which has an adverse effect on permeability. The permeability dropped further during the subsequent groundwater flow. The low ionic strength groundwater likely caused an increase in the movement of sodium-substituted clays.

The chemical data completed on this test is given in Table 6.19. The pH variations during leach were similar to previous bicarbonate tests; pH = 6.7 to 8.2. The Na_2SO_3 seemed to cause a slight increase in the pH to around 8.5. The ammonium, uranium, and bicarbonate variations experienced during the test are shown in Figure 6.35. The variations of bicarbonate and uranium during the leach portion of the test were typical of past bicarbonate tests. The increase of bicarbonate with the introduction of the leach caused an increase in the uranium level. The ammonium variations again indicate that the ore is picking up ammonium from the leach solution. In the 416.8 liters (or 41.3 pore volumes) of leach, a total of 46.5 g of ammonium (0.056 meq of ammonium/g of ore) was lost to the ore. This is approximately the same amount of ammonium sorbed in previous 1.0 g/l ammonium bicarbonate tests, both high and low pressure.

The uranium recovery rate observed in this test is shown in Figure 6.36. In the deionized water portion of the test, about 24% of the ammonium was recovered. In the first 10 pore volumes (101 liters) of actual leach collected, an additional 33% of the uranium was recovered. This recovery rate compares favorably to the low pressure ammonium

TABLE 6.19

Summary of Data Obtained During High Pressure Leaching of Wyoming Ore Using 1.0 g/l NH_4HCO_3
Saturated with Oxygen (120 psig), Followed by 1.0 g/l Na_2SO_3 , Test 67

Duration, Hrs	Solution Vol, l	Σ Vol, l	Σ Ore Pore Volumes (1PV = 10.1 l)	pH	NH_4^+ mg/l	HCO_3^- mg/l	Uranium mg/l	% Uranium Recovery
114.3	37.7	37.7	3.7	6.3	---	---	274	22.4
162.0	29.0	66.7	6.6	7.2	---	---	---	---
192.0	18.7	85.4	8.5	7.0	---	---	18	24.3
240.0	29.6	115.0	11.4	6.7	---	390	169	35.1
285.0	27.1	142.1	14.1	6.8	---	670	242	49.4
360.0	48.2	190.3	18.8	7.5	---	---	---	---
453.0	52.1	242.4	24.0	7.7	51	620	66	63.8
545.0	49.6	292.0	28.9	7.9	105	---	---	---
620.0	43.9	335.9	33.3	7.8	113	---	---	---
695.0	43.9	379.8	37.6	7.9	146	610	13	67.6
766.0	44.2	424.0	42.0	8.1	---	---	---	---
857.0	49.9	473.9	46.9	8.1	171	---	---	---
905.5	28.3	502.2	49.7	8.2	175	660	8	70.1
954.0	24.8	527.0	52.2	8.2	163	400	3	70.3
1032.0	25.3	552.3	54.7	8.5	226	---	2	70.4
1124.0	15.0	567.3	56.2	8.4	187	100	2	70.4
1217.0	12.9	580.2	57.4	8.4	131	250	4	70.5
1343.0	16.0	596.2	59.0	8.3	121	290	4	70.7
1463.0	14.4	610.6	60.5	8.2	---	270	4.8	70.9
1577.0	13.4	624.0	61.8	8.3	---	180	2.0	70.9
1673.0	11.7	635.7	62.9	8.2	---	230	4.0	71.0

Times of Solution Injection: (1) NH_4HCO_3 - 192.0 hrs
 (2) Na_2SO_3 - 905.5 hrs, 1343.0
 (3) Ground H_2O - 1032.0 hrs, 1463.0

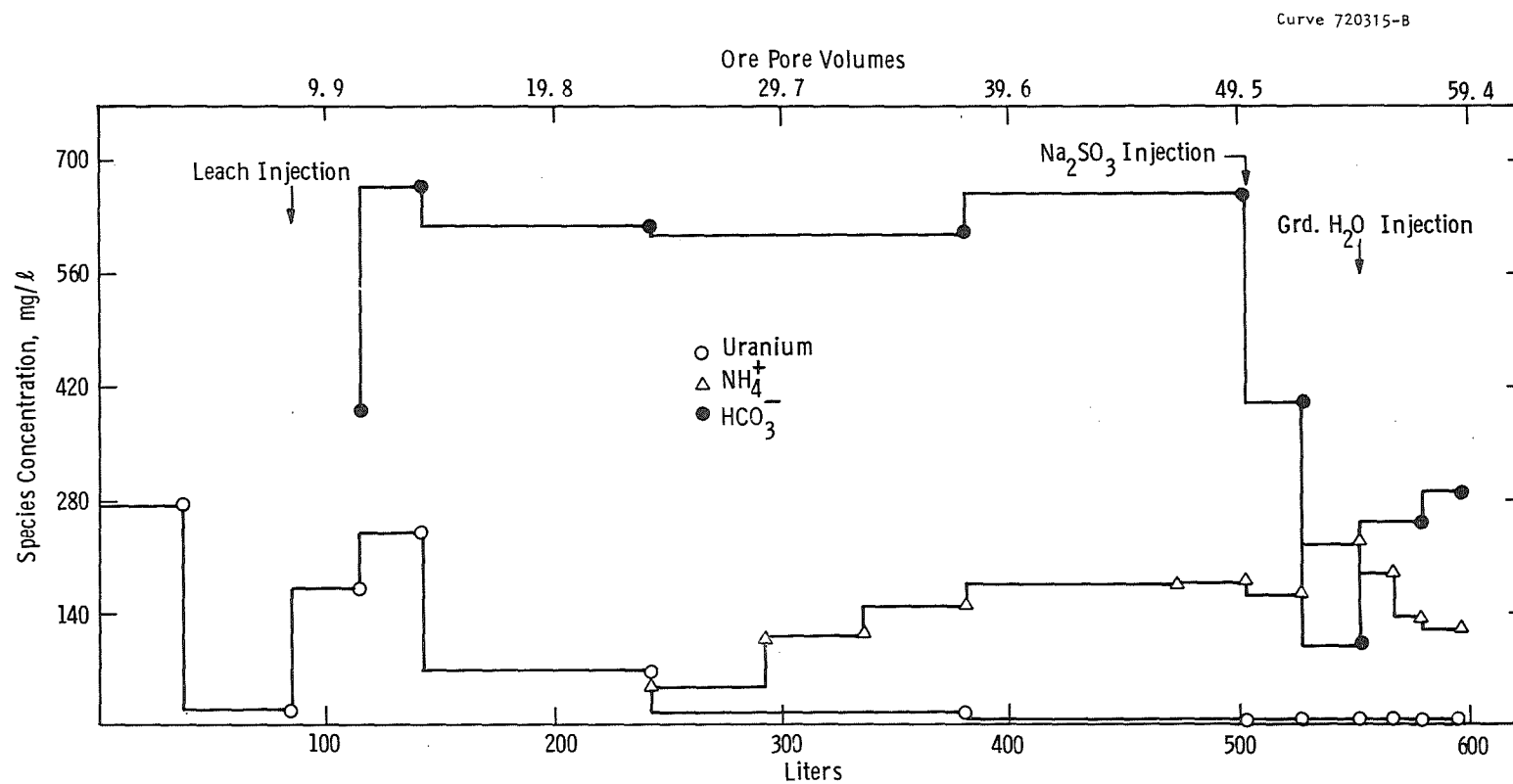


Fig. 6.35 - Concentration variations experienced during leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 saturated with O_2 at 120 psig, followed by 1.0 g/l Na_2SO_3 and ground water, Test 67

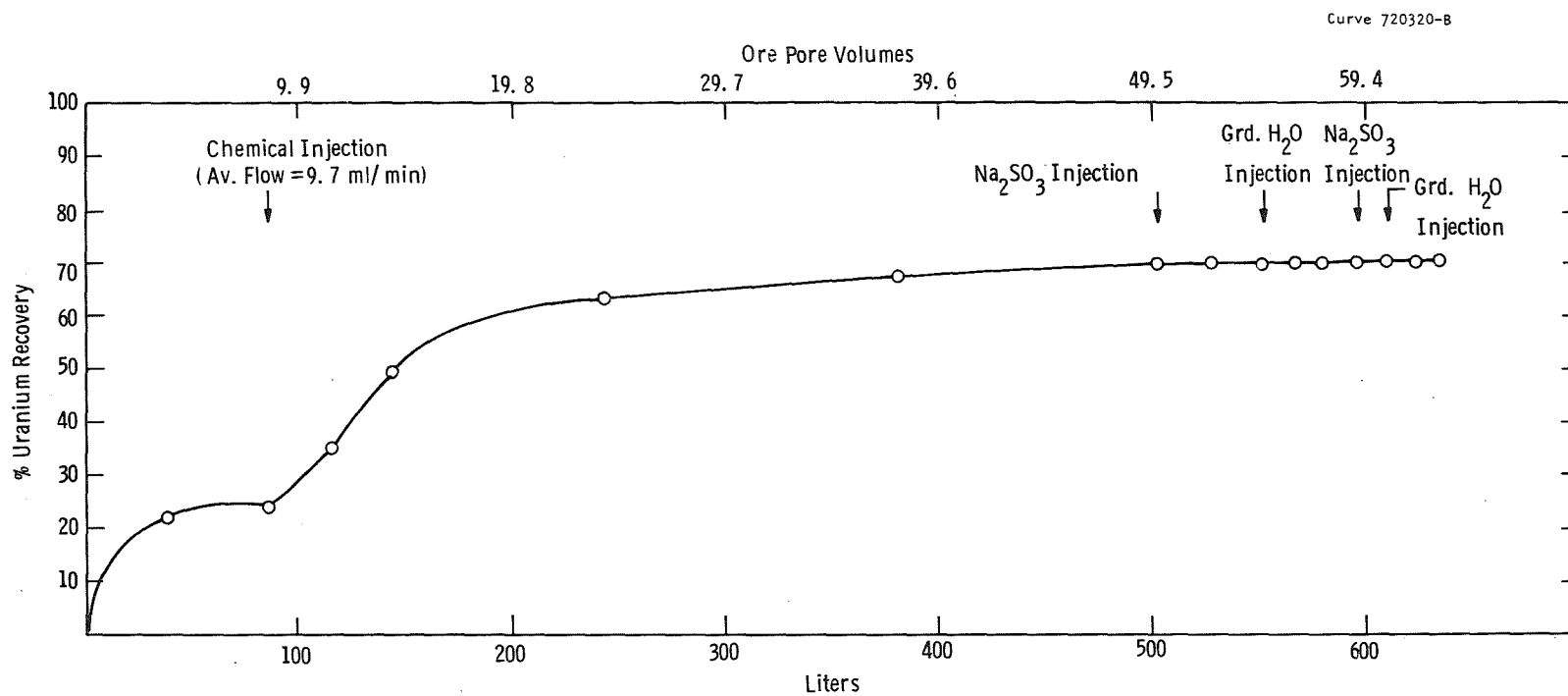


Fig. 6.36 - Uranium recovery rate observed during high pressure leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 saturated in oxygen (120 psig), followed by 1.0 g/l Na_2SO_3 , Test 67.

bicarbonate-dissolved oxygen test (Test 62), where 32% of the uranium was removed with 10 pore volumes of leach. The total recovery by the conclusion of the leaching period for both tests was also comparable; 70% for this test and 68% for the low pressure test. The greater volume of leach solution collected in this test accounts for the slight difference.

The chemical leakage resulting from the sodium sulfite and groundwater flows is given in Table 6.20. Within the first 5 pore volumes of sodium sulfite, the uranium leakage dropped to 2 mg/l. During subsequent groundwater flow the uranium rose to and leveled off at 4 mg/l. After reinjection of a pore volume of the sodium sulfite, the uranium again dropped to 2 mg/l. The final groundwater injection brought the uranium back to 4 mg/l. The uranium leakage after 5 pore volumes of groundwater following the same leach with no post-leach reducing agent was significantly greater (10-20 mg/l) in Test 62, but only a slightly higher (5 mg/l) in Test 78. The reducing agent thus did seem to lower uranium leakage, but the magnitude of the decrease is uncertain. Its use may be more effective at higher concentrations, or for longer flow durations.

The bicarbonate level dropped significantly after the sodium sulfite injection, but rose during the subsequent groundwater flow, which may have caused the uranium increase. However, the bicarbonate level did not go above the background groundwater level (320 mg/l). As expected, the sulfate level increased after the injection of the reducing agent. The sulfate concentration, however, dropped rapidly after the introduction of the groundwater, and was only slightly above the background level (190 mg/l) after about 4 pore volumes of the groundwater. The use of the reducing agent thus did not result in any subsequent long-term adverse bicarbonate or sulfate leakage levels.

The results indicate that the ammonium sorbed onto the ore during leaching was removed during the Na_2SO_3 flow. It is likely that the

TABLE 6.20

Ion Leakage from Wyoming Ore Residue After High Pressure Leaching with
1.0 g/l NH_4HCO_3 Saturated with Oxygen (120 psig), Test 67

Feed	Duration, Hrs	Vol, ℓ	Σ Vol, ℓ	Σ Ore Pore Volumes	pH	NH_4^+ mg/ℓ	HCO_3^- mg/ℓ	$\text{SO}_4^{=}$ mg/ℓ	U mg/ℓ	Se mg/ℓ
1.0 g/ℓ Na_2SO_3	905.5	--	--	--	8.1	175	660	--	8	--
	954.0	24.8	24.8	2.5	8.2	163	400	370	3	0.15
Wyo. Grd. H_2O	1032.0	25.3	50.1	5.0	8.5	226	--	560	2	0.56
	1124.0	15.0	65.1	6.4	8.4	187	100	510	2	0.47
	1217.0	12.9	78.0	7.7	8.4	131	250	210	4	0.19
1.0 g/ℓ Na_2SO_3	1343.0	16.0	94.0	9.3	8.3	121	290	200	4	0.18
Wyo. Grd. H_2O	1463.0	14.4	108.4	10.7	8.2	--	270	240	4	--
	1577.0	13.4	121.8	12.1	8.3	--	180	660	2	--
	1673.0	11.7	133.5	13.2	8.2	--	230	280	4	--

sodium (15.9 meq/l) in the feed exchanged for the sorbed ammonium resulting in the relatively high ammonium removal (12.5 meq/l). Increasing the Na_2SO_3 concentration should result in even higher ammonium removal rates.

The leakage of selenium seemed to increase with the use of Na_2SO_3 . The selenium level did drop during the groundwater flow, but it was still very much higher than the EPA drinking standard of 10 ppb. A study has indicated that selenium can be removed from water by zinc reduction.⁽¹⁰⁾ Perhaps greater amounts of sodium sulfite will lower the selenium level, or perhaps the addition of another reductant (e.g., zinc) will help lower the level.

6.2.2.3 Leaching of Wyoming Ore Using 1.0 g/l NH_4HCO_3 Saturated With Oxygen at 45 psig, Followed by 3.0 g/l NaHSO_3 and Groundwater, Test 80

This test was carried out to determine if sodium bisulfite at a relatively high concentration of 3.0 g/l could be used to reduce chemical (e.g., uranium and selenium) leakage, and to adequately remove ammonium from the ore. The test was run for a total duration of 1608.0 hours. This included, in sequence, 168.0 hours of deionized water, 768.0 hours of leach, 408.0 hours of sodium bisulfite, and 264.0 hours of groundwater. The final groundwater period was used to determine the effectiveness of using sodium bisulfite to reduce the post-leach chemical leakage.

The permeability variations are shown in Figure 6.37. By the conclusion of deionized water flow, the front section had a permeability of about 1.5 darcy, while the middle and end sections had unusually high permeabilities of 3.0 and 2.7 darcy, respectively. The reason for these high permeabilities was not known. Following leach injection, the middle and end sections dropped rapidly, but then improved to about 1.5 and 2.0 darcy, respectively. The front section dropped to about 0.9 darcy within 120 hours after chemical injection, to 0.2 darcy after 300 hours of leach, to 0.09 darcy after 500 hours of leach, and to a

Curve 721820-B

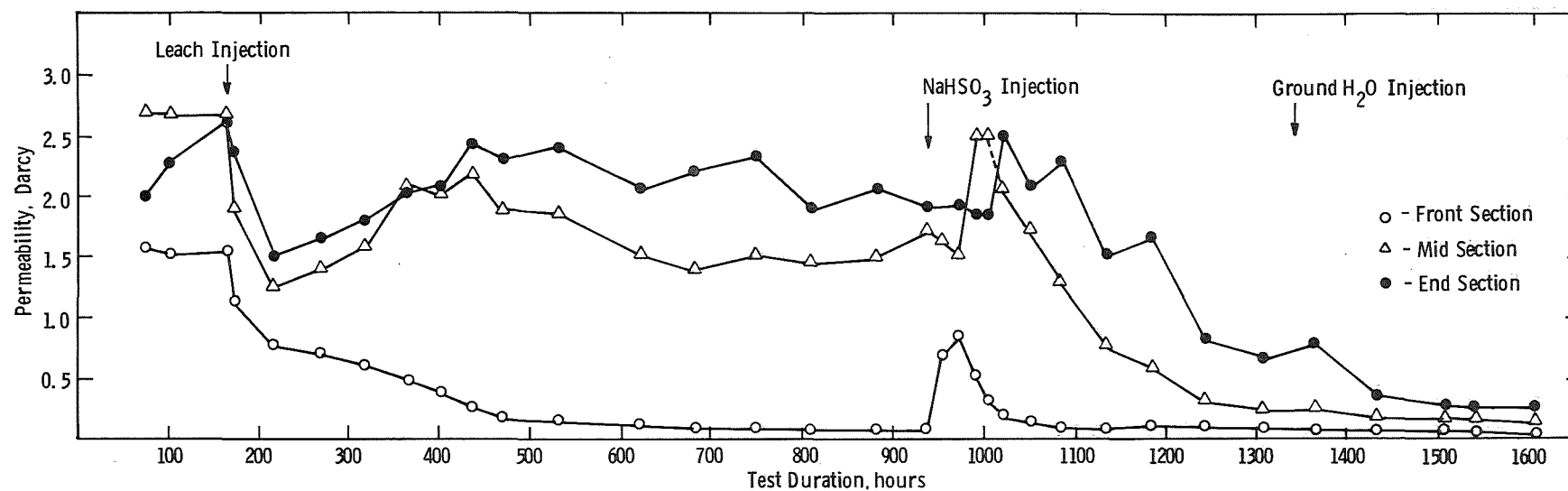


Fig. 6.37 — Permeability variations experienced during leaching of Wyoming ore with 1.0 g/l NH_4HCO_3 saturated O_2 (45 psig), followed by 3.0 g/l NaHSO_3 and ground water, Test 80

fairly constant 0.05 darcy by the leach conclusion. The front section permeability variations were similar to those obtained in Test 78, which was performed under the same leach conditions.

Following sodium bisulfite injection, there was an immediate permeability increase in all three sections. This was then followed by a drop in permeability. The front section permeability rose from 0.05 to 0.82 darcy within the first 40 hours of sodium bisulfite, but then dropped back down to 0.08 darcy after about 100 hours of flow. After initially rising above 2.5 darcy, the middle section dropped to about 0.23 darcy by the conclusion of the sodium bisulfite flow. The end section also rose above 2.5 darcy, but it then showed a continuous decline to about 0.65 darcy. This drop in permeability, following an initial increase, had also occurred in a previous test using a post-leach reducing agent (Test 67 - sodium sulfite). The initial increase in permeability was believed to be due to the dissolution of oxygen gas which had been released in the ore bed during leach. The removal of this gas blockage by the reducing agent, sodium bisulfite, resulted in improved permeability. The subsequent decline in permeability was thought to be caused by the exchange of sodium cations onto the ore's clay. Resulting from the sodium exchange were the permeability damaging effects of clay swelling, and clay dispersion and dissociation.

After groundwater injection, there was again a decline in the permeability of all three sections. The low ionic strength groundwater caused an increase in the dissociation and dispersion of the sodium-clays.

The chemical data collected during this test is given in Table 6.21. The pH variations during leach were typical of previous ammonium bicarbonate leaches (pH 7.2 to 8.1). However, after sodium bisulfite injection (pH = 3.7), the product pH showed a steady decline, reaching a low of 3.8. Following the introduction of groundwater feed, the pH then rose relatively rapidly to above 8. The uranium recovery during leach, shown in Figure 6.38, was also similar to the previous ammonium bicarbonate

TABLE 6.21

Summary of Data Obtained During Leaching of 1.0 g/l NH_4HCO_3 -Sat'd O_2
(45 psig), Followed by 3.0 g/l NaHSO_3 and Groundwater, Test 80

Duration, Hrs.	Product Solution Vol., l	Σ Vol., l	Σ Ore Pore Volumes (1PV=10.1l)	pH	NH_4^+ mg/l	Uranium mg/l	% Uranium Recovery
117.0	38.7	38.7	3.8	6.76	---	275	23.7
168.0	15.2	53.9	5.3	7.00	---	38	24.9
234.0	37.9	91.8	9.1	6.73	---	237	44.9
285.0	26.8	118.6	11.7	7.23	---	194	56.5
360.0	38.8	157.4	15.6	7.62	---	---	---
426.0	35.1	192.5	19.1	7.50	34	53	65.2
501.0	38.3	230.8	22.9	7.70	91	---	---
594.0	47.2	278.0	27.5	7.91	124	---	---
669.0	36.8	314.8	31.2	7.73	---	17	69.8
738.0	34.3	349.1	34.6	7.90	146	---	---
834.0	44.6	393.7	39.0	7.98	---	---	---
936.0	40.4	434.1	43.0	8.06	168	11	72.7
1002.0	18.6	452.7	44.8	7.84	292	10.8	73.2
1074.0	17.8	470.5	46.6	5.96	330	3.8	73.3
1176.0	17.2	487.7	48.3	5.67	263	3.2	73.4
1242.0	19.0	506.7	50.2	3.81	244	0.9	73.5
1344.0	26.0	532.7	52.7	6.02	207	3.2	73.7
1410.0	16.7	549.4	54.4	6.24	---	---	---
1462.0	9.7	559.1	55.4	7.98	94	4.2	73.9
1530.0	14.5	573.6	56.8	8.29	---	---	---
1608.0	15.1	588.7	58.3	8.49	77	0.8	74.0

Times of Solution Injection: 1) NH_4HCO_3 - O_2 - 168.0 hours
 2) NaHSO_3 - 936.0 hours
 3) Wyo. Grd. H_2O - 1344 hours

Curve 721813-B

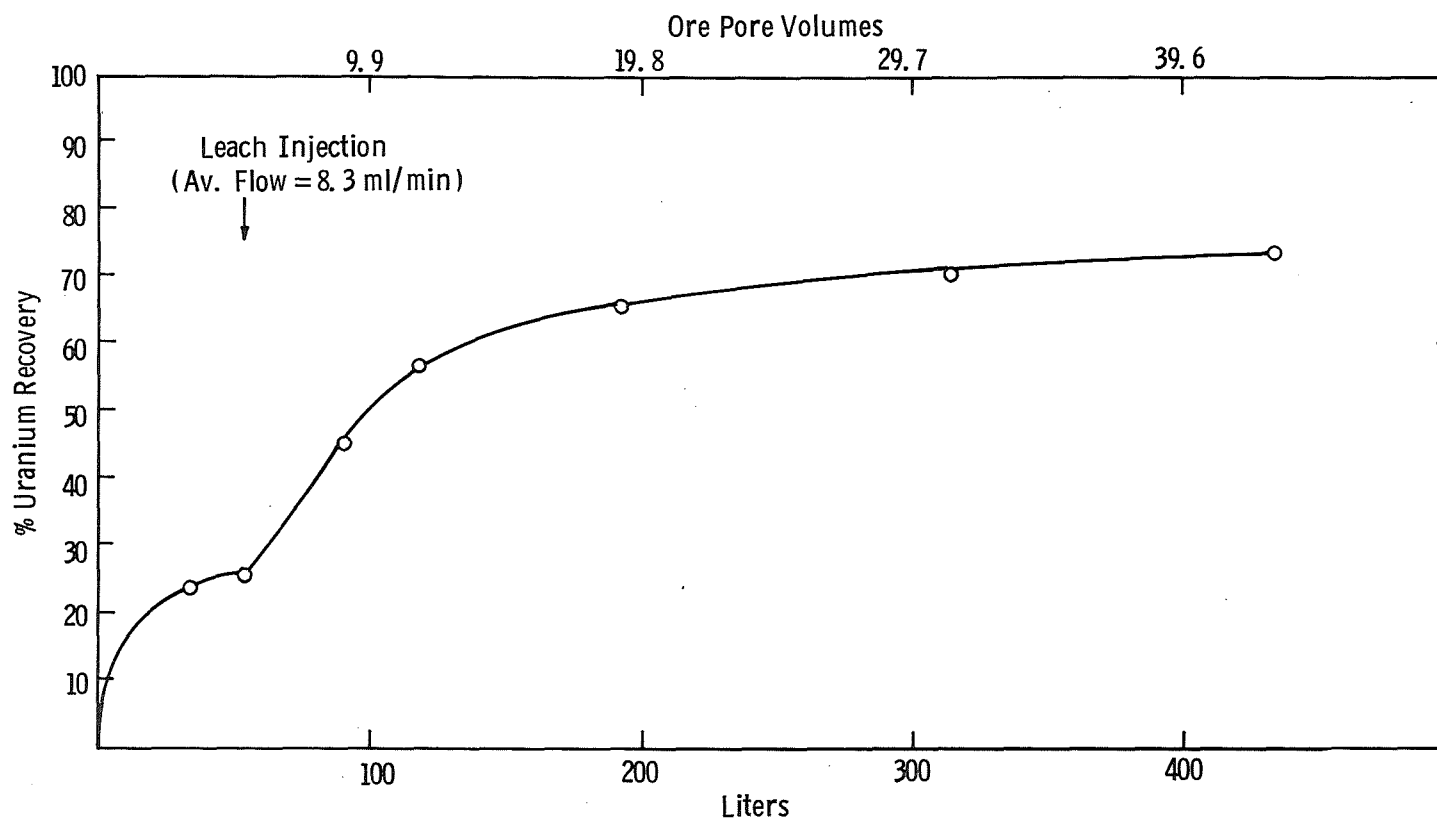


Fig. 6.38 — Uranium recovery rate observed during leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 - sat'd O_2 (45 psig), Test 80

leaches. During deionized water flow, approximately 25% of the uranium was recovered. In the first 10 pore volumes (101 liters) of actual leach solution collected, 34% of the uranium was recovered. The total recovery by the conclusion of leach was 72.7%.

The ammonium and uranium concentration variations experienced during this test are shown in Figure 6.39. During the 380.2 liters of leach, a total of 46.5 g of ammonium was sorbed by the ore. This ammonium ore level (0.053 meq of NH_4^+ /g of ore) compares favorably with the levels obtained in previous 1.0 g/l ammonium bicarbonate tests (e.g., Test 62).

The chemical leakage into the post-leach solutions is given in Table 6.22. The uranium level dropped to below 1 mg/l after about 7 pore volumes sodium bisulfite. After groundwater injection, the uranium initially rose to over 4 mg/l, but then fell to below 1 mg/l again after about 7 pore volumes of groundwater. The selenium level was brought down to 130 ppb by the conclusion of the bisulfite flow, and continued to fall during the subsequent groundwater to about 40 ppb. In the baseline test with no post-leach reducing agent (Test 78), the uranium and selenium remained above 2 mg/l and 130 ppb, respectively, for over 15 pore volumes of groundwater. The leakage of uranium and selenium was thus significantly reduced using sodium bisulfite. The sodium level fell to 275 mg/l by the conclusion of the groundwater. This is above the groundwater feed level of 185 mg/l, but the data indicates that it should continue to fall with additional groundwater flow. Thus, sodium should not add to the restoration requirement.

The ammonium removal rate during sodium bisulfite flow is shown in Figure 6.40. As the data shows, about 29% of the ammonium was removed in the first 4 pore volumes of actual sodium bisulfite solution collected, and about 51% of the ammonium was removed in 8.6 pore volumes. This removal of ammonium resulted in a reduced ammonium leakage into subsequent groundwater. After a total of about 14 pore volumes of total

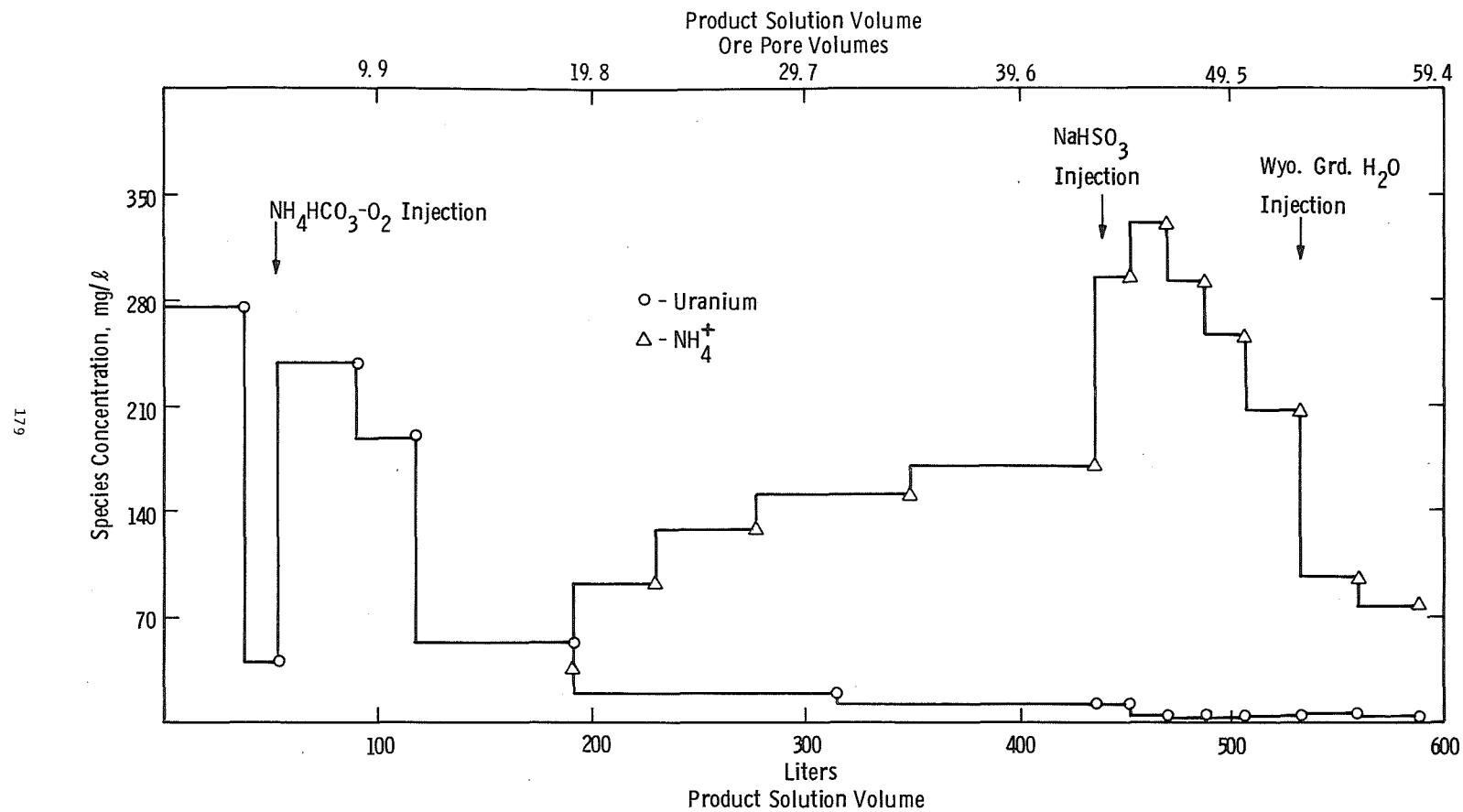


Fig. 6.39—Concentration variations experienced during leaching of Wyoming ore with 1.0 g/l NH_4HCO_3 saturated O_2 (45 psig), followed by 3.0 g/l NaHSO_3 and ground water, Test 80

TABLE 6.22

Ion Leakage From Wyoming Ore After Leaching With
1.0 g/l NH_4HCO_3 -Sat'd O_2 (45 psig), Test 80

Feed	Duration, Hrs.	Vol., ℓ	Σ Vol., ℓ	Σ Ore Pore Volumes	pH	U mg/ℓ	Se mg/ℓ	Na^+ mg/ℓ	NH_4^+ mg/ℓ
3.0 g/l NaHSO_3	936.0	---	---	---	3.70	---	---	---	---
	1002.0	18.6	18.6	1.8	7.84	10.8	0.39	3.8	292
	1074.0	17.8	36.4	3.6	5.96	3.8	0.35	171	330
	1176.0	17.2	53.6	5.3	5.67	3.2	0.21	400	263
	1242.0	19.0	72.6	7.2	3.81	0.9	0.13	530	244
Wyo. Grd. H_2O	1344.0	26.0	98.6	9.8	6.02	3.2	0.13	613	207
	1410.0	16.7	115.3	11.4	6.24	---	---	---	---
	1462.0	9.7	125.0	12.4	7.98	4.2	0.074	345	94
	1530.0	14.5	139.5	13.8	8.29	---	---	---	---
	1608.0	15.1	154.6	15.3	8.49	0.8	0.041	275	77

Curve 721811-B

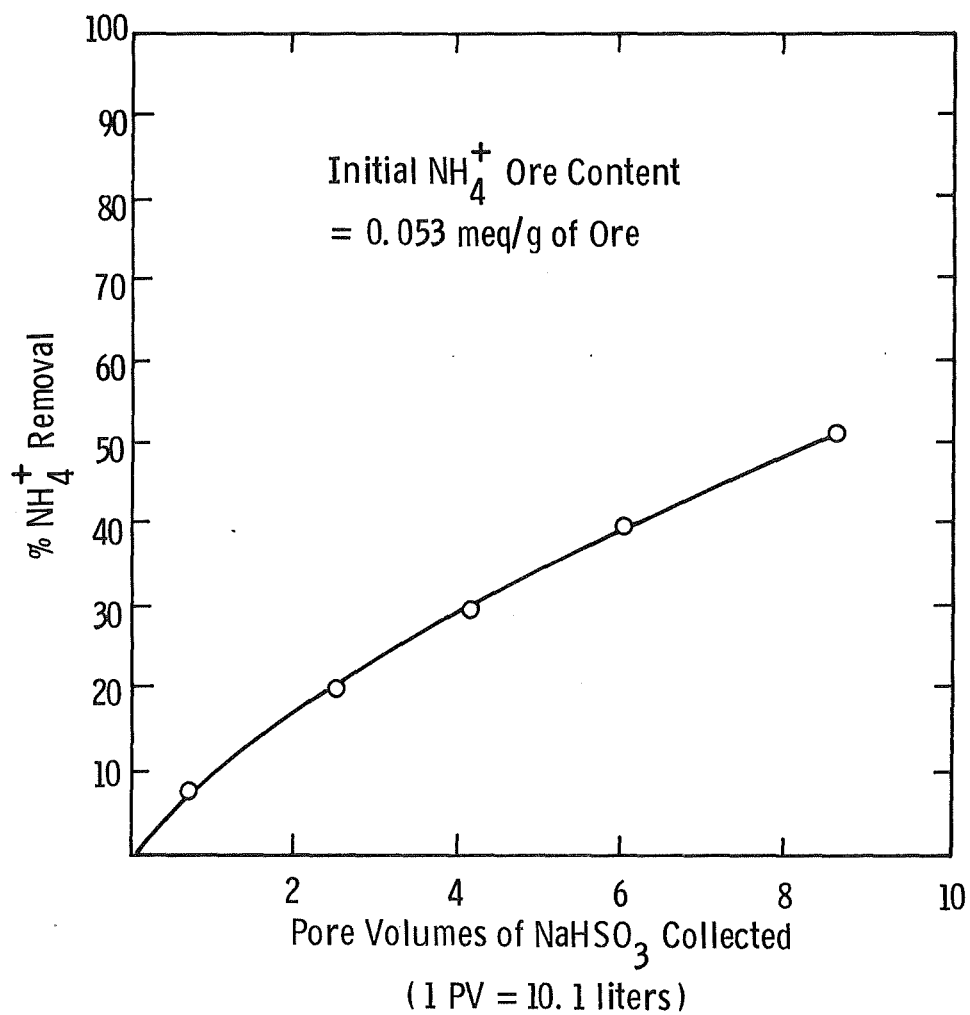


Fig. 6. 40—Ammonium removal rate observed during 3.0 g/l NaHSO_3 flow following 1.0 g/l NH_4HCO_3 sat'd O_2 (45 psig) leach of Wyo. ore, Test 80

post-leach solution (sodium bisulfite and groundwater) were collected, the ammonium leakage level was under 80 mg/l. In the baseline test with no post-leach restoration (Test 78), the ammonium level was about 90 mg/l after 14 pore volumes of post-leach groundwater. Additional pore volumes of sodium bisulfite should result in a greater reduction in ammonium leakage during subsequent groundwater flow. The equivalent cation concentration of the sodium bisulfite feed was 28.9 meq/l. This feed level produced a peak ammonium equivalent concentration of 18.3 meq/l (330 mg/l). Thus, about 63% of the sodium was effectively used in the removal of ammonium. The product solution level indicates that about 26% of sodium just passed through the ore bed. The remainder of the sodium (11%) likely exchanged with other cations on the ore. The increasing sodium levels in the product solution indicate that the amount of the sodium effectively used in the exchange for ammonium continually declines.

Ammonium solution profiles along the ore bed during restoration are shown in Figure 6.41. The results show that initially most of the ammonium exchange is occurring within the front section. Some exchange did occur in all sections, thus showing that ammonium equilibrium between the ore and solution had not been reached by the end of the front or middle sections. The greatest percentage of ammonium exchange shifts to the middle and end sections as the percentage of total ore ammonium remaining in the front section continually declines. The ammonium removal rate from a particular ore section also continually declines as the ammonium ore level decreases in that ore section. The results show that even after 408 hours, or 8.5 pore volumes, of restoration solution, ammonium removal was still occurring in the front section.

6.2.2.4 Leaching of Texas Ore Using Sulfuric Acid of pH = 1.0, Followed By 1.0 g/l NaHSO₃, Test 68

This test studied the effect of a reducing agent on chemical leakage following a sulfuric acid leach of Texas ore. Sodium bisulfite (pH = 3.4), was used instead of sodium sulfite (pH = 7.9), because the

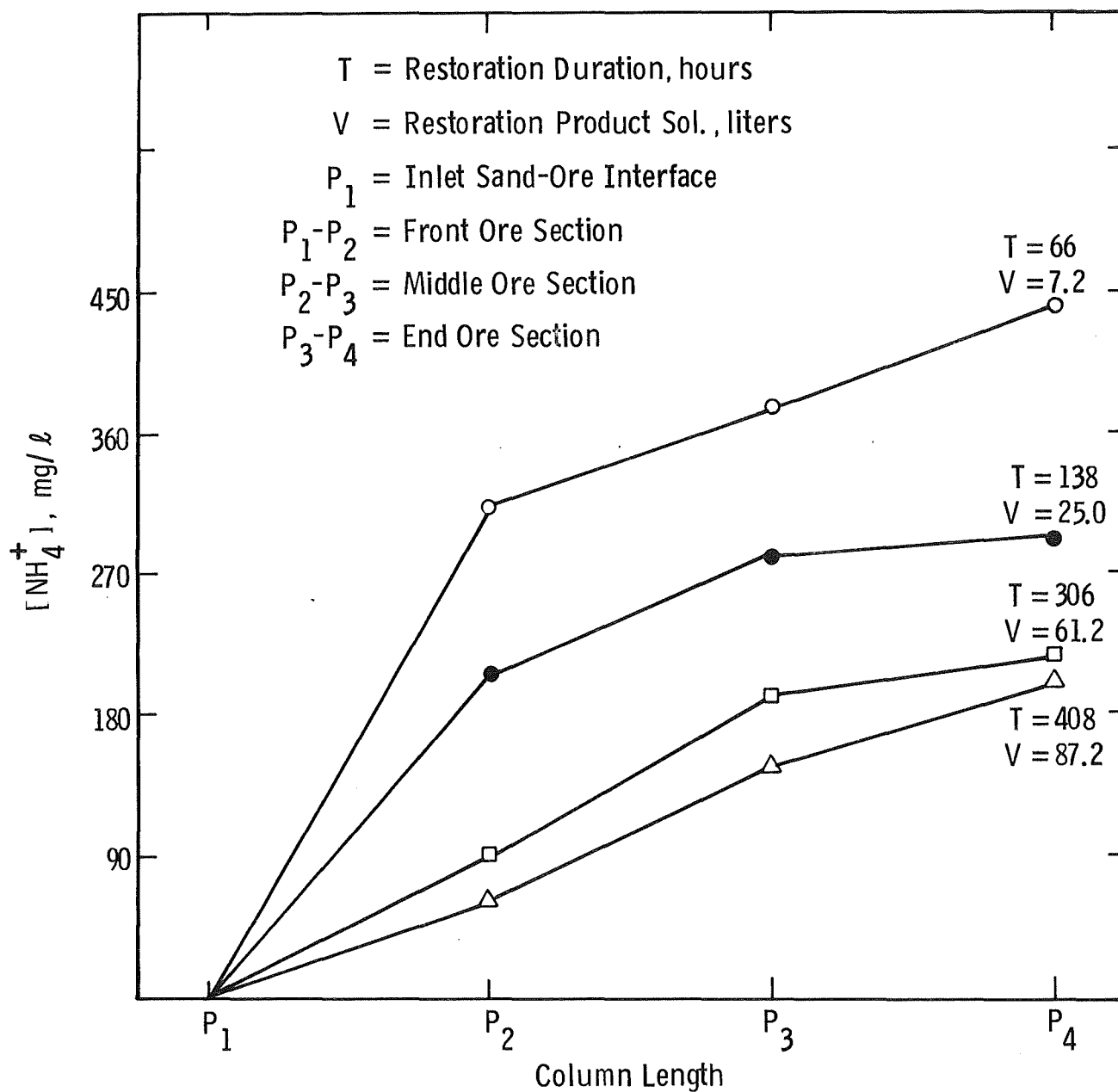


Fig. 6. 41—Ammonium solution concentration profiles along the length of the column during restoration of ammoniated Wyoming ore using 3.0 g/l NaHSO_3 , Test 80

pH was closer to that of the leach (pH = 1.0). It was thought that a dramatic change in pH could have an adverse effect on the ore bed (e.g., precipitation problems). The leakage into the groundwater following the reducing agent can be compared to that obtained with groundwater following an identical leach with no subsequent reducing agent (Test No. 64). The test ran for a total of 1631.0 hours, which included a 126.0-hour deionized water period, a 790.0-hour leach period, and a 715.0-hour post-leach flow period. The post-leach period had the following flow sequence: 119 hours of NaHSO_3 (pH = 3.4), 164 hours of NaHSO_3 (pH = 3.4) in reverse flow direction, 220 hours of NaHSO_3 (pH = 2) in original flow direction, and finally, 212 hours of simulated Texas groundwater.

The permeability variations observed in this test are shown in Figure 6.42. The 8-foot ore bed was divided into only two sections. At the end of the deionized water flow period the permeabilities of the front and end sections were 0.7 and 0.3 darcy, respectively. The permeability of the front section dropped to 0.02 darcy within 50 hours after acid injection. The permeability then showed a more gradual decline, reaching 0.004 darcy after about 600 hours of leach. The flow was then stopped for 72 hours. Upon restarting the leach, the permeability showed a very significant improvement. The front section permeability stayed at about 0.02 darcy for the last 120 hours of acid flow.

The permeability variations during the leach were typical of past acid tests on Texas ore (Test 64). The large initial decrease in permeability is believed to be caused by the release of carbon dioxide gas as the acid reacts with the carbonate in the ore. The more gradual decrease is possibly caused by chemical precipitation, ore dissolution, and particle movement. The increase in permeability following the stoppage in flow may have been due to the impact of restarting the flow causing ore particles to reorient themselves and pores to reopen.

Curve 720309-B

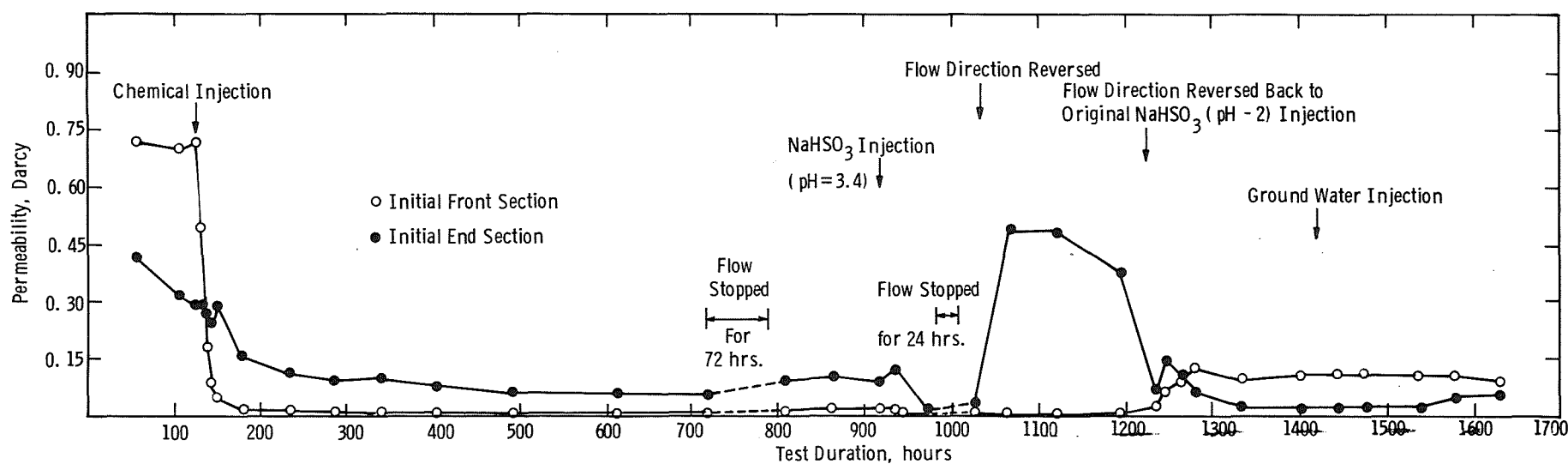


Fig.6.42 - Permeability variations experienced during leaching of Texas ore with H_2SO_4 of pH = 1.0, followed by 1.0 g/l $NaHSO_3$ then ground water, Test 68

The flow of the sodium bisulfite following the acid leach caused a rapid decrease in permeability in both sections of the ore bed. The front section dropped from 0.02 to 0.0008 darcy, while the end section fell from about 0.1 to 0.014 darcy. Stopping the flow for 24 hours and then restarting it caused only a slight increase in permeability as the front section rose to 0.0013 darcy, and the end section rose to about 0.03 darcy.

In an attempt to improve permeability, the flow direction through the column was reversed. The solution now entered the end section and left through the front section. Figure 6.42 shows that the permeability of the end section rose to about 0.5 darcy, while the front section went only to about 0.002 darcy.

The sodium bisulfite feed was then acidified with sulfuric acid to a pH of 2.0, and the flow was reversed back to its original direction. The acidified reducing agent caused an immediate improvement in the front section permeability. The permeability rose to and stabilized at about 0.11 darcy. It thus appears that the pH of the sodium bisulfite (pH = 1) caused the permeability problems. The acid leach was shown to mobilize large amounts of iron in Test 64. Precipitation of iron as ferric hydroxide will occur at a pH of about 3 or above.⁽²⁾ This gelatinous precipitate could have formed and blocked the ore bed during the initial bisulfite flow. By reducing the pH to 2, this precipitate likely dissolved, thus unblocking the ore bed and improving the permeability.

Also, sodium exchange onto the ore may have been a source of the permeability problems (e.g., clay swelling) at the higher pH. The decrease in pH, and thus the increase in hydrogen ions may have decreased this effect. That is, hydrogen ions, which have been shown to have a higher replacing power than sodium ions, could exchange with sodium on the ore and could prevent any further sodium exchange.⁽⁶⁾ The adverse effects of sodium on permeability may, therefore, have been reduced. During the final groundwater flow, no change in permeability occurred.

The chemical data collected during this test is presented in Table 6.23. The pH of the product was less than 1.5 after about 2 pore volumes of leach collected, less than 1.2 after about 3 pore volumes, and less than 1.1 after about 6 pore volumes. The sulfate and uranium variations are shown in Figure 6.43. The sulfate concentration rose rapidly after acid injection and remained at about 12-13 g/l for most of the leach. Upon acid injection, the uranium rapidly reached a peak of 366 mg/l, and then quickly declined.

The uranium recovery rate obtained during this test is shown in Figure 6.44. As has been typical of previous tests on Texas ore, there was a large percentage (50%) of the uranium removed during the deionized water flow period. In the first 3.5 pore volumes of actual chemical leach collected, 21% of the uranium was recovered. This is slightly better than the 19% recovered in the 3.6 pore volumes of acid leach on Texas ore in Test 64. The slower average flow rate obtained in this test (1.10 ml/min vs. 2.8 ml/min for Test 64) and thus the higher residence time may have resulted in the better initial recovery rate. The total recovery obtained in this test (71%) was similar to that obtained in the earlier test (72%).

The chemical leakage data obtained during the post-leach sodium bisulfite and groundwater flows is given in Table 6.24. The volume of solution collected during the flow of sodium bisulfite at pH = 3.4 was too small to allow a leakage comparison to be made with sodium bisulfite at pH = 2. During the bisulfite flows, the uranium dropped to less than 0.1 mg/l within 5 pore volumes. In a previous sulfuric acid test on Texas ore (Test 64), the uranium level in post-leach groundwater did not drop to less than 0.1 mg/l until after 10 pore volumes. The sodium bisulfite thus did cause a significant decrease in uranium leakage. The subsequent groundwater flow did cause an increase in the uranium level to slightly under 2 mg/l, however, the uranium dropped back down to less than 0.1 mg/l after about 4 pore volumes of the groundwater.

TABLE 6.23

Summary of Data Obtained During Leaching of Texas Ore Using H_2SO_4 of pH = 1.0,
Followed by 1.0 g/l NaHSO_3 , Test 68

Duration, Hrs	Product Solution Vol, l	Σ vol, l	Σ Ore Pore Volumes pH (1PV = 7.6 l)	pH	$\text{SO}_4^{=}$ mg/l	Uranium mg/l	% Uranium Recovery
75.0	21.9	21.9	2.9	2.70	4,500	411	49.3
126.0	25.4	47.3	6.2	3.11	2,000	9	50.5
216.0	14.3	61.6	8.1	3.43	1,100	3	50.8
335.0	8.9	70.5	9.3	1.45	9,000	366	68.6
455.0	6.7	77.2	10.2	1.18	--	--	--
575.0	5.5	82.7	10.9	1.16	12,500	36	71.0
719.0	5.1	87.8	11.6	1.15	--	--	--
887.0	8.9	96.7	12.7	1.11	--	--	--
916.0	3.0	99.7	13.1	1.09	12,000	18	71.3
1031.0	3.3	103.0	13.6	1.04	--	--	--
1199.0	4.7	107.7	14.2	1.46	7,000	3	71.4
1295.0	18.2	125.9	16.6	1.48	5,500	2	71.6
1419.0	18.2	144.1	19.0	1.81	2,000	< 0.1	71.6
1493.0	10.2	154.3	20.3	1.97	1,500	1.5	71.8
1559.0	10.3	164.6	21.7	2.15	1,300	1.9	71.9
1631.0	18.8	183.4	24.1	2.33	860	< 0.1	71.9

Times of Solution Injection: (1) H_2SO_4 - 126.0 hours

(2) NaHSO_3 (pH 3.4) - 916.0 hours, NaHSO_3 (pH = 2) - 1223.0 hours

(3) Ground H_2O - 1419.0 hours

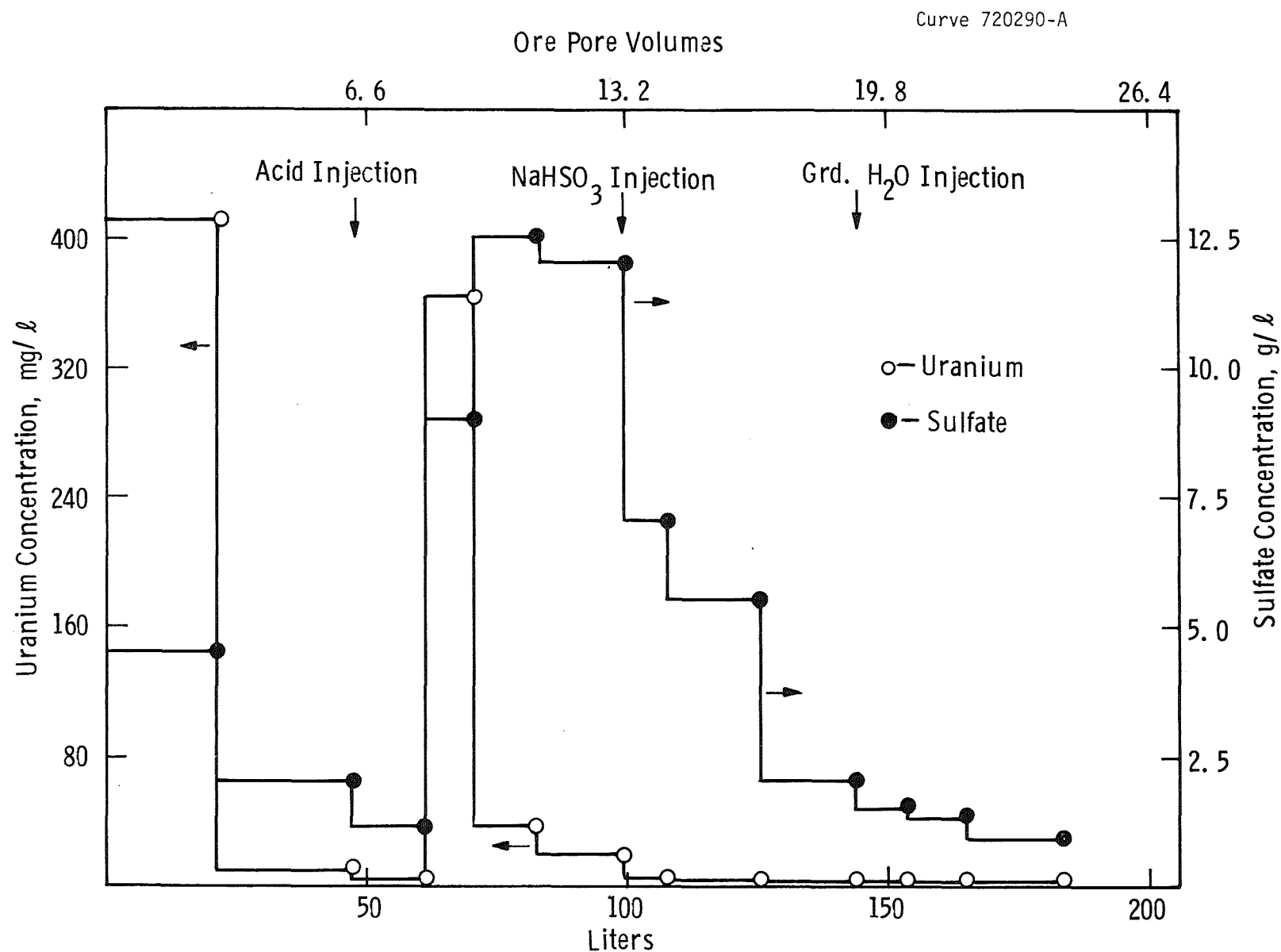


Fig. 6.43—Concentration variations experienced during leaching of Texas ore using H₂SO₄ of pH=1.0, followed by 1.0 g/l NaHSO₃, Test 68.

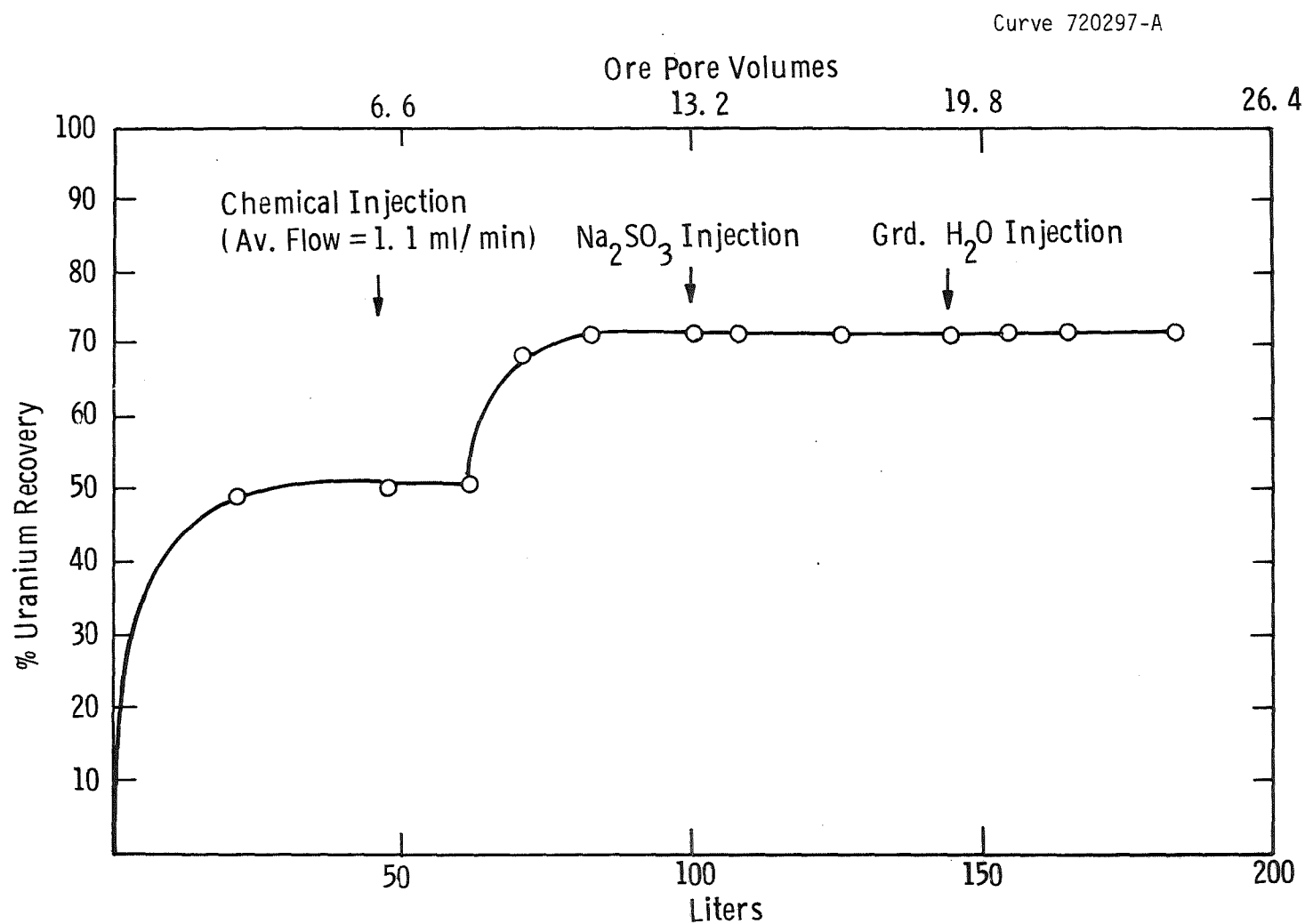


Fig. 6. 44—Uranium recovery rate observed during leaching of Texas ore using H₂SO₄ of pH = 1. 0, followed by 1. 0 g/l NaHSO₃, Test 68.

TABLE 6.24

Ion Leakage From Texas Ore Residue After Leaching With H_2SO_4 of pH = 1.0,
Test 68

Feed	Duration, hrs.	Vol., ℓ	ΣVol., ℓ	ΣOre Pore Volumes	pH	U mg/ℓ	SO_4 mg/ℓ	Fe mg/ℓ	As mg/ℓ	Se mg/ℓ
1.0g/ℓ NaHSO_3 (pH=3.4)	916.0	-	-	-	1.09	18	12,000	-	-	-
1.0g/ℓ NaHSO_3 (pH=2)	1199.0	8.0	8.0	1.1	1.29	3	7,000	46.4	0.019	0.003
	1295.0	18.2	26.2	3.4	1.48	2	5,500	320.0	1.6	0.25
Tex. Grd. H_2O	1419.0	18.2	44.4	5.8	1.81	<0.1	2,000	55.2	0.53	0.033
	1493.0	10.2	54.6	7.2	1.97	1.5	1,500	26.1	0.19	0.041
	1559.0	10.3	64.9	8.5	2.15	1.9	1,300	28.3	0.11	0.008
	1631.0	18.8	83.7	11.0	2.33	<0.1	860	32.2	0.056	0.003

The sulfate level steadily declined during the post-leach solution flows, reaching the background water level (1,100 mg/ℓ) after about 10 pore volumes of the solutions were collected. Iron, which showed groundwater leakage levels of about 150 mg/ℓ in the previously performed H_2SO_4 leach of Texas ore (Test 64), was less than 35 mg/ℓ in the groundwater following the sodium bisulfite.

After the injection of the sodium bisulfite, arsenic and selenium both initially increased, but then dropped relatively rapidly. After about 4 pore volumes of the subsequent groundwater, arsenic dropped to 56 ppb, which is just slightly above the EPA drinking standard of 50 ppb. The results indicate that with additional groundwater the arsenic would have likely reached that lower level. Selenium dropped to less than 5 ppb, which is below the EPA drinking standard of 10 ppb. In the previous H_2SO_4 leach of Texas ore, the selenium and arsenic leakage levels after about 4 pore volumes of post-leach groundwater were 140 ppb and 470 ppb, respectively. Thus, although the sodium bisulfite did seem to cause an initial increase in the leakage of these ions, its continued use did eventually result in a substantial drop in their leakage into post-leach groundwater.

6.2.2.5 Leaching of Wyoming Ore Using Sulfuric Acid of pH = 1.0, Followed By 2.0 g/ℓ NaHSO_3 and Groundwater, Test 71

This test was performed to examine the effect on chemical leakage of the reducing agent, sodium bisulfite, following a sulfuric acid leach of Wyoming ore. The results obtained here can be compared to a previous test (Test 69) which had shown what groundwater chemical leakage could be expected following an identical sulfuric acid leach using no post-leach reducing agent. Also, this reducing agent was tested at a lower concentration following a sulfuric acid leach of Texas ore (Test 68). Therefore, the effect of the reducing agent concentration could perhaps be determined. The test was run for a total of 1749.0 hours. This included, in sequence, 150.0 hours of deionized water, 504.0 hours of leach, 286.0 hours of NaHSO_3 (pH = 2), 212.0 hours of groundwater, 291.0 hours of sodium bisulfite (pH = 3.4), and

306.0 hours of groundwater. The sodium bisulfite was initially acidified to pH = 2 because previous work (Test 68) had indicated that the higher natural pH (3.4) of the reducing agent when used immediately following the sulfuric acid leach, could cause permeability problems.

The permeability variations experienced during this test are shown in Figure 6.45. At the conclusion of the deionized water flow period, the permeabilities of the front and end sections were 0.94 and 1.2 darcy, respectively. After 120 hours of leach, the front section had fallen to about 0.2 darcy. This section then had a more gradual decline, reaching a relatively stable 0.05 darcy by the conclusion of the leach. The end section dropped to about 0.4 darcy after 200 hours of leach and remained at approximately this level for the duration of the leach. These permeability changes were similar to those experienced in a previous sulfuric acid (pH = 1.0) leach of Wyoming ore (Test 69).

After sodium bisulfite injection at a pH of 2.0, the permeability of the front section dropped to about 0.03 darcy, while the end section remained at 0.4 darcy. The drop in the front section permeability was not nearly as severe as that which occurred when sodium bisulfite at a pH of 3.4 was injected into Texas ore immediately following a pH = 1.0 sulfuric acid leach (Test 68). In that test, the front section permeability dropped rapidly from 0.02 darcy to 0.0008 darcy. This large permeability decrease was attributed to iron precipitation, which can occur at a pH of 3 or above. It should be noted that higher amounts of iron (150 mg/l in post-leach groundwater) were mobilized during the acid leach of Texas ore than during acid leaching of Wyoming ore (30-40 mg/l in post-leach groundwater). Thus, iron precipitation problems would likely be less severe for the Wyoming ore. To minimize any iron precipitation effects, however, the lower pH NaHSO_3 should be used initially even with the Wyoming ore.

Following groundwater injection, the front section permeability dropped slightly to about 0.02 darcy, and the end section remained at

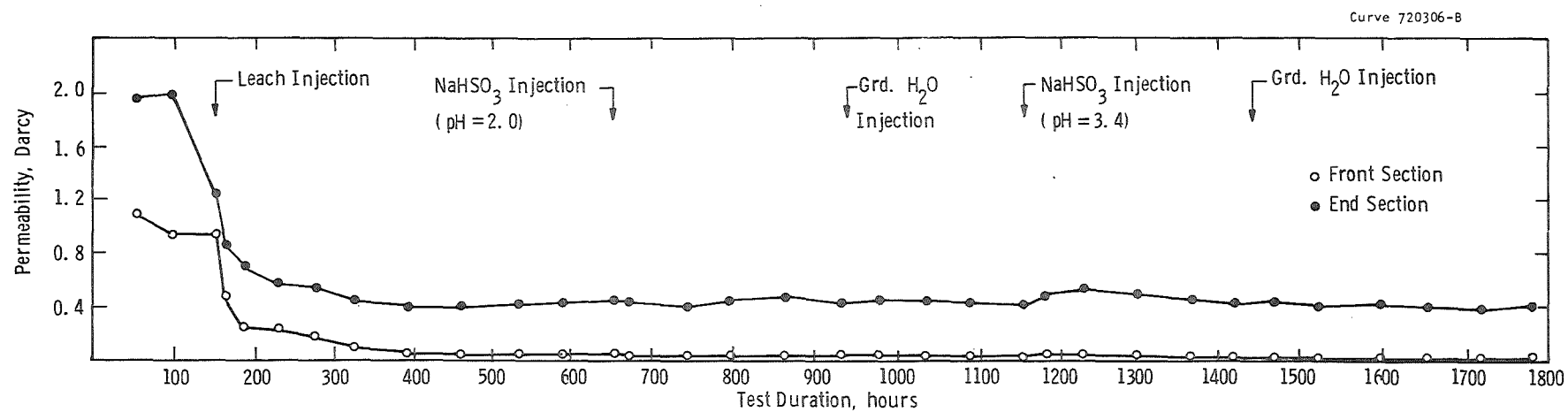


Fig. 6.45 - Permeability variations observed during leaching of Wyoming ore using H₂SO₄ of pH - 1.0, followed by 2.0 g/l NaHSO₃ and ground water, Test 71.

0.4 darcy. During the subsequent sodium bisulfite ($\text{pH} = 3.4$) flow, the front section stayed between 0.02 and 0.04 darcy, and the end section remained virtually unchanged. The final groundwater flow caused a gradual decrease in the front section permeability to 0.01 darcy. The decrease in permeability during the groundwater flows is believed to be caused by clay dissociation and dispersion which results from the low ionic strength of the water.

The chemical data collected during the various solution flows is given in Table 6.25. The pH variations were similar to previous H_2SO_4 ($\text{pH} = 1.0$) leaches of Wyoming ore (Test 69). The product pH was less than 1.3 within 7 pore volumes of leach and less than 1.1 within 23 pore volumes of leach. The uranium recovery, shown in Figure 6.46 was the same as that obtained previously with H_2SO_4 ($\text{pH} = 1.0$) leach of Wyoming ore (Test 69). In the first 6 pore volumes of actual leach collected, approximately 50% of the uranium was recovered. The uranium and sulfate concentration variations experienced during the test are shown in Figure 6.47. As has been true of past acid leach tests, the initial uranium variations followed the same trend as those of the sulfate.

The chemical leakage data obtained during the post-leach solution flows is given in Table 6.26. As was true of the baseline test (Test 69), uranium seemed to pose no problem, as it was less than 1 mg/l for all post-leach samples. Following the sodium bisulfite flow, sulfate dropped to the background groundwater level (190 mg/l) after about 5 pore volumes of groundwater. This was the same volume of groundwater required to obtain an acceptable sulfate level in the baseline test (Test 69). The sodium bisulfite thus did not lengthen the sulfate leakage. The sodium bisulfite did seem to significantly reduce iron and vanadium leakage. The iron dropped to about 10 mg/l after about 5 pore volumes of groundwater following the reducing agent. This was less than the 30 mg/l obtained after about 5 pore volumes of groundwater with no prior reducing agent (Test 69). The vanadium level was less than 1 mg/l within the first 2 pore volumes of the

TABLE 6.25

SUMMARY OF DATA OBTAINED DURING LEACHING OF WYOMING ORE USING
 H_2SO_4 of pH - 1.0, FOLLOWED by 2.0 g/l NaHSO_3 AND GROUND WATER, TEST 71

Duration, Hrs.	Product Solution Vol., l	Σ Vol. l	Σ Ore Pore Volumes (1 PV=6.6l)	pH	$\text{SO}_4^{=}$ mg/l	Uranium mg/l	% U Recovery
100.0	35.8	35.8	5.4	7.57	1720	187	19.4
150.0	24.7	60.5	9.2	7.48	40	17	20.6
198.0	22.9	83.4	12.6	2.68	1990	280	34.2
240.0	24.2	107.6	16.3	1.29	8400	450	70.8
312.0	32.6	140.2	21.2	1.19	---	---	---
384.0	34.0	174.2	26.4	1.15	9260	6.5	72.1
435.0	19.2	193.4	29.3	1.13	---	---	---
504.0	23.8	217.2	32.9	1.01	---	---	---
603.0	30.7	247.9	37.6	1.02	---	---	---
654.0	17.0	264.9	40.1	1.02	8980	2	72.6
744.0	19.4	284.3	43.1	1.65	5180	0.8	72.7
816.0	15.4	299.7	45.4	2.14	2370	0.6	72.7
940.0	22.4	322.1	48.8	2.11	2290	< 0.1	72.7
1008.0	13.2	335.3	50.8	2.78	1450	0.2	72.7
1062.0	10.2	345.5	52.3	3.03	215	< 0.1	72.7
1152.0	12.0	357.5	54.2	3.08	185	< 0.1	72.7
1230.0	17.9	375.4	56.9	2.27	---	---	---
1320.0	18.0	393.4	59.6	2.29	---	---	---

TABLE 6.25
(Continued)

Duration, Hrs.	Product Solution Vol., l	Σ Vol. l	Σ Ore Pore Volumes (1 PV=6.6l)	pH	$\text{SO}_4^{=}$ mg/l	Uranium mg/l	% U Recovery
1443.0	19.0	412.4	62.5	2.25	---	---	---
1518.0	11.6	424.3	64.3	2.19	---	---	---
1614.0	13.2	437.5	66.3	3.10	---	---	---
1749.0	15.9	453.4	68.7	3.28	---	---	---

- Times of Solution Injection:
- 1) H_2SO_4 -- 150 hours
 - 2) NaHSO_3 (pH - 2) -- 654 hours, NaHSO_3 (pH - 3.4) -- 1152.0 hours
 - 3) Grd. H_2O -- 940 hours, 1433.0 hours

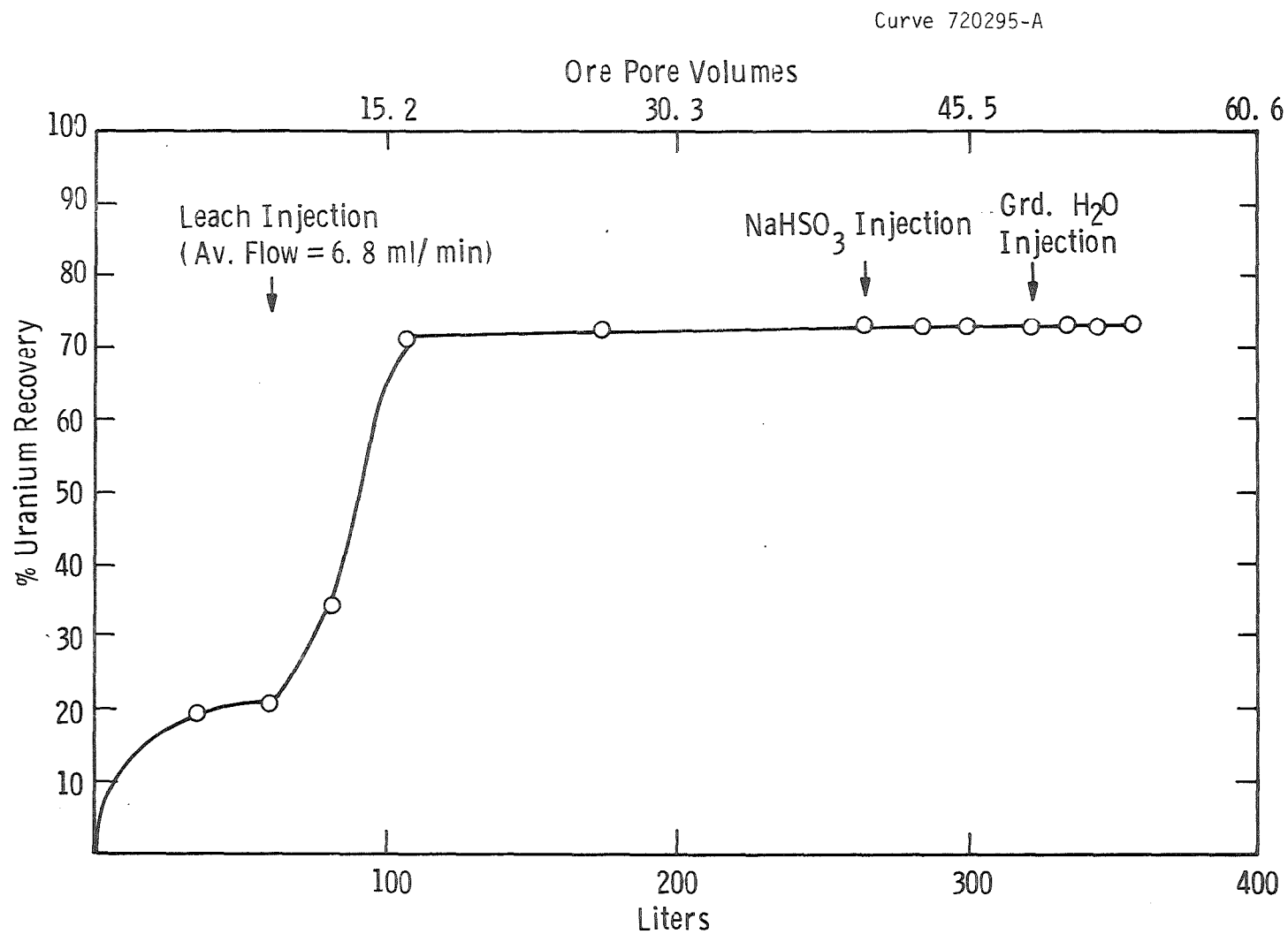


Fig. 6.46—Uranium recovery rate observed during leaching of Wyoming ore using H_2SO_4 of pH = 1.0, followed by 2.0 g/l NaHSO_3 and ground water, Test 71.

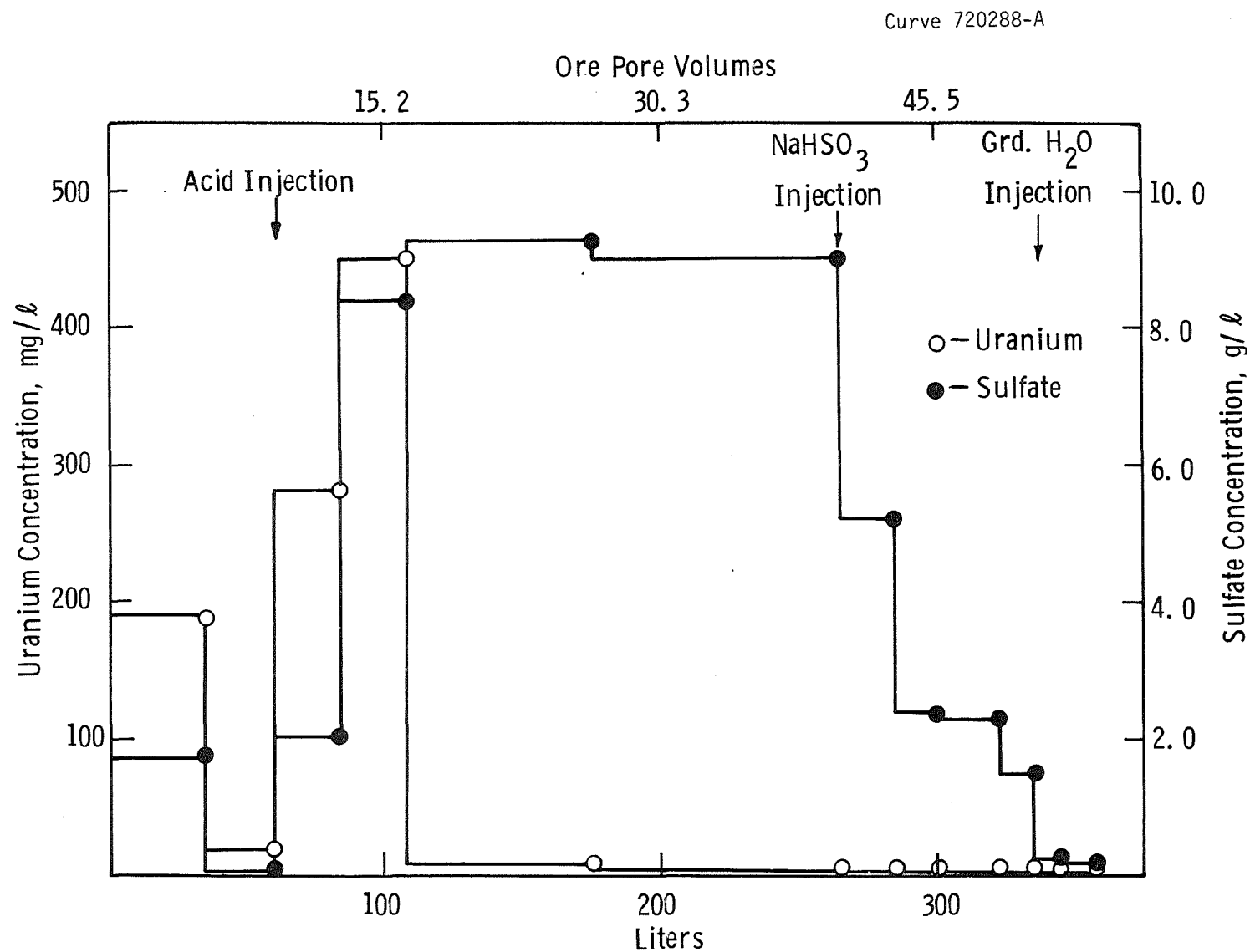


Fig. 6.47 – Concentration variations experienced during leaching of Wyoming ore using H_2SO_4 of pH = 1.0, followed by 2.0 g/l NaHSO_3 and ground water, Test 71.

TABLE 6.26

ION LEAKAGE FROM WYOMING ORE
LEACHED WITH H_2SO_4 of pH = 1.0, TEST 71

Feed	Duration, Hrs.	Vol., ℓ	Σ Vol., ℓ	Σ Ore Pore Volumes	pH	U mg/ℓ	$\text{SO}_4^{=}$ mg/ℓ	Fe mg/ℓ	V mg/ℓ
2.0 g/ NaHSO_3 (pH-2)	654.0	---	---	---	1.02	---	---	---	---
	744.0	19.4	19.4	2.9	1.65	0.8	5180	125	< 1
	816.0	15.4	34.8	5.3	2.14	0.6	2370	88	< 1
Wyo. Grd. H_2O	940.0	22.4	57.2	8.7	2.11	< 0.1	2290	91	< 1
	1008.0	13.2	70.4	10.7	2.78	0.2	1450	74	< 1
	1062.0	10.2	80.6	12.2	3.03	< 0.1	215	9.8	< 1
	1152.0	12.0	92.6	14.0	3.08	< 0.1	185	10	< 1

reducing agent, and stayed at this low level for the remainder of the post-leach solution flows. This is much lower than the vanadium levels obtained with groundwater when no reducing agent was used (Test 69). In that test, the initial vanadium post-leach leakage was as high as 1000 mg/l.

6.2.3 Ammonium Blocking and Ore Stabilizing Agents

This set of tests was designed to examine the use of certain chemical agents during and/or prior to leaching with ammonium bicarbonate. It was hoped that certain chemicals would stabilize ore beds during leaching, thus preventing permeability damage. Improved permeability would result in lower pumping or injection requirements, and hopefully in improved uranium accessibility and thus improved recovery. These same, and other, chemicals were also examined for their effect on ammonium sorption during leaching. A significant reduction in the sorption level would lower the post-leach leakage of the ammonium.

6.2.3.1 Leaching of Wyoming Ore With 1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2 , Preceded by 3.0 g/l AlCl_3 , Test 77

This test was designed to determine the effect of using aluminum chloride prior to leaching. A column test (Test 74) had shown that post-leach aluminum chloride stabilized an ore bed and greatly improved permeability (see Section 6.2.4.1). Also in that test, the trivalent aluminum cation rapidly removed ammonium from the ore. Thus, it was thought that a pretreatment of aluminum might stabilize the bed for the subsequent leach and perhaps prevent or reduce ammonium sorption. The high charge density aluminum will likely be readily exchanged onto the ore but will not be easily displaced by ammonium during leach. This test was also to have a post-leach groundwater flow to examine ion leakage. Just prior to starting the groundwater flow, however, the front column section broke. The cause of the breakage was not known. The pressure had just begun to build up in that section, and perhaps this glass piece had been weakened (e.g., scratched) from use in previous tests and could not withstand the increase in pressure.

The test ran for a total of 1081.0 hours. This included, in sequence, the following flows: 186.0 hours of deionized water, 144.0 hours of aluminum chloride and 751.0 hours of ammonium bicarbonate and peroxide.

The permeability changes observed during this test are shown in Figure 6.48. During the deionized water flow, the permeability of the ore sections were typical of previous tests. Upon the injection of aluminum chloride, however, and during the subsequent ammonium bicarbonate leach, there were some unique permeability variations. During the aluminum chloride flow, the front section permeability stayed between 0.9 and 1.0 darcy, the middle section dropped from 1.0 to about 0.7 darcy and the end section remained greater than 3.0 darcy. The front section permeability being greater than the middle section was atypical. With the injection of ammonium bicarbonate, the front section permeability did drop to slightly below that of the middle section. The permeabilities, however, in both sections were nearly equal.

The front section permeability dropped to about 0.3 darcy after 120 hours of ammonium bicarbonate leach, to 0.25 darcy after 300 hours of leach, and to 0.2 darcy by the conclusion of the leach. This permeability was significantly greater than that obtained in a previous 1.0 g/l ammonium bicarbonate - 0.5 g/l peroxide leach (Test 35), where no aluminum chloride pretreatment was used.⁽³⁾ The front section permeability in that test was about 0.03 darcy after only 120 hours of leach. The large decrease in permeability experienced in that test is attributed to oxygen blockage resulting from the rapid decomposition of peroxide, and to clay dissociation and dispersion. The aluminum chloride pretreatment must therefore have stabilized the bed and/or greatly reduced gas blockage. Post-leach use of aluminum chloride (Test 69) had also indicated that this agent improves permeability.

The chemical data collected during this test is given in Table 6.27. The data shows that pH initially declined during the ammonium bicarbonate

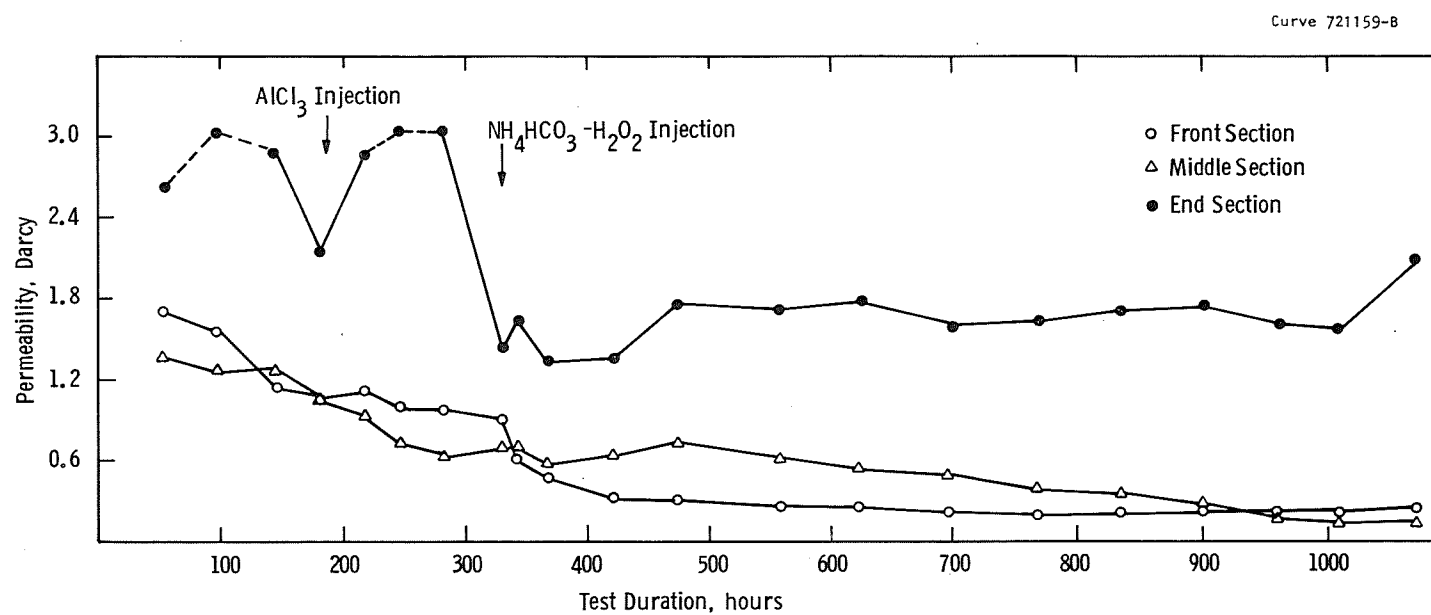


Fig. 6.48 — Permeability variations experienced during leaching of Wyoming ore with 1.0 g/l NH₄HCO₃ - 0.5 g/l H₂O₂, preceded by 3.0 g/l AlCl₃, Test 77

TABLE 6.27

Summary of Data Obtained During Leaching of Wyoming Ore
 With 1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2 , Preceded by 3.0 g/l AlCl_3 , Test 77

Duration, Hrs.	Product Solution Vol., l	Σ Vol., l	Σ Ore Pore Volumes (1 PV=9.8l)	pH	Al^{3+} mg/l	Cl^- mg/l	NH_4^+ mg/l	HCO_3^- mg/l	Uranium mg/l	% U Recovery
120.0	41.8	41.8	4.3	6.27	--	--	--	--	247	21.4
186.0	35.0	76.8	7.8	7.45	--	--	--	--	24	23.1
237.0	17.4	94.2	9.6	7.42	--	--	--	60	9.6	23.5
282.0	12.2	106.4	10.9	6.64	--	--	--	650	353	32.4
330.0	13.9	120.3	12.3	6.33	--	--	--	480	156	36.9
384.0	25.1	145.4	14.8	6.40	< 2	1000	2	430	67	40.3
450.0	31.5	176.9	18.1	6.40	< 2	--	< 2	480	72	45.0
504.0	27.6	204.5	20.9	6.48	< 2	< 1	< 2	--	--	--
573.0	36.7	241.2	24.6	6.44	< 2	< 1	< 2	340	26	48.5
642.0	36.6	277.8	28.3	6.28	--	--	9	240	8.0	49.1
714.0	35.3	313.1	31.9	6.50	--	--	11	340	76	54.7
787.0	33.0	346.1	35.3	7.30	--	--	35	620	57	58.6
859.0	35.4	381.5	38.9	7.51	--	--	--	--	--	--
955.0	40.4	421.9	43.1	7.71	--	--	106	610	19	61.5
1051.0	43.7	465.6	47.5	7.83	--	--	--	--	--	--
1081.7	15.4	481.0	49.1	8.13	--	--	160	710	10	62.8

Times of Solution Injection: 1) AlCl_3 - 186.0 hours.

2) NH_4HCO_3 - H_2O_2 - 330.0 hours.

flow. The data also shows that there is very little aluminum and chloride leakage after the pretreatment. The uranium, bicarbonate, and ammonium variations are shown in Figure 6.49, and the uranium recovery curve is shown in Figure 6.50. During the aluminum chloride flow, a substantial amount of uranium was leached. The high bicarbonate concentration resulting during the aluminum flow, and the presence of chloride (i.e., uranyl chloride is very soluble) are likely responsible for the observed uranium recovery.

Injection of ammonium bicarbonate caused an initial decrease in uranium recovery which coincided with a drop in bicarbonate concentration. This drop in bicarbonate was possibly due to the ammonium bicarbonate coming into contact with the acidic aluminum chloride remaining in the ore bed. Under acidic conditions, bicarbonate will form carbon dioxide and water. As the ammonium leach continued, the bicarbonate level built up and uranium recovery improved.

During the entire test, only about 63% of the uranium was recovered, compared to a 72% recovery obtained in a typical ammonium bicarbonate leach test (e.g., Test 62). This reduced recovery is possibly the result of the aluminum chloride pretreatment. The significant drop in the bicarbonate level (< 250 mg/l) was likely, in part, responsible for the reduced recovery. Perhaps, the aluminum chloride also reduced the uranium leaching by coating the ore and thus making the uranium less accessible. A lower concentration of the aluminum chloride (1.0 to 2.0 g/l) may stabilize the bed without adversely affecting uranium recovery.

The purpose of the aluminum chloride pretreatment was also to hopefully reduce ammonium sorption during subsequent leach. Chemical analysis of the product solutions indicates that in the 36.8 pore volumes (360.7 liters) of ammonium bicarbonate leach, 51.4 g of ammonium was sorbed. This ammonium level (0.058 mg of NH_4^+ /g of ore) was approximately the same as that obtained with a 1.0 g/l ammonium bicarbonate leach using no aluminum chloride pretreatment (Test 62). The aluminum chloride thus did not seem to reduce ammonium sorption.

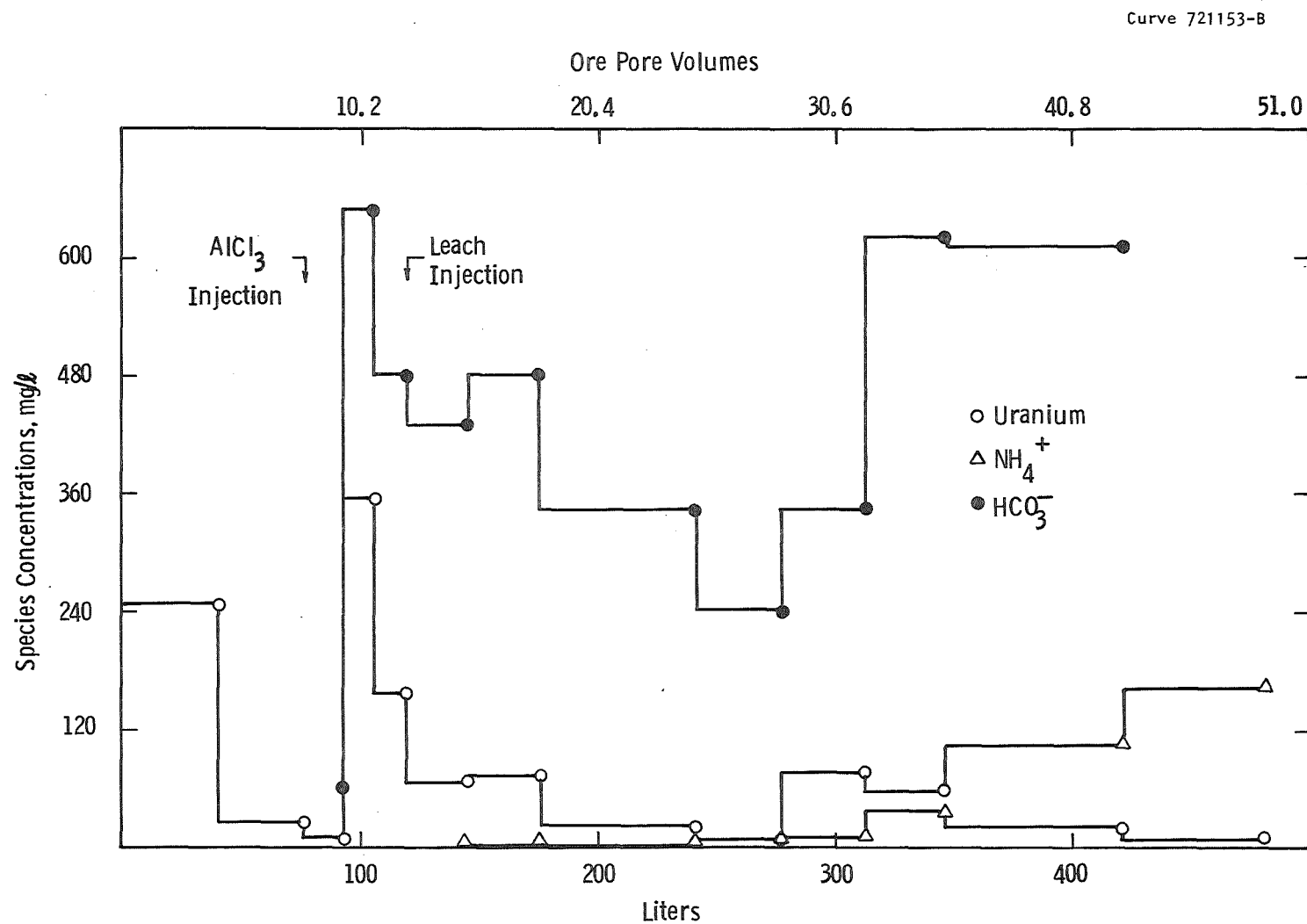


Fig. 6. 49— Concentration variations obtained during leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2 , preceded by 3.0 g/l AlCl_3 , Test 77

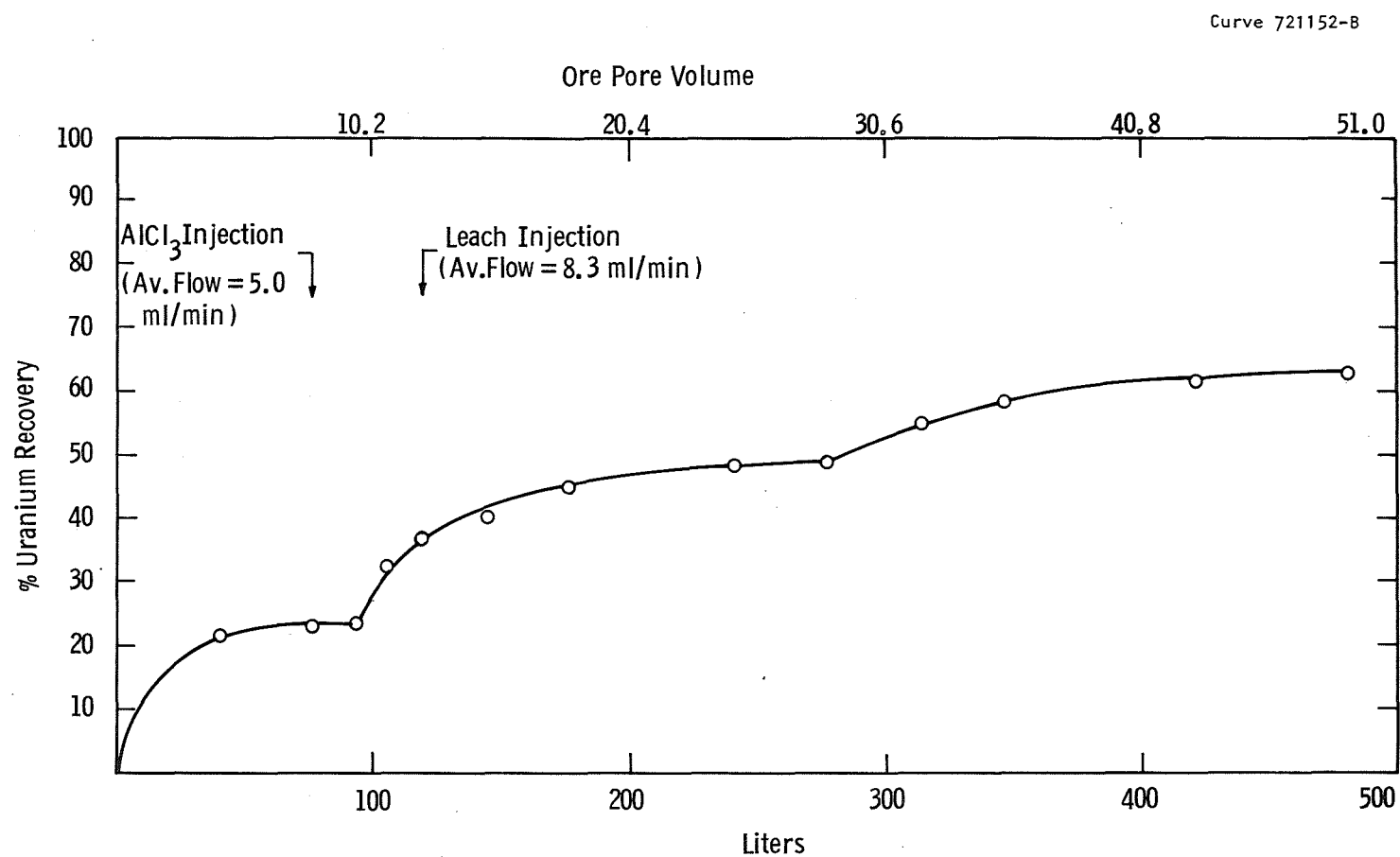


Fig. 6. 50—Uranium recovery rate observed during leaching of Wyoming ore using $1.0 \text{ g/l } \text{NH}_4\text{HCO}_3 - 0.5 \text{ g/l } \text{H}_2\text{O}_2$, preceded by $3.0 \text{ g/l } \text{AlCl}_3$, Test 77

6.2.3.2 Leaching of Wyoming Ore Using 1.0 g/l NH_4HCO_3 - 1.0 g/l Na_2SiO_3 - 0.5 g/l H_2O_2 , Followed by 2.0 g/l NaHSO_3 and Groundwater, Test 73

This test was designed to study the effect of sodium silicate on leaching. An earlier study had indicated that sodium silicate helps to prevent permeability loss and to stabilize peroxide against decomposition.⁽⁹⁾ This test also examined the effect of 2.0 g/l sodium bisulfite on post-leach chemical leakage. This test was run for a total of 1440.0 hours, including 150.0 hours of deionized water, 762.0 hours of leach, and 528.0 hours of post-leach solutions. The post-leach solution flow sequence was as follows: 96.0 hours of groundwater, 198.0 hours of sodium bisulfite, and 234.0 hours of groundwater.

The permeability changes observed during the test are shown in Figure 6.51. At the conclusion of the deionized water flow period, the permeabilities of the front, middle and end sections were approximately 1.0, 0.8, and 0.9 darcy, respectively. Within 120 hours after chemical injection, the permeability of the front section had dropped to only about 0.45 darcy. The middle and end sections were both at about 0.40 darcy. After 300 hours of leach, the front, middle, and end sections had permeabilities of approximately 0.25, 0.25, and 0.30 darcy, respectively. After about 400 hours of leach, the front section permeability began to drop below that of the other sections. At the conclusion of the leach, the permeabilities of the front, middle, and end sections were 0.09, 0.13, and 0.23, respectively.

Unlike previous leaches, the front section permeability did not have the rapid dramatic decline following leach injection, nor was it greatly lower than the other sections. In a previously formed 1.0 g/l ammonium bicarbonate - 0.5 g/l peroxide leach with no sodium silicate (Test 35),⁽³⁾ the front section permeability dropped from 1.6 to 0.03 darcy after 120 hours of leaching, while the middle and end sections remained around 1.0 and 2.0 darcy, respectively. Thus, the sodium silicate did reduce substantially permeability damage. It is speculated that the sodium silicate may have accomplished this in any of several ways. First, it may have

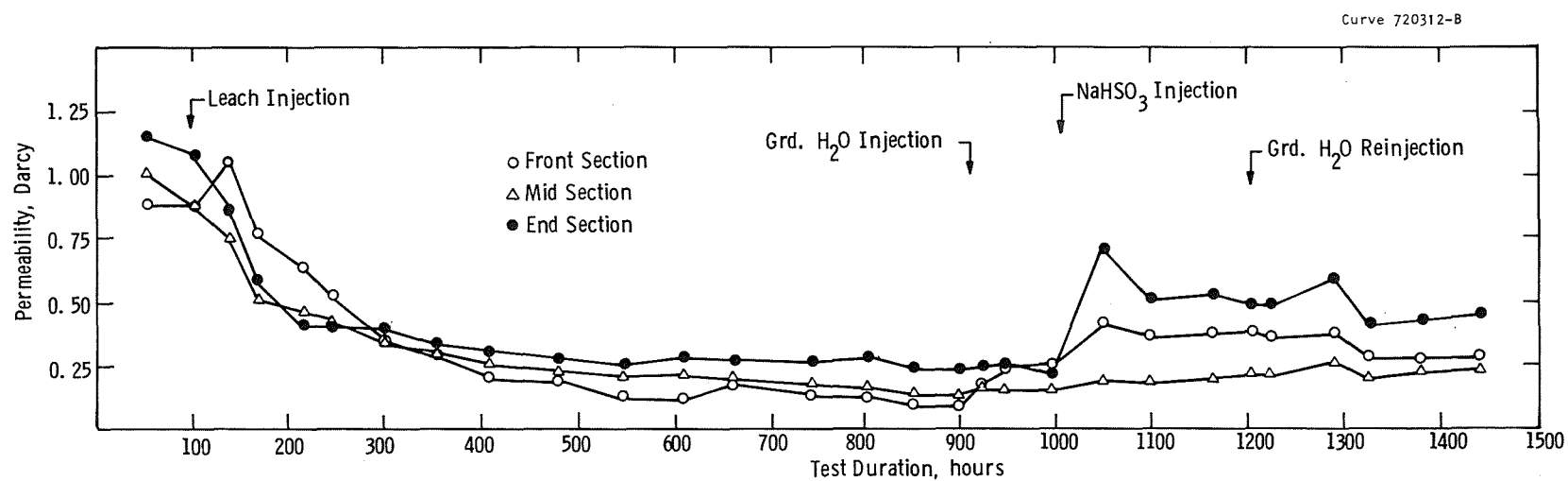


Fig. 6.51— Permeability variations experienced during leaching of Wyoming ore with 1.0 g/l NH_4HCO_3 - 1.0 g/l Na_2SiO_3 - 0.5 g/l H_2O_2 , followed by ground water and 2.0 g/l NaHSO_3 , Test 73.

greatly stabilized the peroxide, thus preventing rapid decomposition and oxygen gas blockage of the ore bed. The results of agitation leach tests, however, given in Table 6.28, indicate that the sodium silicate does not reduce peroxide decomposition in the absence of ore, and may only slightly reduce the decomposition rate in the presence of ore. Even at the reduced decomposition rate, a large excess of oxygen would be produced and oxygen blockage would likely result. Another possibility is that the sodium silicate prevents the dispersion and dissociation of fines thus stabilizing the ore bed. In this same respect, perhaps the sodium silicate coats the ore⁽¹²⁾ and acts as a drag reducer. Oxygen gas released in the ore bed would therefore be more easily displaced from the ore by the solution due to the reduced tension between the gas bubbles and the ore. The release of oxygen from solution would therefore no longer be as serious a problem.

Upon the injection of groundwater immediately following chemical leach, the permeability of the front section rose to 0.25 darcy. The front section permeability again improved (0.38 darcy) following the injection of sodium bisulfite. The improvement in permeability during these solution flows indicates that perhaps some oxygen gas blockage did occur during leach. These solutions would redissolve oxygen gas remaining in the ore bed, which would account for the improved permeability. During the final groundwater flow, the front permeability showed a gradual decline, reaching a final level of about 0.28 darcy. The permeability during these post-leach solution flows was significantly better than that obtained with similar solutions in previous tests (Tests 62 and 67). In those tests, clay dissociation and dispersion were thought to be the causes of the permeability damage that occurred during the post-leach solution flows. The substantially better permeability obtained here indicates that the sodium silicate likely does stabilize the clay (fines) fraction of the ore.

The chemical data obtained during this test is listed in Table 6.29. The product leach solution pH's (pH = 6.8 to 9.0) were much higher than

TABLE 6.28

Na₂SiO₃ STABILIZATION OF H₂O₂

Test No.	Test Conditions*		H ₂ O ₂ Concentration, mg/l		
	[Na ₂ SiO ₃] mg/l	Wyo. Ore g	2 Hrs.	6 Hrs.	24 Hrs.
1	1.0	0	0.57	0.54	0.27
2	0	0	0.62	0.54	0.27
3	1.0	100	0.35	0.07	0.009
4	0	100	0.29	0.04	0.003

* Each 300 ml test solution also contained 1.0 g/l NH₄HCO₃ +
 ~ 0.5 g/l H₂O₂.

TABLE 6.29

SUMMARY OF DATA OBTAINED DURING LEACHING OF WYOMING ORE USING
 1.0 g/l NH_4HCO_3 - 1.0 g/l Na_2SiO_3 - 0.5 g/l H_2O_2 ,
 FOLLOWED BY 2.0 g/l NaHSO_3 AND GROUND H_2O , TEST 73

Duration, Hrs.	Product Solution Vol., l	Σ Vol., l	Σ Ore Pore Volumes (1 PV=9.5l)	pH	HCO_3^- mg/l	NH_4^+ mg/l	Uranium mg/l	% U Recovery
72.0	29.0	29.0	3.1	6.31	580	---	282	16.4
150.0	46.8	75.8	8.0	7.24	160	---	39	20.0
195.0	22.6	98.4	10.4	7.12	320	---	126	25.7
246.0	27.0	125.4	13.2	6.82	540	---	188	35.9
294.0	29.4	154.8	16.3	7.17	---	---	---	---
342.0	29.9	184.7	19.4	7.70	570	4	98	47.5
408.0	41.7	226.4	23.8	8.60	---	24	---	---
462.0	31.2	257.6	27.1	8.93	---	76	---	---
532.0	35.9	293.5	30.9	9.03	810	106	13	50.4
600.0	28.6	322.1	33.9	9.05	---	---	---	---
654.0	26.9	349.0	36.7	9.01	---	130	---	---
699.0	20.1	369.1	38.9	9.05	940	---	6	51.3
768.0	28.0	397.1	41.8	9.03	---	137	---	---
840.0	26.8	423.9	44.6	8.89	---	---	---	---
912.0	22.3	446.2	47.0	8.92	970	147	4.5	52.0
936.0	10.5	456.7	48.1	8.91	920	145	2.8	52.0

TABLE 6.29
(Continued)

Duration, Hrs.	Product Solution Vol., l	Σ Vol., l	Σ Ore Pore Volumes (1 PV=9.5l)	pH	HCO_3^- mg/l	NH_4^+ mg/l	Uranium mg/l	% U Recovery
966.0	14.0	470.7	49.5	8.95	460	160	0.6	52.0
1008.0	18.6	489.3	51.5	8.86	560	146	2.7	52.1
1034.0	16.9	506.2	53.3	8.69	590	204	2	52.2
1106.0	22.0	528.2	55.6	8.23	930	265	8.3	52.6
1158.0	15.9	544.1	57.3	7.81	810	254	9.9	52.9
1206.0	19.5	563.6	59.3	7.50	930	287	12.5	53.4
1278.0	11.3	574.9	60.5	7.70	---	---	---	---
1326.0	11.7	586.6	61.7	7.89	---	---	---	---
1440.0	22.4	609.0	64.1	8.17	---	---	---	---

Times of Solution Injection: 1) NH_4HCO_3 - Na_2SiO_3 - H_2O_2 -- 150 hours
 2) Grd. H_2O -- 912 hours, 1206 hours
 3) NaHSO_3 -- 1008 hours

those obtained in previous ammonium bicarbonate leaches (pH = 7 to 8.2). The 1.0 g/l sodium silicate (pH = 10.5) increases and maintains a high leach solution pH. The uranium recovery data is shown graphically in Figure 6.52. In the first 10 pore volumes of actual leach collected, only 27% of the uranium was recovered. This is significantly less than the 32% recovery obtained with 10 pore volumes of ammonium bicarbonate leach using no sodium silicate (Test 62). The total recovery by the conclusion of the leach (37.9 leach pore volumes) in this test was only 52%, which is much less than the 68% recovery obtained with essentially the same number of leach pore volumes in Test No. 62. The uranium recovery was lower even though the permeability was significantly better in this test. This is again an indication that sodium silicate may coat the ore. It seems to prevent the leach solution from contacting some of the normally accessible uranium. Also, the silicate may have lowered the uranium recovery by forming a precipitate with some of the solubilized uranium.⁽¹³⁾ In addition, the high pH of this solution (> 9) can cause precipitation of the uranyl carbonate.⁽²⁰⁾ It may be desirable to use just an initial short duration of sodium silicate during leaching. This could stabilize the ore without significantly reducing uranium recovery.

The uranium, bicarbonate, and ammonium concentration variations experienced during the test are shown in Figure 6.53. The uranium and bicarbonate followed the same trends typical of previous alkaline leaches. However, the actual uranium concentrations were lower and the bicarbonate concentrations were higher than the previous tests. The bicarbonate level went above 900 mg/l, while feed concentration was only about 775 mg/l.

The ammonium concentration remained below 5 mg/l for approximately the first 100 liters of leach. This is similar to previous ammonium bicarbonate leach tests. The ammonium concentration then gradually increased reaching a final value of about 150 mg/l, which is less than the feed level of 220 mg/l. Based on the ammonium concentration

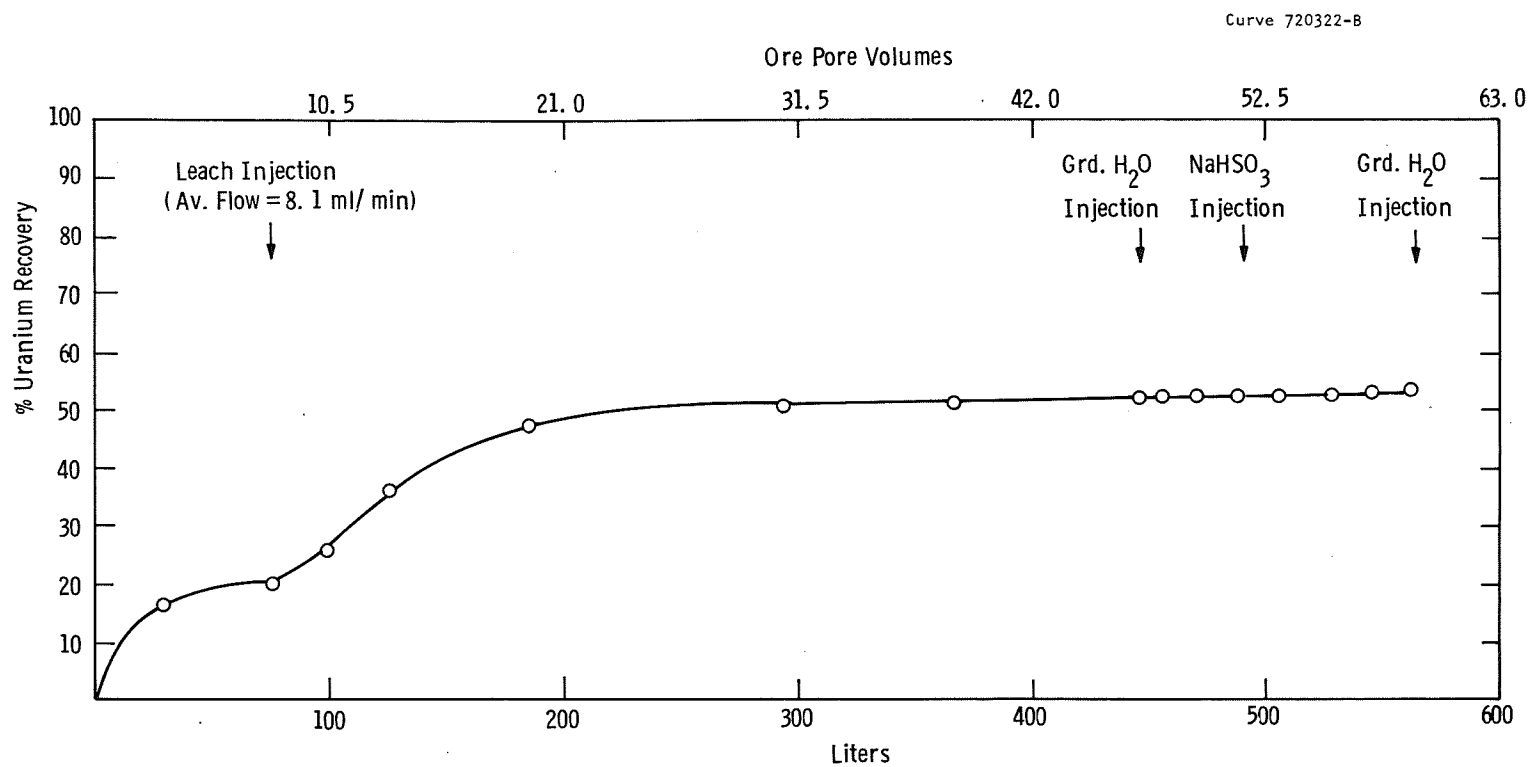


Fig. 6. 52 - Uranium recovery rate observed during leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 - 1.0 g/l Na_2SiO_3 - 0.5 g/l H_2O_2 , followed by 2.0 g/l NaHSO_3 and ground H_2O , Test 73.

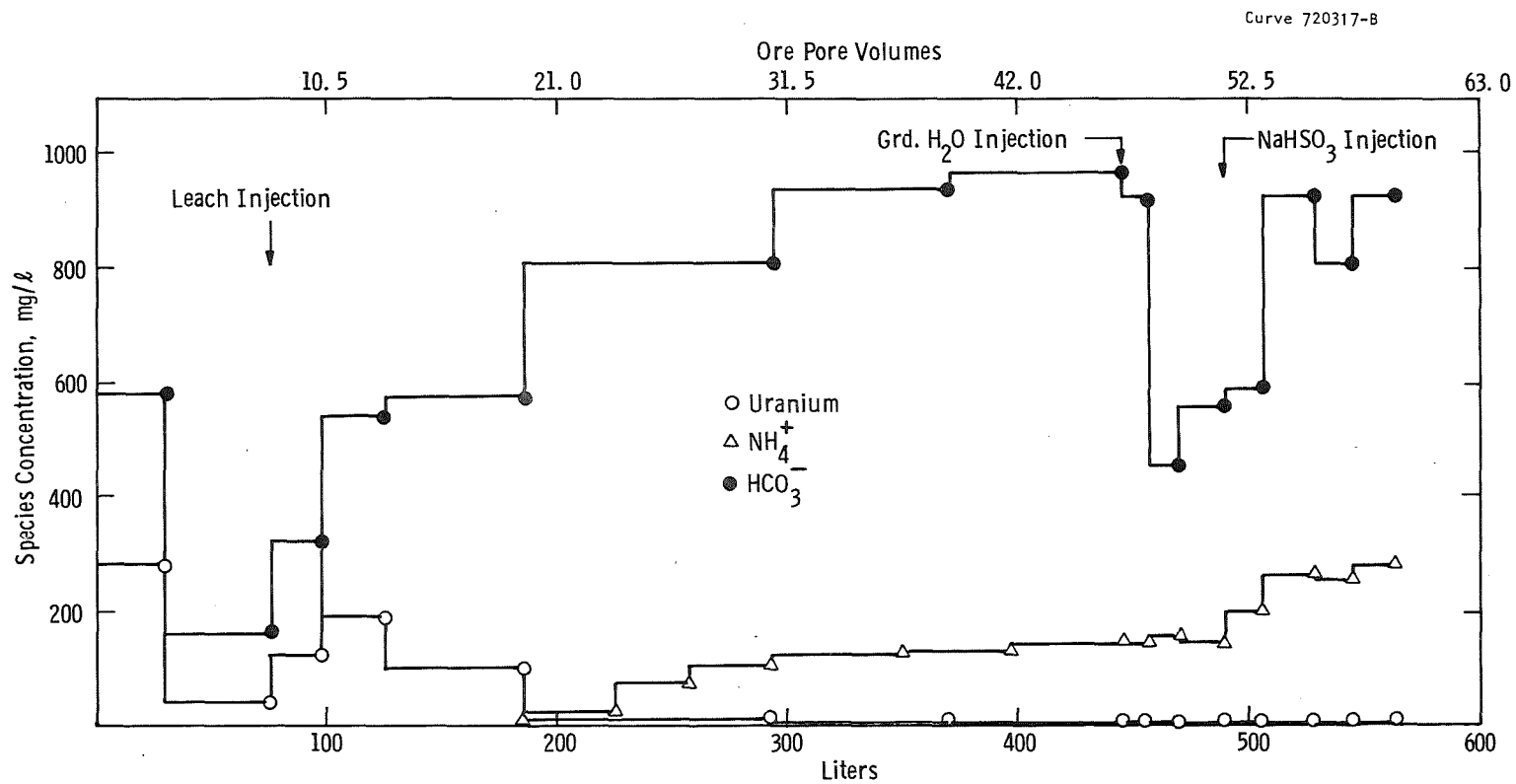


Fig. 6.53 - Concentration variations experienced during leaching of Wyoming ore with 1.0 g/L NH₄HCO₃ - 1.0 g/L Na₂SiO₃ - 0.5 g/L H₂O₂, followed by 2.0 g/L NaHSO₃ and ground water, Test 73.

differences between the feed and products, a total of 52.1 g of ammonium (or 0.058 meq of NH_4^+ /g of ore) was sorbed during leaching. This is slightly more than that which has typically been found to be sorbed during 1.0 g/l ammonium bicarbonate leaching (e.g., Test 62--0.056 meq of NH_4^+ /g of ore). Ammonium analyses on the post-leach ore showed that the average level was 0.37 mg of ammonium/g of ore. This compares favorably with the ammonium ore level indicated by the ammonium solution levels during leach and post-leach; 0.36 mg/g of ore. It is thus likely that ammonium sorption was slightly higher than normal during leaching in this test.

The post-leach ion leakage data obtained during the test is given in Table 6.30. Within the first 2 pore volumes of post-leach groundwater flow, the uranium was less than 1 mg/l and the selenium was only about 30 ppb. These concentrations were significantly less than the uranium ($\sim$ 15 mg/l) and selenium ($\sim$ 150 ppb) leakage levels into groundwater following an ammonium bicarbonate leach with no sodium silicate (Test 62). This thus indicates that sodium silicate may be an effective post-leach restoration solution.

Unlike previous tests using a post-leach reducing agent, the uranium concentration increased during the subsequent sodium bisulfite flow. Perhaps the acidic nature of the reducing agent, along with the formation of sulfate during its flow, increased the leachability of the uranium. That is, the blocking ability of sodium silicate, which seemed to significantly reduce the uranium recovery during leaching, was broken down by the sodium bisulfite. Uranium that would have normally been leached if no sodium silicate was used, was now able to come into solution. However, the uranium concentration does again drop when the groundwater is reinjected. It should be noted that the effectiveness of sodium bisulfite cannot be reasonably determined because of significant differences between the leach portion of this test and the baseline test (Test 62).

TABLE 6.30

ION LEAKAGE FROM WYOMING ORE RESIDUE AFTER LEACHING
 WITH $1.0 \text{ g/l NH}_4\text{HCO}_3$ - $1.0 \text{ g/l Na}_2\text{SiO}_3$ - $0.5 \text{ g/l H}_2\text{O}_2$, TEST 73

Feed	Duration, Hrs.	Vol., ℓ	Σ Vol., ℓ	Σ Ore Pore Volumes	pH	U mg/ℓ	HCO ₃ mg/ℓ	NH ₄ ⁺ mg/ℓ	Se mg/ℓ
Wyo. Grd. H ₂ O	912.0	--	--	--	8.92	4.5	970	147	--
	936.0	10.5	10.5	1.1	8.91	2.8	920	145	0.07
	966.0	14.0	24.5	2.6	8.95	0.6	460	160	0.05
2.0 g/ℓ NaHSO ₃	1008.0	18.6	43.1	4.5	8.86	2.7	560	146	0.03
	1034.0	16.9	60.0	6.3	8.69	2.0	590	204	--
	1106.0	22.0	82.0	8.6	8.23	8.3	--	265	--
	1158.0	15.9	97.9	10.3	7.81	9.9	--	254	--
Wyo. Grd. H ₂ O	1206.0	19.5	117.4	12.4	7.50	12.5	--	287	--
	1278.0	11.3	128.7	13.5	7.70	15.5	--	278	--
	1326.0	11.7	140.4	14.8	7.89	8.5	--	192	--
	1440.0	22.4	162.8	17.1	8.17	5.2	--	158	--

The ammonium leakage level (~ 145 - 160 mg/l) during the initial groundwater flow was slightly less than that obtained (~ 170 - 190 mg/l) when no sodium silicate was used during leaching (Test 62). This indicates that sodium silicate may slightly reduce ammonium desorption.

The injection of 2.0 g/l sodium sulfite increased the ammonium removal level to over 280 mg/l (~ 16.0 meq/l). The sodium feed level (~ 19.0 meq/l) would account for the observed ammonium leakage. However, the increased ammonium removal did not result in a significantly lower ammonium leakage during the subsequent groundwater flow. The ammonium level was still above 150 mg/l. In the 9 pore volumes of NaHSO_3 , only about 39% of the ammonium sorbed during leaching was removed; leaving an average ammonium ore level of 0.645 mg/g. In order to reduce sufficiently subsequent ammonium leakage, a significantly greater volume of sodium bisulfite would be required. The ammonium removal rate could be increased by increasing the sodium bisulfite concentration.

6.2.3.3 Leaching of Wyoming Ore Using 1.0 g/l NH_4HCO_3 - 0.5 g/l CaCl_2 - 0.5 g/l MgSO_4 - Oxidant, Followed by 1.0 g/l NaHSO_3 and Groundwater, Test 72

This test was performed to determine if magnesium and calcium salts could be used to reduce ammonium sorption during leaching. Agitation leach tests had shown that the presence of magnesium and calcium in solution reduced the amount of ammonium displaced from solution onto the ore (see Section 5.3). Also, the use of sodium bisulfite to lower post-leach chemical leakage was examined in this test. Its effect could hopefully be compared to sodium sulfite which has been used in a previous ammonium bicarbonate leach test (Test 67).

The total test duration was 1466.0 hours. There was an initial 144.0 -hour deionized water flow, and then 750.0 hours of leach. In the first 291.0 hours of leach, the oxidant used was dissolved oxygen. Peroxide was then used in the last 459.0 hours of leach. The oxidant was switched because significant amounts of precipitate formed in feed lines, including the flow meter, thus making flow control difficult. It was believed that the oxygen-saturated leach was producing magnesium and

calcium oxides, which are very insoluble. The use of peroxide, in a feed tank separate from that of the leach solution, eliminated this precipitation problem. The post-leach portion of the test had the following flow sequence: 144.0 hours of ground H_2O , 238.0 hours of $NaHSO_3$, and 170.0 hours of ground H_2O .

The permeability variations experienced during the test are shown in Figure 6.54. By the conclusion of the deionized water flow, the permeabilities of the front, middle, and end sections were 0.94, 1.2, and 1.2 darcy, respectively. The front section permeability dropped to about 0.73 darcy within 120 hours of leach, but then showed a gradual increase. Just prior to changing the oxidant, the front section permeability was about 0.88 darcy. The permeability of this section during this portion of the leach was significantly greater than that obtained in previous 1.0 g/l ammonium bicarbonate-saturated oxygen (45 psig) test (e.g., Test 62). The front section permeability in that test dropped from 1.1 to about 0.1 darcy after 300 hours of leach. The presence of magnesium and calcium in the leach solution must be responsible for the much improved permeability of this test. The magnesium and calcium may have aided the permeability in several ways. First, the increased ionic strength of leach would lower the damaging effects of clay dispersion and dissociation. Second, oxygen content of the feed may have been decreased due to the presence of magnesium and calcium, thus reducing the amount of oxygen gas released in the ore bed. And finally, the reduction in ammonium sorption may have resulted in less clay swelling which occurs to some degree with ammonium-substituted clays.

After changing the oxidant to peroxide, the front section permeability showed a gradual decline. At the conclusion of the leach, the permeability was at about 0.55 darcy, which is still very much higher than that experienced in previous ammonium bicarbonate leach tests. The decrease experienced during this portion of the test is believed caused by oxygen blockage which results from the large excess of oxygen produced by the rapid decomposition of peroxide. The oxygen produced by

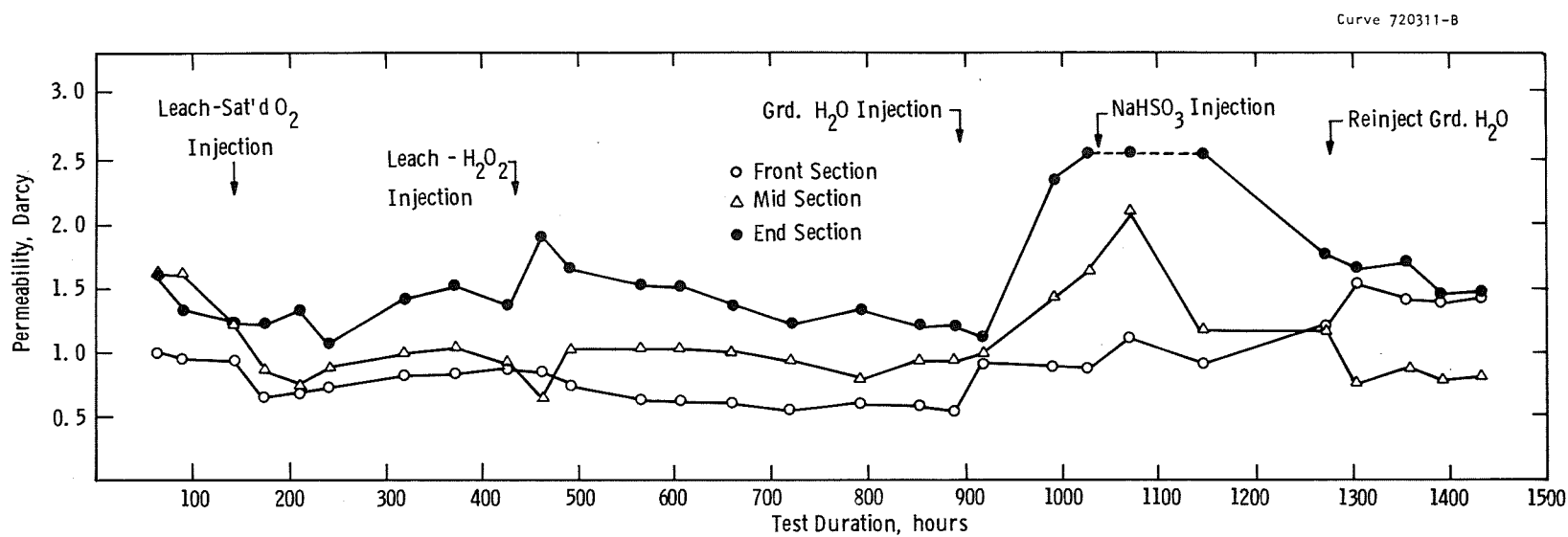


Fig. 6. 54— Permeability variations observed during leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 — 0.5 g/l $CaCl_2$ — 0.5 g/l $MgSO_4$ — oxidant, followed by 1.0 g/l $NaHSO_3$ and ground H_2O , Test 72.

the peroxide (≈ 250 mg/l) is much greater than that used in the initial portion of the leach (≈ 125 mg/l). The effect of oxygen blockage was still not nearly as great as that experienced in previous tests using 0.5 g/l peroxide.

The injection of groundwater caused the permeability of the front to increase to about 0.87 darcy. The permeability increased further with the introduction of NaHSO_3 . The permeability ranged from 0.9 to 1.2 darcy. During the final groundwater flow, the permeability increased to about 1.4 darcy. The permeability increases during these post-leach flows may have been caused by the dissolution of oxygen gas and precipitates (e.g., magnesium and calcium oxides and carbonates) formed during leaching.

The chemical data collected during this test is given in Table 6.31. The pH variations during leach, pH 7.1 to 7.8, were slightly lower than previous ammonium bicarbonate leaches (Test 62). The uranium recovery is shown in Figure 6.55. In the first 10 pore volumes of actual leach collected, 34% of the uranium was recovered. This is slightly better than 32% recovered in the first 10 pore volumes of leach during a previously performed ammonium bicarbonate leach (Test 62). The higher recovery can perhaps be attributed to the improved permeability obtained in this test. The ore pores are more open, thus leading to greater uranium accessibility.

The concentration variations experienced during the test are shown in Figure 6.56. The uranium and bicarbonate changes were typical of previous 1.0 g/l ammonium bicarbonate leach tests. The ammonium breakthrough was much more rapid than in tests using just ammonium bicarbonate leach (no calcium or magnesium salts). The ammonium concentration remained at less than 3 mg/l for about the first 70 liters of leach. The ammonium concentration then increased relatively rapidly, reaching a level of over 200 mg/l after approximately 160 l of leach had passed through the bed. Unlike the previous ammonium bicarbonate tests (Test 62), the ammonium level in the product essentially reached that of the feed (≈ 220 mg/l), thus indicating that ammonium sorption equilibrium

TABLE 6.31

SUMMARY OF DATA OBTAINED DURING LEACHING OF WYOMING ORE
 USING 1.0 g/l NH_4HCO_3 - 0.5 g/l CaCl_2 - 0.5 g/l MgSO_4 - OXIDANT,
 FOLLOWED BY 1.0 g/l NaHSO_3 AND GROUND WATER, TEST 72

Duration, Hrs.	Product Solution Vol., l	Σ Vol., l	Σ Ore Pore Volumes (1 PV=9.7l)	pH	HCO_3^- mg/l	NH_4^+ mg/l	Uranium mg/l	% U Recovery
72.0	26.9	26.9	2.8	6.19	600	---	299	16.8
144.0	38.3	65.2	6.7	7.03	170	---	49	20.7
216.0	27.6	92.8	9.6	7.08	440	---	221	33.5
267.0	19.9	112.7	11.6	7.17	520	< 2	270	44.7
336.0	33.5	146.2	15.1	7.60	---	2	---	---
384.0	29.9	176.1	18.2	7.79	---	70	---	---
435.0	30.9	207.0	21.3	7.81	550	183	86	61.7
504.0	25.0	232.0	23.9	7.82	---	242	---	---
552.0	22.5	254.5	26.2	7.79	---	219	---	---
603.0	34.0	288.5	29.7	7.71	---	---	---	---
672.0	32.7	321.2	33.1	7.80	550	203	21	66.7
726.0	32.8	354.0	36.5	7.78	---	---	---	---
773.5	25.4	379.4	39.1	7.74	---	219	---	---
840.0	32.2	411.6	42.4	7.71	---	---	---	---
894.0	32.4	444.0	45.8	6.86	520	199	9	69.0
939.0	21.8	465.8	48.0	7.30	---	180	3.8	69.2
1008.0	26.8	492.6	50.8	7.59	310	142	3.0	69.4
1038.0	11.8	504.4	52.0	7.27	---	103	3.0	69.5

TABLE 6.31
(Continued)

Duration, Hrs.	Product Solution Vol., l	Σ Vol., l	Σ Ore Pore Volumes (1 PV=9.7l)	pH	HCO_3^- mg/l	NH_4^+ mg/l	Uranium mg/l	% U Recovery
1107.0	19.2	523.6	54.0	7.92	320	86	5.3	69.7
1176.0	18.9	542.5	55.9	8.16	440	77	11	70.1
1224.0	20.5	563.0	58.0	7.12	130	---	2.0	70.2
1276.0	23.7	586.7	60.5	7.02	20	74	1.4	70.2
1344.0	14.2	600.9	61.9	6.83	40	78	1.5	70.3
1392.0	13.7	614.6	63.4	7.63	---	62	---	---
1446.0	17.2	631.8	65.1	8.28	---	54	---	---

Times of Solution Injection: 1) NH_4HCO_3 sat'd O_2 -- 144.0, NH_4HCO_3 - 0.5 g/ H_2O_2 --
435.0

2) Grd H_2O -- 894.0, 1276.0

3) NaHSO_3 -- 1038.0

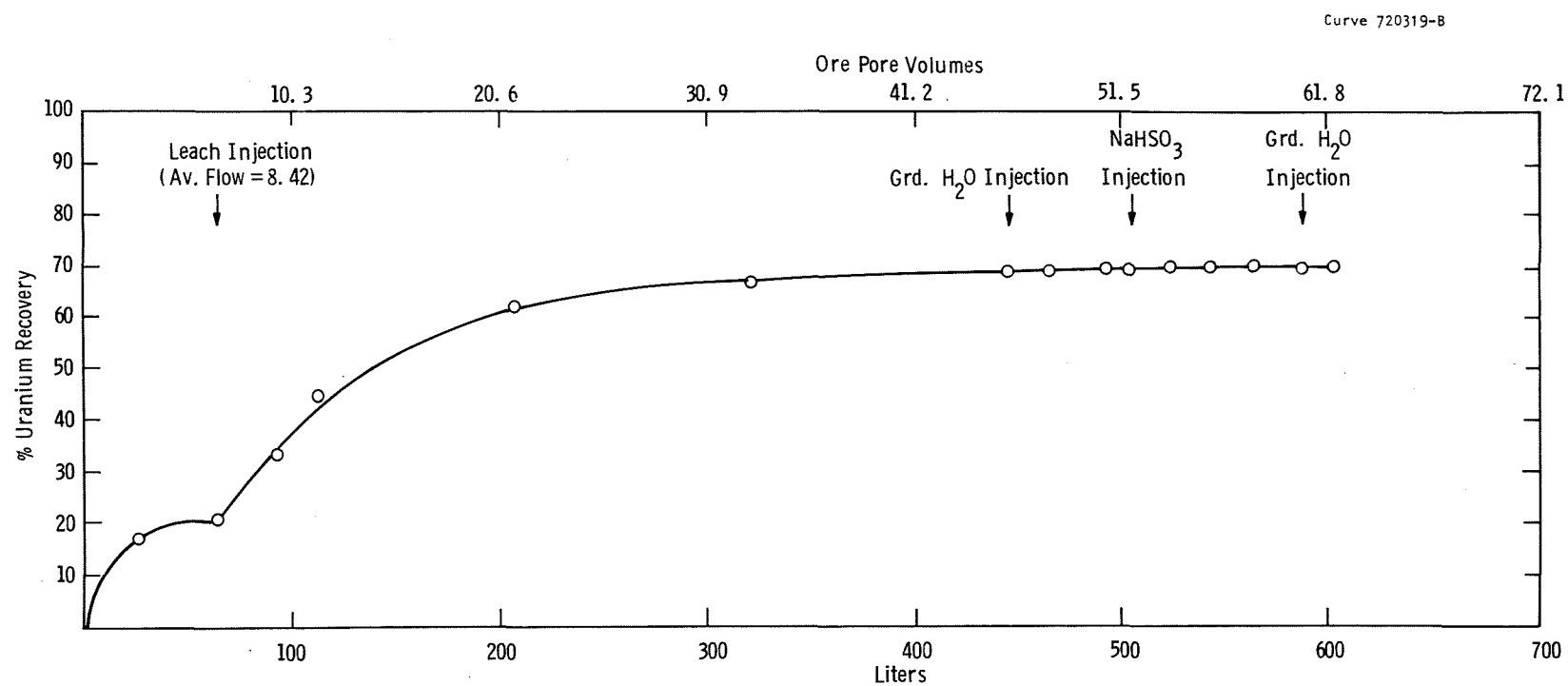


Fig.6.55 - Uranium recovery rate observed during leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 - 0.5 g/l CaCl_2 - 0.5 g/l MgSO_4 - oxidant, followed by 1.0 g/l NaHSO_3 and ground water, Test 72.

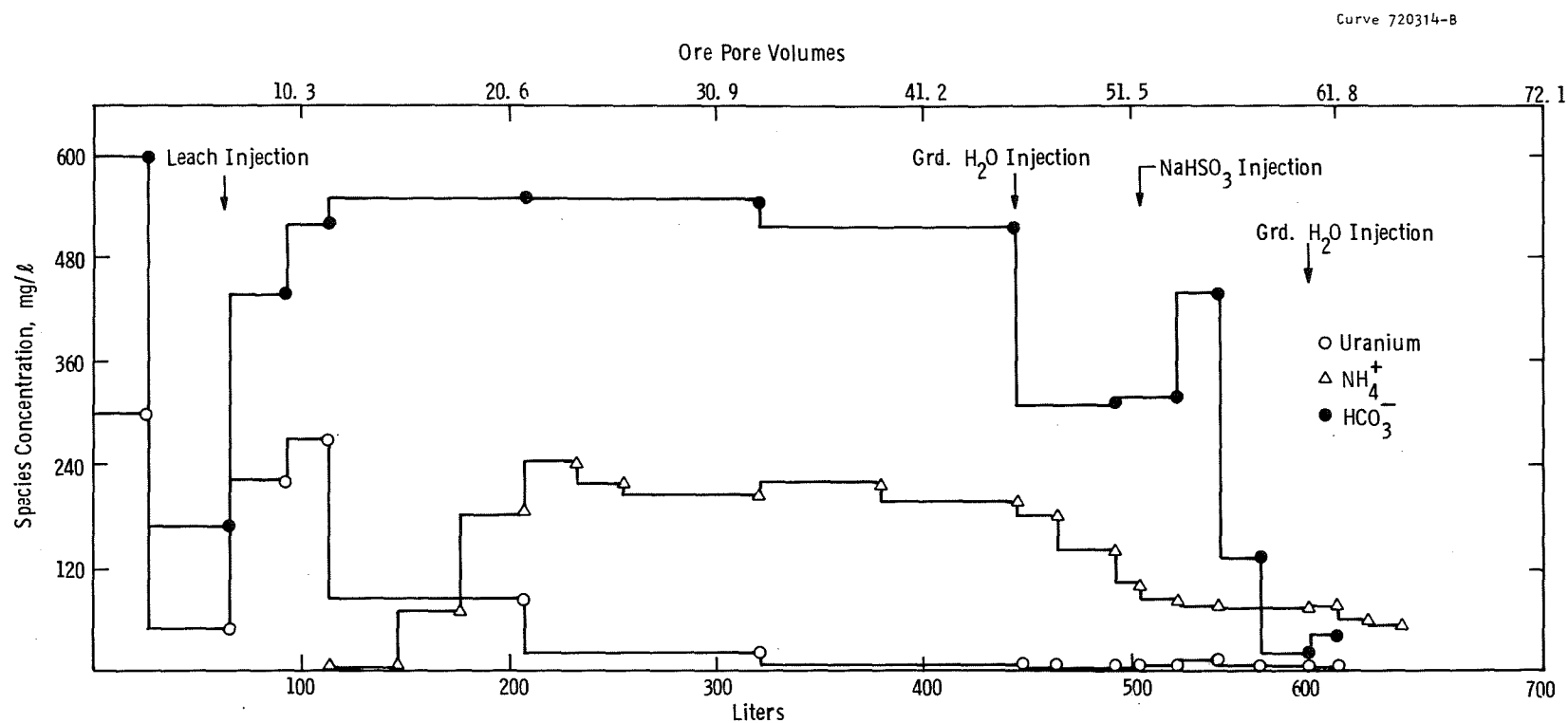


Fig. 6.56 - Concentration variations experienced during leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 - 0.5 g/l CaCl_2 - 0.5 g/l MgSO_4 - oxidant, followed by 1.0 g/l NaHSO_3 and ground water, Test 72.

was reached. In the 379 liters (39 pore volumes) of chemical leach, only 23.0 g of ammonium was sorbed by the ore ($0.026 \text{ meq of } \text{NH}_4^+/\text{g}$ of ore). In Test 62, a total of 50 g of ammonium (or about $0.056 \text{ meq of ammonium/g of ore}$) was picked up by the ore in 39 pore volumes of 1.0 g/l ammonium bicarbonate leach. The presence of magnesium and calcium salts in the leach thus reduced ammonium sorption by 54%. The Series II agitation leach tests indicated that a similar mixture of magnesium and calcium salts (0.5 g/l CaSO_4 and 0.5 g/l MgSO_4) would reduce ammonium sorption by 55%. There thus seems to be excellent agreement between the small rapid batch tests and the large long-term column tests when performing ammonium sorption studies. The results obtained here indicate that ammonium sorption by the ore can be reduced by increasing the cationic strength (Ca^{++} and/or Mg^{++}) of the leach solution, which also aids in maintaining the permeability of the ore bed.

The ion leakage data obtained during the post-leach solution flows is given in Table 6.32. During the initial post-leach groundwater flow, the selenium ($\sim 50 \text{ ppb}$) and uranium (3 mg/l) levels were both lower than in previous post- NH_4HCO_3 leach groundwater flow (e.g., Test 62: U - 15 mg/l , Se $\sim 150 \text{ ppb}$). After sodium bisulfite injection, the uranium and selenium levels both rose. The levels, however, did drop with subsequent solution flow. The uranium and selenium were less than 2 mg/l and 110 ppb , respectively, by the end of the second groundwater flow period. Initially, significant amounts of sulfate are formed during the sodium bisulfite flow, which, along with the acidic nature of the solution, perhaps caused the additional uranium and selenium to be leached. The sulfate level, which was significantly above the background groundwater level (190 mg/l) during the bisulfite flow, dropped to 265 mg/l within 4 pore volumes of the second groundwater flow. The bicarbonate level was not excessive as it fell to less than 50 mg/l by the start of the second groundwater flow. Again, the effectiveness of the sodium bisulfite cannot be reasonably determined in this test because of the significant changes from the baseline test (Test 62) that were introduced during the leaching portion of this test.

TABLE 6.32

Ion Leakage from Wyoming Ore Residue After Leaching
With 1.0 g/l NH_4HCO_3 - 0.5 g/l CaCl_2 - 0.5 g/l MgSO_4 - Oxidant, Test 72

Feed	Duration Hrs.	Vol., Σ l	Vol., Σ l	Ore Pore Volumes	pH	HCO_3^- mg/l	$\text{SO}_4^{=}$ mg/l	NH_4^+ mg/l	U mg/l	Se mg/l
Wyo. Grd. H_2O	894.0	--	--	--	6.86	520	--	199	9	--
	939.0	21.8	21.8	2.2	7.30	--	260	180	3.8	0.06
	1008.0	26.8	48.6	5.0	7.59	310	--	142	3.0	0.04
1.0 g/l NaHSO_3	1038.0	11.8	60.4	6.2	7.27	--	175	103	3.0	0.05
	1107.0	19.2	79.6	8.2	7.92	320	295	86	5.3	0.74
	1176.0	18.9	98.5	10.2	8.16	440	600	77	11.0	0.49
	1224.0	20.5	119.0	12.3	7.12	130	830	--	2.0	--
Wyo. Grd. H_2O	1276.0	23.7	142.7	14.7	7.02	20	710	74	1.4	0.40
	1344.0	14.2	156.9	16.2	6.83	40	910	78	1.5	0.24
	1392.0	13.7	170.6	17.6	7.63	--	420	62	--	0.12
	1446.0	17.2	187.8	19.4	7.28	--	265	54	--	0.11

The initial ammonium leakage (180-200 mg/l) during the groundwater flow was comparable to that obtained with groundwater following an ammonium bicarbonate leach with no calcium or magnesium added to the leach. This was so even though only about half as much ammonium was put on the ore in this test. The reason for this may have been that the calcium and magnesium compounds, which precipitated during the leach, redissolved into the groundwater thus increasing its cationic strength. The added calcium and magnesium were then able to exchange for ammonium. The results indicate that the ammonium leakage did drop significantly below the previous leakage levels with the further passage of the post-leach solutions. Once the calcium and magnesium were no longer dissolving into the solution, the reduction in the ore ammonium level obtained during leaching did result in significantly lower ammonium leakage. The ammonium leakage during the sodium bisulfite flow was only 70 to 80 mg/l. During the second water flow, it dropped to less than 54 mg/l.

Analysis of the ore after testing, showed the front, middle, and end ore sections to have ammonium levels of 0.04, 0.06, and 0.26 mg/g of ore, respectively. The results thus indicate that the magnesium was most effective in preventing ammonium sorption in the front portion of the column, and/or that during the post-leach solution flows the ammonium was removed to the greatest extent in this portion. The average ammonium ore level based on leach and post-leach ammonium solution concentrations was 0.13 mg of ammonium/g of ore, which compares very favorably with average post test ammonium ore level of 0.12 mg/g of ore.

6.2.3.4 Leaching of Wyoming Ore Using 1.0 g/l NH_4HCO_3 - 1.0 g/l MgSO_4 - Saturated O_2 (25 psig), Followed by Groundwater, Test 79

This test was performed to determine the combined beneficial effects of adding magnesium to the leach solution and of reducing the dissolved oxygen level of the feed solution. Previous test work (Test 72) had indicated that the presence of magnesium in an ammonium bicarbonate leach would reduce ammonium sorption by the ore as well as maintain a higher

permeability. Column tests (e.g., Test 75) have also shown that a reduction in the oxidant feed level will also result in improved permeability.

In this test, one feed tank contained a 1.0 g/l ammonium bicarbonate solution saturated with oxygen at 50 psig (120 mg of O_2 /l), while the other feed tank contained 1.0 g/l ammonium bicarbonate and 2.0 g/l magnesium sulfate. Previous test work with magnesium (Test 72) had indicated that saturating a magnesium solution with oxygen resulted in precipitation problems (i.e., magnesium oxides), and was thus avoided in this test. The solutions from the two feed tanks, flowing at equal rates, were mixed in-line just prior to injecting the solution into the ore bed. The mixed solution thus contained an oxygen level essentially equal to 25 psig oxygen saturation (60 mg of O_2 /l), and a magnesium sulfate level of 1.0 g/l.

The test ran for a total of 1338.0 hours. This included, in sequence, the following flows: 168.0 hours of deionized water, 792.0 hours of leach, and 378.0 hours of groundwater.

The permeability variations observed during this test are shown in Figure 6.57. The front and middle section permeabilities were approximately 1.4 and 2.1 darcy, respectively, by the conclusion of the deionized water flow. During this period, the end section showed an abnormally high permeability of greater than 5 darcy. Following leach injection, there was an initial drop in the permeability of all three sections. There was then a gradual increase in permeability. The end section went above 5 darcy, while the middle section stayed mainly between 2.5 and 3.0 darcy. The front section permeability varied between 1.6 and 2.0 darcy. The leach thus did not cause any significant change in permeability.

In a previous test (Test 62), using a 1.0 g/l ammonium bicarbonate leach saturated with oxygen (45 psig), the front section permeability dropped from 1.1 darcy to about 0.05 darcy. This decline was believed to be caused by oxygen blockage and clay dissociation and

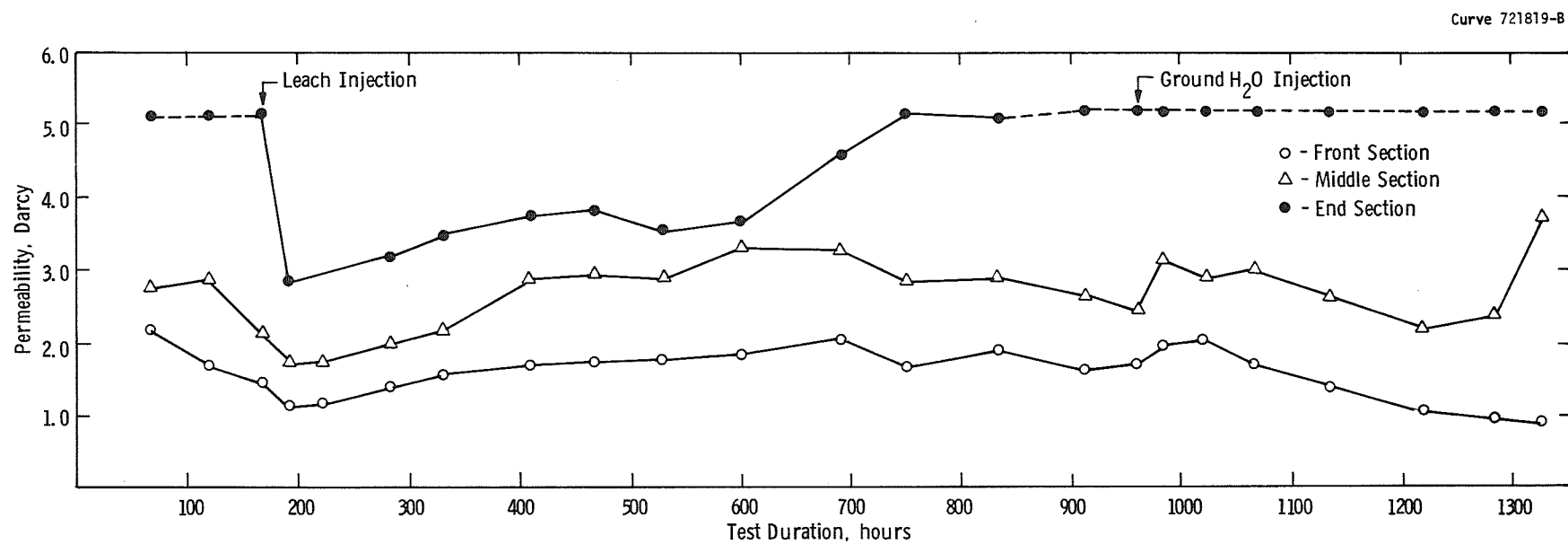


Fig. 6. 57 — Permeability variations observed during leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 -1.0 g/l MgSO_4 - sat'd O_2 (25 psig), followed by ground water, Test 79

dispersion. Thus, the addition of magnesium and the reduced oxygen level in this feed must have eliminated these permeability damaging effects. The increased ionic strength of the leach due to the presence of magnesium reduces clay dispersion and dissociation. The magnesium also results in less ammonium sorption, and thus less clay swelling which occurs with ammonium substituted clays. The reduction in the oxygen feed level causes less oxygen to be available to block the pores. Also, the magnesium may decrease the likelihood of excess oxygen coming out of solution in the ore bed.

The injection of groundwater caused a decrease in the front section permeability. The permeability dropped to about 0.9 darcy. The low ionic strength of the groundwater, which results in clay dissociation and dispersion, may have caused this decline.

The chemical data collected during this test is presented in Table 6.33. The uranium recovery is shown graphically in Figure 6.58. During deionized water flow, approximately 23% of the uranium was recovered. In the first 10 pore volumes (100 liters) of actual leach collected, about 38% of the uranium was recovered. As was true in Test 72, which also had cation (magnesium and calcium) addition to an ammonium bicarbonate leach, the initial leach uranium recovery rate was better than with no cation addition (Test 62 - 32% in 10 pore volumes). Higher recovery is attributed to the higher permeability and thus greater uranium accessibility. The total recovery obtained in this test (~ 70%) was similar to previous ammonium bicarbonate tests.

The concentration variations experienced during the test are shown in Figure 6.59. The ammonium breakthrough was rapid, with the ammonium level remaining at 30 mg/l or below for only the first 56 liters of leach collected. The ammonium concentration then rapidly increased, reaching the feed level (~ 220 mg/l) after only about 190 liters of leach were collected. An ammonium equilibrium had thus been reached between the ore and the leach solution. In the 473 liters (47.3 pore volumes) of leach, only 19.0 g of ammonium was sorbed by the ore (0.022 meq NH_4^+ /g of ore). This is much less than that obtained with no

TABLE 6.33

Summary of Data Obtained During Leaching of Wyoming Ore Using
1.0 g/l NH_4HCO_3 -1.0 g/l MgSO_4 -Saturated O_2 (25 psig), Followed
By Ground Water, Test 79

Duration Hrs.	Product Solution Vol., l	Σ Vol., l	Σ Ore Pore Volumes (1PV=10.0%)	pH	NH_4^+ mg/l	Uranium mg/l	% Uranium Recovery
120.0	45.3	45.3	4.5	6.81	---	226	21.5
168.0	29.4	74.7	7.5	7.23	---	21	22.8
216.0	29.0	103.7	10.4	6.88	---	241	37.4
282.0	38.6	142.3	14.2	7.11	3	231	56.1
330.0	30.7	173.0	17.3	7.44	58	---	---
381.0	32.3	205.3	20.5	7.40	165	50	62.8
429.0	30.0	235.3	23.5	7.58	208	---	---
498.0	40.5	275.8	27.6	7.49	221	20	65.7
618.0	75.0	350.8	35.1	7.76	---	---	---
690.0	42.4	393.2	39.3	8.01	228	9	68.1
741.0	31.9	425.1	42.5	7.96	---	---	---
810.0	40.3	465.4	46.5	7.93	241	---	---
882.0	43.9	509.3	50.9	7.90	---	---	---
960.0	38.7	548.0	54.8	7.91	203	5.5	69.9
1002.0	18.8	566.8	56.7	8.13	192	2.6	70.0
1050.0	18.7	585.5	58.6	8.24	140	1.4	70.1
1077.0	14.6	600.1	60.0	8.35	116	1.8	70.1
1125.0	13.9	614.0	61.4	8.38	95	2.3	70.2
1170.0	15.2	619.2	61.9	8.47	87	2.4	70.3
1245.0	18.2	637.4	63.7	8.53	67	---	---
1338.0	19.3	656.7	65.7	8.32	57	---	---

Times of Solution Injection: 1. NH_4HCO_3 - MgSO_4 - O_2 - 168.0 hours
2. Wyo. Grd. H_2O - 960.0 hours

Curve 721816-B

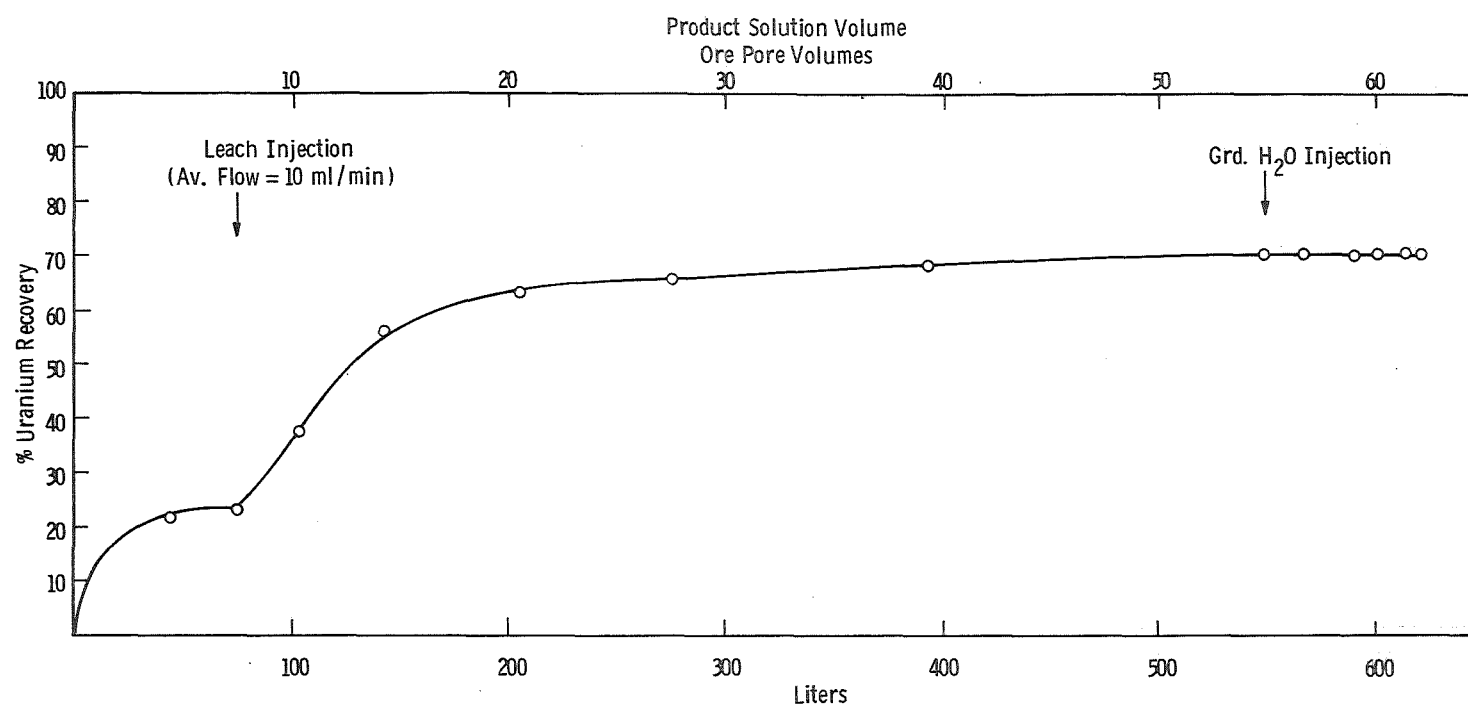


Fig. 6.58 — Uranium recovery rate observed during leaching of Wyoming ore with 1.0 g/l NH_4HCO_3 - 1.0 g/l MgSO_4 saturated O_2 (25 psig), followed by ground water, Test 79

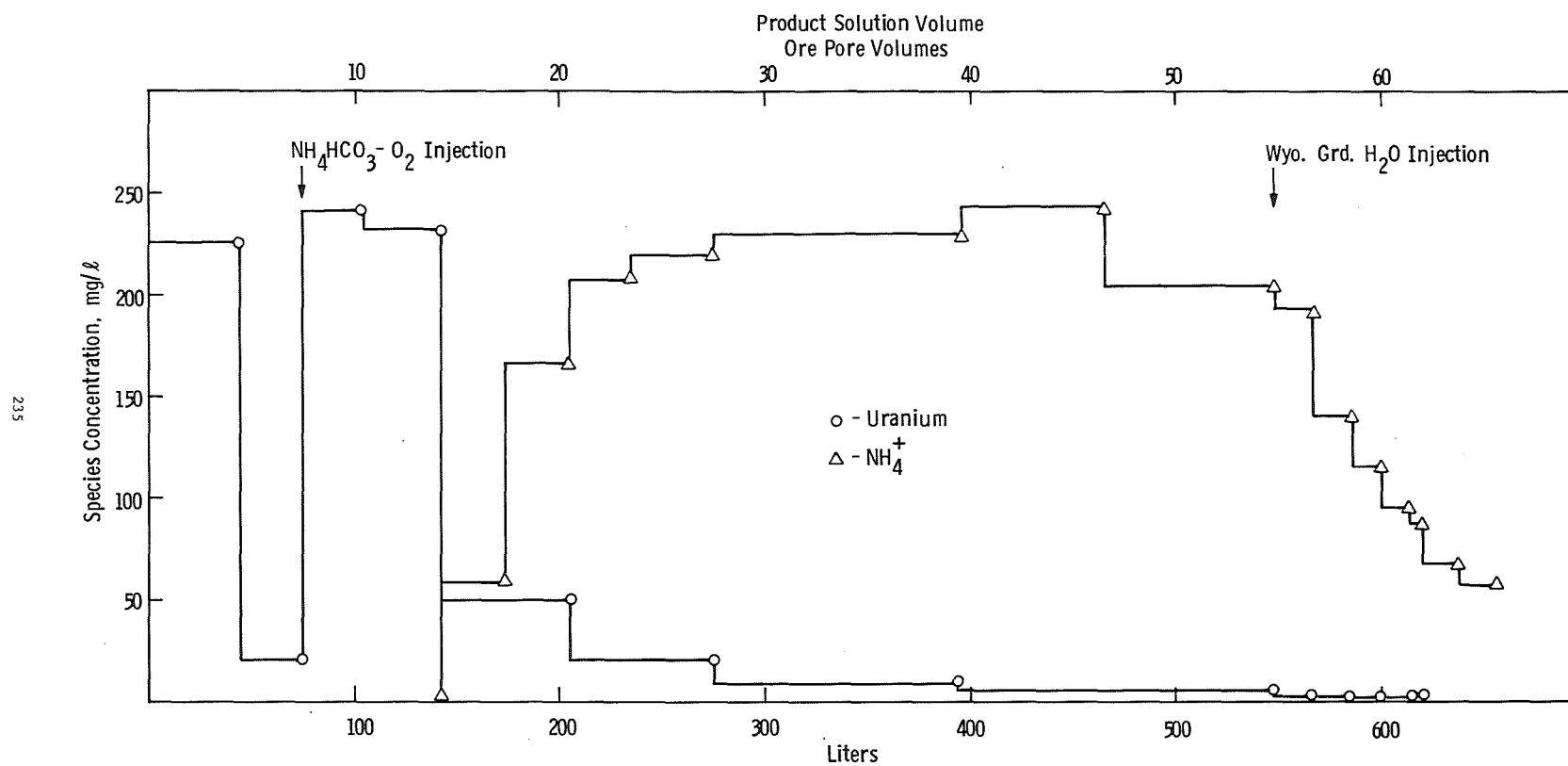


Fig. 6. 59 - Concentration variations experienced during the leaching of Wyoming ore with 1.0 g/l NH_4HCO_3 - 1.0 g/l MgSO_4 -saturated with O_2 (25 psig), followed by ground water, Test 79

cation addition, (e.g., Test 62 - 0.056 meq of NH_4^+ /g of ore). The presence of magnesium in the leach solution thus reduced ammonium sorption by about 60%. The Series II agitation leach tests indicated that the addition of 1.0 g/l magnesium sulfate would reduce ammonium sorption by 58%. Again, there seems to be excellent agreement between the small rapid batch tests and the long-term column tests when performing ammonium sorption studies. The ammonium sorption obtained with the 1.0 g/l MgSO_4 addition (16.6 meq of Mg/l) was also less than that obtained when 0.5 g/l CaCl_2 and 0.5 g/l MgSO_4 (17.3 meq of Ca and Mg/l) were added to the leach (Test 72), which was also predicted by the Series II agitation leach tests. Thus, for the same total meq of cations added, the addition of magnesium alone appears to be most effective.

The ion leakage data obtained during the post-leach groundwater flow is given in Table 6.34. The selenium level was excessive (90 to 140 ppb), which has been typical of bicarbonate leaches. The uranium level (2 to 3 mg/l) was less than that obtained when no magnesium was added to the leach (e.g., Test 62 - 15 mg of U/l and Test 78 - 5 mg of U/l). The sulfate level dropped quickly to baseline (within 4 pore volumes), thus the addition of sulfate to the leach did not seem to add to the post-leach restoration problem. The data also shows that the ammonium desorption was low which was likely the result of the reduced ammonium sorption during leaching. After less than 10 pore volumes of actual post-leach groundwater was collected, the ammonium concentration was less than 60 mg/l. In the baseline test (Test 78), in which no cation addition was made to leach, and thus in which substantially more ammonium was sorbed during leaching, the post-leach ammonium leakage did not drop below 60 mg/l until 22 pore volumes of groundwater had been collected.

6.2.4 Ammonium Displacement Tests

The objective of this last set of tests was to examine the use of chemicals that were thought to be capable of rapidly removing ammonium from ores that had been leached with ammonium bicarbonate. The removal

TABLE 6.34

Ion Leakage From Wyoming Ore After Leaching With
1.0 g/l NH_4HCO_3 - 1.0 g/l MgSO_4 - Saturated O_2 (25 psig), Test 79

Feed	Duration, Hrs.	Vol., ℓ	Σ Vol., ℓ	Σ Ore Pore Volumes	pH	Uranium mg/ℓ	NH_4^+ mg/ℓ	Se mg/ℓ	$\text{SO}_4^{=}$ mg/ℓ
Wyo. Grd. H_2O	960.0	---	---	---	8.0	0	0	0	190
	1002.0	18.8	18.8	1.9	8.13	2.6	192	0.11	500
	1050.0	18.7	37.5	3.8	8.24	1.4	140	0.09	200
	1077.0	14.6	52.1	5.2	8.35	1.8	116	0.11	180
	1125.0	13.9	66.0	6.6	8.38	2.3	95	0.13	170
	1170.0	15.2	81.2	8.1	8.47	2.4	87	0.14	180
	1245.0	18.2	99.4	9.9	8.53	---	67	---	---
	1338.0	19.3	108.7	10.9	8.32	---	57	---	---

of ammonium would prevent, or lower, the leakage of ammonium into groundwater. The chemicals examined were those that have been found to be most successful in the ammonium displacement agitation leach tests (see Section 5.7).

6.2.4.1 Leaching of Wyoming Ore Using 1.0 g/l NH_4HCO_3 Saturated O_2 (45 psig), Followed by 3.0 g/l AlCl_3 and by Groundwater, Test 74

This test examined the use of aluminum chloride to restore ammoniated ore beds. Agitation leach tests had indicated that aluminum chloride was extremely effective in removing ammonium. Groundwater was passed through after the aluminum solution in order to determine what post-restoration leakage would occur (e.g., Al, Cl, NH_4^+ , U, etc.). The test ran for a total of 1734.0 hours including 168.0 hours of deionized water, 834.0 hours of leach, 246.0 hours of aluminum chloride, and 189.0 hours of groundwater.

The permeability variations experienced during this test are shown in Figure 6.60. At the end of the deionized water flow period, the permeabilities of the front, middle and end sections were 1.35, 1.5, and 2.1 darcy, respectively. The front section dropped to about 0.5 darcy after 120 hours of leach, to about 0.15 darcy after 300 hours of leach, and to about 0.05 darcy by the conclusion of the leach. During most of the leach, the middle and end section permeabilities were approximately 0.4 and 0.7 darcy, respectively. The front section permeability decline during the leach was initially not as rapid as previous 1.0 g/l ammonium bicarbonate saturated oxygen (45 psig) tests (e.g., Test 62), but the final permeability obtained was similar to those tests.

After aluminum chloride injection, the front section rose rapidly, reaching 0.8 darcy within 100 hours. The middle and end sections rose to 0.5 and 1.6 darcy, respectively. The dramatic improvement in permeability may have had several causes. First, the aluminum could form a gelatinous precipitate $[\text{Al}(\text{OH})_3]$ at the initial pH of the ore bed (pH $\approx$ 8). This precipitate could coat and stabilize the ore. Also,

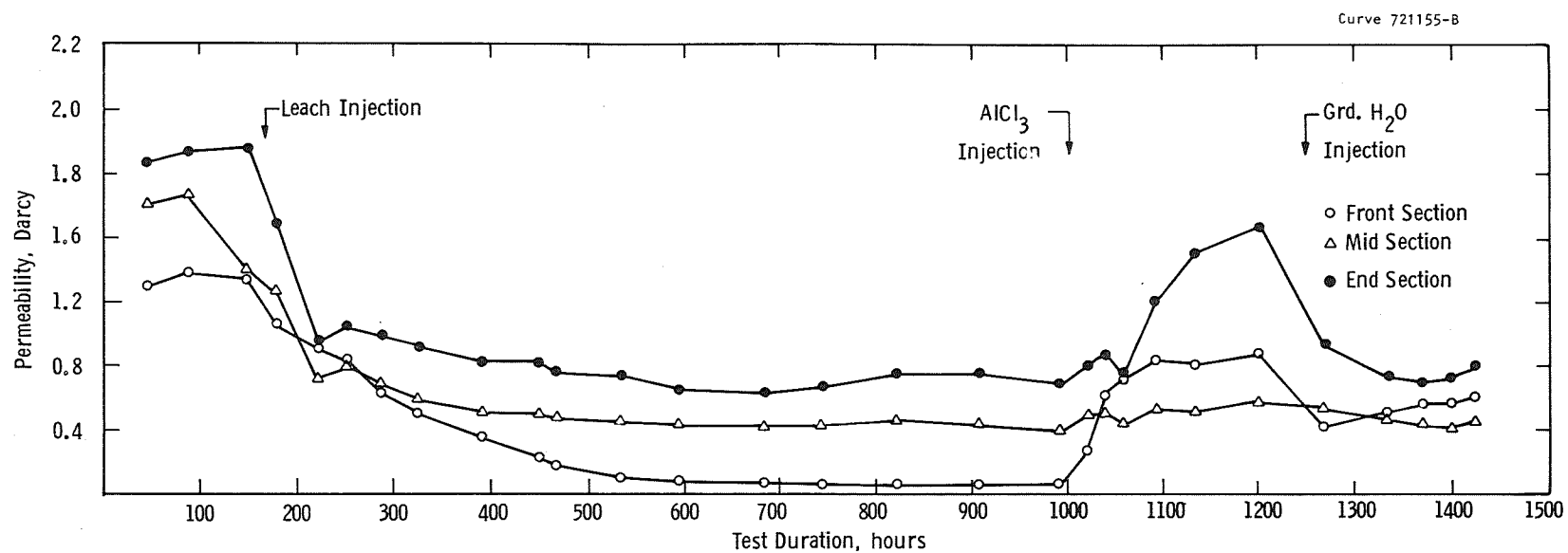


Fig. 6.60 — Permeability variations observed during leaching of Wyoming ore using 1.0 g/l $\text{NH}_4 \text{HCO}_3$ saturated O_2 (45 psig), followed by 3.0 g/l AlCl_3 and ground water, Test 74

the exchange of aluminum onto clay particles, as well as the high ionic strength of the aluminum chloride solution, would greatly reduce the permeability damaging effects of clay dissociation and dispersion. Finally, the aluminum chloride may in some way reduce the existing oxygen blockage. Perhaps the dissolution of oxygen is increased, or the aluminum hydroxide coating on the ore reduces the surface tension forces between the gas and solid, thus allowing the gas to be more easily removed from the bed.

After groundwater injection, the permeabilities of the front, middle, and end sections dropped to 0.6, 0.4, and 0.8 darcy, respectively. The decline is likely the result of the low ionic strength of the water solution. However, the permeability drop is not nearly as severe as that experienced during post-leach Wyoming groundwater flow in previous tests (e.g., Test 62). Thus, the aluminum chloride does seem to stabilize the ore bed.

The uranium recovery rate obtained during this test is shown in Figure 6.61. During the deionized water flow, approximately 25% of the uranium was recovered. In the first 10 pore volumes (96 liters) of actual leach solution collected, 36% of the uranium was recovered--slightly higher than the uranium recovery ($\sim 32\%$) obtained in previous tests using the same leach solution (e.g., Test 62). This perhaps is due to the less severe permeability decline experienced in this test, and thus, the greater uranium accessibility. However, the total recovery in this test ($\sim 72\%$) was approximately the same as the earlier tests.

The chemical data from this test is given in Table 6.35. The pH variations during leach were typical of previous bicarbonate leaches. The product pH then showed an initially gradual decline during aluminum chloride flow. There was then a rather abrupt drop in pH after about 10 pore volumes of the restoration solution. The rapid drop in pH occurred simultaneously with the aluminum cation breakthrough. The pH then increased with the injection of groundwater.

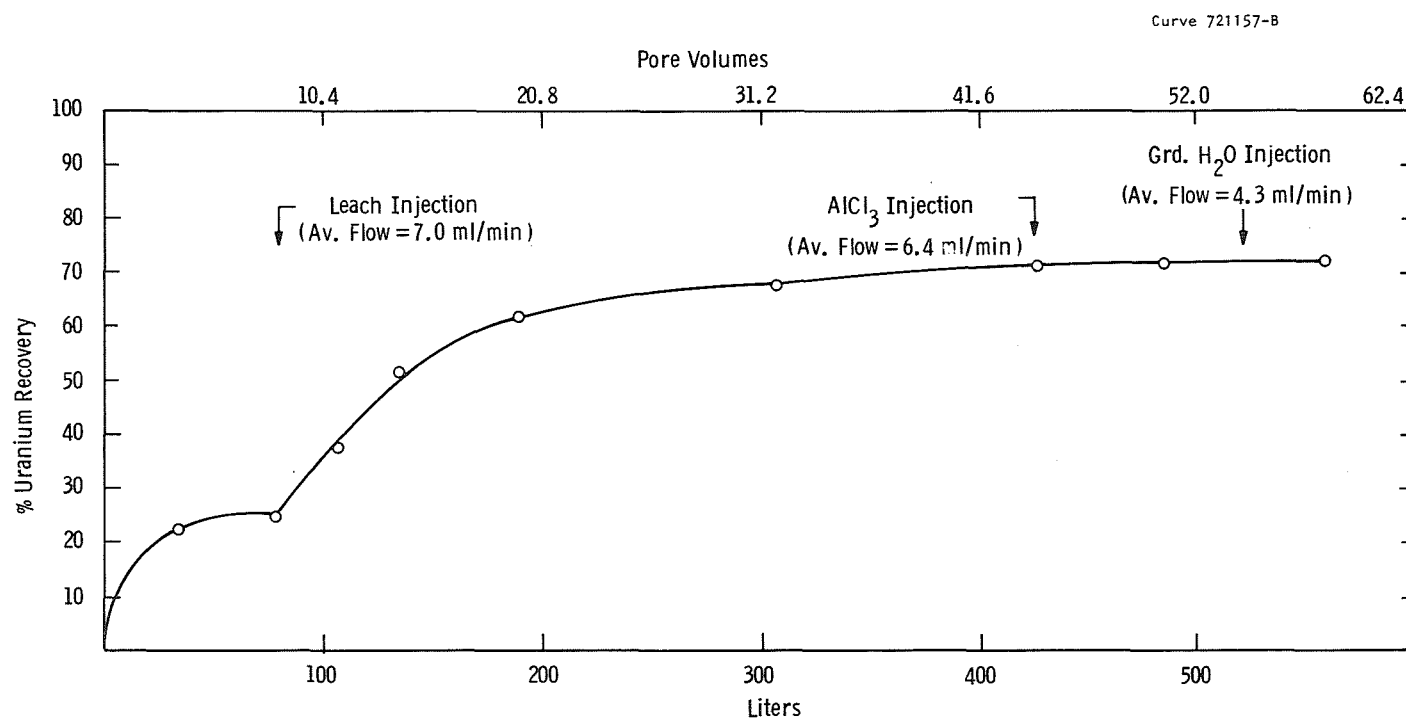


Fig.6. 61 -Uranium recovery rate observed during leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 saturated O_2 (45 psig) . followed by 3.0 g/l AlCl_3 and ground water, Test 74

TABLE 6.35

SUMMARY OF DATA OBTAINED DURING LEACHING OF WYOMING
ORE USING 1.0 g/ℓ NH_4HCO_3 SATURATED WITH O_2 (45 psig)
FOLLOWED BY 3.0 g/ℓ AlCl_3 AND GROUND WATER, TEST 74

Duration, Hrs.	Product Solution Vol., ℓ	Σ Vol., ℓ	Σ Ore Pore Volumes (1 PV=9.6)	pH	NH_4^+ mg/ℓ	HCO_3^- mg/ℓ	Uranium mg/ℓ	% Uranium Recovery
93.0	34.7	34.7	3.6	6.68	--	--	311	22.5
168.0	44.1	78.8	8.2	6.99	--	--	25	24.8
216.0	29.0	107.8	11.2	7.09	--	480	221	38.2
261.0	27.0	134.8	14.0	7.38	--	650	240	51.8
312.0	28.8	163.6	17.0	7.67	--	--	--	--
360.0	26.8	190.4	19.8	7.38	3	650	89	62.1
428.0	35.6	226.0	23.5	7.35	38	--	--	--
504.0	39.1	265.1	27.6	7.52	96	560	--	--
598.0	42.2	307.3	32.0	7.72	--	--	23	67.7
696.0	32.0	339.3	35.3	7.64	139	--	--	--
765.0	20.5	359.8	37.5	7.76	--	--	--	--
858.0	25.7	385.5	40.2	7.63	140	460	--	--
933.0	22.3	407.8	42.5	7.59	--	--	--	--
1002.0	19.1	426.9	44.5	7.47	141	--	14	71.2
1050.0	25.0	451.9	47.1	7.41	427	310	5.2	71.5
1080.0	14.6	466.5	48.6	7.20	730	--	--	--
1146.0	19.3	485.8	50.6	7.04	752	290	2.2	71.7
1194.0	21.5	507.3	52.8	6.94	438	--	--	--
1248.0	13.9	521.2	54.3	6.49	105	140	1	71.7
1272.0	11.3	532.5	55.5	4.88	41	<15	11	72.0
1338.0	13.1	545.6	56.8	6.25	5	--	--	--
1386.0	13.3	558.9	58.2	6.78	3	110	3.9	72.3
1437.0	10.6	569.5	59.3	6.92	--	--	--	--

Times of Solution Injection: (1) $\text{NH}_4\text{HCO}_3\text{-O}_2$ - 168.0 hours; (2) AlCl_3 -1002.0 hours;
(3) Wyo. Grd. H_2O -1248.0 hours.

The uranium, ammonium, and bicarbonate concentration variations experienced during the test are shown in Figure 6.62. The concentration changes were typical of previous ammonium bicarbonate leaches of Wyoming ore. The ammonium product levels indicate that 49.8 g of ammonium was sorbed during the 348.1 liters (36.3 pore volumes) of leach. This is identical to the ammonium sorption level (0.056 meq of NH_4^+ /g of ore) experienced under the same leach conditions in an earlier test (Test 62).

The post-leach ion leakage data is given in Table 6.36. The uranium level dropped to 1 mg/l during the aluminum chloride flow, but increased to 11 mg/l when the acidic pH breakthrough occurred ($\text{pH} < 5$). The uranium increase was likely due to the acidity of this solution as the uranium concentration did drop when the pH increased during subsequent groundwater flow. As expected, the bicarbonate level dropped and the chloride level rapidly increased during the aluminum chloride flow. The chloride level did drop to less than 150 mg/l after the 4 pore volumes of solution were collected after groundwater injection. The selenium dropped to an environmentally acceptable level of less than 2 ppb by the end of the aluminum chloride flow.

The ammonium levels in solution indicated a very rapid removal rate during the aluminum chloride flow. The ammonium removal rate observed is shown in Figure 6.63. As the figure shows, almost 69% of the ammonium sorbed during leaching was removed in the first 5 pore volumes of aluminum chloride solution collected, and over 90% of the ammonium was removed in 9 pore volumes. As Table 6.36 shows, within the first pore volume of groundwater collected, the ammonium concentration was only about 5 mg/l, which compares to an ammonium leakage level of 140 mg/l obtained after 7.5 pore volumes of groundwater which immediately followed a 1.0 g/l ammonium bicarbonate leach (Test 62). Analysis of the ore after testing showed the ammonium level on the ore to be no greater than 0.03 mg of ammonium/g of ore, which is very much less than the 0.69 mg/g of ore obtained after the same leach with no restoration (Test 62).

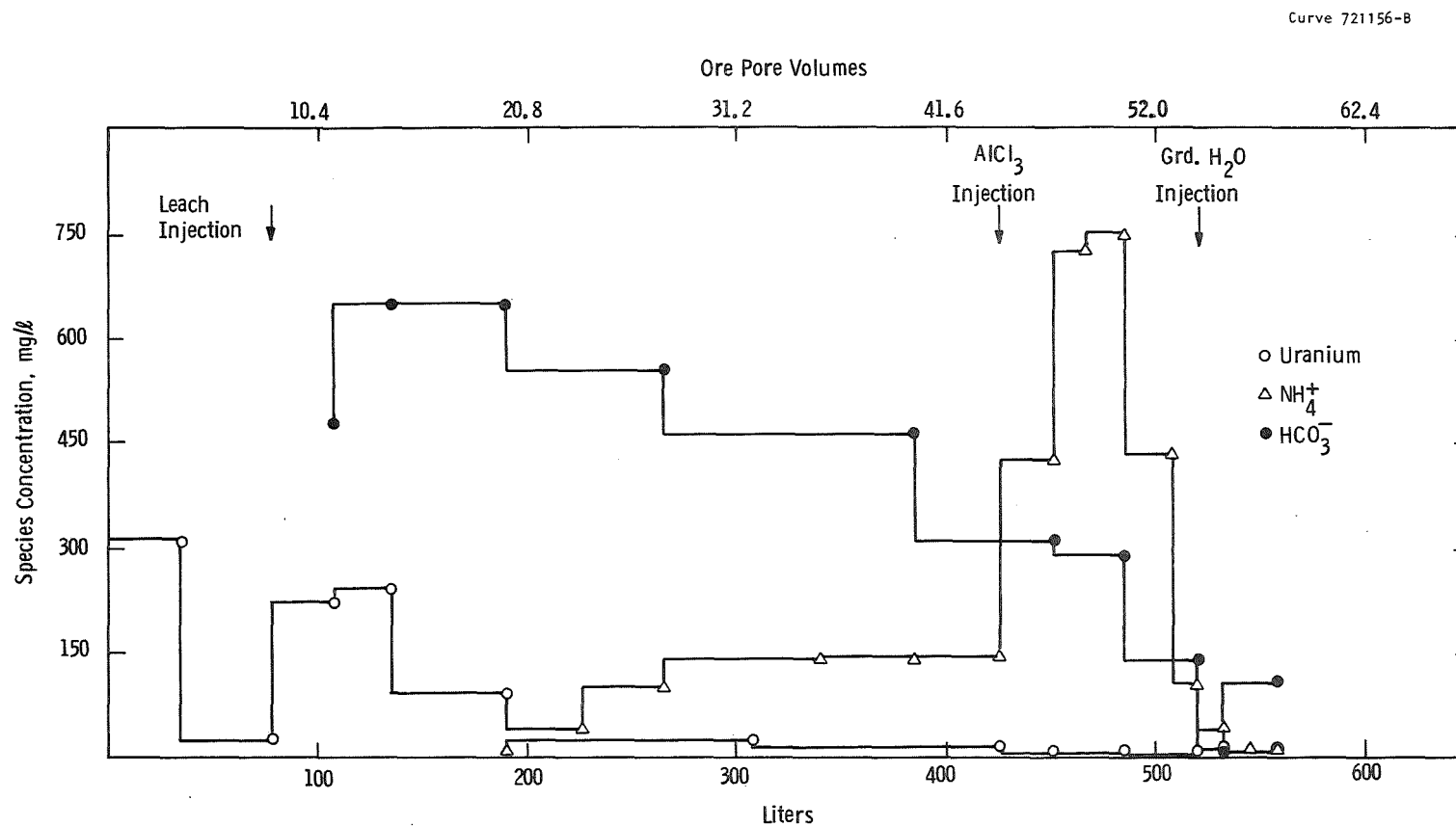


Fig. 6.62—Concentration variations experienced during leaching of Wyoming ore with 1.0 g/l NH_4HCO_3 saturated O_2 (45 psig), followed by 3.0 g/l AlCl_3 and ground water, Test 74

TABLE 6.36

ION LEAKAGE FROM WYOMING ORE AFTER LEACHING
 WITH 1.0 g/l NH_4HCO_3 SATURATED O_2 (45 psig), TEST 74

Feed	Duration Hrs.	Vol., l	Σ Vol., l	Σ Ore Pore Volumes	pH	U mg/l	NH_4^+ mg/l	Al^{+3} mg/l	Cl^- mg/l	HCO_3^- mg/l	Se mg/l
3.0 g/l AlCl_3	1002.0	--	--	--	7.47	14	141	--	--	--	--
	1050.0	25.0	25.0	2.6	7.41	5.2	427	<1	1560	310	0.112
	1080.0	14.6	39.6	4.1	7.20	--	730	<1	2540	--	--
	1146.0	19.3	58.9	6.1	7.04	2.2	752	<1	2620	290	0.051
	1194.0	21.5	80.4	8.4	6.94	--	438	<1	2550	--	--
Wyo. Grd. H_2O	1248.0	13.9	94.3	9.8	6.49	1.0	105	<1	2460	140	<0.002
	1272.0	11.3	105.6	11.0	4.88	11.0	41	15.0	2690	<15	<0.002
	1338.0	13.1	118.7	12.4	6.25	--	5	<1	324	--	--
	1386.0	13.3	132.0	13.8	6.78	3.9	3	<1	145	110	<0.002
	1437.0	10.6	142.6	14.9	6.92	--	--	--	--	--	--

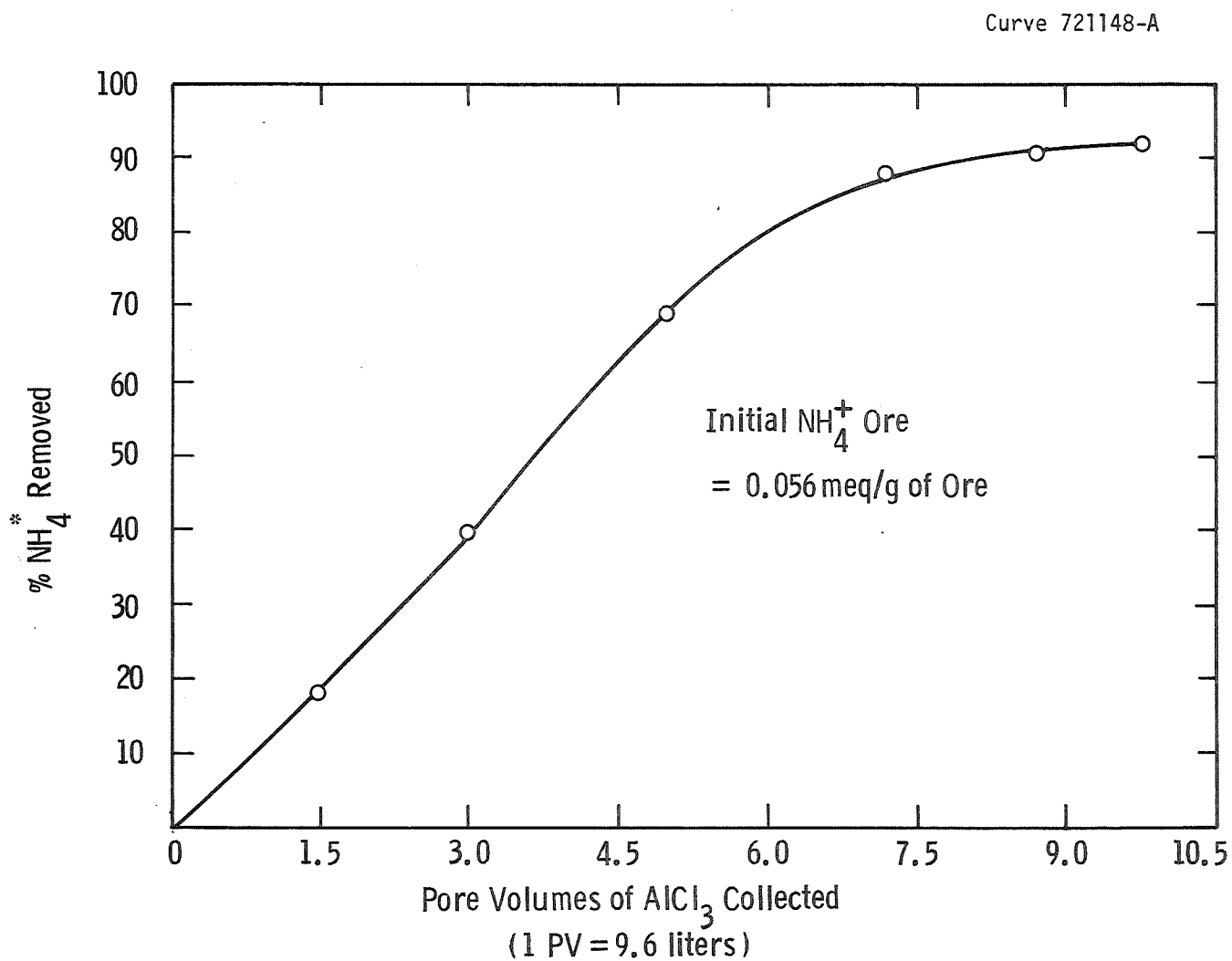


Fig. 6.63—Ammonium removal rate observed during 3.0 g/l AlCl_3 flow following 1.0 g/l NH_4HCO_3 sat'd O_2 leach of Wyo. ore, Test 74³

The aluminum analyses indicate the aluminum only appeared in the product at a pH of less than 5. There was no significant aluminum leakage during the post-leach groundwater flow, and was thus not a restoration problem. The equivalent cation concentration of 3.0 g/l aluminum chloride solution was 67.4 meq/l, while the peak ammonium equivalent concentration during restoration was only 41.8 meq/l. Thus about 62% of the aluminum cations was effectively used. As no aluminum was present in the product solution, it must have precipitated and/or exchanged with other cations initially present on the ore. The aluminum cation may be more efficiently used at a lower concentration.

6.2.4.2 High Pressure Leaching of Wyoming Ore With 1.0 g/l NH_4HCO_3 Saturated O_2 (45 psig), Followed by 0.5 g/l LaCl_3 - 0.5 g/l $\text{La}_2(\text{SO}_4)_3$ and Groundwater, Test 75

This test served two purposes. The leaching portion of the test examined the use of ammonium bicarbonate solution saturated with oxygen at a pressure which was less than that of the entire ore bed. Previous tests had indicated that oxygen is rapidly released from solution when a saturated leach comes into contact with an ore bed that is at a lower pressure than the oxygen saturation pressure (e.g., Test 62). In this test one feed tank contained 1.0 g/l ammonium bicarbonate solution saturated with oxygen at 90 psig (2.5 mg of O_2 /l), while the other tank contained just 1.0 g/l ammonium bicarbonate solution. The unoxygenated feed was pressurized with 90 psig of nitrogen, which was separated from the solution by a rubber tank liner. The two feed solutions, flowing at equal rates, were mixed in-line just prior to injecting the solution into the ore bed. The mixed solution thus contained an oxygen level essentially equivalent to 45 psig oxygen saturation (110 mg of O_2 /l). The high pressure stainless steel column was used in this test. At the outlet of the column a back pressure regulator was set at 50 psig. Thus, the leach solution always saw at least 50 psig pressure throughout the column. This test was also designed to examine the use of lanthanum chloride and sulfate to restore ammoniated ore.

The test ran for a total of 1627.1 hours. This included an initial 192.0-hour deionized water flow, a 816.0-hour leach, a 264.0-hour chemical restoration, and a 355.1-hour groundwater flow.

The permeability variations observed during this test are shown in Figure 6.64. As has been typical of previous high pressure tests, the permeability of the ore bed during the deionized water flow was higher than in low pressure ore beds. At the conclusion of the deionized water period, the permeabilities of the front, middle, and end sections were approximately 2.3, 2.3, and 2.4 darcy, respectively. Upon chemical injection, the permeability of the front section showed a gradual decline. The front section was about 1.0 darcy after 120 hours of leach, 0.4 after 300 hours, and 0.25 by the conclusion of the leach. The middle and end sections also showed gradual declines reaching 0.8 and 1.1 darcy, respectively, by the conclusion of the leach.

The permeability experienced during this leach was significantly higher than in previous 1.0 g/l ammonium bicarbonate saturated oxygen (45 psig) leaches (e.g., Test 62). The front permeability in those tests was about 0.05 darcy by the conclusion of the leach. The permeability improvement in this test is attributed to the fact that the ore bed was pressurized to a level greater than the oxygen saturation pressure of the feed. Oxygen gas blockage should therefore have been greatly reduced or eliminated. If the difference in permeability between this test and the previous oxygen saturated feed tests can be assumed to be due to the elimination of gas blockage, then one sees that oxygen blockage can result in substantial permeability damage. The elimination or significant reduction of oxygen blockage has resulted in a 5-fold increase in the front section permeability (0.05 darcy to 0.25 darcy).

The fact that the permeability did in fact decrease during leach indicates that factors other than gas blockage are involved in the permeability decline. Clay swelling, dispersion and dissociation are possible causes. Previous column results (Test 72) have indicated that increasing the ionic strength of the leach solution could result

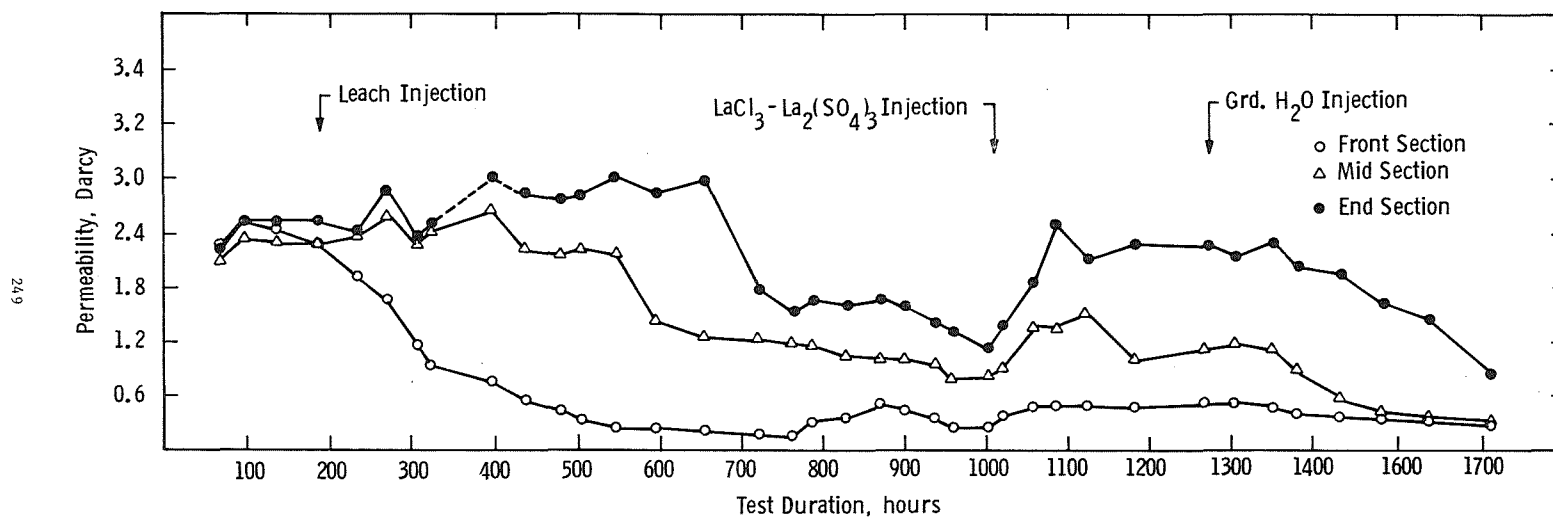


Fig. 6. 64—Permeability variations observed during high pressure leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 saturated O_2 (45 psig), followed by 0.5 g/l LaCl_3 - 0.5 g/l $\text{La}_2(\text{SO}_4)_3$ and ground water, Test 75

in reduced clay dispersion and dissociation. These test results also showed that the addition of cations to the leach reduced ammonium sorption onto the clays and thus perhaps reduced clay swelling. The addition of salts to a leach like the one used in this test should therefore result in an even better permeability (see Section 6.2.3.4, Test 79).

Upon injection of the lanthanum solution, the permeability of the bed increased. The front section permeability increased to 0.45 darcy 50 hours after the restoration solution injection and to about 0.5 darcy by that flow's conclusion (250 hours). The relatively high ionic strength of this solution and the exchange of lanthanum cations for ammonium on the clay would result in less clay dispersion, dissociation, and perhaps swelling.

The injection of groundwater caused a gradual decrease in permeability. The front section had a permeability of approximately 0.3 darcy by the conclusion of the water flow. This was substantially better than in previous post-leach Wyoming groundwater flows with no prior chemical restoration (e.g., Test 62). The lanthanum, like aluminum in Test 74, seemed to stabilize the bed. The presence on the clay of the trivalent lanthanum likely resulted in less clay dissociation and dispersion.

The chemical data obtained during this test is given in Table 6.37. The uranium and ammonium concentration variations are shown in Figure 6.65. The ammonium and uranium levels during leach were similar to past tests performed under the same conditions. The ammonium product concentrations showed that 52.0 g of ammonium was sorbed during the 455.1 liters (47.9 pore volumes) of leach. This is a higher ammonium sorption level (0.063 meq of NH_4^+ /g of ore) than that (0.056 meq of NH_4^+ /g of ore) experienced under the same leach conditions in earlier tests. The greater volume of leach solution collected in this test could account for the higher sorption level observed. The uranium recovery rate is shown in Figure 6.66. In the first 10 pore volumes (95 liters) of actual leach collected, 32% of the uranium was recovered. This rate is

TABLE 6.37

Summary of Data Obtained During High Pressure Leaching
Of Wyoming Ore Using 1.0 g/l NH_4HCO_3 Saturated O_2
(45 psig), Followed by 0.5 g/l LaCl_3 and 0.5 g/l $\text{La}_2(\text{SO}_4)_3$, Test 75

Duration, Hrs.	Product Solution Vol., l	Σ Vol., l	Σ Ore Pore Volumes (1 PV=9.5l)	pH	U mg/l	NH_4^+ mg/l	% Uranium Recovery
117.0	48.5	48.5	5.1	6.65	216	--	21.4
192.0	47.4	95.9	10.1	7.19	18	--	23.1
258.0	35.9	131.8	13.9	6.88	216	--	38.9
330.0	42.5	174.3	18.3	7.63	175	--	54.1
384.0	31.0	205.3	21.6	7.44	--	--	--
432.0	27.9	233.2	24.5	7.36	--	27	--
498.0	36.8	270.0	28.4	7.39	38	86	61.5
552.0	30.1	300.1	31.6	7.49	--	112	--
620.0	36.7	336.8	35.5	7.65	--	--	--
672.0	25.3	362.1	38.1	7.74	--	143	--
738.0	37.9	400.0	42.1	7.83	11	--	64.4
789.0	31.1	431.1	45.4	7.85	--	164	--
858.0	43.0	474.1	49.9	7.90	--	--	--
930.0	39.2	513.3	54.0	7.94	--	--	--
1008.0	37.7	551.0	58.0	7.99	5.8	181	66.2
1050.0	20.8	571.8	60.2	8.11	2.7	188	66.3
1098.0	20.0	591.8	62.3	8.11	0.88	173	66.4
1170.0	18.4	610.2	64.2	8.26	--	178	--
1218.0	17.3	627.5	66.1	8.35	1.0	177	66.4
1272.0	18.3	645.8	68.0	8.36	--	177	--
1338.0	15.6	661.4	69.6	8.39	0.96	178	66.5
1386.0	16.9	678.3	71.4	8.55	--	187	--
1434.0	14.7	693.0	72.9	8.49	--	176	66.6
1507.0	17.0	710.0	74.7	8.34	--	--	--
1555.0	15.6	725.6	76.4	8.42	--	--	--
1630.0	21.0	746.6	78.6	8.46	--	--	--

Times of Solution Injection: 1) NH_4HCO_3 - O_2 -192.0 hours
2) LaCl_3 - $\text{La}_2(\text{SO}_4)_3$ -1008.0 hours
3) Wyo. Grd. H_2O -1272.0 hours

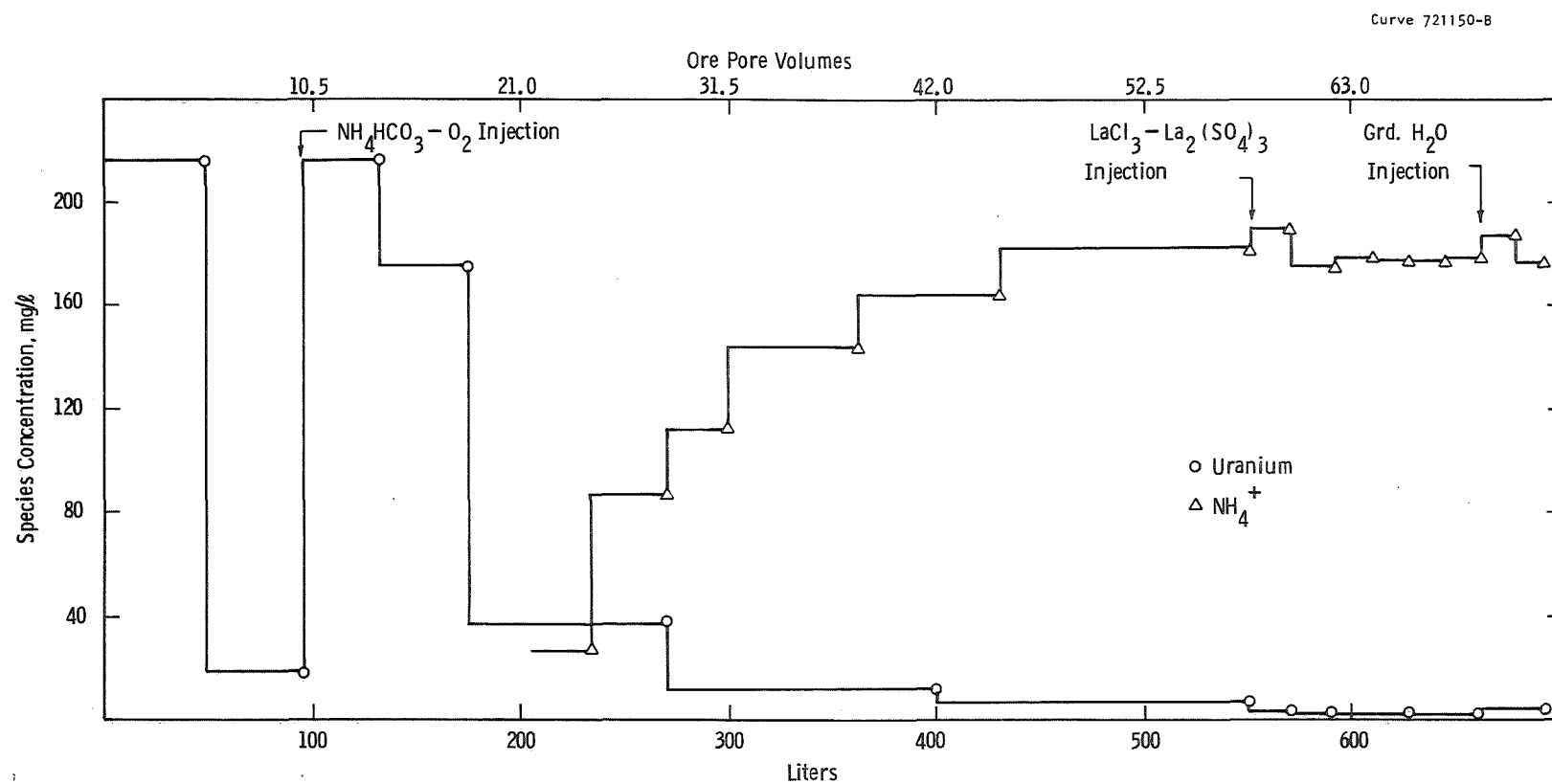


Fig. 6.65 - Concentration variations experienced during high pressure leaching of Wyoming ore with 1.0 g/l NH_4HCO_3 saturated O_2 (45 psig), followed by 0.5 g/l $\text{LaCl}_3 - 0.5 \text{ g/l } \text{La}_2(\text{SO}_4)_3$ and ground water, Test 75.

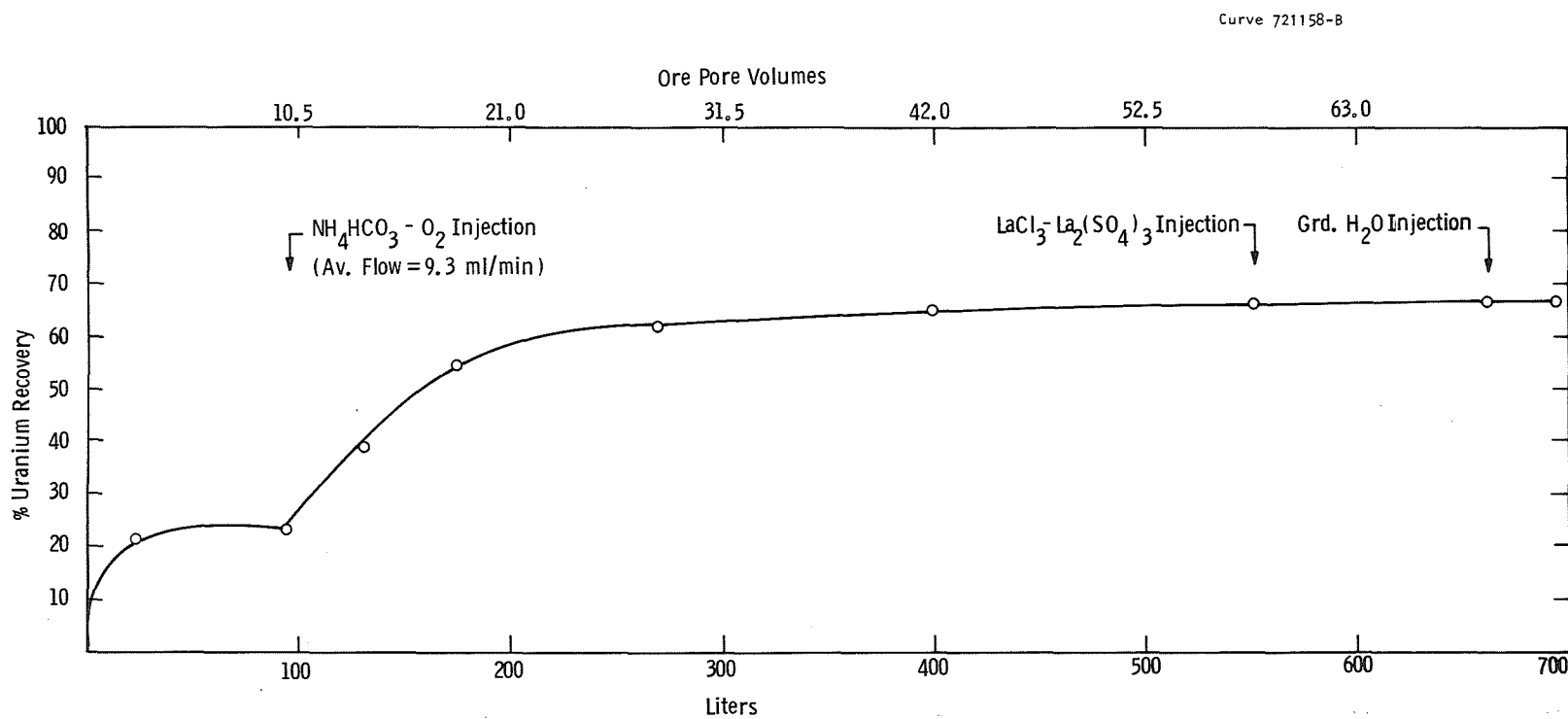


Fig. 6.66—Uranium recovery rate observed during high pressure leaching of Wyoming ore with 1.0 g/l NH_4HCO_3 sat'd O_2 (45 psig), followed by 0.5 g/l $\text{LaCl}_3 - 0.5 \text{ g/l } \text{La}_2(\text{SO}_4)_3$ and ground water, Test 75

similar to that obtained in previous leach tests using the same leach solution (e.g., Test 62). The total recovery ($\sim 66\%$), however, was less than in the previous tests ($\sim 72\%$). The higher average flow rate (9.3 ml/min vs. 7.9 ml/min in Test 62) and thus the lower residence leach time may account for the lower recovery. The higher flow rate is the result of the better permeability experienced during this test.

The chemical leakage data obtained during the post-leach solution flows is given in Table 6.38. The data shows that the uranium level is only about 1.0 mg/l, indicating that the lanthanum solution may reduce uranium leakage. During restoration, the sulfate level went only slightly above the background level of the groundwater (190 mg/l). The chloride concentration during restoration (160 mg/l) was above the baseline groundwater level (60 mg/l). During subsequent groundwater flow, the sulfate fell to background level while the chloride remained at about 160 mg/l. Chloride may, therefore, present a post-restoration leakage problem.

The main purpose of the lanthanum restoration solution was to remove ammonium from the ore. The data indicates that the ammonium level during restoration (170-190 mg/l) was slightly higher than that (~ 140 mg/l) obtained with post-leach groundwater (e.g., Test 62). The product solutions indicate that essentially all of the lanthanum was removed from solution. If all of the lanthanum in the feed (11.5 meq/l) exchanged with ammonium on the ore, then an ammonium solution level of 205 mg/l should have been obtained. The results indicate that over 85% of the lanthanum was effective in removing ammonium.

6.2.4.3 Leaching of Wyoming Ore With 1.0 g/l NH_4HCO_3 Saturated O_2 (45 psig), Followed by 1.0 g/l Na_2SiO_3 and Groundwater, Test 76

This test examined the use of sodium silicate as a post-leach restoration solution and as pre-leach ore bed stabilizer. The sodium silicate was passed through the ore bed after leaching to determine its effect on ion leakage. It was also added to the first 2 or 3 pore volumes of leach solution in order to determine its effect on permeability and uranium recovery when used for only a short duration. A previous test (Test 73) demonstrated that when sodium silicate was added

TABLE 6.38

Ion Leakage From Wyoming Ore After Leaching
With 1.0 g/l NH_4HCO_3 Saturated O_2 (45 psig), Test 75

Feed	Duration, Hrs.	Vol., ℓ	Σ Vol., ℓ	Σ Ore Pore Volumes	pH	U mg/ℓ	NH_4^+ mg/ℓ	La^{3+} mg/ℓ	$\text{SO}_4^{=}$ mg/ℓ	Cl^- mg/ℓ
LaCl_3 - LaSO_4	1008.0	--	--	--	7.99	--	181.0	--	--	--
	1050.0	20.8	20.8	2.2	8.11	2.7	188.0	< 10	120	80
	1098.0	20.0	40.8	4.3	8.11	0.88	173.0	--	--	--
	1170.0	18.4	59.2	6.2	8.26	--	178.0	< 10	240	160
	1218.0	17.3	76.5	8.0	8.35	1.0	177.0	--	--	--
Wyo. Grd. H_2O	1272.0	18.3	94.8	10.0	8.36	--	177.0	< 10	230	160
	1338.0	15.6	110.4	11.6	8.39	0.96	178.0	< 10	240	160
	1386.0	16.9	127.3	13.4	8.55	--	187.0	< 10	200	170
	1434.0	14.7	142.0	14.9	8.49	--	176.0	< 10	190	160

for the entire leach duration, permeability was significantly improved. However, uranium recovery was significantly reduced.

The test ran for a total of 1825.0 hours. The leach with sodium silicate ran for 42.0 hours, and the leach without sodium silicate ran for 750.0 hours. The post-leach sodium silicate flow was 385.0 hours long. The groundwater period was 456.0 hours in duration.

The permeability variations experienced during the solution flows are shown in Figure 6.67. By the conclusion of the deionized water period, the permeabilities of the front, middle, and end sections were 1.5, 2.0, and 3.0 darcy, respectively. Upon the injection of ammonium bicarbonate with sodium silicate, the permeabilities of all three sections showed an initial rapid decline and then a leveling off. Prior to injection of the leach without sodium silicate, the permeabilities of the front, middle, and end sections were 0.76, 1.1, and 1.5 darcy, respectively. The front section showed a gradual decline in permeability during subsequent leach. The permeability was 0.6 darcy after 120 hours of total leach, 0.25 darcy after 300 hours, and 0.04 darcy by the leach's conclusion. As is shown in Figure 6.68, the front section permeability during most of the leach was significantly higher than previous 1.0 g/l ammonium bicarbonate saturated oxygen tests (e.g., Test 62) using no sodium silicate pretreatment. The initial use of sodium silicate thus seems to be capable of stabilizing an ore bed during leaching. The effect, however, of the silicate treatment does seem to eventually wear off,⁽¹²⁾ as the permeability did eventually drop to the same level obtained in the previous tests. This is shown in Figure 6.68, which indicates that after about 550 hours of leach the front section permeability in the test with sodium silicate pretreatment equals that of the test with no silicate.

Following the injection of the post-leach 1.0 g/l sodium silicate, there was a gradual increase in the front section permeability. The permeability went from 0.03 darcy to 0.06 darcy within 100 hours after silicate injection, to 0.075 darcy within 200 hours after

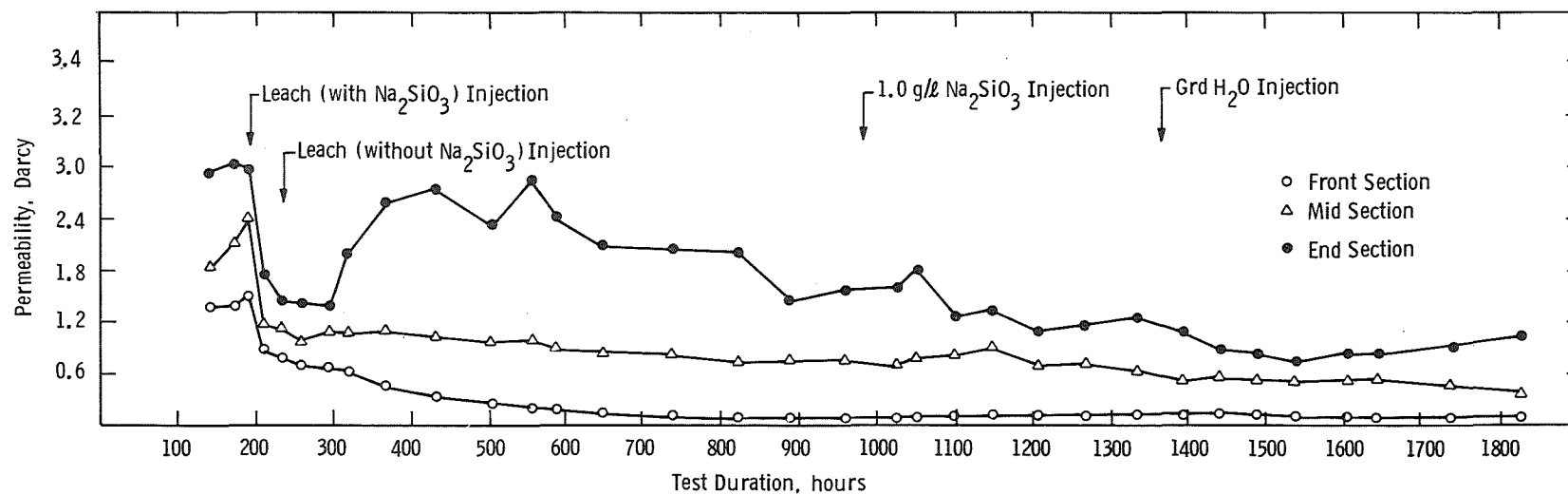


Fig. 6.67 - Permeability variations observed during leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 saturated O_2 (45 psig) (with 1.0 g/l Na_2SiO_3 initially), followed by 1.0 g/l Na_2SiO_3 and ground water, Test 76

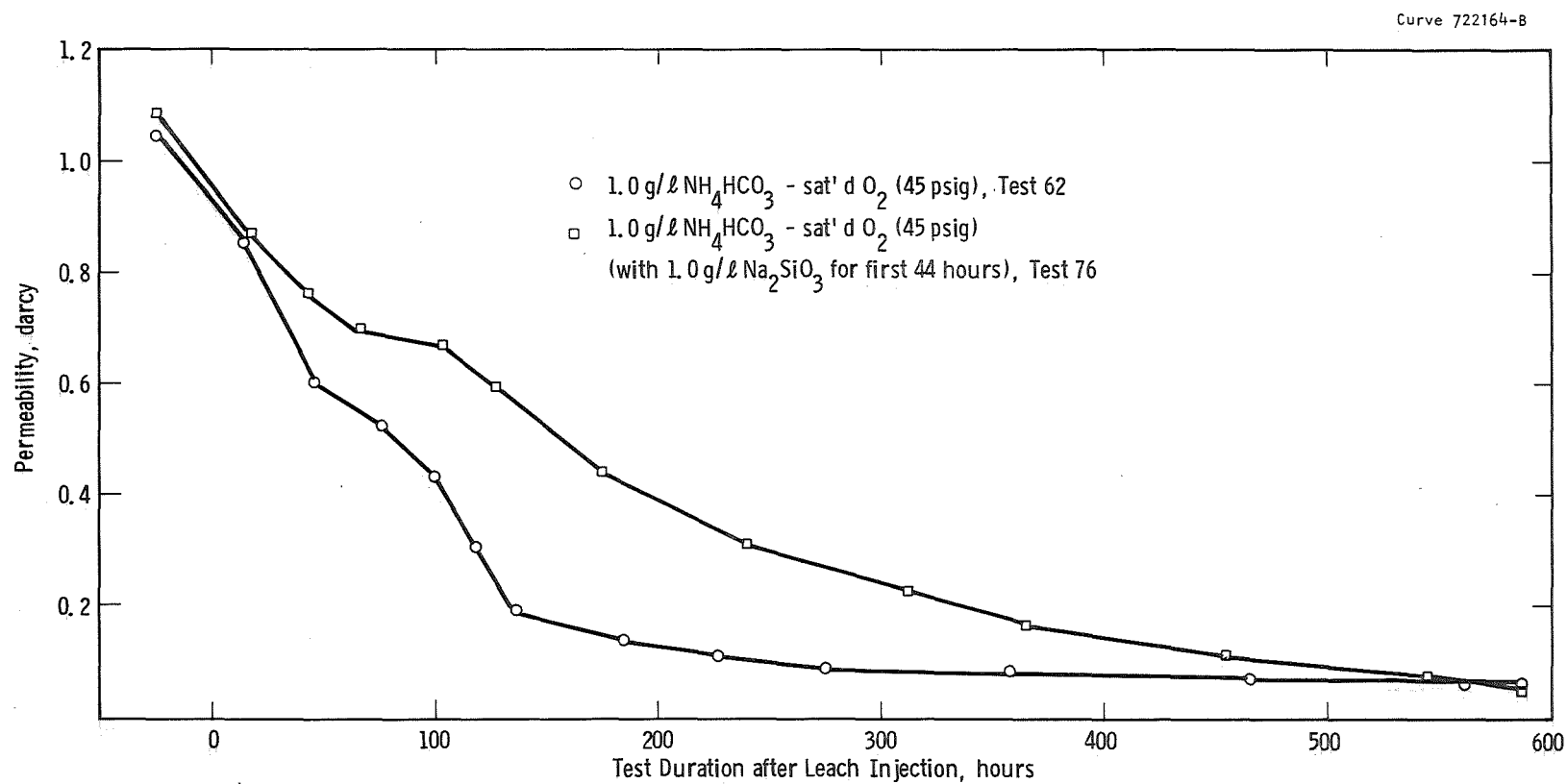


Fig. 6. 68 — Effect of Na_2SiO_3 pretreatment on permeability during leaching of Wyoming ore with 1.0 g/l NH_4HCO_3 - sat' d O_2 (45 psig)

injection, and to 0.09 darcy within 300 hours after injection. With the injection of groundwater, the front section permeability initially increased, then showed a gradual decrease and then finally increased again. It fell to 0.06 darcy within the first 150 hours of groundwater, and then rose to 0.08 darcy by the conclusion of the groundwater flow. This is significantly higher than the permeability (0.02 darcy) obtained with groundwater following an ammonium bicarbonate-saturated oxygen leach with no post-leach sodium silicate (Test 62). Thus, the use of sodium silicate seems to slowly improve permeability in leached ore beds where permeability has been greatly reduced, and to prevent permeability damage in subsequent solution flow.

The chemical data collected during the test is given in Table 6.39. The pH variations during leach (pH 7 to 8.3) were typical of previous ammonium bicarbonate leaches. During post-leach sodium silicate flow, the pH increased to between 9.6 and 9.8. During the subsequent groundwater flow, the pH slowly began to decrease reaching a final value of about 8.9. The concentration variations experienced during the various solution flows are given in Figure 6.69. The uranium and bicarbonate concentrations followed trends typical of previous ammonium bicarbonate leaches (e.g., Test 62). The ammonium variations indicate that in the 372.0 liters (38.0 pore volumes) of leach, a total of 46.9 g of ammonium was sorbed by the ore. This sorption level ($0.053 \text{ meq of } \text{NH}_4^+/\text{g of ore}$) was similar to that obtained in previous 1.0 g/l ammonium bicarbonate leach tests.

The uranium recovery rate observed is shown in Figure 6.70. In the first 10 pore volumes (98 liters) of actual leach collected, about 32% of the uranium was recovered. This is about the same initial recovery rate as that obtained in previous 1.0 g/l ammonium bicarbonate leaches (e.g., Test 62). The total recovery ($\sim 66\%$) by the conclusion of leach was also similar to the previous leaches. Thus, the use of 1.0 g/l sodium silicate initially with the leach (2.6 pore volumes) did improve permeability without adversely affecting uranium recovery.

TABLE 6.39

Summary of Data Obtained During Leaching of Wyoming Ore
Using 1.0 g/l NH_4HCO_3 -saturated O_2 (45 psig),
Followed by 1.0 g/l Na_2SiO_3 , Test 76

Duration, Hrs.	Product Solution Vol., l	Σ Vol., l	Σ Ore Pore Volumes (1 PV=9.8l)	pH	U mg/l	NH_4^+ mg/l	HCO_3 mg/l	% Uranium Recovery
192.0	51.7	51.7	5.3	6.70	219	---	430	22.9
234.0	25.4	77.1	7.9	6.93	171	---	380	31.6
306.0	34.5	111.6	11.4	6.80	212	---	650	46.4
360.0	31.8	143.4	14.6	7.03	118	---	650	54.0
428.0	38.9	182.3	18.6	7.43	---	15	---	---
480.0	28.6	210.9	21.5	7.75	41	58	680	59.5
546.0	37.8	248.7	25.4	7.70	---	105	---	---
597.0	28.1	276.8	28.2	7.94	---	---	---	---
666.0	36.9	313.7	32.0	8.02	18	146	660	63.3
738.0	35.7	349.4	35.7	8.06	---	---	---	---
816.0	27.0	376.4	38.4	8.11	---	159	---	---
906.0	27.0	403.4	41.2	8.09	---	---	---	---
984.0	20.3	423.7	43.2	8.34	11	176	700	65.7
1050.0	16.2	439.9	44.9	8.32	9.4	153	600	66.0
1101.0	20.5	460.4	47.0	9.26	3.4	114	380	66.2
1146.0	17.4	477.8	48.8	9.65	1.8	153	600	66.2
1218.0	18.6	496.4	50.7	9.70	---	---	---	---
1269.0	16.5	512.9	52.3	9.67	<0.1	121	400	66.2
1315.0	17.8	530.7	54.2	9.80	---	---	---	---
1369.0	20.8	551.5	56.3	9.83	<0.1	129	430	66.2
1438.0	17.8	569.3	58.1	9.66	0.68	169	450	66.3
1555.0	17.0	586.3	59.8	9.33	---	177	400	66.3
1657.0	21.2	607.5	62.0	8.90	0.56	140	350	66.3
1747.0	22.0	629.5	64.2	8.98	---	---	---	---
1825.0	27.9	657.4	67.1	8.88	---	---	---	---

Times of Solution Injection: 1) NH_4HCO_3 - Na_2SiO_3 - O_2 - 192.0 hours
 2) NH_4HCO_3 - O_2 - 234.0 hours
 3) Na_2SiO_3 - 984.0 hours
 4) Wyo. Grd. H_2O - 1369.0 hours

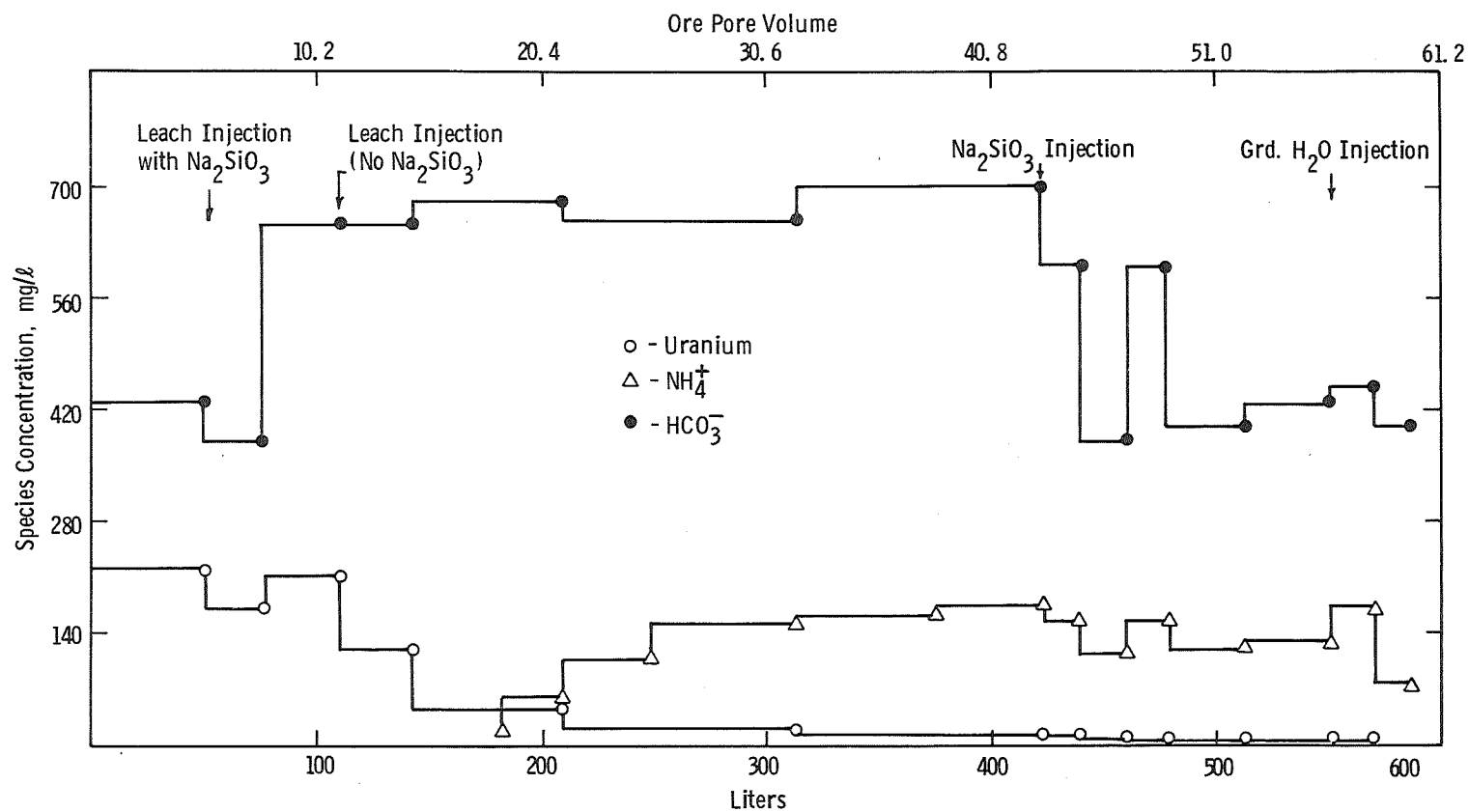


Fig. 6.69 - Concentration variations experienced during leaching of Wyoming ore with 1.0 g/l NH_4HCO_3 saturated O_2 (45 psig), followed by 1.0 g/l Na_2SiO_3 , Test 76.

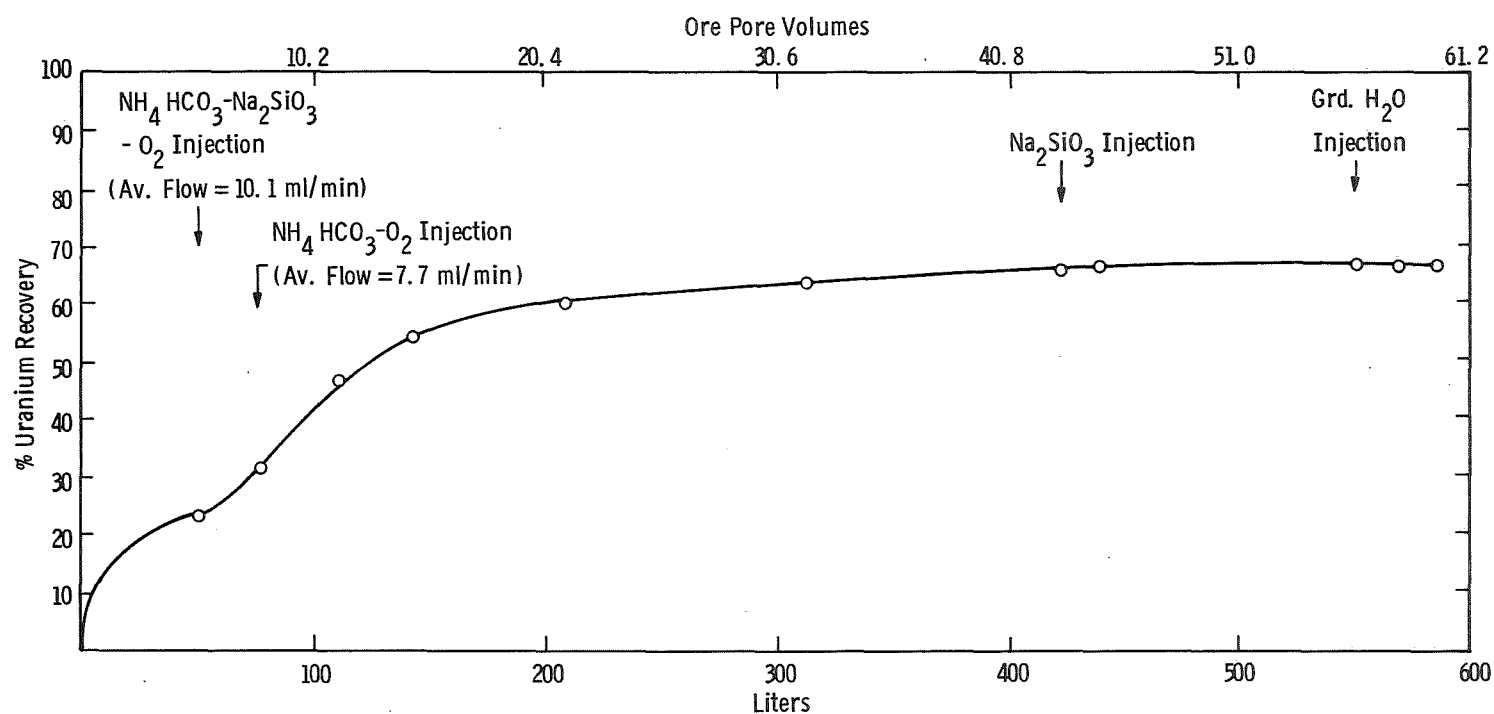


Fig. 6.70 - Uranium recovery rate observed during leaching of Wyoming ore with 1.0 g/l NH_4HCO_3 saturated O_2 (45 psig), followed by 1.0 g/l Na_2SiO_3 , Test 76.

The chemical leakage data obtained during the post-leach solution flows is given in Table 6.40. The uranium level dropped to less than 1.0 mg/l during the sodium silicate flow thus indicating that this solution is effective in reducing post-leach uranium leakage. During this solution flow, the ammonium level stayed between 114 and 153 mg/l (or 6.3 and 8.5 meq/l). The sodium product levels indicate that essentially all of the sodium in the feed (16.4 meq/l) was lost from solution. The results thus indicate that only about half of the sodium lost from solution exchanged with the ammonium. The rest of the sodium may have exchanged with other cations (e.g., Ca^{++} or Mg^{++}) present on the ore, and/or may have precipitated with silicate. The silicate product concentrations indicate that it too was lost from solution.

During the groundwater flow, the ammonium level initially increased to about 170 mg/l (9.4 meq/l). The milliequivalent cation concentration of the groundwater (10.7 meq/l) would account for the observed leakage. This ammonium leakage level was similar to that obtained in previous groundwater flows with no restoration (e.g., Test 62). Thus, the sodium silicate did not seem to be effective in reducing ammonium leakage. Sodium and silicate leakage did occur during the groundwater flow, indicating that perhaps some of the sodium silicate lost during restoration was now being removed from the ore bed. The uranium leakage remained below 1 mg/l during the groundwater flow.

6.2.4.4 Leaching of Wyoming Ore Using 1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2 , Followed by 3.0 g/l LaCl_3 - $\text{La}_2(\text{SO}_4)_3$, then 1.0 g/l Na_2SiO_3 - 2.0 g/l NaCl , and Finally Groundwater, Test 81

This test was designed to initially examine the post-leach restoration effectiveness of a relatively high concentration lanthanum solution; in particular, its ability to remove ammonium from the ore bed. The test then examined the restoration ability of a sodium silicate-sodium chloride solution. A previous test (Test 76) had shown that sodium silicate could reduce post-leach uranium leakage. That test had also shown that a high solution pH (~ 9.5) was maintained by the sodium silicate. Studies ⁽¹⁴⁾ have shown that a high solution pH will improve ammonium removal. Thus, it was hoped that a sodium silicate solution,

TABLE 6.40
Ion Leakage from Wyoming Ore Following 1.0 g/l NH_4HCO_3
Saturated O_2 (45 psig) Leach, Test 76

Feed	Duration, Hrs.	Vol., ℓ	Σ Vol., ℓ	Σ Ore Pore Volumes	pH	U mg/ℓ	NH_4^+ mg/ℓ	Si mg/ℓ	HCO_3^- mg/ℓ	Na^+ mg/ℓ
1.0 g/ℓ Na_2SiO_3	984.0	---	---	---	8.34	---	176	---	700	---
	1050.0	16.2	16.2	1.7	8.32	9.4	153	10	600	0.14
	1101.0	20.5	36.7	3.7	9.26	3.4	114	60	380	0.17
	1146.0	17.4	54.1	5.5	9.65	1.8	153	70	600	0.12
	1218.0	18.6	72.7	7.4	9.70	---	---	---	---	---
	1269.0	16.5	89.2	9.1	9.67	0.1	121	90	400	0.10
	1315.0	17.8	107.0	10.9	9.80	---	---	---	---	---
Wyo. Grd. H_2O	1369.0	20.8	127.8	13.0	9.83	0.1	129	150	430	0.50
	1438.0	17.8	145.6	14.9	9.66	0.68	169	130	450	11
	1555.0	17.0	162.6	16.6	9.33	---	177	50	400	72
	1657.0	21.2	183.8	18.8	8.90	0.56	140	60	350	108

with sodium chloride added to build up the sodium cation feed concentration, would show a relatively high ammonium removal rate in addition to lowering uranium leakage. Groundwater was passed through the ore bed at the end of the test to determine if the restoration effort was in fact successful.

The test was run for a total of 1710.0 hours. The solution flow sequence and duration was as follows: deionized water - 216.0 hours, ammonium bicarbonate - 798.0 hours, lanthanum solution - 145.0 hours, sodium solution - 215.0 hours, and groundwater - 336.0 hours.

The permeability variations experienced during this test are illustrated in Figure 6.71. During deionized water flow, the front section permeability was higher than usual at about 2.8 darcy. The middle and end sections were at about 1.8 and 1.0 darcy, respectively. Following leach injection, the front section dropped rapidly, while the middle and end sections fluctuated between 0.75 and 1.5 darcy. The front section dropped to 0.2 darcy by 120 hours of leach, to 0.06 darcy by 200 hours, and a relatively stable 0.03 darcy after 300 hours. This permeability decline was more severe than when using 1.0 g/l ammonium bicarbonate saturated with oxygen at 45 psig (Test 62). In that test, the front section permeability was 0.1 darcy after 300 hours. The greater permeability damage was the result of the higher oxygen content (~ 235 mg/l), formed by the rapid decomposition of the peroxide, used in this test.

With the injection of the lanthanum chloride-sulfate solution, there was an immediate improvement in permeability. The middle and end sections rose to about 2 and 2.5 darcy, respectively. The front section rose to, and leveled off at, about 0.25 darcy. The permeability improvement is thought to be caused in part by the exchange of the tri-valent lanthanum cation for ammonium on the ore's clay. This exchange, and the high ionic strength of the solution, could reduce clay swelling and clay dissociation and dispersion. Also, perhaps oxygen gas released during leaching is redissolved in this oxygen-free solution.

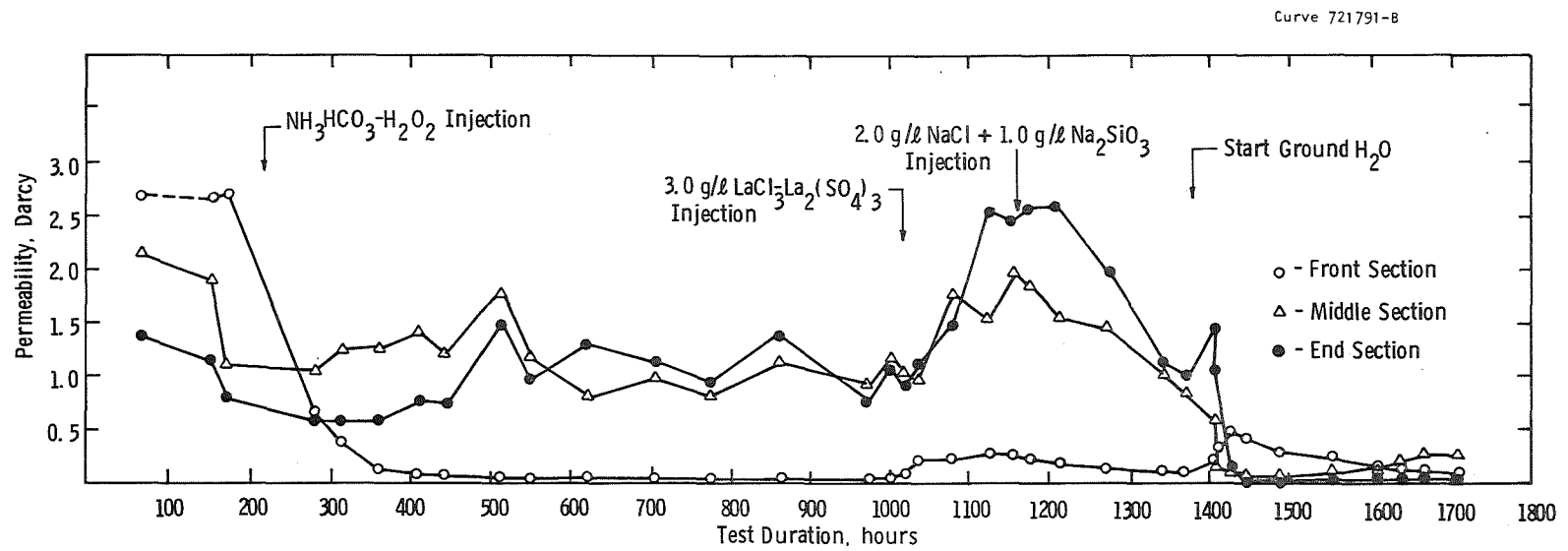


Fig. 6.71 — Permeability variations experienced during leaching of Wyoming ore with 1.0 g/l $\text{NH}_4\text{HCO}_3\text{-0.5 g/l H}_2\text{O}_2$, followed by 3.0 g/l $\text{LaCl}_3\text{-La}_2(\text{SO}_4)_3$, then 2.0 g/l NaCl - 1.0 g/l Na_2SiO_3 , and finally ground water, Test 81

After the injection of the sodium silicate-sodium chloride, there was a gradual decline in the front section permeability, and a more severe decline in the middle and end sections. By the conclusion of this solution flow, the front, middle, and end sections had fallen to about 0.08, 1.0, and 1.0 darcy, respectively. Sodium exchange onto the ore was the likely cause for this decline. Sodium-substituted clays swell, and more easily dissociate and disperse. The greater permeability damage occurred in the middle and end sections because it is likely that it is in those sections where a majority of the sodium exchange is occurring. This is likely true because lanthanum exchange during the previous solution should have occurred to a greater extent in the front section. The highly-charged lanthanum cation will be readily picked up by the ore, thus most of the exchange would have occurred in the front end of the column. Sodium will not exchange as readily with lanthanum as it will with the lower charged ammonium,⁽⁶⁾ which should be present in the greatest amounts in the middle and end sections.

During the final groundwater flow, there were some unique permeability variations. The permeability in all three sections tended to become equal. The front section permeability initially rose then gradually declined. The middle section permeability initially dropped then showed a gradual increase. The end section dropped rapidly and seemed to remain at the low level. The previous sodium silicate tests (Tests 73 and 76) had also shown unique variations. Perhaps the coating of silicate on the ore body is responsible. Also, the sodium exchange onto the clay is likely responsible, in part, for the permeability damage that occurs in all three ore bed sections.

The chemical data obtained during this test is given in Table 6.41. The variations in pH during leach were typical of the previous bicarbonate leaches. The pH dropped slightly (from 8.1 to 7.8) with the injection of the acidic lanthanum solution (pH = 3.7). The pH then rose with the injection of the basic sodium solution (pH = 10.6), and

TAB' E 6.41

Summary of Data Obtained During Leaching of Wyoming Ore Using 1.0 g/l NH_4HCO_3 -0.5 g/l H_2O , Followed by 3.0 g/l LaCl_3 - $\text{La}_2(\text{SO}_4)_3$, then 1.0 g/l Na_2SiO_3 -2.0 g/l NaCl , and Finally Grd. H_2O , Test 81

Duration, Hrs	Product Solution Vol, l	Σ Vol, l	Σ Ore Pore Volumes (1PV = 10.2 l)	pH	NH_4^+ mg/l	Uranium mg/l	% Uranium Recovery
75.0	27.3	27.3	2.7	6.09	-	290	15.7
123.0	6.8	34.1	3.3	6.99	-	-	-
216.0	40.0	74.1	7.3	7.45	-	27	18.2
291.0	32.2	106.3	10.4	7.03	-	241	33.7
360.0	35.7	142.0	13.9	7.20	-	199	47.8
456.0	39.6	181.6	17.8	7.61	6	-	-
579.0	31.8	213.4	20.9	7.85	29	56	55.7
702.0	25.2	238.6	23.4	7.97	58	-	-
840.0	27.0	265.6	26.0	7.98	77	-	-
1014.0	35.8	301.4	29.5	8.09	97	27	60.5
1038.0	11.7	312.1	30.6	7.93	131	2.2	60.5
1083.0	12.4	324.5	31.8	7.93	208	4.5	60.6
1158.0	14.2	338.7	33.2	7.83	218	1.8	60.7
1206.0	12.2	350.9	34.4	7.82	250	2.1	60.7
1251.0	13.9	364.8	35.8	7.79	315	1.4	60.8
1302.0	14.2	379.0	37.2	8.02	231	4.7	60.9
1374.0	17.2	396.2	38.8	8.25	175	1.8	61.0
1464.0	16.4	412.8	40.5	8.49	106	3.1	61.1
1588.0	12.6	425.4	41.7	8.83	49	5.0	61.2
1710.0	13.2	438.6	43.0	8.80	42	4.2	61.3

Times of Solution Injection: (1) NH_4HCO_3 - H_2O_2 - 216.0 hrs
 (2) LaCl_3 - $\text{La}_2(\text{SO}_4)_3$ - 1014.0 hrs
 (3) NaCl - Na_2SiO_3 - 1158.0 hrs
 (4) Wyo. Grd. H_2O - 1374.0 hrs

continued to rise to about a pH of 8.8 during the subsequent groundwater flow. The uranium recovery rate observed in this test is shown in Figure 6.72. In the first 10 pore volumes of leach, approximately 35% of uranium was recovered, which is slightly higher than the previous ammonium bicarbonate leaches. The lower than usual leach flow rate (4.8 ml/min), and thus the higher residence time, could account for this higher initial uranium recovery. However, the total recovery was only 60.5% after the 238 liters of leach. This recovery was less than that obtained in previous ammonium bicarbonate leaches (e.g., Test 62 - 63.5% after 238 liters of leach). The lower total recovery was likely due to the greater permeability damage experienced in this test, which could have resulted in less uranium accessibility.

The concentration variations experienced during this test are shown in Figure 6.73. The uranium and ammonium concentration variations during leach were similar to previous ammonium bicarbonate leaches. The ammonium product levels indicate that in the 238 liters (23.3 pore volumes) of leach, a total of 40.4 g of ammonium was sorbed by the ore. This ammonium sorption level (0.047 meq of NH_4^+ /g of ore) was slightly higher than obtained in previous 1.0 g/l ammonium bicarbonate leaches during the same volume of leach (e.g., Test 62 - 0.042 meq of NH_4^+ /g of ore). The much slower flow rate permitted ammonium equilibrium between the ore and solution to be more nearly reached.

The post-leach chemical leakage data is given in Table 6.42. During the lanthanum solution flow, the uranium and selenium dropped to less than 2 mg/l and to 50 ppb, respectively. During this flow, the ammonium level peaked at about 220 mg/l (12.2 meq/l). This indicates that only about 36% of the lanthanum in the feed (34.2 meq/l) was effective in removing ammonium. The product solution levels indicate that essentially no lanthanum passed through the ore bed, thus the lanthanum must have exchanged with other cations (e.g., Ca^{++}) on the ore, and/or precipitated out of solution. The substantial increase in pH (from 3.7 to 8) and carbonate level after the solution contacted the ore may have resulted in the precipitation of the lanthanum.

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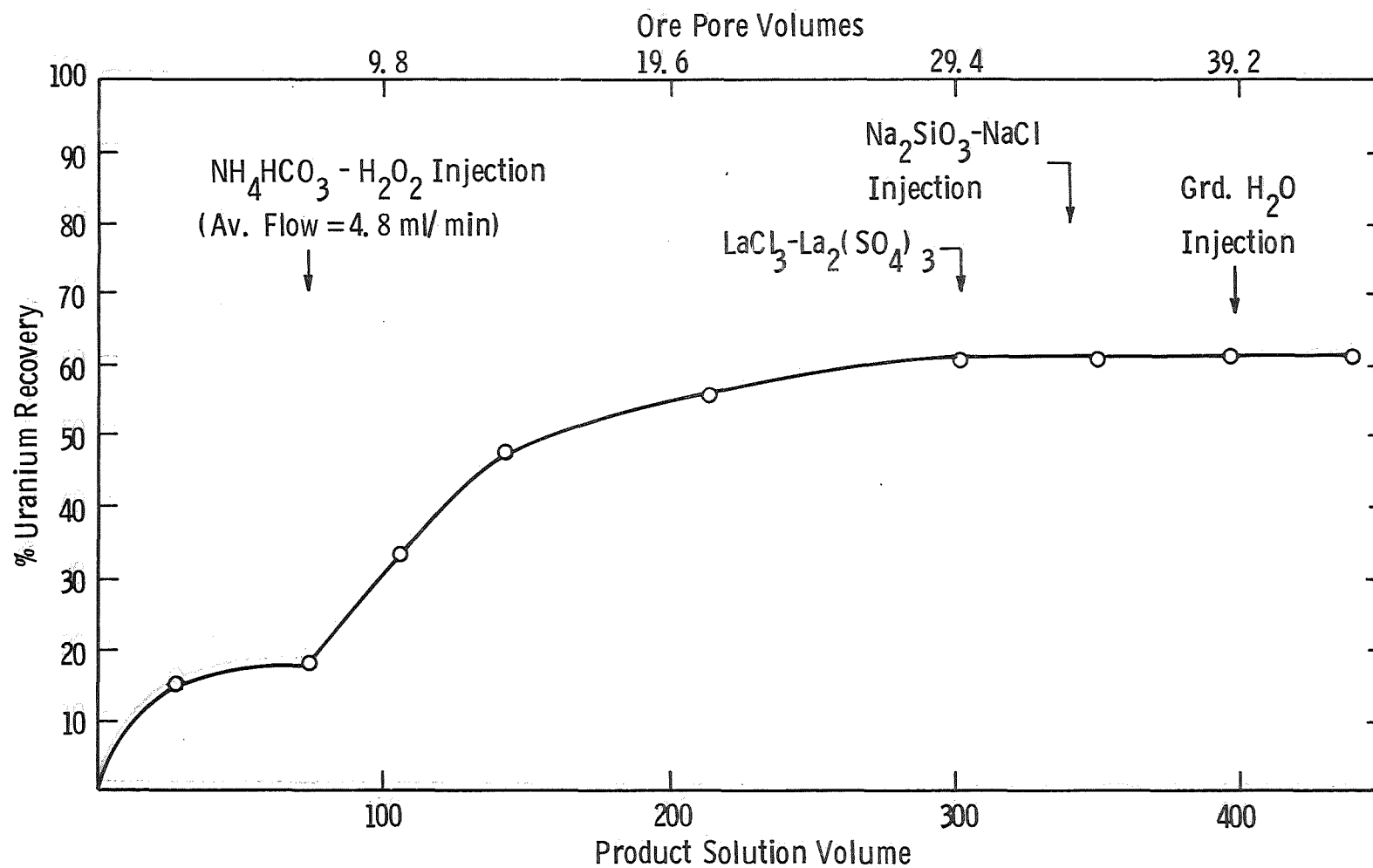


Fig. 6.72—Uranium recovery rate observed during leaching of Wyoming ore using 1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2 , Test 81

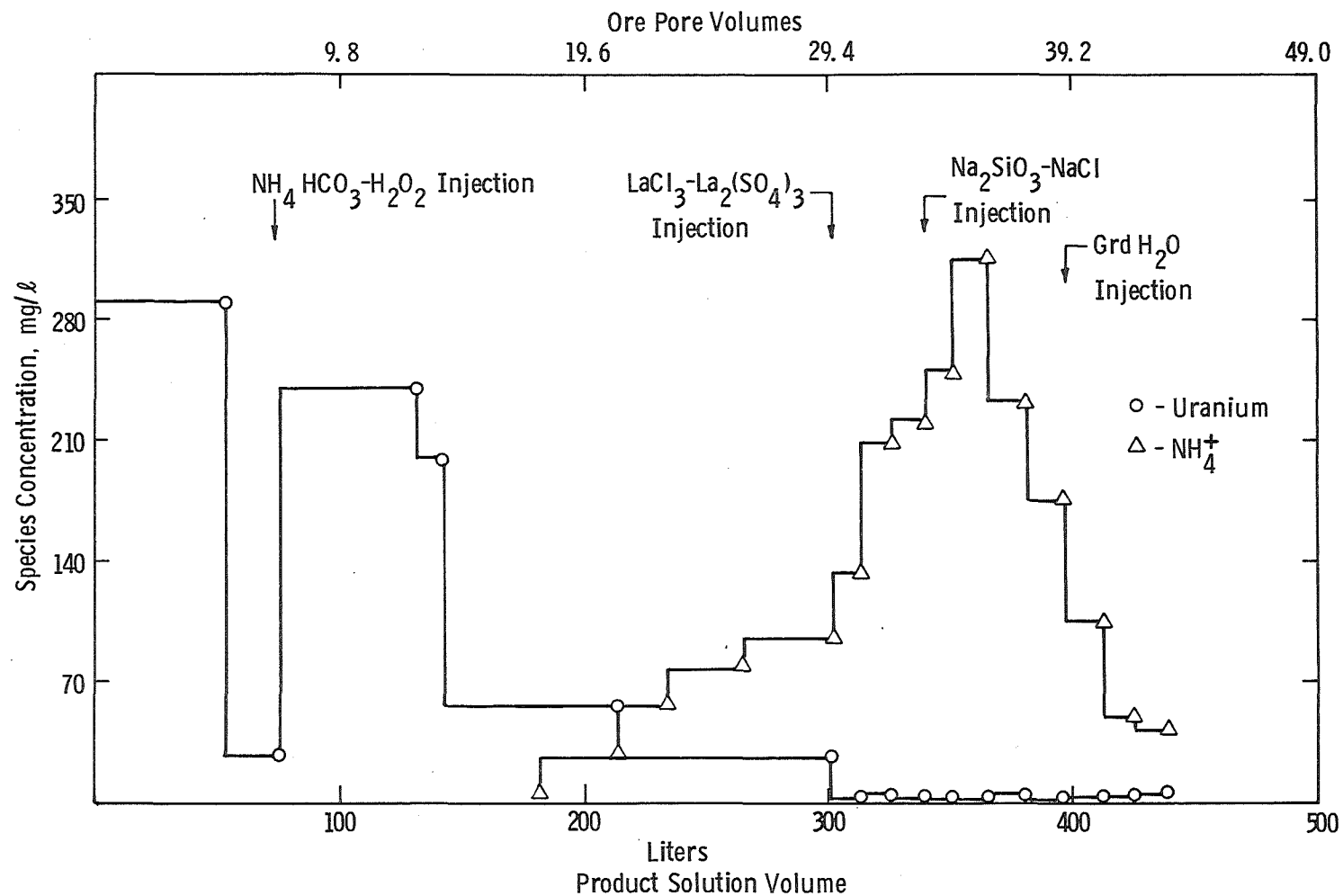


Fig. 6.73—Concentration variations experienced during leaching of Wyoming ore using 1.0 g/l $\text{NH}_4\text{HCO}_3\text{-0.5 g/l H}_2\text{O}_2$, followed by 3.0 g/l $\text{LaCl}_3\text{-La}_2(\text{SO}_4)_3$, then 1.0 g/l $\text{Na}_2\text{SiO}_3\text{-2.0 g/l NaCl}$, and finally ground water, Test 81

TABLE 6.42

Ion Leakage from Wyoming Ore After Leaching
with 1.0 g/l NH_4HCO_3 -0.5 g/l H_2O_2 , Test 81

Feed	Duration, hrs	Vol, ℓ	Σ Vol, ℓ	Σ Ore Pore Volumes	pH	U mg/ℓ	NH_4^+ mg/ℓ	Se mg/ℓ	La mg/ℓ	Na mg/ℓ
3.0 g/ LaCl_3 - $\text{La}_2(\text{SO}_4)_3$	1014.0	-	-	-	-	-	-	-	-	-
	1038.0	11.7	11.7	1.1	7.93	2.2	131	0.130	<0.5	-
	1083.0	12.4	24.1	2.4	7.93	4.5	208	0.064	<0.5	-
1.0 g/ Na_2SiO_3 -2.0 g/ NaCl	1158.0	14.2	38.3	3.8	7.83	1.8	218	0.050	<0.5	-
	1206.0	12.2	50.5	5.0	7.82	2.1	250	0.039	<0.5	-
	1251.0	13.9	64.4	6.3	7.79	1.4	315	0.049	<0.5	0.6
	1302.0	14.2	78.6	7.7	8.02	4.7	231	0.053	-	-
Wyo. Grd H_2O	1374.0	17.2	95.8	9.4	8.25	1.8	175	-	-	464
	1464.0	16.4	112.2	11.0	8.49	3.1	106	0.123	-	-
	1588.0	12.6	124.8	12.2	8.83	5.0	49	-	-	178
	1710.0	13.2	138.0	13.5	8.80	4.2	42	1.14	-	176

As shown in Figure 6.74, with the injection of the sodium silicate-sodium chloride there was a substantial increase in the ammonium removal rate. The increase in pH due to the addition of sodium silicate thus did seem to benefit ammonium removal. The ammonium level peaked at 330 mg/l, or 18.3 meq/l. At the cation concentration level of this feed (50.6 meq/l), 36.2% of the sodium was effective in removing ammonium. A greater percentage of the sodium would likely have been utilized (i.e., a higher ammonium solution level) at the higher ammonium ore level which existed prior to the lanthanum restoration. The greater ammonium removal may have been in part due to the higher cation equivalent concentration used in the sodium test as well as the higher pH.

The injection of the sodium solution resulted in an increase in uranium and selenium leakage. The increased mobilization of uranium and selenium may have been due to several causes. During leaching, only about 60% of the uranium was removed, which was much less than the 70 to 75% which is typically removed. There was thus an unusually high amount of uranium still available in the ore bed. The presence of significant chloride in the restoration solution may have aided in the removal of this uranium, since uranyl chloride is very soluble. In addition, the selenium is much more soluble at the higher pH of this solution. During the subsequent groundwater flow, the ammonium concentration dropped to less than 50 mg/l. However, the uranium level was the same as with no restoration (Test 62), while the selenium was very much higher (1.14 vs. 0.13 mg/l). This higher leakage level was possibly due to the higher pH (8.8 vs. 8.2 in Test 62) experienced during the groundwater flow following the sodium restoration solution. Perhaps it would be advantageous to contact the leached ore with just sodium silicate after a certain percentage of the ammonium has been removed with a mixture of sodium silicate and a soluble cation salt. Sodium silicate alone (Test 76) has shown the ability to reduce uranium leakage.

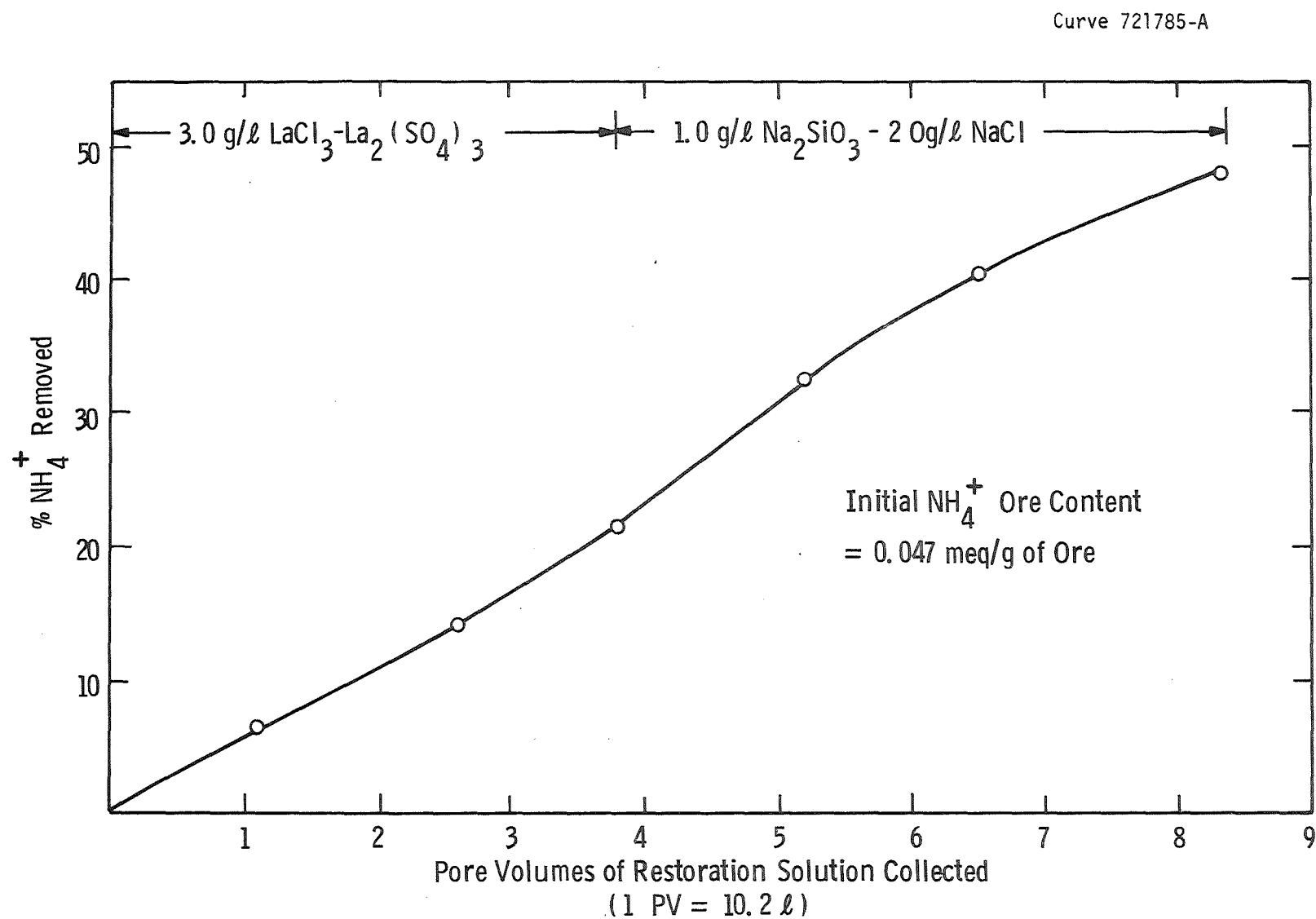


Fig. 6.74—Ammonium removal rate observed during 3.0 g/l $\text{LaCl}_3\text{-La}_2(\text{SO}_4)_3$ flow and 1.0 g/l Na_2SiO_3 -2.0 g/l NaCl flow after leaching with 1.0 g/l NH_4HCO_3 -0.5 g/l H_2O_2 . Test 81

6.3 DISCUSSION OF TEST RESULTS

6.3.1 Discussion of Baseline Test Results

The baseline tests performed allow a comparison of the leaching characteristics to be made between the various leach solutions and between the different ores. A comparison of the leach solutions is useful in understanding and determining potential pumping or injection problems, the factors which influence the total and rate of uranium recovery, and the environmental effects and restoration requirements associated with a given leach solution.

A comparison of the operating conditions and the leach characteristics on Wyoming ore of the ammonium, potassium, and sodium bicarbonate solutions, and the sulfuric acid solution are given in Table 6.43. For the comparison, the results of Test 62 will be used for the ammonium bicarbonate leach. The results of Test 78 were very similar. The results of the column tests suggest several mechanisms that are responsible for many of the permeability changes that occurred. The mechanisms include:

1. Clay interaction with leach.
2. Gas blockage.
3. Adverse reactions with ore material.

Although these mechanisms do seem to explain many of the permeability changes observed in the column studies, other mechanisms may also exist.

Some of the permeability decreases experienced are attributed to the damaging effects of clay swelling, and clay deflocculation and dispersion. A significant fraction of the ore (10 wt%) is clay. The Montmorillonite clay found in the ore studied is capable of large volume expansions due to the sorption of water between layers of clay.⁽¹⁵⁾ This swelling is a function of the cations present on the clay. Also, the cations, sorbed on the clay surfaces to neutralize the particle, tend to dissociate causing a negative charge to exist on the particle.⁽¹⁶⁾ The negatively-charged clay particles thus tend to repel each other and disperse. The tendency of the cation to dissociate determines the

TABLE 6.43

Operating Conditions and Leaching Characteristics
of the Baseline Uranium Leach Tests on Wyoming Ore

Test No	Leach Solution	Average Leach Flow Rate, ml/min	Vol. of Leach Collected ℓ	% U Recovered By Conclusion of Leach	Amt. of Leach Cation Sorbed meq/g of ore	Permeability (Front Ore Section) at Various Leach Durations, Darcy		
						50 hrs.	150 hrs.	300 hrs.
62	1.0 g/ℓNH ₄ HCO ₃	7.9	364.3	68.0	0.056	0.7	0.2	0.1
65	1.0 g/ℓKHCO ₃	8.9	409.0	70.2	0.053	0.9	0.2	0.1
63	2.0 g/ℓNaHCO ₃	3.6	162.4	74.7	0.030	0.2	0.04	0.03
69	H ₂ SO ₄ , pH=1.0	8.1	219.9	76.6	---	0.6	0.2	0.1

strength of this repulsion. Dissociation is greater for a monovalent cation than a multivalent cation because it is less positive and thus is less tightly held. The dissociation rate also increases with a decrease in the surrounding salt concentration and ionic strength.

The bicarbonate leach tests indicate the likely presence of these mechanisms, and demonstrate the effect of the leach cation on permeability. As Figure 6.75 shows, potassium and ammonium bicarbonate leaches had similar permeabilities, while sodium bicarbonate leach produced a much lower permeability. Sodium cations have been found to be more loosely held on the clay surface,⁽¹⁷⁾ thus greater clay dispersion and resulting migration were a likely cause of the more pronounced permeability damage with sodium. Further evidence for clay dispersion is the significant permeability decline that occurs during post-leach groundwater flow. The low ionic strength of the groundwater would result in an increase in clay movement and, thus, a decrease in permeability. Restarting the groundwater flow seems to cause a re-opening of the pores, perhaps by moving clay particles slightly simply by the initial impact of the solution. However, this improvement is short-lived, as the flow rate drops and the particles re-orient themselves and again block the pores.

It has been postulated that clay migration should occur equally in all sections of the ore bed. It may in fact occur in all sections; however, the permeability damage is greatest in the front section, and if clay dispersion is a major contributor to this damage, then most of the clay dispersion must be occurring here. This is possible for several reasons. The front section is where most of the cation substitution on the clay has occurred. The clay that then migrates may move only a very short distance before blocking a pore. Also, the ionic strength of the leach solution can increase as it passes through the ore bed, as ore material dissolves, thus less dispersion will occur in the end sections of the ore bed. The results of Test 78, in fact, indicate that if a low ionic strength solution is passed through the column for a long enough period then clay dissociation and dispersion do

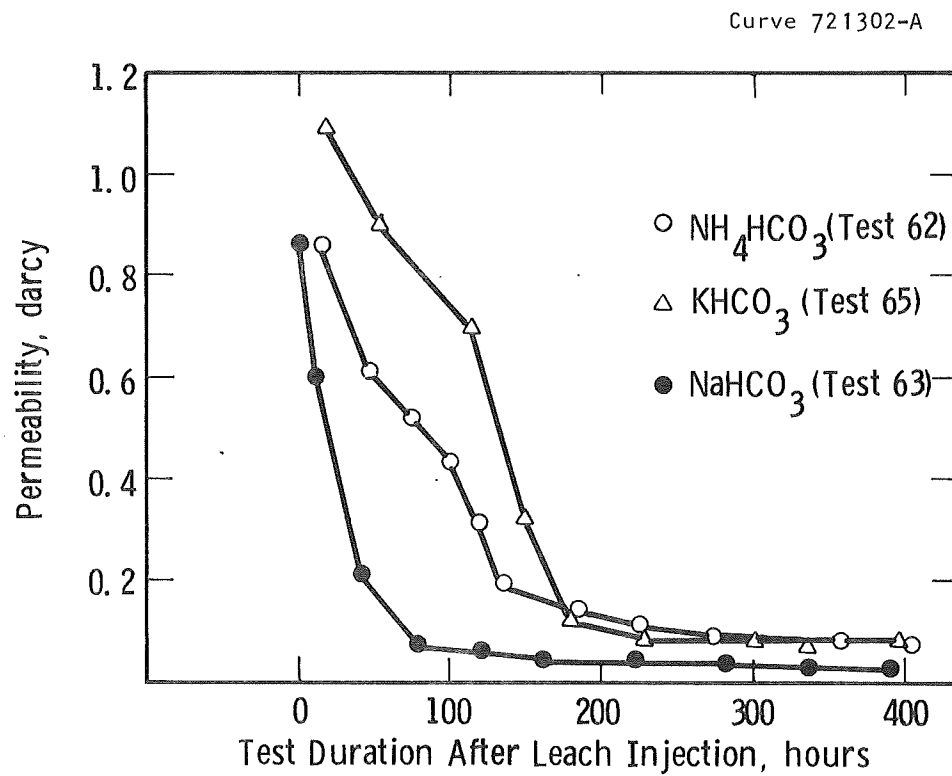


Fig. 6.75 - Effect of bicarbonate leach cation on permeability in front ore section

likely occur in the middle and end sections, as permeability damage does eventually occur there. In the bicarbonate tests, the gradual decline in permeability is attributed to clay swelling. The total effect of swelling should be a function of the type and amount of cation sorbed, which occurs over the entire test duration. In the acid leach tests, the gradual permeability decline is perhaps caused by gypsum precipitation, or by an increase in fines in the packing leading to greater tortuosity, or by a change in the ore minerals caused by the action of the acid.

The major cause of permeability damage is gas blockage. In the bicarbonate tests, the oxidant, 110 mg/l of dissolved oxygen, is the source of this gas problem. At the initial pressure of the ore bed (1 atm) only about 35 mg/l of oxygen is soluble. The remainder of the oxygen in the feed (75 mg/l) must either react rapidly with the ore or is released from solution. The time required for the oxidation reactions to occur and the presence of an excess of oxygen to react with the ore results in the oxygen concentration exceeding its solubility limit. Oxygen gas is thus released from solution, and nucleates on the ore particles in the void areas of the bed. This gas blockage thus reduces the flow area, increases tortuosity, and increases the gas-liquid surface tension forces. This release of gas occurs because the solutions are saturated with oxygen at pressures greater than those existing in the ore bed. The tests thus point out the desirability of using a dissolved oxygen content that does not exceed the level that can remain in solution at the pressure existing in the ore bed. Exceeding the solubility limit in the ore bed can result in oxygen gas blockage and thus immediate permeability damage.

Another source of gas blockage is the generation of carbon dioxide during acid leaching. The high carbonate content of the Wyoming ore can produce, when contacted with acid, significant levels of carbon dioxide. The rapid decrease in permeability in this low pH test is an example of this gas blockage problem.

The chemical data collected during the column tests provide insight into the actual leaching process and into the simulation of this process. First, initial solution flow through the ore bed suggests the possibility of ore pre-oxidation. A substantial amount (20-30%) of the uranium was removed when deionized water was used initially. The deionized water data indicates that the uranium is recovered when sufficient bicarbonate and/or sulfate are solubilized from the ore. The solubilized uranium must have been oxidized during ore processing, or by an oxidant solubilized in the water. Calculations show that 40 liters of water, containing oxygen at a level of 8 mg/l, could oxidize about 10% of the available uranium. The possibility also exists that oxidants (e.g., Fe^{+++}) were solubilized from ore. This, however, was not examined during the tests.

Pre-oxidation of the ore might help to explain what is occurring during the actual leaching process. Upon chemical injection, there is typically an immediate high uranium pulse, after which the uranium tends to level off. This high amount of uranium may be that which is pre-oxidized and/or easily accessible. It is likely that the easily accessible would be most readily pre-oxidized. If this is the case, then the uranium leaching would be controlled by only the dissolution rate. As unoxidized or less accessible uranium is leached, the oxidation rate, complexation rate, and/or the diffusion rate are likely to control the uranium recovery. In order to effectively use any overall kinetic data obtained from the leach test responses, it is essential to know how the oxidation state and the accessibility of the uranium has changed during processing. A significant change from that of the actual ore could greatly distort the observed recovery rate in the simulation tests.

The uranium recovery rates observed during the various leaches, shown in Figure 6.76, seem to point out the importance of several operating variables. The potassium and ammonium bicarbonate leaches showed similar uranium recovery rates. Sodium bicarbonate, while having a total uranium recovery similar to the other bicarbonate leaches, had

Curve 721303-A

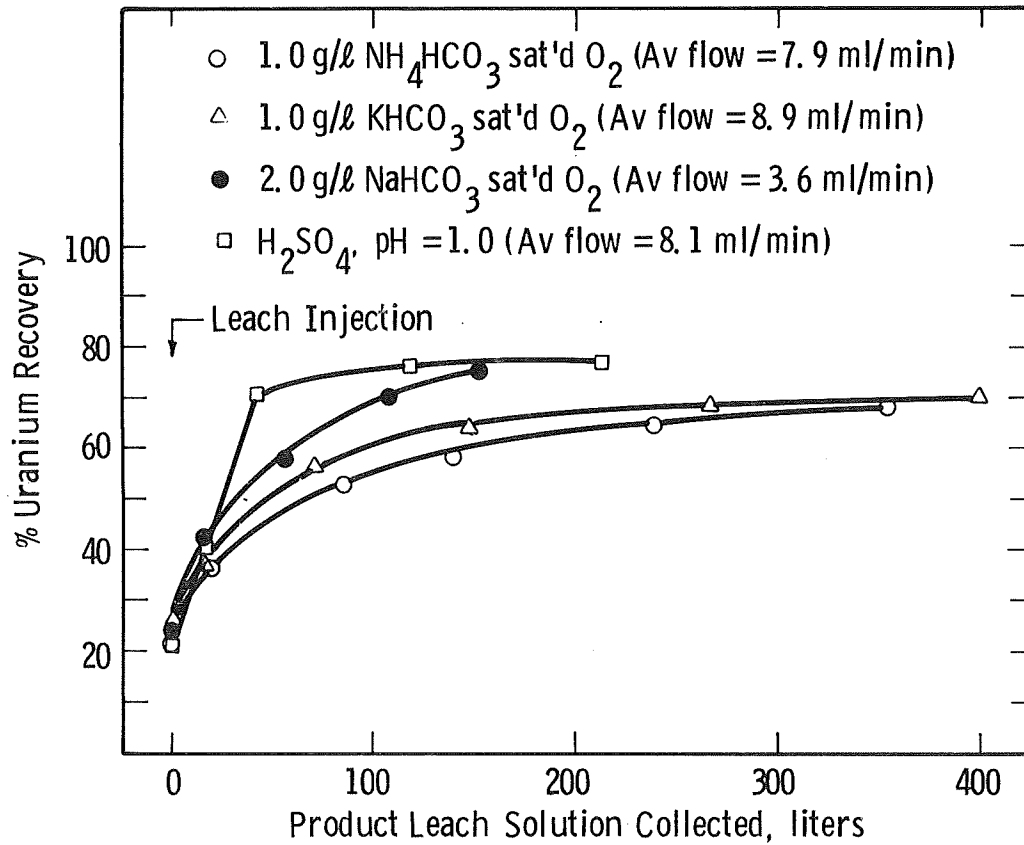


Fig. 6.76—Uranium recovery rates obtained with various leach reagents

a significantly higher initial uranium recovery rate. Although a higher bicarbonate level was used in this test, previous column test results have shown that the bicarbonate level in this concentration range (0.76 to 1.52 g/l) does not affect the uranium recovery rate at average leach flow rates of between 7 and 9 ml/min.⁽⁴⁾ However, the much slower flow rate (3.6 vs. 8.9 ml/min), caused by the poor permeability obtained in this test may have caused the better uranium recovery and perhaps resulted in the higher bicarbonate level being utilized. Previous test results have indicated that bicarbonate leaches are reaction and/or mass transfer controlled in this system; therefore, increasing the leach solution residence time should result in a greater recovery per volume collected.^(3,4) The higher uranium solution levels obtained may have made use of the higher bicarbonate level. The initial acid leach recovery, shown by an essentially straight line recovery curve, indicates that the uranium recovery was equilibrium constrained, or limited by available reagent.

The effect of leach time with the bicarbonate reagents is taken into account in Figure 6.77, in which the percentage of uranium recovered per day is plotted versus the cumulative leach volume. The ammonium and potassium had similar daily uranium recovery rates, while sodium dropped significantly below that of ammonium and potassium. The lower recovery per day for sodium indicates that the flow rate (and thus residence time) in this test may not be optimal. The slower flow rate did result in a greater percentage of uranium being extracted in a given volume of leach; however, this greater extraction may not compensate for the greater leach time required. It is likely that a residence time exists for these bicarbonate solutions, which will provide a maximum daily uranium recovery for a given volume of leach. Additional testing with this system would likely provide this information. It is also important to note from Figure 6.77 that the daily percentage of uranium recovered decreases with increasing leach volume collected.

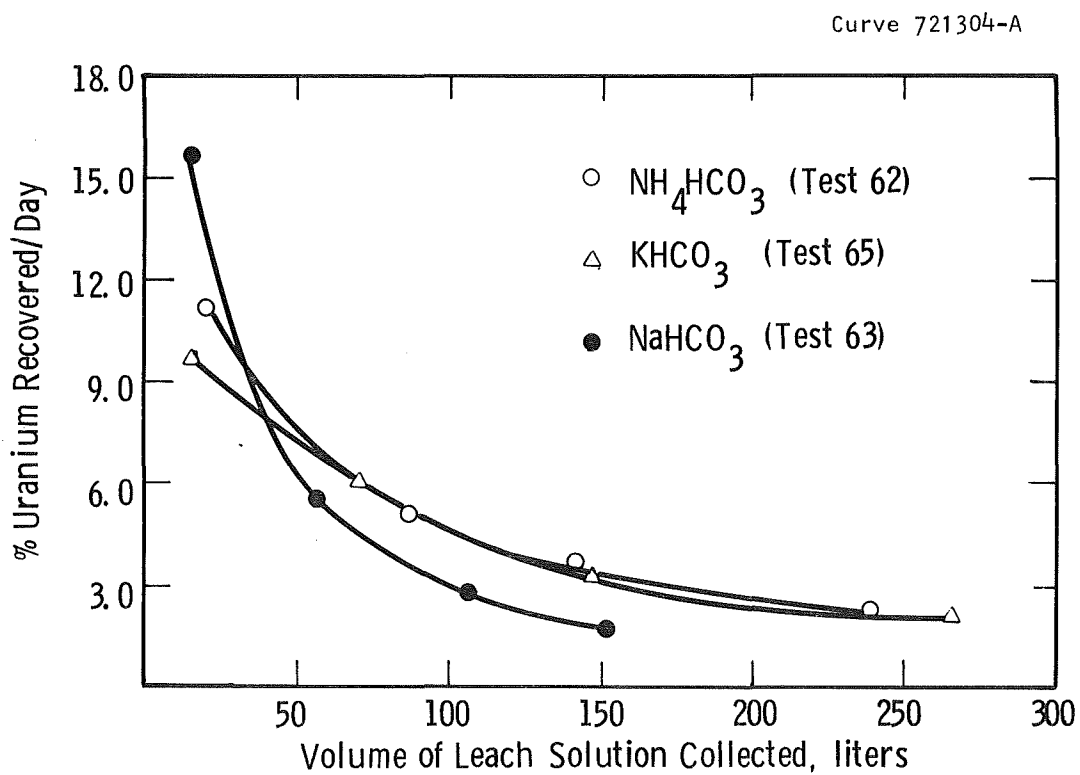


Fig. 6.77 – Daily uranium recovery rates for ammonium, potassium and sodium bicarbonate leach solutions

This is a reasonable result because the rates of diffusion and reactions involved in the leaching process should decrease as the amount and accessibility of the uranium decreases.

In all of the tests, there was a certain percentage of uranium that was not leached. Perhaps the permeability damage that occurred made some uranium totally inaccessible. Ore characterization results indicated that uranium present in the pyrite cement or coalified material would be more difficult to leach because of limited access.⁽⁴⁾ There is also the possibility that some uranium is just not leachable with the solutions tested. Studies have indicated that the poor leachability of certain ores was due to the association of uranium with phosphate and zirconium.⁽¹⁸⁾ As is shown in Figure 6.78, the rate of uranium recovery decreases as the fraction of uranium remaining decreases. The easily accessible uranium is rapidly removed, while the less accessible uranium is slowly leached. In all of the tests, after approximately 70 to 75% of the uranium was removed, the uranium solution concentration dropped to less than 20 mg/l, which produced a recovery rate of less than 1%/25 liters of leach. These observations indicate that 25 to 30% of the uranium is relatively inaccessible to, or unleachable with, any of the leaches tested.

The bicarbonate test results showed that the leach cation can be sorbed by the ore's clay in significant quantities during leaching. The results indicate that ammonium and potassium will be sorbed by the ore to a similar degree. However, sodium exchange onto the ore was relatively small. This is in part due to the fact that sodium has a lower exchange ability than ammonium or potassium.⁽⁶⁾ Also, sodium is already present on the ore's clay, and thus the concentration driving force is lower for the sodium ions to move to the clay exchange sites and exchange with other cations (e.g., Ca) present on the clay.

The differences in the cation sorption can perhaps be more clearly understood by examining the cation exchange reaction and equilibrium. Assuming the exchange reaction can be expressed as follows;

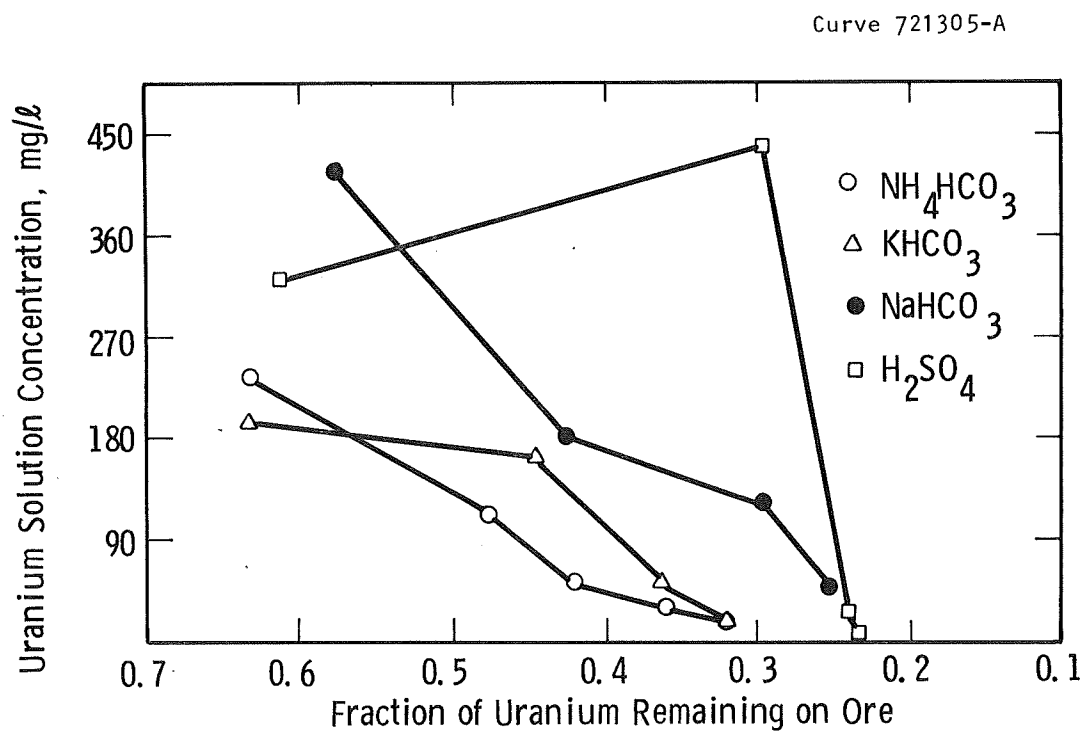
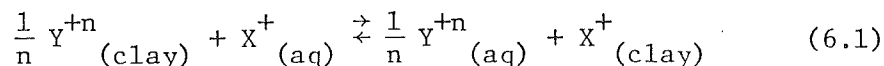


Fig. 6.78-Variations in uranium solution levels during uranium removal from an ore using various leach reagents



where Y is the cation (Na^+ and Ca^{++}) of charge n initially present on the ore's clay and X^+ is the leach cation, then the exchange is governed by the following equilibrium:

$$\text{Keq} = \frac{[Y^{+n}(\text{aq})]^{1/n} [X^+(\text{clay})]}{[Y^{+n}(\text{clay})]^{1/n} [X^+(\text{aq})]} \quad (6.2)$$

where Keq is an equilibrium constant. As NH_4^+ (or K^+) comes into contact with the ore, which initially contains no NH_4^+ (or K^+), there is strong concentration driving force for the NH_4^+ (or K^+) to exchange onto the ore. This exchange will continue until the NH_4^+ (or K^+) on the ore is in equilibrium with the NH_4^+ (or K^+) leach solution concentration. The exchange of Na^+ differs from that of NH_4^+ (or K^+) because Na^+ is already present in significant amounts (~ 0.02 meq/g) on the ore before leaching, which results in a reduced concentration driving force for Na^+ to exchange onto the ore. The Na^+ exchanges with other cations present on the clay, which, for this ore, is Ca^{++} . Generally, divalent cations are more difficult to displace than monovalent cations (i.e., a smaller Keq). Thus, Na^+ will not exchange with the ore's Ca^{++} as readily as NH_4^+ (or K^+) can exchange with the Na^+ on the ore. Table 6.44 shows the final leach cation sorption levels and solution concentrations obtained in each test. The data shows that the ratio of cation meq on the ore to cation meq in solution is much greater for NH_4^+ and K^+ than for Na^+ which, again, indicates the reduced ability of Na^+ to exchange onto this ore.

A comparison of the ion leakage resulting after 4 to 5 pore volumes of post-leach groundwater for each of the tests is given in Table 6.45.

TABLE 6.44

Cation Sorption Equilibrium During Leaching with Sodium,
Ammonium, and Potassium Bicarbonate Solutions

Test No	Leach Solution	Final Ore Level meq of cation/g of ore	Final Solution Level meq of cation/l of solution	meq of cation/g of ore meq of cation/l of solution
62	1.0 g/l NH_4HCO_3	0.056	9.4	6.0×10^{-3}
65	1.0 g/l KHCO_3	0.053	8.2	6.5×10^{-3}
63	2.0 g/l NaHCO_3	*0.050	19.6	2.6×10^{-3}

* Assuming an initial Na ore content of 0.02 meq/g

TABLE 6.45

Ion Leakage into Ground Water Following Various Chemical
Leach Reagents (After 4-5 Pore Volumes of Ground Water Collected)

Test No	Leach Solution	pH	U mg/l	Se mg/l	HCO ₃ mg/l	V mg/l	Fe mg/l	Principal Cation mg/l
62	NH ₄ HCO ₃	8.2	26	0.12	400	< 0.5	<0.1	193 (NH ₄ ⁺)
65	KHCO ₃	8.1	18	0.14	380	< 0.5	<0.1	358 (K ⁺)
63	NaHCO ₃	8.3	12	0.27	335	< 0.5	<0.1	224 (Na ⁺)
69	H ₂ SO ₄	2.7	<0.1	0.006	---	180	36.9	---

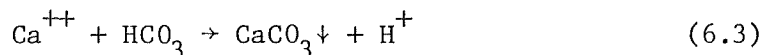
The leakage after acid leaching differed significantly from that after bicarbonate leaching. In the acid leach, vanadium, iron, and hydrogen ion concentration remained at high levels, while selenium, uranium, and bicarbonate were at high levels after the bicarbonate leaches. The higher selenium leakage after bicarbonate leaching is likely due to the greater mobility of selenium in alkaline conditions than in acidic conditions.⁽⁹⁾ Iron⁽²⁾ and vanadium⁽⁸⁾ solubility is greater in acidic media thus resulting in the high leakage levels following the sulfuric acid leach. The lower uranium level after the acid leach is likely due to the greater uranium recovery in that test. The accessible uranium has been leached, thus reducing the leakage level.

The data seems to indicate, by the low rate of decline in the leakage levels of these chemicals, that these concentrations would remain high with the passage of significantly more groundwater. The long-term groundwater flow following ammonium bicarbonate leach (Test 78) showed that the leakage of these ions does in fact occur for a long time. Thus, restoration is required to reduce chemical leakage to acceptable levels in a reasonable number of solution pore volumes. Due to the differences in chemical leakage, the acid leach would likely require a different restoration approach than the bicarbonate leach. That is, it would require the neutralization of residual acidic conditions (i.e., the addition of a base) and the reduction of the vanadium and iron levels. While requiring the reduction of uranium, selenium, and bicarbonate, the bicarbonate leaches also showed the possible need to lower the leakage of the principle leach cation.

Following the sodium bicarbonate leach, the cation leakage was only slightly above the background level. This low leakage level was likely the result of the low sodium sorption during leaching and the high sodium content of the groundwater. By examining the reverse reaction of Equation 6.1, it should be clear that under these conditions the driving force for the small amount of exchangeable cations in the groundwater

(3 meq of Ca^{++}/ℓ) to exchange with the sorbed Na^+ would be small. Potassium and ammonium showed high leakage levels. Again, examining the reverse reaction of Equation 6.1 and noting that K^+ or NH_4^+ is not initially present in the groundwater indicates the reason for these high leakage levels. Ammonium leakage is presently environmentally unacceptable, thus the ammonium leakage after leaching must be reduced.⁽⁵⁾ If potassium levels shown to occur here are environmentally acceptable, then the removal of this cation may not be required, which would significantly reduce the restoration requirement for this leach.

It is also interesting to note that the greater cation exchange that occurred during the ammonium and potassium bicarbonate leaches may have resulted in the higher post-leach uranium leakage in these tests compared to the sodium leach test. As ammonium or potassium exchanges with calcium present on the ore's clay, calcium can precipitate in the presence of the leach solution bicarbonate:



During subsequent post-leach groundwater flow, the calcium carbonate can redissolve. The additional carbonate in solution can cause an increase in uranium dissolution. This reaction sequence is supported by the fact that both the carbonate and the uranium levels are higher in the groundwater following the potassium and ammonium bicarbonate leaches. The fact that sodium exchanges less during leaching results in less calcium carbonate precipitation. Thus, during post-sodium bicarbonate leach groundwater flow, there is less bicarbonate redissolution and less subsequent uranium dissolution.

A comparison of the data obtained from the ammonium bicarbonate leach tests (Tests 62 and 66) performed on the new and old Wyoming ores permits an evaluation of the ability to apply leaching data from ores obtained from the same mining site, but from a different location at that site. As pointed out in Section 4.2, there are substantial

differences between the two ore samples. These differences (e.g., uranium content and distribution, and particle size distributions) forewarned of possible leaching differences between the two ores. A summary of the packing and leaching characteristics of the two tests is given in Table 6.46.

The permeability during leach was substantially lower with the new ore. Although the same packing method was used on both ores, the new ore packing was less dense (1.59 vs. 1.71 g/mL) and subsequently less stable as the front section of the ore bed compressed and collapsed. Likely due to particle size distribution differences, the new ore required a different packing method (e.g., less ore per batch addition and more tamping) in order to obtain a stable packing. The low density of the packing perhaps was an indication that the packing method used was unsuccessful.

The chemical data collected during the leaching portion of the tests showed that the ammonium sorption levels (in the same pore volumes of leach) were similar, which indicated that the clay contents were also similar. After taking into account the differences in leach flow rate (3.0 mL/min vs. 7.9 mL/min), the ores also had a similar uranium recovery per pore volume of leach collected. The leaching characteristics of the two ores were thus comparable. However, while the type of chemical post-leach leakage was similar, the leakage levels of uranium, selenium, bicarbonate, and ammonium were significantly lower with the new ore. A comparison of the leakage levels is given in Table 6.47. This may have resulted from the poor permeability: fewer leach pore volumes were passed through the ore, which resulted in less total ammonium sorption, less calcium carbonate precipitation, etc. Also, due to the slight collapse of the ore body, the ore bed may have had some channelling during the post-leach groundwater flow, thus causing a portion of the ore bed to be by-passed by the groundwater. The results from these two tests show the desirability of processing ore samples identically, obtaining stable ore packings, and characterizing the ore in order to identify any important differences.

TABLE 6.46

Packing and NH_4HCO_3 Leaching Characteristics
of the Old and New Wyoming Ores*

Test No.	Ore	Packing Density, g/ml	Initial Uranium Ore Content, g	Average Leach Flow Rate, ml/min	Vol. of Leach Collected, ℓ (pore volumes)	% U Recovered (after 13 pore volumes)	NH_4^+ Ore Level (after 13 pore volumes), meq/g of ore	Permeability (Front Ore Section) During Leach, Darcy	
								120 hrs	300 hrs
62	Old Wyo	1.71	48.9	7.9	364.3 ℓ (39 pv)	55%	0.030	0.20	0.10
66	New Wyo	1.59	25.7	3.0	137.0 ℓ (13.2 pv)	55%	0.034	0.05	0.02

* - Old Wyoming ore obtained from Shirley Basin on April 12, 1976.
New Wyoming ore obtained from Shirley Basin on December 8, 1978.

TABLE 6.47

Chemical Leakage into Ground Water Following
 NH_4HCO_3 Leaching of New and Old Wyoming Ores*
 (after 3-5 Pore Volumes of Ground Water Collected)

Test No.	Ore	U mg/l	Se mg/l	NH_4^+ mg/l	HCO_3^- mg/l	Fe mg/l	As mg/l	Mo mg/l	V mg/l
62	Old Wyo	26.0	0.12	193	400	<0.1	0.0024	<0.2	<0.5
66	New Wyo	8.8	0.022	45	280	<0.1	0.0018	<0.2	<0.5

* - Old Wyoming ore obtained from Shirley Basin on April 12, 1976.
 New Wyoming ore obtained from Shirley Basin on December 8, 1978.

The data obtained from the sulfuric acid leach tests on Wyoming and Texas ores (Tests 69 and 64) allowed the effect of ore characteristics on post-leach leakage to be examined. A summary of the preleach ore characteristics⁽³⁾ and the post-leach groundwater leakage levels are given in Tables 6.48 and 6.49, respectively. A comparison of the data in the two tables shows that the initial chemical content of the ore certainly does not solely determine the leakage level of the chemical following a given leach. That is, although Wyoming ore had a significantly higher initial iron and uranium content, the leakage level of these chemicals was lower than with Texas ore after the same volume of groundwater. In this same respect, Texas ore had a significantly higher initial vanadium ore level, but a much lower post-leach leakage into groundwater. Differences in leach operating conditions between the two tests may have been responsible for this seemingly peculiar leakage behavior.

Due to the poor permeability in the Texas test, much less leach solution (11.1 vs. 32.3 pore volumes in the Wyoming test) was passed through the ore bed. Uranium, iron, and molybdenum were thus leached to a lesser extent in this test. Higher levels of chemical species were thus still available at the conclusion of leach, leading to higher leakage levels. Also, the high leakage levels in the Texas test could have occurred due to the lower pH (1.8 vs. 2.8) and the higher sulfate level (2900 vs. 250 mg/l) of the groundwater collected, which should increase the solubility of these species. The high vanadium level following the leach of Wyoming ore is more difficult to explain. Perhaps the vanadium was more accessible, or leachable, in the Texas ore, and thus was completely removed during the leach portion of the test.

These two acid tests point out the importance leach operating conditions (e.g., total leach volume, uranium recovery, etc.) have on subsequent leakage into groundwater. Also shown to be important is the presence of other chemical species and the pH of the product post-leach solution. The amount and accessibility of the chemicals in the ore also influence the chemical leakage.

TABLE 6.48

Summary of Pre-leach Chemical Data on
Texas and Wyoming Ores

Ore	U wt. %	Fe wt. %	V ₂ O ₅ wt. %	MoO ₃ wt. %
Wyoming	0.091	0.94	0.014	0.001
Texas	0.056	0.58	0.041	0.0015

TABLE 6.49

Chemical Leakage into Ground Water Following
 H_2SO_4 (pH=1) Leach of Wyoming and Texas Ores
(After 4-5 Pore Volumes of Ground Water Collected)

Test No	Ore	pH	U mg/l	Fe mg/l	V mg/l	Mo mg/l	$\text{SO}_4^{=}$ mg/l
64	Texas	1.8	3.3	135	<0.5	0.6	2,900
69	Wyoming	2.7	<0.1	36.9	180	<0.2	~ 250

6.3.2 Discussion of Reducing Agents Test Results

The tests examining the use of reducing agents produced data that provided for a more complete understanding of the leaching and the post-leach processes. The data obtained is considered valuable in dealing with the post-leach restoration of a given leach solution and in determining the causes of permeability changes. A comparison of the reducing agent tests to the baseline test, which used the same leach solution, allows the usefulness of the agents and the data obtained with an agent to be better evaluated.

Following 1.0 g/l ammonium bicarbonate leach, the use of three different reducing agents was examined; 1.0 g/l ammonium bisulfite, 1.0 g/l sodium sulfite, and 3.0 g/l sodium bisulfite. The post-leach permeability variations of the front ore section during these tests and the baseline test are shown in Figure 6.79. All of the reducing agents showed an initial improvement in permeability. This improvement is believed to be due to the reduction of gas blockage which occurred during leaching. The almost immediate improvement in permeability shows that the sulfite, or bisulfite, must rapidly remove the oxygen gas from the ore bed. The dissolution of oxygen gas [$O_2(g)$] is governed by the following reaction:



The reaction of sulfite with oxygen in solution [$O_2(l)$] occurs as follows:



while the reaction of bisulfite and oxygen in solution is:



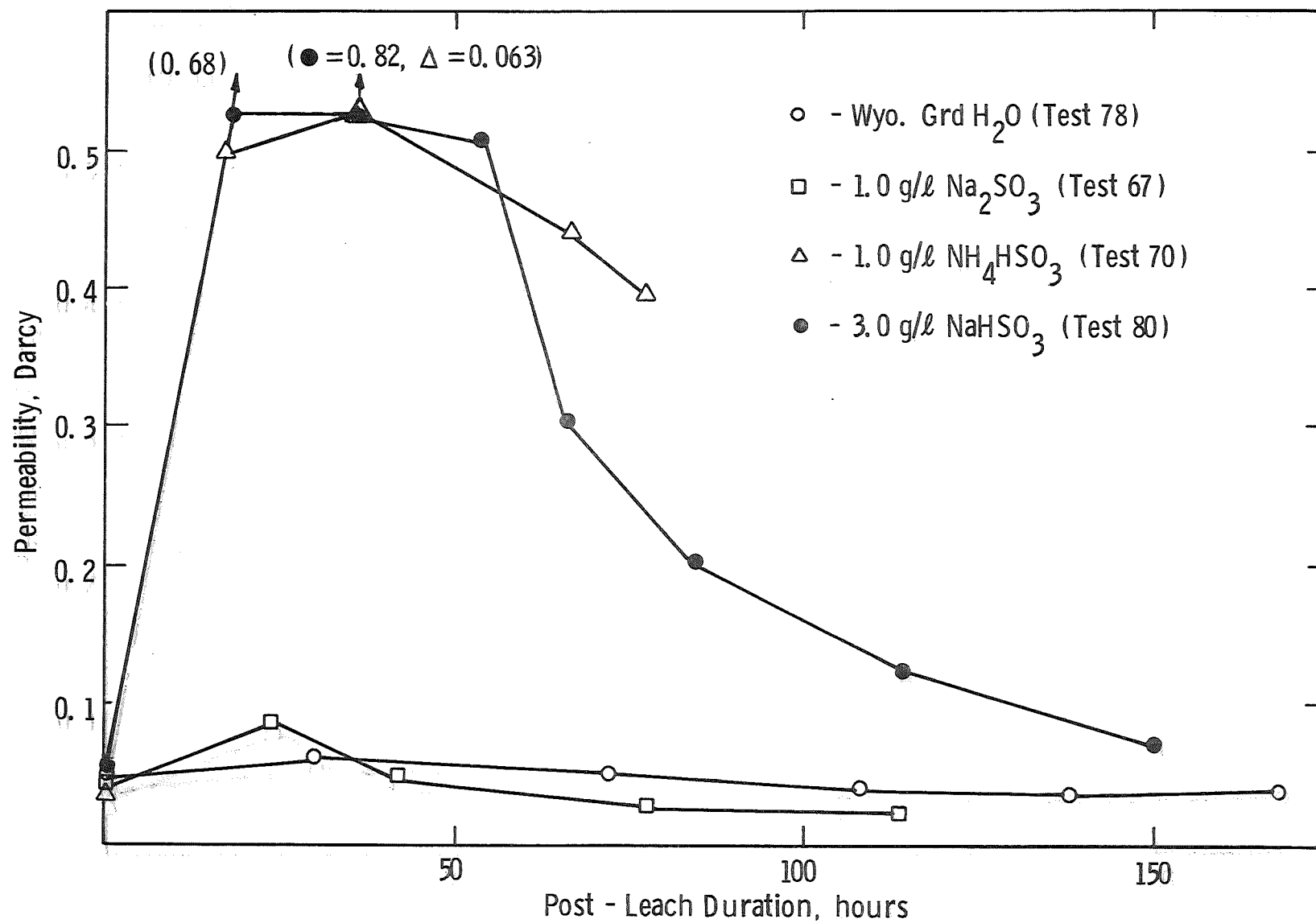


Fig. 6. 79—Effect of reducing agent on front ore section permeability, following 1.0 g/l NH₄HCO₃ leach.

As the oxygen in solution reacts with the bisulfite, or sulfite, more oxygen gas will redissolve, thus unblocking the ore bed. The removal of oxygen gas in this manner is much more rapid than simply attempting to dissolve the gaseous oxygen into a solution where no reaction occurs. Reducing agents thus appear to be effective in restoring permeability that has been damaged by oxygen gas blockage.

With continued use of the reducing agents, permeability did decline. As shown in Figure 6.79, using 1.0 g/l sodium sulfite, the initial permeability improvement was the shortest in duration and the subsequent decline was the most severe. The likely reason for this is the damaging effects of sodium exchange onto the ore's clay. As pointed out previously, sodium exchange causes clay swelling and clay dissociation and dispersion. The 3.0 g/l sodium bisulfite test shows that increasing the concentration of the reducing agent results in a higher and a longer duration improvement. This is so even though increasing the sodium concentration would result in more sodium exchange and thus more clay swelling. The increase in the sodium concentration likely benefits permeability by increasing the ionic strength of the solution. This has been found to decrease clay dissociation and dispersion.^(16,17) The 1.0 g/l ammonium bisulfite test maintains a higher permeability for a longer duration than the sodium reducing agents. The ammonium does not have the swelling and dispersion disadvantages of sodium. These tests thus point out the importance of the solution cation and ionic strength on permeability.

The effect of these reducing agents on post-leach leakage is shown in Table 6.50. All of the agents seem to lower uranium and bicarbonate leakage levels. The sulfate concentration rises but then relatively rapidly drops to an acceptable level during subsequent groundwater flow (within approximately 4 pore volumes). The selenium level initially rises with the injection of the reducing agent, but was shown to drop to a much lower level than the baseline test (Test 78) if sufficient reducing agent was passed through the ore bed. Test 70

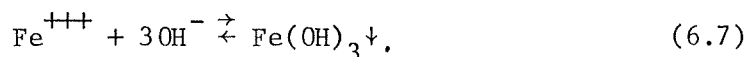
TABLE 6.50

Effect of Reducing Agent on Ion Leakage Following NH_4HCO_3 Leach

Test No	Post-Leach Solution	Σ Pore Volumes (pv) of Post-Leach Sol. Collected	pH	U mg/ℓ	Se mg/ℓ	$\text{SO}_4^{=}$ mg/ℓ	HCO_3^- mg/ℓ
78	Wyo. Grd. H_2O	5.3	8.2	4.7	0.14	180	400
		11.9	8.3	3.5	0.17	---	---
		15.3	8.3	2.8	0.16	---	---
67	1.0g/ℓ Na_2SO_3	5.0	8.5	2.0	0.56	560	250
	1.0g/ℓ Na_2SO_3 (1pv)	9.3	8.3	4.0	0.18	200	290
	Wyo. Grd. H_2O (3.3pv)						
70	1.0g/ℓ NH_4HSO_3	4.7	4.7	5.0	0.52	600	270
	1.0g/ℓ NH_4HSO_3 (1pv)	11.8	7.6	2.4	0.10	160	270
	Wyo. Grd. H_2O (6.1pv)						
80	3.0g/ℓ NaHSO_3	5.3	5.7	3.2	0.21	---	---
		7.2	3.8	0.9	0.13	---	---
	3.0g/ℓ NaHSO_3 (3.6pv)	15.3	8.5	0.8	0.04	---	---
	Wyo. Grd. H_2O (4.5pv)						

showed that about 10 pore volumes of 0.028M bisulfite resulted in acceptable leakage levels. In Test 67, it is possible that an insufficient amount (9.3 pore volumes of 0.008M $\text{SO}_3^{=}$) of the reducing agent, sodium sulfite, was used as the selenium level was not lowered. Also, the higher pH of this reducing agent (pH 8 vs. 3 for the bisulfites) aids the mobility of the selenium. Like uranium, selenium is insoluble when reduced.⁽¹⁰⁾ The results seem to indicate, however, that the reduction of uranium (and oxygen) occurs more rapidly than the reduction of selenium.

The use of sodium bisulfite was also examined following sulfuric acid (pH = 1) leaches of Wyoming and Texas ores. The results point out the importance of the solution pH following an acid leach. As shown in Table 6.51, the permeability of the front ore section was shown to drastically decrease if the ore bed was hit immediately following the acid leach with a reducing agent solution having a pH greater than 3. It is believed that the decrease is due to the significant amount of ferric ion mobilized during the acid leach. Ferric hydroxide precipitation occurs at a pH above about 3;⁽²⁾



In order to maintain the permeability, a solution pH of around 2 is needed. Perhaps, however, the precipitation of ferric hydroxide can be used to isolate the leached ore field. Contacting the ore bed initially with sodium bisulfite caused the permeability to drop to less than 1 millidarcy (Test 68). Subsequent groundwater would have great difficulty passing through the almost impermeable ore bed. The leakage from this partially reduced ore bed, due to contact with the bisulfite, would likely thus be small.

The effect of the reducing agent on post-leach ion leakage is examined in Table 6.52. For both ores, the reducing agents seemed to effectively lower ion leakage. This was expected as the solubilities

TABLE 6.51

Permeability Effect of NaHSO_3 pH Following H_2SO_4 (pH=1) Leach

Test No	Ore	NaHSO_3 Feed pH	Front Section Permeability, darcy				
			0 hr	50 hr	100 hr	350 hr	400 hr
68	Tex.	3.6 (Initially)	0.02	0.0008	0.0013	0.089	0.11
		2.0 (After 283 hrs)					
71	Wyo.	2.0	0.027	0.030	0.032	---	----

TABLE 6.52

Effect of NaHSO_3 on Ion Leakage After Leaching with H_2SO_4 , pH=1

Test No.	Ore	Post-Leach Solutions	Pore Volumes (pv) of Solutions Collected	pH	U mg/l	$\text{SO}_4^{=}$ mg/l	Fe mg/l	V mg/l	As mg/l	Se mg/l
64	Tex	Texas Grd. H_2O	4.8	1.79	3.3	2900	135	-	0.47	0.14
68	Tex	1.0 g/l NaHSO_3 (4.4 pv) -Tex. Grd. H_2O (6.6 pv)	11.0	2.33	<0.1	860	32	-	0.06	0.003
69	Wyo	Wyo. Grd. H_2O	6.0	2.67	<0.1	195	27	131	-	-
71	Wyo	2.0 g/l NaHSO_3 (9.7 pv) -Wyo. Grd. H_2O (2.5 pv)	12.2	3.03	<0.1	215	10	<1	-	-

of uranium, selenium, arsenic, and vanadium are very low when in their reduced states. The leakage of arsenic and iron may also have been low because work has shown that arsenic will form insoluble salts with iron.⁽⁹⁾ The only restoration problem that seemed to remain after bisulfite restoration was the low pH. This can perhaps be dealt with by the addition of an alkaline buffer solution.

6.3.3 Discussion of Ore Stabilizing Results

The tests performed to examine the use of ammonium blocking and/or ore stabilizing compounds provided additional insight into the conditions affecting permeability, ammonium sorption, and uranium recovery. A comparison of the permeabilities experienced during these various tests and the baseline ammonium bicarbonate tests (Tests 62 and 18) are shown in Figures 6.80 and 6.81. Figure 6.80 compares those tests using dissolved oxygen as the oxidant, while Figure 6.81 compares those tests using hydrogen peroxide. The figures show that all of the agents examined were effective in maintaining a higher permeability. A comparison of the uranium recovery, and ammonium sorption and desorption characteristics of the leaching tests is given in Table 6.53. As the data shows, uranium recovery was improved with the addition of magnesium sulfate-calcium chloride and magnesium sulfate alone, and was reduced with the addition of aluminum chloride and sodium silicate. Ammonium sorption during leach and the desorption during post-leach groundwater flow were shown to decrease with magnesium sulfate and with magnesium sulfate and calcium chloride addition, but were not significantly affected by the sodium silicate or the aluminum chloride.

The major causes of permeability damage during leaching are thought to be oxygen gas blockage, clay swelling, and clay dissociation and dispersion. The improvement in permeability with the addition of these chemicals must in some way reduce or prevent these adverse effects. In the aluminum chloride test, there was an initial large drop in permeability which was comparable to that experienced in the baseline

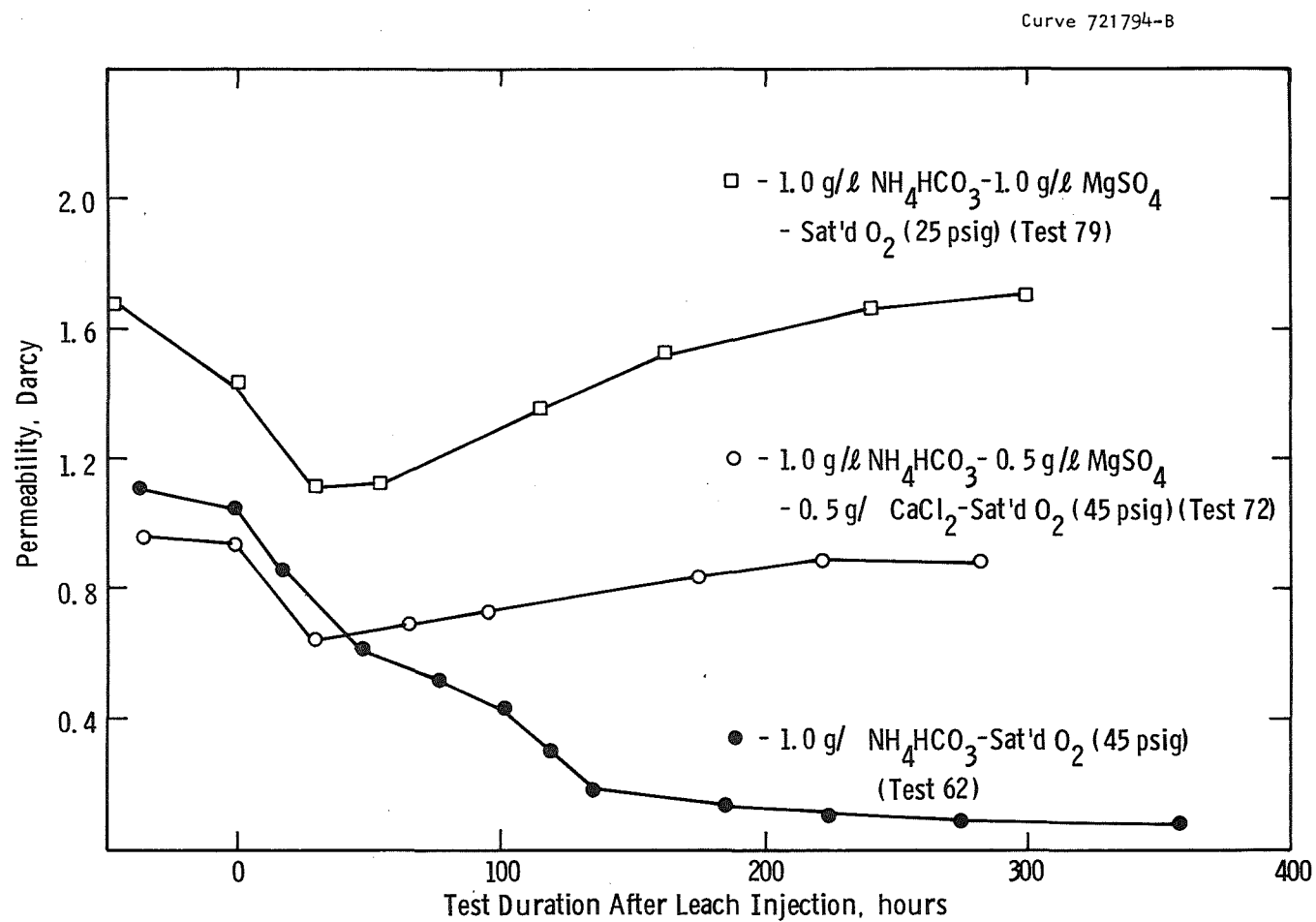


Fig. 6. 80 - Effect of MgSO_4 and MgSO_4 - CaCl_2 on front section permeability during leaching of Wyoming ore with 1.0 g/l NH_4HCO_3 sat'd O_2

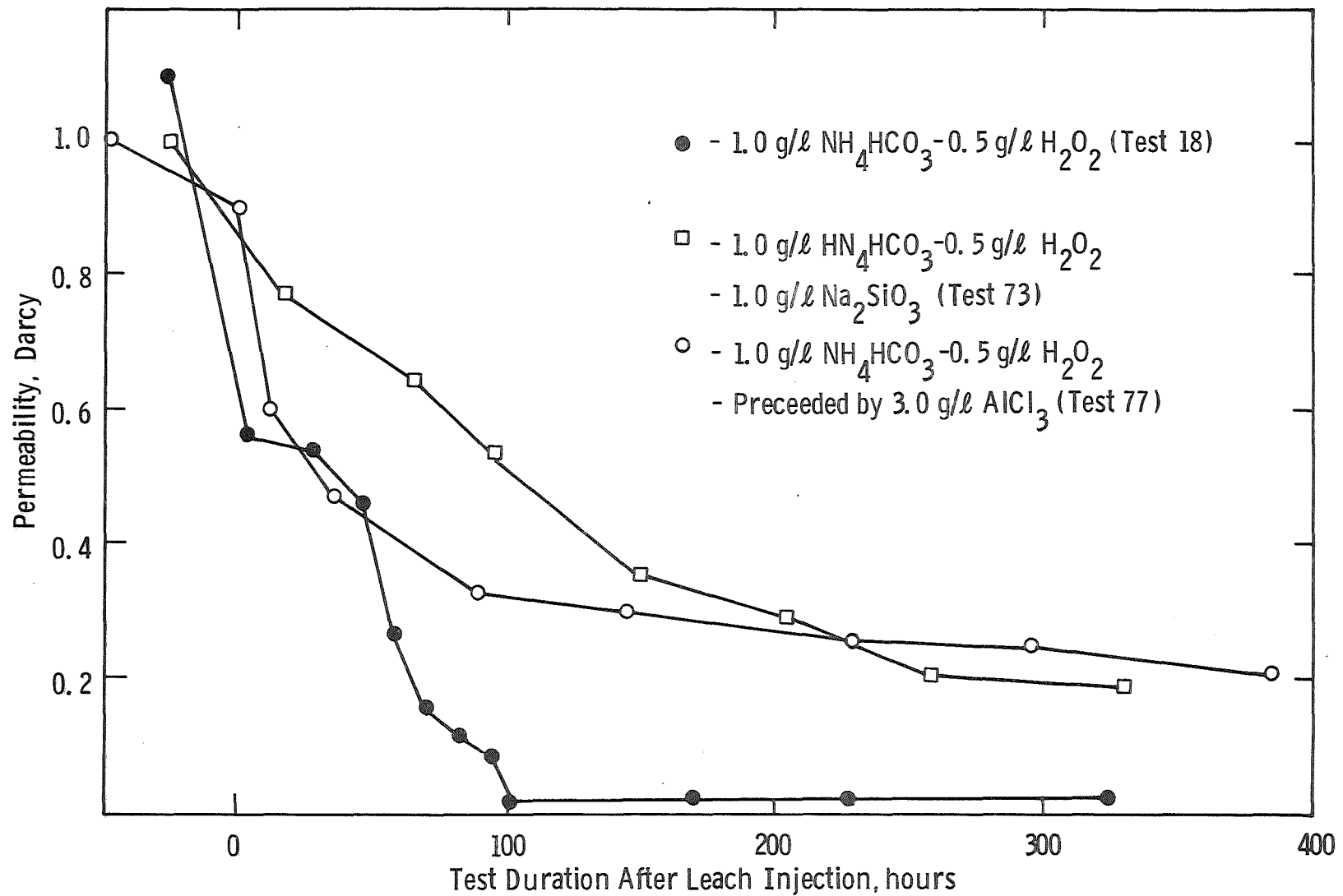


Fig. 6. 81—Effect of AlCl_3 and Na_2SiO_3 on front section permeability during leaching of Wyoming ore with 1.0 g/l NH_4HCO_3 -0.5 g/l H_2O_2

TABLE 6.53

Effect of Using Various Chemicals During, or Prior to, Leaching with NH_4HCO_3

Test No.	Leach Solution	Pretreatment Solution	% U-Recovery		Total NH_4^+ Sorption During Leach meq/g of Ore	NH_4^+ Desorption (mg/l) Post-Leach Grd. H_2O	
			First 10 pv [•] of Leach	Total at Conclusion of Leach		4 pv	6 pv
62	1.0 g/l NH_4HCO_3 sat'd O_2 O_2 (45 psig)	None	32%	68%	0.056	173	153
73	1.0 g/l NH_4HCO_3 -1.0 g/l Na_2SiO_3 -0.5 g/l H_2O_2	None	27%	52%	0.058	146	-
77	1.0 g/l NH_4HCO_3 -0.5 g/l H_2O_2	3.0 g/l AlCl_3	-	63%	0.058	-	-
72	1.0 g/l NH_4HCO_3 -0.5 g/l CaCl_2 -0.5 g/l MgSO_4 -sat'd O_2 (45 psig)	None	34%	69%	0.026	142	103
79	1.0 g/l NH_4HCO_3 -1.0 g/l MgSO_4 -sat'd O_2 (25 psig)	None	38%	70%	0.022	116	95

• pv = pore volume

test (Test 18). This rapid initial drop in permeability has been attributed to gas blockage, as the effects of the clay interaction with the leach should not occur as rapidly. Thus, the aluminum chloride did not likely reduce the initial effects of gas blockage. The permeability did level off at a much higher level than the baseline test, indicating that the clay damaging effects were reduced. The data shows that ammonium sorption was not lowered, thus clay swelling should not have been reduced. Therefore, the aluminum chloride must have stabilized the clay fraction, preventing clay dissociation and dispersion. The lower than baseline uranium recovery indicates that the aluminum likely coated the ore, which while preventing clay movement, also lowered uranium accessibility. It should be noted that by preventing the clay movement, the oxygen gas blockage problem was also likely reduced. That is, when both occur, oxygen blockage may become worse due to the blockage of pores by clay movement. That is, it would be more likely for the oxygen gas to be trapped in the ore bed.

The sodium silicate test showed a more gradual initial decline in permeability. This indicates that initially the oxygen blockage was not as severe. Agitation tests (see Table 6.28) had shown that the decomposition rate of peroxide was not significantly lowered by sodium silicate, so there should have been just as much oxygen present in this test. Perhaps the sodium silicate reduces the interfacial tensions among the gas, solution, and ore, thus allowing the oxygen gas and solution to more easily pass through the ore bed. The results do show that eventually ($\sim$ 200 hours of leach) the permeability in this test reaches that of the aluminum chloride test (Test 77). This indicates that oxygen blockage likely occurred in this test, but at a much slower rate. Like aluminum chloride, sodium silicate perhaps maintains a higher than baseline final permeability by reducing clay dissociation and dispersion. Again, the lower than baseline uranium recovery indicates that the sodium silicate may have coated the ore, which could result in less clay movement. The low uranium recovery may also have been caused by the precipitation of the solubilized uranium with the silicate,⁽¹²⁾ or due to the high pH.⁽²⁰⁾

The effects of adding magnesium sulfate and magnesium sulfate-calcium chloride were very similar. Both tests showed an initial decline in permeability. However, the magnitude of the drop was not nearly as severe as in the baseline test. The drop was likely due to oxygen blockage. The lower decline in these tests was, in part, because the oxygen level of the feeds in these tests was not as high as in the baseline test. In Test 79, the feed only contained about half as much oxygen as was used in the baseline test. In Test 72, the presence of the magnesium and calcium salts in the solution being saturated with oxygen likely reduced the oxygen solubility,⁽¹⁹⁾ thus resulting in a slightly lower than baseline oxygen feed level. The results also indicate that the presence of magnesium (and possibly calcium) in the leach must in some way reduce oxygen blockage, as the permeability in both tests improved relatively rapidly back to their preleach levels. This occurred in both tests even though a higher oxygen feed level was likely used in Test 72 compared to Test 79. This apparent ability of magnesium and calcium to reduce oxygen blockage may, in part, be due to the other beneficial effects they have on permeability.

The magnesium and calcium will more readily exchange than ammonium for the sodium cations on the ore.⁽⁶⁾ The replacement of monovalent cations by divalent cations has been shown to decrease the tendency for clay dispersion and dissociation by minimizing electrostatic repulsion between clay particles.⁽¹⁷⁾ The clay dispersion is also decreased by the increase in the ionic strength of the solution. In addition, the results show that the amount of ammonium sorption is greatly lowered, thus perhaps reducing clay swelling. The decrease in clay dissociation and dispersion, and clay swelling resulted in a more permeable ore body which perhaps allowed the oxygen gas to be more easily removed.

The test data obtained in these tests point out the importance of how permeability is improved. In the aluminum chloride and sodium silicate tests permeability was improved; however, the mechanism by which this occurred (e.g., coating of the ore) caused a reduction in uranium recovery. In the magnesium sulfate tests, the improved permeability also

accompanied an increase in uranium recovery rate. This increased recovery could be due to improved uranium accessibility which resulted from the higher permeability. The aluminum chloride and sodium silicate likely caused a reduction in uranium accessibility. As shown in Table 6.54, the use of magnesium solutions had the additional advantage of greatly reducing ammonium sorption, which resulted in significantly lowering post-leach ammonium desorption.

6.3.4 Discussion of Ammonium Displacement Solutions

A comparison of the test results using ammonium-displacing agents provides an indication of the most desirable restoration agent in terms of permeability, ammonium removal, and subsequent ion leakage into groundwater. The data obtained also shows what factors influence each of these post-leach characteristics. The restoration solutions examined were 1) 3.0 g/l aluminum chloride, 2) 1.0 g/l sodium silicate, 3) 0.5 g/l lanthanum chloride - 0.5 g/l lanthanum sulfate, 4) 1.5 g/l lanthanum chloride - 1.5 g/l lanthanum sulfate, 5) 1.0 g/l sodium silicate - 2.0 g/l sodium chloride, and 6) 3.0 g/l sodium bisulfite.

The front section permeability variations after injection of the restoration solution are shown in Figure 6.82. All of the solutions that immediately followed the ammonium bicarbonate leach at least initially improved permeability. The sodium silicate-sodium chloride solution that followed the lanthanum restoration solution did cause a gradual permeability decline. The permeability improvement was most dramatic with aluminum chloride and with sodium bisulfite. However, the sodium bisulfite showed an almost as rapid permeability decline with continued flow.

The effect of these solutions on the permeability during subsequent groundwater flow is shown in Figure 6.83. Following the aluminum chloride and the lanthanum chloride-sulfate tests, there was a decline in permeability but it did stabilize very much above the baseline test (Test 62). The permeability initially increased following the

TABLE 6.54

Effect of Chemical Restoration on Ion Leakage from NH_4HCO_3 Leached Wyoming Ore

Test No.	Restoration Solution	Ion Leakage after 6 Pore Volumes of Restoration Solution (mg/l)						Ion Leakage after 5 Pore Volumes of Post-Restoration Grd. H_2O (mg/l)					
		pH	U	NH_4^+	Se	Restoration Solution Cation	Restoration Solution Anion	pH	U	NH_4^+	Se	Restoration Solution Cation	Restoration Solution Anion
62	None	-	-	-	-	-	-	8.2	26.0	193	0.12	-	320 ($\text{SO}_4^{=}$) 60 (Cl^-)
74	3.0 g/ AlCl_3	7.0	2.2	752	0.051	<1.0 (Al)	2620 (Cl)	6.8	3.9	3	<0.002	<1 (Al)	145 (Cl)
75	0.5 g/ LaCl_3 -0.5 g/ $\text{La}_2(\text{SO}_4)_3$	8.3	1.0	178	-	<10 (La)	160 (Cl) 240 ($\text{SO}_4^{=}$)	8.5	3.5	176	-	<10 (La)	190 ($\text{SO}_4^{=}$) 160 (Cl^-)
76	1.0 g/ Na_2SiO_3	9.7	1.8	153	-	0.12 (Na)	70 (Si)	8.9	0.56	140	-	108 (Na)	60 (Si)
80	3.0 g/ NaHSO_3	5.7	3.2	263	0.21	400 (Na)	-	8.5	0.80	77	0.041	275 (Na)	-
81	1.5 g/ LaCl_3^* -1.5 g/ $\text{La}_2(\text{SO}_4)_3$	7.8	1.8	218	0.05	<0.5 (La)	-	-	-	-	-	-	-
	1.0 g/ Na_2SiO_3 -2.0 g/ NaCl	8.0	4.7	231	0.05	-	-	8.8	4.2	42	1.14	176 (Na)	-

* - 4 pore volumes of restoration solution

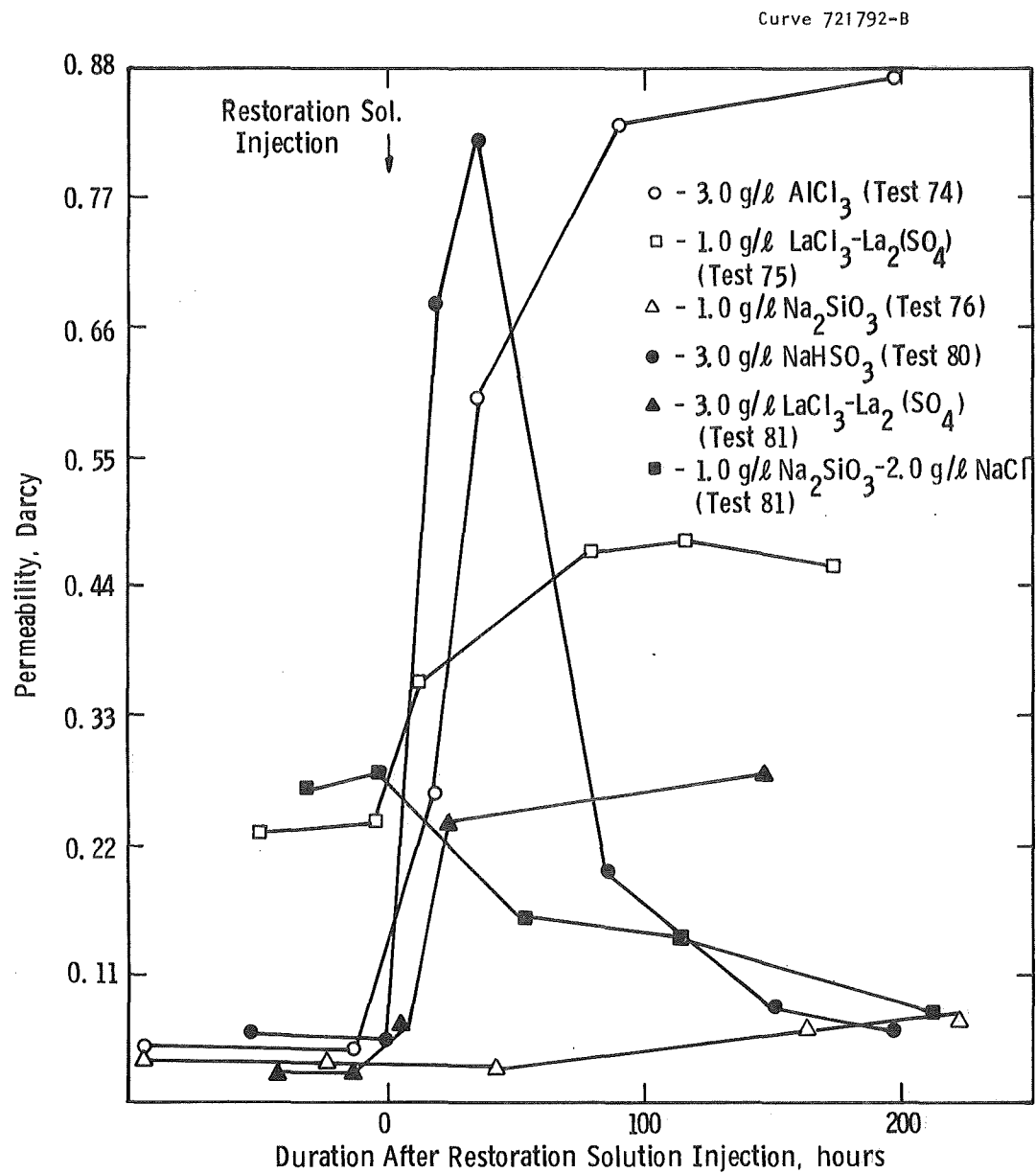


Fig. 6.82—Effect of various restoration solutions on front section permeability after leaching with 1.0 g/l NH_4HCO_3

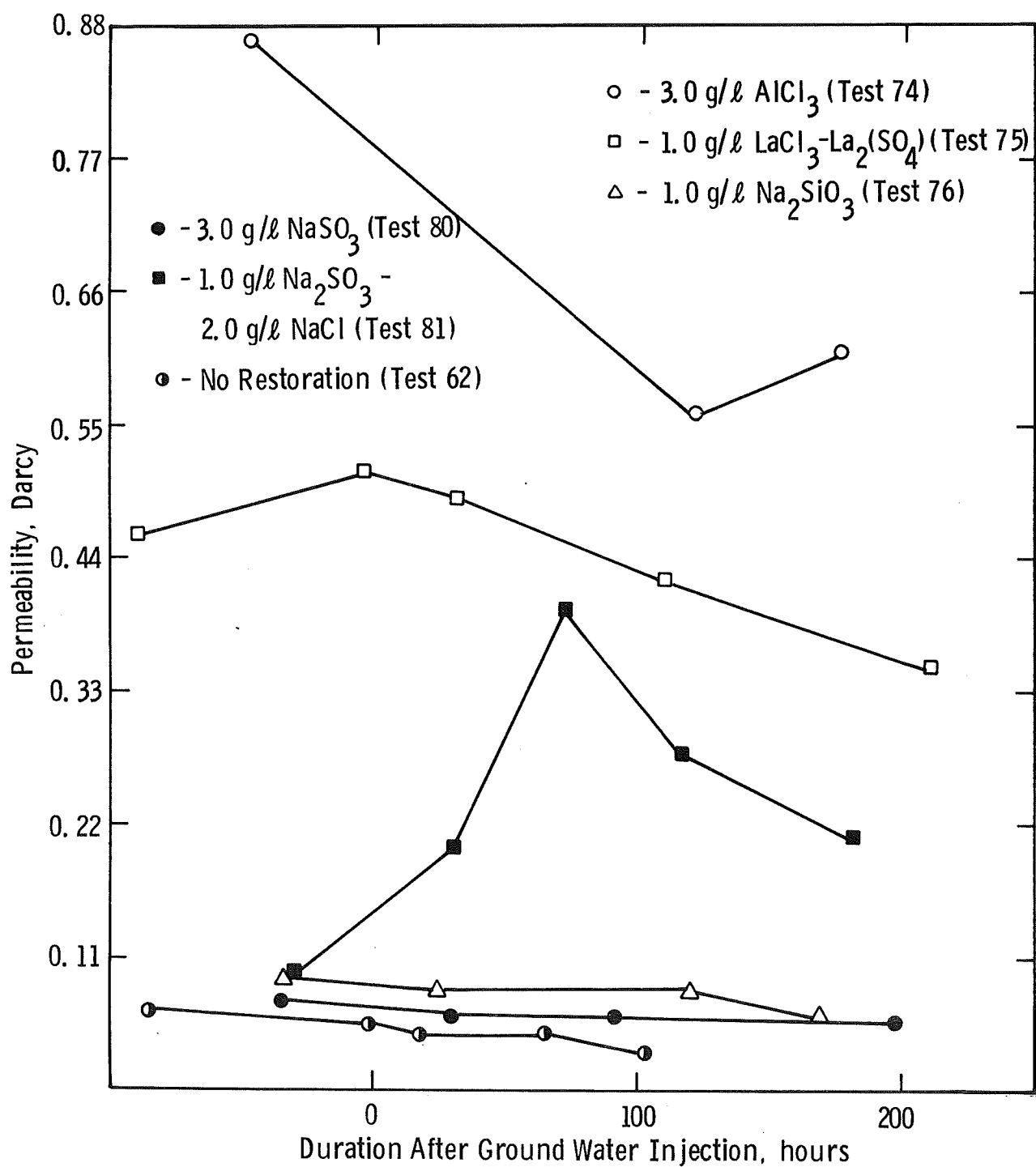


Fig. 6.83 — Effect of chemical restoration on subsequent ground water permeability

sodium silicate-sodium chloride (Test 81), but then showed a steady decline. The permeability following sodium bisulfite and following sodium silicate (Test 76) stayed slightly above the baseline level. The higher permeability following the sodium silicate-sodium chloride may have been due in part to the previous lanthanum restoration on that column of ore.

These tests point out the influence of various factors on permeability. Solutions having trivalent cations, aluminum, and lanthanum result in and maintain a higher permeability. The exchange of the highly-charged cations onto the clay likely reduces clay dissociation and dispersion during the restoration flow and during the subsequent groundwater flow. This is in contrast to the sodium solutions. Sodium exchange onto the ore eventually results in permeability damage by clay dispersion and swelling. Sodium silicate seems to coat the ore, which reduces dispersion and/or perhaps allows the oxygen gas blocking the ore bed to be more easily removed, thus overcoming some of the adverse effects of sodium exchange. The sodium bisulfite causes a very rapid initial permeability improvement. This reducing agent causes a rapid dissolution of oxygen gas blocking the ore bed. However, the adverse effects of sodium exchange eventually overcome any beneficial effects of this agent. The aluminum chloride showed a very rapid permeability improvement which indicated that oxygen blockage, as well as clay dispersion, was rapidly lowered. The aluminum chloride may have coated the ore, which along with the opening of the pores due to the lowered clay dispersion, may have allowed the oxygen gas to easily pass through the ore bed.

A comparison of the ammonium removal rates for the various chemicals is shown in Figure 6.84. Note that in Test No. 81, the sodium silicate-sodium chloride ammonium removal rate is based on the ammonium ore level (0.037 meq/g of ore) after lanthanum restoration. Of the solutions examined, the most rapid removal was obtained with the 3.0 g/l aluminum chloride (67.4 meq of Al/l). The trivalent aluminum was

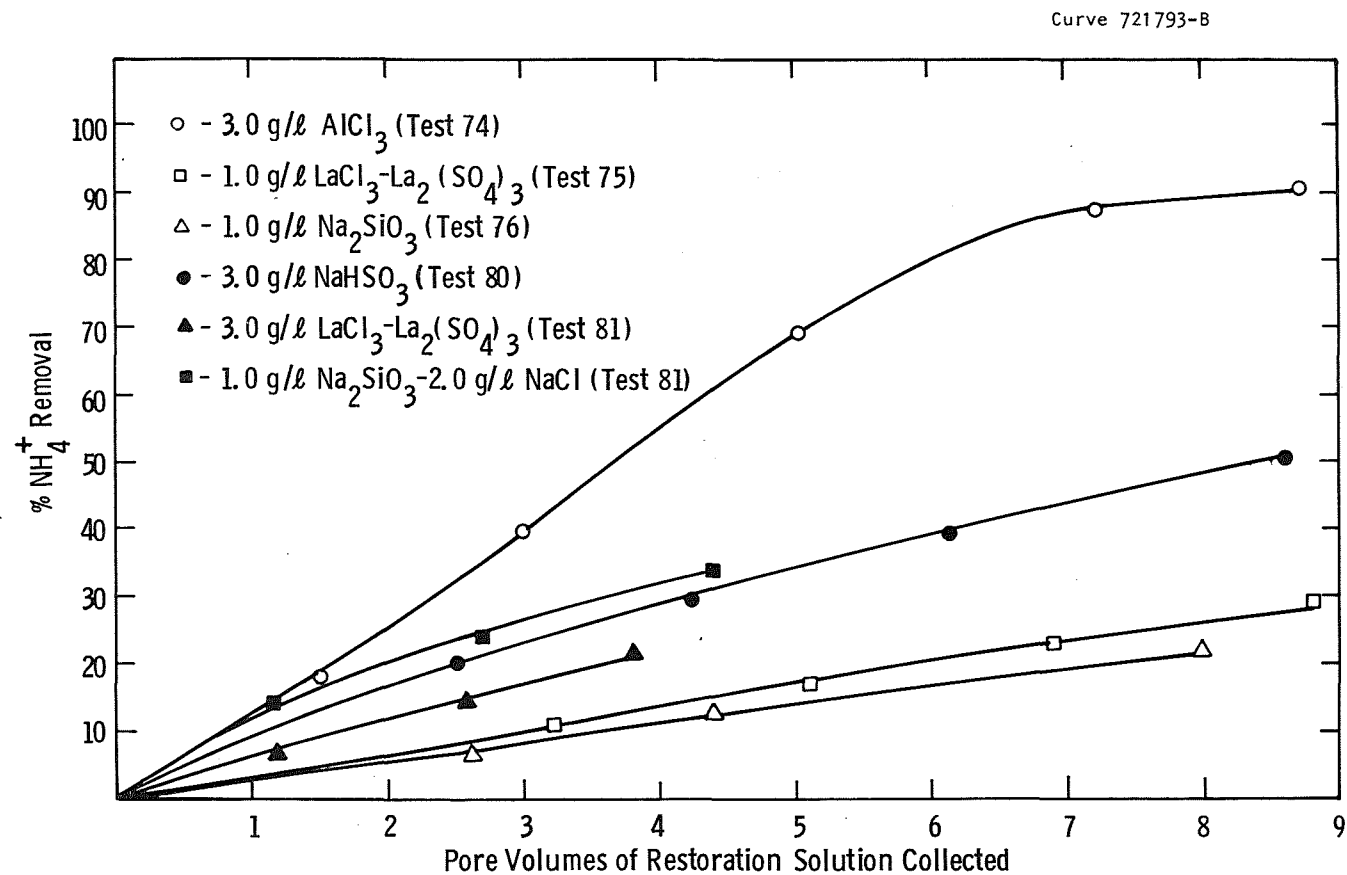
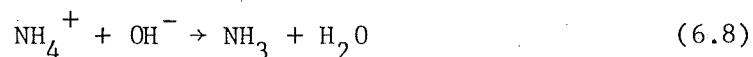


Fig. 6. 84—Ammonium removal from 1.0 g/l NH_4HCO_3 leached Wyoming ore using various chemical solutions

much more effective than the trivalent lanthanum. The removal with aluminum was about twice as great as that of the 3.0 g/l $\text{LaCl}_3 - \text{La}_2(\text{SO}_4)_3$ (34.2 meq/l). Although the aluminum equivalent concentration was about twice that of the lanthanum, doubling this lanthanum concentration would not result in as high an ammonium removal as the aluminum. Comparing the results in Tests 75 and 81, increasing the lanthanum concentration did increase ammonium removal, but not in the same portion as the concentration increase. The 3-fold increase in the lanthanum equivalent concentration only increased the ammonium removal rate by about 50%. Other studies have also found that the increased replacement by a given cation with an increase in concentration is not in direct proportion to the cation concentration.⁽⁶⁾ However, this was not the case with the sodium silicate tests (Test 76 and 81). Tripling the sodium content of a 1.0 g/l Na_2SiO_3 solution by the addition of sodium chloride caused about a 3-fold increase in the ammonium removal rate. The high pH of these solutions (~ 10), due to the sodium silicate, may have caused the more effective use of the cation concentration increase, as well as improving the ammonium removal ability of sodium. Work has shown that the high pH solutions produce a more rapid and complete exchange with ammonium.⁽¹⁴⁾ The presence of hydroxide is required because it converts the ammonium to the unionized and thus unexchangeable ammonia:



The ammonium thus comes off the clay more readily as the ammonium level in solution is kept low. The sodium silicate has the ability to maintain a high pH throughout the ore bed, even though the ore has shown a very strong buffering capacity (pH 7 to 8) with other solutions.

The sodium bisulfite solution showed the best ammonium removal ability of the sodium solutions tested. The low pH of this solution (pH = 3.5) could have been the cause of this improvement. Hydrogen ions have been found to have a very strong affinity for clays.⁽⁶⁾

The ion leakages resulting during the chemical restoration flows and during the subsequent groundwater flow are given in Table 6.54. During restoration solution flow the pH's in the aluminum chloride (pH = 7) and sodium bisulfite (pH = 5.7) tests were both lower than the typical pH's ($\sim$ 7.5 to 8.5) experienced with this ore. The pH of the groundwater following the aluminum chloride (pH = 6.8) was still lower than normal, but was not severe enough to require pH restoration. The sodium silicate tests (Tests 76 and 81) resulted in a higher than normal groundwater pH ($\sim$ 8.8), but should not be a restoration problem. All of the restoration solutions caused a reduction in uranium and ammonium leakage compared to the baseline, or no restoration, test (Test 62). The sodium silicate (Test 76) and sodium bisulfite (Test 80) dropped the uranium leakage to 1 mg/l or less. The ability of sodium silicate to reduce uranium leakage is related to its possible coating of the ore,⁽¹²⁾ and its ability to form precipitates with heavy metals.⁽¹³⁾ The sodium bisulfite is likely effective because it reduces the uranium to its insoluble plus four state.

The ammonium leakage into the post-leach groundwater was less than 100 mg/l after aluminum chloride, sodium bisulfite, and sodium silicate-sodium chloride restoration. The aluminum chloride caused the most dramatic decline as ammonium leakage dropped to less than 5 mg/l. The lanthanum (Test 75) and sodium silicate (Test 76) restorations resulted in only a slight reduction in ammonium leakage. The differences in ammonium leakages can, in part, be related to the ammonium level remaining on the ore. As shown in Table 6.55, generally the lower the ammonium ore level, the lower the ammonium leakage into solution. However, as pointed out in Section 5.3, the ammonium leakage is also related to the other cations in solution and on the ore, to pH, and possibly many other factors.

The selenium leakage levels were lowered to less than 0.002 mg/l with aluminum chloride and to about 0.04 mg/l with sodium bisulfite. Studies have shown that aluminum can be effective in precipitating selenium.⁽¹⁾ The reduction of selenium by the bisulfite results in lower solubility.

TABLE 6.55

NH_4^+ Ground Water Leakage as a Function of the Ore NH_4^+ Level

Test No	NH_4^+ Ore level mg/g of ore	NH_4^+ Grd H_2O Leakage mg/l
62	0.88	193
74	0.05	3
75	0.59	176
76	0.40	140
80	0.37	77
81	0.37	42

In none of the tests was there a significant leakage into groundwater of the restoration cation. Depending on the acceptable levels for chloride and sulfate in the groundwater at the given ore site, some clean-up of the restoration anion may be required. The preliminary data obtained here indicates that simply sweeping the leached ore with groundwater will lower the leakages of chloride and sulfate.

6.3.5 Utilization of Leach Test Results

By examining all of the column test results, an attempt can be made to identify those test conditions which would be effective in improving an ammonium bicarbonate leach in terms of permeability, uranium recovery, ore ammoniation, and ion leakage. That is, based on the test data obtained, what is the best leaching and restoration chemistry scheme. Leach conditions should be chosen so as to produce the highest permeability and uranium recovery, while minimizing ore ammoniation and ion leakage. It has become apparent from the test work that all of the leaching characteristics (permeability, uranium recovery, etc.) are inter-related.

The use of conditions that increase permeability will reduce the pressure required to obtain a desired flow rate. This results in lower pumping or energy costs. Also, improved permeability seems to increase uranium accessibility thus improving the uranium recovery rate. Increasing the uranium recovery rate will reduce the required mining time and thus increase profits. In addition, results have shown that increasing the total recovery reduces the post-leach uranium leakage. Minimizing ore ammoniation during leaching results in a reduction in the post-leach ammonium leakage. Any reduction in post-leach leakage will lower the restoration requirements.

Pretreatment of the ore with aluminum chloride or sodium silicate was found to be effective in maintaining permeability, but caused a reduction in uranium recovery and was not effective in lowering ammonium sorption. Thus, none of the chemicals tested showed characteristics which would make it worthwhile to use prior to leaching. Permeability

can be more effectively maintained by appropriate choice of leach conditions. The leaching test results have shown that the oxidant feed level and the presence of appropriate cations in the leach solution are important permeability determinants.

The ammonium bicarbonate leach should be no greater than 1.0 g/l, as results have shown that higher concentrations do not aid uranium recovery, but do result in higher ammonium sorption of the ore.⁽⁴⁾ The test data has also indicated that during leaching, oxygen gas blockage and clay dispersion can cause permeability damage. This permeability damage is compounded if both occur simultaneously. That is, if the pores of the ore are being blocked due to clay dispersion, then more oxygen gas is likely to be trapped in the ore bed than would be if no clay dispersion occurred. Oxygen blockage can be greatly reduced or eliminated by saturating the feed with oxygen at a pressure slightly below that of the ore bed pressure. However, there must be sufficient oxygen in the feed so as not to reduce the uranium recovery rate. Test results (Test 79) have indicated that using an oxygen concentration as low as 60 mg/l does not adversely affect the recovery. If oxygen gas blockage should occur during leaching, a short duration ($\sim$ 0.5 pore volume) of 1.0 g/l ammonium bisulfite can be used to restore the lost permeability. The adverse effects of clay dispersion and perhaps clay swelling can be greatly reduced by the addition of magnesium salts to the leach. Magnesium sulfate at a concentration of 1.0 g/l (Test 79) greatly aided permeability and reduced ammonium sorption by over one half. This reduction in ammoniation resulted in less post-leach ammonium leakage. The addition of greater amounts of magnesium salts may further reduce the ammonium sorption, and thus subsequent desorption.

The post-leach restoration will likely require the lowering of uranium, selenium, ammonium, and bicarbonate leakage levels. The use of aluminum chloride (Test 74) has been shown to rapidly remove ammonium from the ore, to greatly lower selenium levels, and also to reduce uranium and bicarbonate levels. Complete uranium reduction and ammonium

removal can then be accomplished using 3.0 g/l sodium bisulfite (Test 80). The combination of these two restoration solutions may be more effective than just one of them alone. The aluminum chloride is more effective at removing ammonium and reducing selenium, while the sodium bisulfite can more quickly obtain lower uranium levels. The proper duration of each solution could be determined in a column test(s). The aluminum chloride should precede the sodium solution because it would maintain a higher permeability and the cation exchange for ammonium would be more effective. That is, if the sodium exchange for ammonium occurred first, then during the subsequent aluminum flow, aluminum would readily exchange for sodium as well as ammonium. By having the sodium flow second, sodium will much more readily exchange for ammonium than for the trivalent aluminum. In addition, sodium exchange will result in some permeability damage, and the amount of sodium exchange will likely be reduced if the sodium solution follows the aluminum solution. Also, the sodium solution will flush out any excessive residual chloride remaining from the aluminum chloride flow. Thus the optimum ammonium bicarbonate leach conditions and restoration conditions as determined by the tests performed here would be as follows:

A. Leach Conditions

1. 1.0 g/l NH_4HCO_3 saturated with O_2 at a pressure slightly below that of the ore bed pressure; the oxidant level should, however, be at least 60 mg/l.
2. Add to the leach 1.0 g/l (or more) Mg salt.
3. If permeability damage by oxygen gas should occur during leach, contact the bed with 1.0 g/l NH_4HSO_3 for a very short duration ($\sim$ 0.5 pore volume).

B. Restoration

1. 3.0 g/l AlCl_3 for $\sim$ 5-7 pore volumes.
2. 3.0 g/l NaHSO_3 for $\sim$ 3-5 pore volumes.
3. Groundwater for $\sim$ 5 pore volumes.

7. REFERENCES

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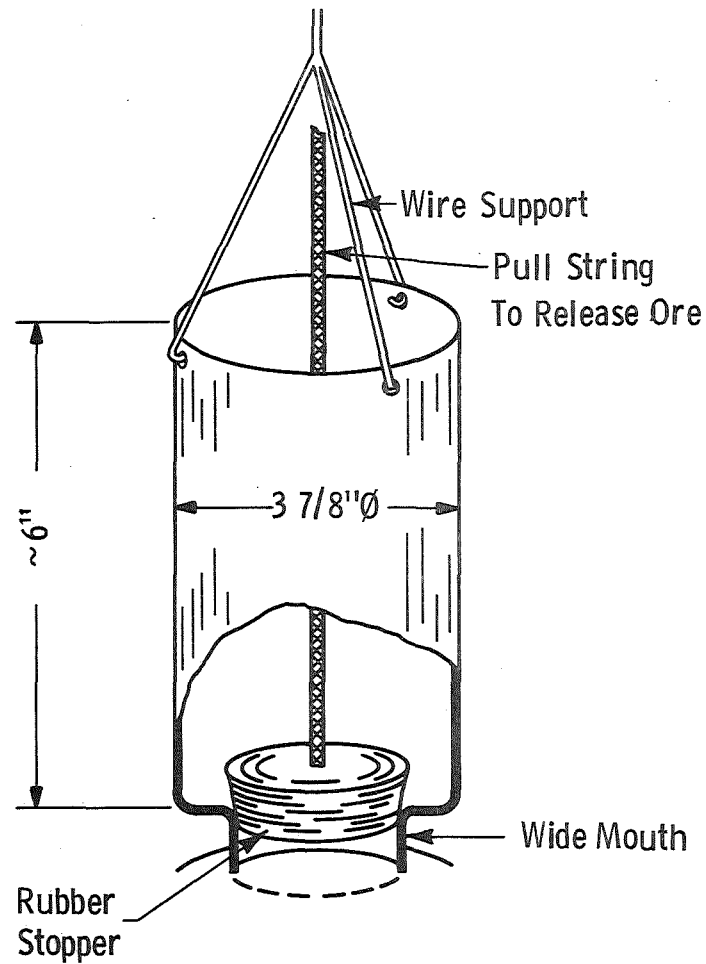
The author appreciates the technical and administrative assistance given to him by H. A. Burgman and D. C. Seidel. Their knowledge and guidance contributed much to the success of this program. The cooperation given to the author by D. J. Locke in excellently preparing the many reports, by the Drafting Department of the R&D Center in preparing the numerous figures, and by the Analytical Chemistry Department at the R&D Center in developing and performing the required analyses is also appreciated.

APPENDIX A

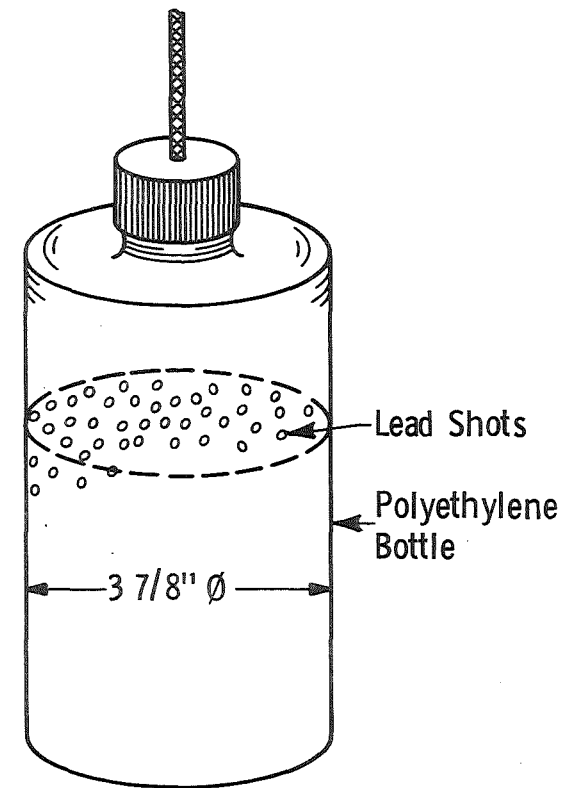
Procedure for Preparing the Four-Inch Diameter Column for Leach Simulation Tests

The following steps are followed in preparing the packing assembly for simulation tests:

- A. Weigh out one 3.5 kg batch and one 2.5 kg batch of -80 AFS subangular sand and a 60.0 kg batch of ore sample for packing. Record the weight of each batch.
- B. Determine the weight of empty 4-inch inside diameter glass cylinder assembly on the sub-frame. The assembly includes all gaskets, all flanges, all end plates, all fasteners (nuts and bolts), sample and pressure taps and Lexan safety shields. It does not include the sampling valves, the pressure gauges, and differential pressure gauges and all the tubing used to connect these to the assembly.
- C. Close all sample ports on the cylinder with rubber stoppers and anchor the cylinder vertically to the ore packing platform. The cylinder should be positioned with the solution inlet end at the bottom. Attach the dust exhaust manifold to the triangular sub-frame.
- D. Place -80 AFS subangular sand using the ore placement container at the bottom of the cylinder, until the sand level is up to the sample port opening (approximately 7-7.5 in. from the inlet and plate). Pack the inlet sand by tamping with the flat-bottom drop-weight tamper (Figure A-1). Drop the tamper from a height of 2 feet approximately 10 times.



Ore Placement Container

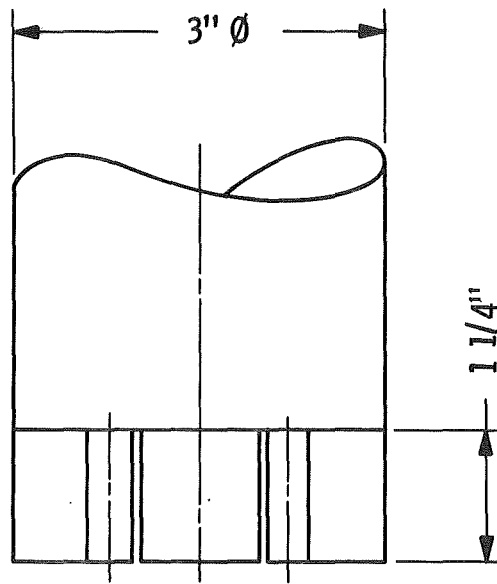


Tamper

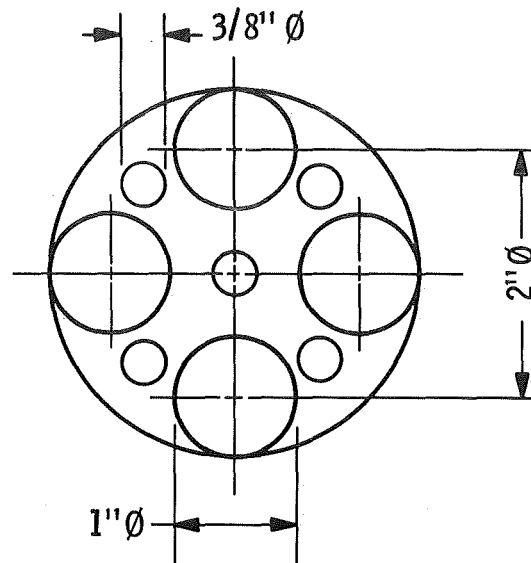
Fig. A-1 — Details of ore placement container and the flat bottom drop weight tamper

- E. Insert the sample and pressure tap and fasten the sample port and plate finger tight.
- F. Place more -80 AFS sand to cover that sample and pressure tap.
- G. Place approximately 4-in. batch of ore sample (batch size expressed in terms of packing length) on top of the -80 AFS sand packing at the bottom.
- H. Wiggle the sample and pressure tap in all directions until the packing material is uniformly distributed around it. Make sure there are no empty spaces left.
- I. Pack the ore using the suitable packing method derived for that ore to achieve a desired permeability. The following is an example of the procedure used to pack the Wyoming and Texas ores in this study: Place ore, using the ore placement container (Figure A-1), batch wise into the column followed by tamping using a peg-bottom drop-weight tamper (Figure A-2). Use an 8-inch batch size for each batch. Use a 2-foot amplitude for tamping with a frequency of 10 tamps/8 in. of Wyoming ore and a frequency of 15 tamps/8 in. of Texas ore.
- J. Continue step (I) in the bulk of the cylinder and steps (E), (G), and (H) at the sample ports until the ore packing is 6 in. from the top.

NOTE: An additional 4-in. inside diameter, 3-ft. long glass pipe is connected to the top of the leach cylinder using a coupling similar to that in the assembly. This 3-ft. section is useful in tamping the last 2 ft. of the packing.
- K. Add from the second batch of -80 AFS subangular sand to fill the last 6 in. of the cylinder and pack as before.



Elev



Plan

Fig.A-2 -The bottom detail of the peg bottom drop weight tamper

- L. Disconnect the 3-ft. long extension pipe, clean any sand spills over the lip and close the cylinder packing using the outlet end plate. Torque all the bolts on the outlet end plate to 4 ft/lb.
- M. Disconnect the cylinder assembly from the ore packing platform and lower it to a horizontal position. Brush off all packing spills off the sub-frame. Torque the sample port end plate bolts to 3 ft/lb on the torque wrench.
- N. Weigh the packed cylinder assembly prior to leach.
- O. Weigh and record the two sand and the ore batches remaining from the original batches after packing operation.
- P. Determine the difference between weights of the sands and ore batches before and after (the packing operation) to determine the weight of inlet, the ore, and the outlet packings.
- Q. Move the packed cylinder assembly to the in-situ leach system and connect (1) solution feed line, (2) sampling valves, (3) absolute pressure gauges and differential pressure gauges, and (4) the packing outlet to the product solution tank.

APPENDIX B

Observations from the Simulation Leach Tests

No. 62 - 81

Permeability, Pressure Drop, and Leach

Solution Flow Rate Variations

Data With Time

Observations from the Simulation Leach Test #62

Ore used = Wyoming

Solution used = 1.0 g/l NH_4HCO_3 - Sat'd O_2 at 45 psig.

Inlet section packing material = -80 AFS Subangular Sand

Inlet section packing length = 10.0 in.

Length of the front ore section = 46.88 in.

Length of the middle ore section = 50.00 in.

Length of the end ore section = 44.38 in.

Outlet section packing material = -80 AFS Subangular Sand

Outlet section packing length = 5.25 in.

Ore packing bed density = 1.71 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = 10 tamps/8 in. of ore. Column position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.

† indicates introduction of fresh feed solution(s).

Test #62

Ore - Wyoming

Sol - 1.0 g/% NH_4HCO_3
Sat'd O_2 (45 psig)

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
30.0	6.24	2.40	2.10	4.25	0.936	1.141	0.500
*36.0	6.24	2.05	2.10	3.10	1.096	1.141	0.686
41.6	6.24	2.10	2.20	2.10	1.069	1.089	1.012
47.9	6.24	1.90	2.10	1.75	1.182	1.141	1.215
54.0	6.28	2.00	2.15	1.75	1.130	1.121	1.223
59.9	5.65	1.85	2.00	1.60	1.099	1.085	1.203
65.8	7.06	1.90	2.00	1.60	1.337	1.355	1.503
71.8	6.39	1.80	1.95	1.55	1.278	1.258	1.404
78.0	6.18	2.05	2.25	1.70	1.085	1.054	1.239
83.9	5.93	2.00	2.20	1.60	1.067	1.035	1.263
*90.0	7.38	2.30	2.65	1.90	1.155	1.069	1.323
96.5	9.49	3.30	3.85	2.70	1.035	0.946	1.197
101.9	10.80	3.00	3.65	2.70	1.296	1.136	1.363
108.0	10.38	3.25	4.00	2.90	1.149	0.996	1.219
114.0	10.83	3.15	4.15	3.15	1.237	1.002	1.171
†120.0	8.33	3.95	4.35	1.30	0.758	0.735	2.183
*126.1	10.93	3.55	5.05	4.00	1.108	0.831	0.931
132.0	11.02	3.60	5.25	4.10	1.102	0.806	0.916
138.0	11.39	3.65	5.60	4.40	1.123	0.781	0.882
144.5	10.77	3.45	5.50	4.35	1.124	0.752	0.844
150.0	11.82	3.80	5.80	4.60	1.119	0.782	0.875
156.0	11.11	3.90	6.00	4.70	1.025	0.711	0.805

Test #62. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*162.0	10.83	3.75	6.00	4.75	1.039	0.693	0.777
163.8		STARTED CHEMICAL FLOW					
†168.0	7.14	3.35	5.50	4.45	0.767	0.498	0.547
174.0	10.28	3.90	5.65	5.00	0.949	0.698	0.700
*179.9	11.30	4.75	6.95	5.55	0.856	0.624	0.694
186.0	11.48	4.85	7.15	5.70	0.852	0.616	0.686
192.0	11.11	5.30	7.00	5.85	0.754	0.609	0.647
198.0	9.72	5.90	7.00	4.95	0.593	0.533	0.669
203.6	11.61	6.25	7.45	5.25	0.669	0.598	0.753
*210.1	10.0	5.95	7.50	5.10	0.605	0.512	0.668
216.0	10.45	6.20	8.00	5.65	0.607	0.501	0.630
221.8	8.91	5.95	7.85	5.45	0.539	0.436	0.557
228.0	9.95	6.10	7.70	5.40	0.587	0.496	0.628
233.9	9.89	6.25	7.70	5.50	0.570	0.493	0.613
*239.9	9.17	6.30	7.40	5.20	0.524	0.476	0.600
245.9	9.17	6.65	7.50	5.45	0.496	0.469	0.573
251.8	9.04	6.55	7.00	5.00	0.497	0.496	0.616
258.0	9.94	7.30	7.40	5.50	0.490	0.516	0.616
*264.2	10.48	8.70	7.15	5.40	0.434	0.563	0.661
270.0	9.48	10.1	7.20	5.35	0.338	0.505	0.604
275.9	10.73	10.3	6.80	4.80	0.375	0.606	0.762
*282.0	10.11	11.9	6.65	4.35	0.306	0.584	0.792
288.2	8.33	14.5	6.40	4.30	0.207	0.500	0.660

Test #62. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
293.9	9.36	16.2	6.80	4.45	0.208	0.528	0.717
*299.9	9.72	18.2	6.80	4.35	0.192	0.549	0.761
306.0	9.29	19.0	6.60	4.00	0.176	0.540	0.791
312.0	8.61	20.1	6.50	3.60	0.154	0.508	0.815
317.8	9.20	22.0	6.60	3.85	0.151	0.535	0.814
323.9	9.02	22.2	6.55	3.65	0.146	0.529	0.842
+330.0	9.02	23.2	6.60	3.60	0.140	0.525	0.854
336.0	8.06	25.4	6.25	3.70	0.114	0.495	0.742
341.9	10.45	26.0	6.25	3.50	0.145	0.642	1.017
*347.9	10.28	27.0	6.30	3.20	0.137	0.626	1.094
354.0	7.92	26.7	6.15	3.25	0.107	0.494	0.830
361.1	9.15	27.3	6.25	3.00	0.121	0.562	1.039
365.5	9.85	28.2	6.25	3.00	0.126	0.605	1.119
371.9	8.85	29.0	6.50	2.85	0.110	0.523	1.058
377.8	8.76	30.2	6.65	3.05	0.104	0.506	0.979
384.0	11.29	33.4	7.05	3.40	0.122	0.615	1.131
*389.8	10.63	34.0	6.65	3.10	0.113	0.614	1.168
396.0	8.60	34.5	6.70	3.00	0.0897	0.493	0.977
402.1	10.66	34.3	6.85	3.00	0.112	0.597	1.211
408.0	9.04	34.3	6.80	3.00	0.0949	0.510	1.027
413.8	8.62	34.5	6.70	2.95	0.0899	0.494	0.996
420.0	8.06	34.5	6.70	2.85	0.0841	0.462	0.964

Test #62. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
426.0	10.00	34.5	6.55	2.50	0.104	0.586	1.363
432.0	8.06	35.5	5.50	2.60	0.0817	0.563	1.056
*438.0	8.61	35.3	5.75	2.65	0.0878	0.575	1.146
444.6	8.84	35.0	5.95	2.70	0.0909	0.570	1.115
450.0	8.95	34.9	5.95	2.80	0.0923	0.577	1.089
456.0	9.17	35.0	5.80	2.35	0.0943	0.607	1.329
462.2	8.87	35.0	5.65	2.40	0.0912	0.603	1.259
467.8	7.44	35.1	5.80	2.00	0.0763	0.492	1.267
474.0	7.53	35.8	5.70	2.55	0.0757	0.507	1.006
480.0	7.78	36.1	5.30	2.00	0.0776	0.564	1.325
486.0	8.33	35.5	5.45	2.40	0.0844	0.587	1.183
491.8	6.61	35.5	5.35	2.10	0.0670	0.474	1.072
498.0	7.80	35.5	5.45	2.05	0.0791	0.549	1.296
†504.0	9.17	35.5	5.70	2.40	0.0930	0.618	1.302
510.0	8.61	36.2	5.80	2.40	0.0856	0.570	1.222
516.2	7.53	37.3	5.70	2.35	0.0727	0.507	1.092
*522.0	8.05	36.6	5.60	2.00	0.0792	0.552	1.371
528.0	7.50	37.1	5.05	2.55	0.0728	0.570	1.002
534.0	7.78	37.1	5.20	2.35	0.0755	0.574	1.128
539.8	7.18	37.2	5.15	1.95	0.0695	0.535	1.254
546.2	7.55	37.7	5.05	2.35	0.0721	0.574	1.095
552.0	7.18	37.7	5.10	2.40	0.0685	0.540	1.019

Test #62. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
558.0	7.22	37.1	5.10	2.30	0.0700	0.543	1.070
564.0	6.94	37.1	5.15	1.90	0.0673	0.517	1.244
*569.9	7.06	37.5	5.20	2.30	0.0678	0.521	1.046
575.9	6.39	37.5	5.15	1.95	0.0613	0.476	1.116
581.9	7.50	37.4	5.25	2.30	0.0722	0.548	1.111
587.9	6.11	37.5	5.25	2.35	0.0586	0.447	0.886
594.0	7.38	37.3	5.25	2.25	0.0712	0.540	1.117
600.0	7.22	37.7	5.10	1.80	0.0689	0.543	1.367
606.5	6.41	37.5	5.30	2.05	0.0615	0.464	1.065
611.9	6.48	37.5	5.40	2.20	0.0622	0.461	1.004
618.0	7.38	37.8	5.65	2.25	0.0703	0.501	1.117
624.0	7.50	37.7	5.35	2.00	0.0716	0.538	1.278
*629.9	6.78	37.5	5.35	1.90	0.0651	0.487	1.216
636.0	6.56	38.0	5.40	2.05	0.0621	0.466	1.090
642.0	6.94	38.0	5.50	2.15	0.0657	0.484	1.100
648.0	6.37	38.0	4.95	2.00	0.0603	0.494	1.085
654.0	6.37	38.5	4.95	1.90	0.0595	0.494	1.142
660.0	6.37	38.8	5.15	1.65	0.0591	0.475	1.315
666.0	6.94	38.6	5.10	2.10	0.0647	0.522	1.126
672.0	6.67	38.8	5.00	2.00	0.0619	0.512	1.136
678.2	6.18	39.0	4.80	1.90	0.0570	0.494	1.108
*684.0	6.61	38.8	5.05	1.85	0.0613	0.502	1.217

Test #62. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
690.6	7.07	38.5	5.10	2.00	0.0661	0.532	1.204
+696.0	7.10	38.7	5.10	2.00	0.0660	0.534	1.209
702.0	7.22	38.4	5.50	2.10	0.0677	0.504	1.171
708.0	7.50	38.5	5.70	2.20	0.0701	0.505	1.161
714.1	7.65	38.0	5.85	2.20	0.0725	0.502	1.184
720.0	7.34	38.0	5.70	2.10	0.0695	0.494	1.191
726.1	6.83	38.5	5.30	1.90	0.0638	0.495	1.225
732.1	6.56	38.0	5.40	2.00	0.0621	0.466	1.117
738.0	6.21	37.9	5.50	2.05	0.0590	0.433	1.032
744.0	7.50	38.0	5.50	2.20	0.0710	0.524	1.161
750.1	6.56	38.5	5.60	2.05	0.0613	0.450	1.090
*755.5	6.79	38.5	5.55	1.95	0.0635	0.470	1.186
762.0	6.67	38.0	5.45	2.10	0.0632	0.470	1.082
768.0	6.67	38.8	5.20	2.10	0.0619	0.492	1.082
773.9	6.80	38.8	5.15	1.95	0.0631	0.507	1.188
780.0	6.56	38.6	5.30	1.95	0.0612	0.475	1.146
786.0	6.67	38.0	5.60	2.15	0.0632	0.457	1.057
792.0	6.67	38.0	5.65	2.15	0.0632	0.453	1.057
798.0	8.33	37.2	6.00	2.15	0.0806	0.533	1.320
*804.0	6.94	37.5	6.40	2.25	0.0666	0.416	1.051
810.0	7.78	36.8	6.50	2.00	0.0761	0.459	1.325
816.0	7.78	37.5	6.10	2.35	0.0747	0.490	1.128

Test #62. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
821.9	7.63	37.5	6.00	2.15	0.0732	0.488	1.209
827.9	6.94	38.0	6.10	2.20	0.0657	0.437	1.075
834.1	6.99	37.8	6.15	2.20	0.0666	0.436	1.082
840.0	7.06	37.6	5.95	2.25	0.0676	0.456	1.069
*845.9	7.06	37.6	5.90	1.70	0.0676	0.459	1.415
852.0	6.57	37.9	5.90	2.00	0.0624	0.427	1.119
858.0	6.11	38.4	5.95	2.15	0.0573	0.394	0.968
864.0	6.11	38.2	5.55	2.05	0.0576	0.423	1.015
869.9	6.50	38.2	5.50	1.90	0.0612	0.454	1.166
875.9	6.39	38.7	5.45	1.95	0.0594	0.450	1.116
882.0	6.01	38.7	5.40	1.90	0.0559	0.427	1.078
887.8	6.03	38.7	5.65	1.90	0.0561	0.410	1.081
893.8	5.83	38.4	5.65	1.85	0.0546	0.396	1.074
*900.0	5.91	38.5	5.65	1.85	0.0552	0.402	1.088
905.9	5.37	38.5	5.70	1.85	0.0502	0.362	0.989
911.9	5.56	39.5	5.80	1.85	0.0507	0.368	1.024
918.0	5.19	39.7	5.80	1.85	0.0470	0.344	0.956
*923.9	5.93	39.5	5.95	2.05	0.0540	0.383	0.986
929.4	5.76	39.8	5.82	1.75	0.0521	0.380	1.121
+930.0		START SIMULATED GROUND WATER					
937.3	4.79	37.1	5.30	1.70	0.0465	0.347	0.960
942.2	3.40	37.3	5.25	1.60	0.0328	0.249	0.724

Test #62. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*947.6	4.94	37.0	5.85	1.80	0.0481	0.324	0.935
954.0	7.29	35.0	7.55	2.75	0.0750	0.371	0.903
961.5	8.67	34.3	7.15	2.45	0.0910	0.466	1.206
965.9	7.58	35.0	6.90	2.05	0.0779	0.472	1.260
*971.8	7.06	35.0	6.95	2.45	0.0726	0.390	0.982
978.0	7.26	35.1	6.80	2.30	0.0744	0.410	1.075
984.0	6.39	37.0	5.90	1.95	0.0622	0.416	1.116
990.2	4.84	37.5	5.10	1.60	0.0465	0.364	1.031
*995.9	4.89	38.3	4.60	1.40	0.0460	0.408	1.190
1002.0	4.37	39.1	4.40	1.30	0.0402	0.381	1.145
1008.0	3.89	39.8	3.75	1.15	0.0352	0.398	1.152
1013.9	3.67	39.7	3.30	0.90	0.0333	0.427	1.389
1020.5	3.03	40.3	3.10	0.85	0.0271	0.375	1.214
1026.0	2.42	41.0	2.90	0.85	0.0212	0.320	0.970
*1032.0	3.33	40.1	2.65	0.75	0.0299	0.482	1.513
1033.0		RUN STOPPED FOR 1 WEEK					
†1201.0		RUN RESTARTED					
1206.2	6.09	40.6	3.00	0.85	0.0540	0.779	2.441
1211.7	4.24	41.0	2.80	0.80	0.0372	0.581	1.806
1217.9	4.03	41.6	2.65	0.70	0.0349	0.584	1.961
1223.9	3.33	41.5	2.50	0.60	0.0289	0.511	1.891
*1229.8	3.39	41.5	2.45	0.50	0.0294	0.531	2.310

Test #62. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1236.0	3.23	42.0	2.40	0.50	0.0277	0.517	2.201
1242.0	2.78	42.0	2.35	0.40	0.0238	0.454	2.368
1248.0	2.78	42.5	2.30	0.40	0.0235	0.464	2.368
1254.1	2.46	42.5	2.30	0.40	0.0208	0.411	2.095
1260.1	2.50	42.5	2.30	0.30	0.0212	0.417	2.839
*1266.0	2.82	42.7	2.35	0.35	0.0238	0.461	2.745
1272.0	2.78	43.2	2.50	0.40	0.0232	0.427	2.368
1277.9	3.11	42.2	2.40	0.35	0.0265	0.497	3.027
1283.9	3.06	42.0	2.40	0.35	0.0262	0.489	2.979
1290.0	2.46	41.8	2.45	0.35	0.0212	0.385	2.395
1296.0	2.50	42.2	2.50	0.35	0.0213	0.384	2.434
*1302.0	2.50	41.7	2.50	0.30	0.0216	0.384	2.839
1308.2	2.42	41.7	2.50	0.30	0.0209	0.372	2.748
1314.0	2.01	42.1	2.55	0.35	0.0172	0.303	1.957
1320.0	1.94	41.6	2.55	0.30	0.0168	0.292	2.203
1325.9	2.26	41.0	2.60	0.30	0.0198	0.334	2.567
1331.9	2.22	41.1	2.65	0.30	0.0194	0.322	2.521
1338.0	1.64	41.1	2.60	0.20	0.0144	0.242	2.794
1344.0	1.67	41.5	2.75	0.30	0.0145	0.233	1.897
1350.5	1.79	41.5	2.90	0.30	0.0155	0.237	2.033
1356.2	1.75	41.0	2.95	0.30	0.0154	0.228	1.987
*1362.0	2.01	41.4	3.00	0.25	0.0175	0.257	2.739

Test #62. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1368.0	2.22	41.1	3.15	0.30	0.0194	0.271	2.521
1369.0			RUN STOPPED 1 WEEK				
†1536.0			RUN RESTARTED				
1542.0	2.50	39.9	4.70	0.50	0.0226	0.204	1.704
1548.1	2.73	39.9	4.80	0.50	0.0246	0.218	1.860
1553.8	2.63	39.9	5.00	0.45	0.0237	0.202	1.991
*1560.0	2.69	39.2	5.25	0.55	0.0247	0.197	1.667
1566.0	2.78	38.4	5.45	0.50	0.0261	0.196	1.894
1572.1	2.19	38.3	5.75	0.50	0.0206	0.146	1.492
1578.1	2.22	37.5	6.30	0.60	0.0213	0.135	1.261
*1583.9	2.59	36.5	7.10	0.65	0.0255	0.140	1.358
1590.0	3.01	35.7	7.80	0.65	0.0303	0.148	1.578
*1596.2	2.96	34.8	8.60	0.65	0.0306	0.132	1.551
1601.1			RUN TERMINATED				

Observations from the Simulation Leach Test #63

Ore used = Wyoming
Solution used = 2.0 g/l NaHCO_3 - Sat'd O_2 at 45 psig
Inlet section packing material = -80 AFS Subangular Sand
Inlet section packing length = 10.0 in.
Length of the front ore section = 46.75 in.
Length of the middle ore section = 50.13 in.
Length of the end ore section = 44.25 in.
Outlet section packing material = -80 AFS Subangular Sand
Outlet section packing length = 5.0 in.
Ore packing bed density = 1.72 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = 10 tamps/8 in. of ore. Column position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.

† indicates introduction of fresh feed solution(s).

Test #63

Ore - Wyoming

Sol - 2.0 g/l NaHCO₃
Sat'd O₂ (45 psig)

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
30.0	4.26	2.10	2.45	3.60	0.728	0.669	0.403
36.0	4.26	2.15	2.05	4.80	0.711	0.800	0.302
*41.7	4.26	2.20	2.20	3.70	0.695	0.745	0.392
48.0	4.26	2.40	2.55	3.00	0.637	0.643	0.484
54.0	3.89	2.20	2.40	2.40	0.635	0.624	0.552
59.9	5.08	2.15	2.30	2.20	0.848	0.850	0.787
65.8	4.52	2.20	2.35	2.30	0.737	0.740	0.670
71.9	4.10	2.15	2.30	2.20	0.684	0.686	0.635
78.0	4.92	2.20	2.30	2.20	0.803	0.823	0.762
84.0	3.89	2.20	2.30	2.30	0.635	0.651	0.576
*90.0	4.17	2.15	2.25	2.30	0.696	0.713	0.618
96.5	6.92	3.05	3.30	3.60	0.814	0.807	0.655
102.0	7.88	3.10	3.40	3.55	0.912	0.892	0.756
108.0	7.78	3.10	3.35	3.50	0.901	0.894	0.757
114.0	7.22	3.00	3.30	3.50	0.864	0.842	0.703
120.0	6.67	2.45	2.55	3.05	0.977	1.007	0.745
126.1	6.01	2.80	2.95	3.10	0.770	0.784	0.661
*132.0	5.37	2.45	2.55	2.75	0.787	0.810	0.665
138.0	5.83	2.25	2.40	2.70	0.930	0.935	0.736
+144.5	3.59	1.70	1.70	1.90	0.758	0.813	0.644
150.1	4.76	2.35	2.40	2.60	0.727	0.763	0.624
156.0	5.93	2.80	3.05	3.10	0.760	0.748	0.652

Test #63. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
162.0	7.50	3.05	3.50	3.60	0.883	0.825	0.710
*168.0			START CHEMICAL LEACH				
†168.0	7.22	3.00	3.40	3.40	0.864	0.817	0.723
174.1	10.38	3.95	4.60	4.80	0.943	0.868	0.737
*180.0	8.76	5.25	5.25	5.15	0.599	0.642	0.580
186.0	10.00	6.50	5.50	5.65	0.552	0.700	0.603
*192.0	9.72	8.55	5.70	6.10	0.408	0.656	0.543
198.1	10.93	11.4	6.00	6.75	0.344	0.701	0.552
203.7	10.12	13.5	6.00	6.65	0.269	0.649	0.518
*210.1	9.38	16.4	6.05	6.45	0.205	0.597	0.495
216.0	11.58	22.7	7.20	7.90	0.183	0.619	0.499
221.9	8.47	26.0	6.50	6.35	0.117	0.501	0.454
227.9	8.33	27.5	6.20	5.80	0.109	0.517	0.489
234.0	6.28	29.0	5.90	5.25	0.0777	0.410	0.408
240.0	6.11	29.0	5.65	5.30	0.0756	0.416	0.393
*246.0	5.56	30.0	5.30	4.85	0.0665	0.404	0.391
251.9	5.65	30.2	5.05	4.75	0.0671	0.431	0.405
258.0	5.74	31.0	4.90	4.70	0.0665	0.451	0.416
264.2	5.91	32.6	4.90	4.70	0.0651	0.464	0.428
270.0	5.46	33.0	4.60	4.40	0.0594	0.457	0.423
276.0	5.56	32.7	4.35	4.10	0.0610	0.492	0.462
282.0	5.28	33.7	4.20	4.00	0.0562	0.484	0.450
*288.2	5.38	34.0	4.15	3.95	0.0568	0.499	0.464

Test #63. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
294.0	4.31	34.2	3.90	3.75	0.0452	0.425	0.392
299.9	4.80	34.1	3.85	3.60	0.0505	0.480	0.454
306.0	5.19	35.1	3.60	3.45	0.0531	0.555	0.513
312.0	4.17	35.3	3.45	3.35	0.0423	0.465	0.424
317.9	4.24	35.2	3.25	2.90	0.0432	0.502	0.498
324.0	4.10	35.3	3.20	2.75	0.0417	0.493	0.508
*330.0	4.17	36.0	3.20	2.55	0.0416	0.501	0.557
336.0	4.72	36.0	3.10	2.80	0.0471	0.586	0.574
342.0	3.61	36.5	2.90	2.50	0.0355	0.479	0.492
348.0	3.89	36.2	2.80	2.35	0.0386	0.535	0.564
354.0	4.17	35.9	2.80	2.15	0.0417	0.573	0.661
361.2	3.94	36.0	2.75	2.30	0.0393	0.551	0.584
365.6	3.79	35.7	2.60	1.95	0.0381	0.561	0.662
372.0	3.65	35.7	2.60	1.95	0.0367	0.540	0.638
377.9	3.67	36.0	2.90	2.20	0.0366	0.487	0.568
†384.1	3.76	35.6	2.65	2.10	0.0379	0.546	0.610
*390.0	3.95	36.5	2.75	1.95	0.0388	0.553	0.690
396.0	3.61	37.0	2.60	1.90	0.0350	0.534	0.647
402.2	3.76	37.5	2.60	1.80	0.0360	0.556	0.712
408.0	3.74	36.7	2.50	1.80	0.0366	0.576	0.708
413.8	3.74	37.3	2.45	1.75	0.0360	0.587	0.728
420.0	3.76	37.5	2.40	1.65	0.0360	0.603	0.776

Test #63. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
426.0	3.33	38.0	2.40	1.70	0.0315	0.534	0.667
432.0	3.33	37.5	2.30	1.60	0.0319	0.557	0.709
438.1	3.28	37.5	2.05	1.35	0.0314	0.616	0.828
444.7	3.28	37.9	2.25	1.45	0.0311	0.561	0.771
*450.0	3.46	38.0	2.30	1.40	0.0327	0.579	0.842
456.0	3.61	38.5	2.10	1.45	0.0337	0.661	0.848
462.3	3.17	38.8	2.10	1.25	0.0293	0.581	0.864
467.9	2.98	38.2	2.30	1.45	0.0280	0.499	0.700
474.0	3.28	37.7	2.65	2.00	0.0312	0.476	0.559
480.0	3.33	38.3	2.40	1.30	0.0312	0.534	0.873
486.0	3.06	38.0	2.30	1.40	0.0289	0.512	0.747
491.9	2.82	37.2	2.25	1.30	0.0272	0.482	0.739
498.0	3.01	37.5	2.20	1.35	0.0288	0.526	0.760
*504.0	2.78	36.9	2.20	1.35	0.0270	0.486	0.702
510.0	2.50	37.4	1.95	1.30	0.0240	0.493	0.655
516.3	2.65	37.1	2.00	1.20	0.0256	0.510	0.752
522.0	2.63	37.3	2.15	1.25	0.0253	0.471	0.717
528.0	2.78	37.8	2.15	1.25	0.0264	0.498	0.758
534.0	2.50	38.5	2.00	1.20	0.0233	0.481	0.710
540.0	2.78	38.5	2.10	1.30	0.0259	0.509	0.729
546.3	2.91	38.8	2.20	1.30	0.0269	0.509	0.763
552.1	2.59	38.4	2.25	1.35	0.0242	0.443	0.654

Test #63. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*558.0	2.53	38.8	2.00	1.25	0.0234	0.487	0.690
564.1	2.19	38.8	2.20	1.25	0.0203	0.383	0.597
570.1	2.22	38.8	2.25	1.30	0.0205	0.380	0.582
576.0	2.54	38.8	2.20	1.30	0.0235	0.444	0.666
582.0	2.22	38.1	2.20	1.35	0.0209	0.388	0.560
588.0	2.50	38.5	2.15	1.30	0.0233	0.447	0.655
594.0	2.78	38.3	2.45	1.75	0.0261	0.437	0.541
600.0	2.78	39.2	2.35	1.50	0.0255	0.455	0.631
606.6	2.53	38.2	2.10	1.10	0.0238	0.464	0.784
612.0	2.78	38.4	2.15	1.25	0.0260	0.498	0.758
618.0	2.50	38.4	2.50	1.75	0.0234	0.385	0.487
*624.0	2.78	39.1	2.35	1.40	0.0255	0.455	0.677
630.0	2.78	38.9	2.05	1.05	0.0256	0.522	0.902
636.0	2.50	38.9	2.20	1.20	0.0231	0.437	0.710
642.0	2.22	39.4	2.35	1.75	0.0202	0.364	0.432
648.0	2.50	40.0	1.90	1.50	0.0224	0.506	0.568
654.1	2.46	39.0	2.00	1.45	0.0226	0.473	0.578
660.0	2.82	39.0	2.00	1.40	0.0260	0.543	0.686
666.0	2.83	39.5	2.25	1.65	0.0257	0.484	0.584
*672.0	2.78	40.7	2.05	1.70	0.0245	0.522	0.557
678.3	2.65	40.7	1.85	1.50	0.0234	0.551	0.602
684.0	2.34	40.5	1.85	1.30	0.0207	0.487	0.613

Test #63. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
690.0	2.22	40.3	1.75	1.55	0.0198	0.488	0.488
+696.0	2.78	39.5	1.75	1.35	0.0253	0.611	0.702
702.1	2.19	39.5	1.80	1.35	0.0199	0.468	0.553
708.2	2.19	40.5	1.80	1.30	0.0194	0.468	0.574
714.1	2.26	40.4	1.90	1.40	0.0201	0.458	0.550
720.0	2.54	40.2	2.00	1.70	0.0227	0.489	0.509
*726.2	2.69	40.5	1.85	1.60	0.0238	0.560	0.573
732.3	2.46	40.3	1.85	1.05	0.0219	0.512	0.798
738.0	2.34	40.8	1.90	1.40	0.0206	0.474	0.569
744.0	2.22	40.5	1.90	1.55	0.0197	0.450	0.480
750.1	2.19	40.5	1.80	1.55	0.0194	0.468	0.481
755.6	2.12	40.8	1.90	1.40	0.0186	0.429	0.516
762.0	2.34	40.2	2.05	1.65	0.0209	0.439	0.483
768.0	2.78	40.6	2.05	1.55	0.0246	0.522	0.611
774.0	2.78	41.0	1.80	1.60	0.0243	0.594	0.592
*780.1	2.19	41.0	1.80	1.35	0.0192	0.468	0.553
786.0	1.98	40.5	1.65	1.40	0.0175	0.462	0.482
792.0	1.94	41.0	1.65	1.45	0.0170	0.452	0.456
798.0	1.94	40.2	1.45	1.15	0.0173	0.515	0.575
804.1	2.19	39.7	1.70	1.20	0.0198	0.496	0.622
810.0	2.26	40.3	1.70	1.35	0.0201	0.512	0.570
816.0	2.22	40.5	1.70	1.50	0.0197	0.503	0.504

Test #63. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
822.1	1.91	40.5	1.50	1.20	0.0169	0.490	0.542
827.9	2.01	40.0	1.70	1.05	0.0180	0.455	0.652
834.0	2.19	40.6	1.85	1.55	0.0194	0.456	0.481
*840.0	1.94	41.0	1.60	1.55	0.0170	0.467	0.426
845.9	1.69	41.0	1.40	1.20	0.0148	0.465	0.480
852.1	1.88	40.5	1.40	1.00	0.0167	0.517	0.641
858.0	1.98	41.0	1.65	1.45	0.0173	0.462	0.465
864.0	1.94	41.1	1.50	1.30	0.0169	0.498	0.508
869.9	1.70	41.1	1.50	1.30	0.0148	0.436	0.445
876.0	1.64	40.5	1.30	1.35	0.0145	0.485	0.414
882.1	1.64	40.5	1.45	0.95	0.0145	0.435	0.588
*887.9	1.72	40.1	1.65	1.10	0.0154	0.401	0.533
893.9	1.67	40.1	1.55	1.00	0.0149	0.415	0.569
900.0	1.64	40.0	1.60	1.00	0.0147	0.394	0.559
906.1	1.64	40.0	1.60	1.00	0.0147	0.394	0.559
912.0	1.70	40.1	1.70	1.20	0.0152	0.385	0.483
917.0	2.00	40.0	2.00	1.15	0.0179	0.385	0.593
924.0	2.14	41.5	1.90	1.60	0.0185	0.433	0.456
*929.4	1.85	41.5	1.85	1.60	0.0160	0.385	0.394
†930.2		START SIMULATED GRD H ₂ O					
937.2	1.40	39.0	1.45	1.25	0.0129	0.351	0.382
942.3	1.33	39.0	1.30	0.85	0.0122	0.394	0.533

Test #63. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*947.7	1.33	39.0	0.90	0.80	0.0122	0.569	0.566
954.0	1.59	40.5	1.15	1.15	0.0139	0.532	0.471
960.0	1.11	41.2	0.85	0.70	0.0097	0.503	0.540
966.0	0.46	40.8	0.80	0.60	0.0040	0.221	0.261
971.9	0.46	40.2	0.65	0.60	0.0041	0.272	0.261
*978.0	0.55	40.0	0.70	0.85	0.0049	0.302	0.220
984.0	0.55	40.5	0.65	0.85	0.0049	0.326	0.220
990.2	0.46	40.8	0.70	0.60	0.0040	0.302	0.261
996.0	0.46	39.5	0.70	0.60	0.0042	0.302	0.261
1002.0	0.46	40.5	0.70	0.65	0.0041	0.302	0.241
1008.0	0.46	40.9	0.80	0.65	0.0040	0.221	0.241
1014.0	0.46	40.3	0.85	0.50	0.0041	0.279	0.313
1020.6	0.46	39.5	0.85	0.50	0.0042	0.279	0.313
1026.0	0.46	40.2	1.00	0.70	0.0041	0.177	0.224
*1032.0	0.46	39.6	0.95	0.55	0.0042	0.186	0.285
1032.0		RUN STOPPED FOR 70 HOURS					
1102.0		RUN RESTARTED					
1104.0	1.73	36.6	2.55	1.85	0.0170	0.261	0.319
1109.7	1.73	37.5	1.60	1.15	0.0166	0.416	0.513
1116.1	2.34	38.5	1.35	0.85	0.0218	0.667	0.938
1122.0	1.13	39.0	1.40	0.95	0.0104	0.311	0.405
*1128.0	1.39	39.1	1.00	0.95	0.0128	0.535	0.359

Test #63. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1134.1	1.09	39.0	1.20	0.85	0.0100	0.350	0.437
1140.0	1.41	38.5	1.30	0.75	0.0131	0.417	0.641
1146.0	1.39	38.6	1.40	0.90	0.0129	0.382	0.526
1152.0	1.67	37.0	2.00	1.25	0.0162	0.321	0.455
1158.7	2.24	37.1	1.90	1.10	0.0217	0.454	0.694
*1164.0	2.20	36.5	2.00	1.20	0.0216	0.423	0.625
1170.0	2.78	36.3	2.15	1.30	0.0275	0.498	0.729
1176.0	2.78	36.5	2.15	1.25	0.0273	0.498	0.758
1182.3	2.91	35.9	1.90	1.45	0.0291	0.589	0.684
*1188.0	2.92	36.0	2.10	1.40	0.0291	0.535	0.711
1194.0	2.78	35.7	2.15	1.55	0.0279	0.498	0.611
1200.0	2.50	35.4	2.10	1.45	0.0253	0.458	0.587
1206.3	2.65	35.4	2.05	1.45	0.0269	0.497	0.623
1211.7	3.09	36.0	2.15	1.60	0.0308	0.553	0.658
1218.0	3.44	35.0	2.40	1.65	0.0353	0.552	0.710
1224.0	3.44	34.7	2.25	1.60	0.0356	0.588	0.733
1229.9	3.39	34.7	2.25	1.45	0.0351	0.580	0.797
1236.0	3.01	34.4	2.25	1.30	0.0314	0.515	0.789
*1242.0	2.78	34.5	2.30	1.25	0.0289	0.465	0.758
1248.0	2.78	34.5	2.30	1.25	0.0289	0.465	0.758
1254.1	2.73	35.0	2.30	1.20	0.0280	0.457	0.775
1260.1	2.50	34.5	2.25	1.15	0.0260	0.428	0.741

Test #63. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*1266.0	2.82	35.3	2.15	1.60	0.0287	0.505	0.600
1266.0			RUN STOPPED 1 WEEK				
+1434.0			RUN RESTARTED				
1440.0	6.11	36.5	3.85	1.70	0.0601	0.611	1.225
1446.1	5.19	35.7	4.15	1.55	0.0522	0.481	1.141
*1452.0	5.37	34.8	4.70	1.65	0.0554	0.440	1.109
1459.0	6.67	33.7	5.70	2.10	0.0710	0.450	1.082
1464.9	7.91	32.8	6.25	2.35	0.0866	0.487	1.147
1470.0	8.82	32.2	6.40	2.55	0.0983	0.530	1.178
*1476.5	7.95	32.0	6.65	2.65	0.0892	0.460	1.022
1482.0	7.58	31.8	6.80	2.80	0.0855	0.429	0.922
1488.0	9.17	31.1	6.90	2.90	0.106	0.511	1.077
1494.0	8.33	30.6	6.95	2.70	0.0977	0.461	1.051
1500.7	7.46	31.4	7.00	2.60	0.0853	0.410	0.978
1506.0	7.55	31.7	7.50	3.05	0.0855	0.387	0.843
*1512.0	8.61	30.8	7.50	3.00	0.100	0.442	0.978
1518.0	8.33	29.7	7.45	2.85	0.101	0.430	0.996
1523.8	7.47	29.5	7.45	2.80	0.0909	0.386	0.909
*1530.0	8.07	29.7	7.70	2.85	0.0975	0.403	0.965
1530.0			RUN STOPPED 6 DAYS				
+1674.0			RUN RESTARTED				
1680.0	7.50	29.0	6.95	3.65	0.0928	0.415	0.700

Test #63. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*1686.3	7.14	23.2	6.35	3.15	0.110	0.433	0.772
1692.0	7.31	24.0	6.70	3.10	0.109	0.420	0.803
1698.0	7.22	23.0	6.90	3.15	0.113	0.403	0.781
1704.0	6.94	23.7	7.05	3.20	0.105	0.379	0.739
1710.1	6.56	23.4	7.15	3.05	0.101	0.353	0.733
1716.4	6.61	23.8	7.05	3.00	0.100	0.361	0.751
*1722.0	6.84	23.4	7.00	3.00	0.105	0.376	0.777
1728.0	6.67	22.7	7.20	3.20	0.105	0.356	0.710
1734.5	6.67	23.0	7.20	3.10	0.104	0.356	0.733
1740.7	6.72	23.0	7.15	3.00	0.105	0.362	0.763
1746.0	6.92	23.4	7.15	3.05	0.106	0.372	0.773
*1752.0	6.67	23.0	7.15	3.10	0.104	0.359	0.733
1758.0	6.39	22.5	7.15	3.10	0.102	0.344	0.702
1763.9	5.93	22.6	7.20	3.00	0.094	0.317	0.673
1770.0	6.28	22.7	7.75	3.30	0.099	0.312	0.648
1776.0	6.67	22.4	7.70	3.10	0.107	0.333	0.733
1782.2	4.84	16.0	6.30	2.15	0.109	0.297	0.770
1788.1	4.52	15.1	6.05	2.00	0.107	0.287	0.770
1794.0	4.80	16.0	6.35	2.30	0.108	0.291	0.711
*1800.0	4.72	15.8	6.60	2.30	0.107	0.275	0.699
RUN TERMINATED							

Observations from the Simulation Leach Test #64

Ore used	= Texas
Solution used	= H_2SO_4 , pH = 1.0
Inlet section packing material	= -80 AFS Subangular Sand
Inlet section packing length	= 10.0 in.
Length of the front ore section	= 46.75 in.
Length of the middle ore section	= (Not used in 8-ft column)
Length of the end ore section	= 52.38 in.
Outlet section packing material	= -80 AFS Subangular Sand
Outlet section packing length	= 5.00 in.
Ore packing bed density	= 1.47 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = 15 tamps/8 in. of ore. Column Position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.

† indicates introduction of fresh feed solution(s).

Test #64

Ore - Texas

Sol - H_2SO_4 , pH 1.0

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
30.0	6.67	6.05	7.75	0.396	0.346
36.1	6.67	6.30	8.35	0.380	0.321
41.7	6.67	6.50	8.70	0.368	0.308
*48.0	6.67	6.50	9.00	0.368	0.298
54.0	7.50	6.50	9.30	0.414	0.324
59.9	6.78	6.40	9.30	0.380	0.293
65.8	6.78	6.20	9.30	0.392	0.293
71.9	6.28	6.00	9.35	0.376	0.270
*78.0	6.83	5.85	9.30	0.419	0.295
84.0	6.94	5.80	9.30	0.429	0.300
90.0	5.83	5.70	9.60	0.367	0.244
96.5	8.97	7.70	14.7	0.418	0.245
102.0	9.70	7.40	13.7	0.470	0.285
*108.0	8.88	7.20	13.9	0.443	0.257
114.0	10.00	7.30	14.9	0.492	0.270
†114.0	START CHEMICAL LEACH - H_2SO_4 @ pH 1				
*120.0	10.55	12.1	14.8	0.313	0.287
126.1	9.02	26.0	13.9	0.125	0.261
*132.0	7.63	29.5	12.4	0.0928	0.247
138.0	5.28	30.5	11.4	0.0615	0.186
144.5	4.87	31.5	11.0	0.0549	0.178
150.1	4.17	31.9	10.7	0.0464	0.157
*156.0	4.24	32.0	10.5	0.0471	0.162

Test #64. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
162.0	4.17	32.0	10.5	0.0463	0.160
168.0	3.61	32.0	10.0	0.0401	0.145
174.1	3.55	31.8	10.0	0.0396	0.143
*180.0	3.39	31.9	10.0	0.0377	0.136
186.0	3.33	32.0	10.0	0.0370	0.134
192.0	3.61	32.0	10.0	0.0401	0.145
198.1	3.55	32.0	9.9	0.0394	0.144
203.8	3.22	32.1	9.9	0.0356	0.131
*210.1	2.91	31.6	9.9	0.0327	0.118
216.0	2.82	32.0	10.0	0.0313	0.113
221.9	2.82	31.2	9.8	0.0321	0.116
228.0	2.73	31.5	10.0	0.0308	0.110
234.0	2.78	32.3	9.8	0.0306	0.114
240.0	3.05	32.0	10.0	0.0338	0.123
246.0	2.78	31.7	9.8	0.0311	0.114
251.9	2.82	31.6	9.9	0.0317	0.115
258.0	2.73	32.0	10.0	0.0303	0.110
*264.2	2.69	32.0	10.0	0.0299	0.108
270.0	2.59	31.7	9.8	0.0290	0.106
276.0	2.78	31.5	9.5	0.0313	0.118
282.0	2.78	32.1	9.4	0.0308	0.119
288.2	2.69	32.5	9.5	0.0294	0.114

Test #64. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
294.0	2.59	32.0	9.5	0.0287	0.110
300.0	2.50	32.2	9.3	0.0276	0.108
306.0	2.50	32.4	9.1	0.0274	0.110
+312.0	2.50	33.0	9.0	0.0269	0.112
317.9	2.26	33.0	9.0	0.0243	0.101
324.0	2.46	33.4	8.6	0.0262	0.115
330.0	2.22	33.2	8.8	0.0237	0.101
336.0	2.22	33.1	8.9	0.0238	0.100
342.0	2.22	32.0	9.0	0.0246	0.0992
348.0	2.22	31.3	9.2	0.0252	0.0970
*354.0	2.50	30.3	9.7	0.0293	0.104
361.2	2.77	31.3	10.2	0.0314	0.109
365.6	2.65	31.3	10.2	0.0301	0.104
372.0	2.60	31.4	10.1	0.0294	0.104
377.9	2.54	31.4	10.1	0.0287	0.101
384.1	2.42	31.5	10.5	0.0273	0.0927
390.0	2.54	31.0	10.0	0.0291	0.102
396.0	2.50	31.0	10.0	0.0286	0.101
*402.2	2.42	31.0	10.0	0.0277	0.0973
408.1	2.54	31.0	10.0	0.0291	0.102
413.9	2.30	31.0	10.0	0.0263	0.0925
420.0	2.19	31.0	10.5	0.0251	0.0839

Test #64. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
426.0	2.22	31.0	10.5	0.0254	0.0850
432.0	1.94	30.7	10.8	0.0224	0.0722
438.1	2.19	31.0	10.5	0.0251	0.0839
444.7	2.27	31.0	10.5	0.0260	0.0869
450.0	2.52	30.7	10.8	0.0291	0.0938
*456.0	2.22	30.9	11.1	0.0255	0.0804
462.4	2.08	31.0	10.5	0.0238	0.0797
467.9	2.12	30.7	10.2	0.0245	0.0836
474.0	2.19	31.2	10.8	0.0249	0.0815
480.0	2.22	30.6	10.9	0.0258	0.0819
486.0	2.22	30.0	11.0	0.0263	0.0812
491.9	1.98	29.5	11.0	0.0238	0.0724
498.0	1.91	30.0	11.0	0.0226	0.0698
504.0	2.22	30.0	11.0	0.0263	0.0812
510.0	2.22	30.0	11.0	0.0263	0.0812
*516.4	2.08	30.0	11.0	0.0246	0.0760
522.0	1.78	30.0	11.0	0.0211	0.0651
528.0	1.94	30.0	11.0	0.0230	0.0709
534.0	1.94	30.0	11.0	0.0230	0.0709
540.0	1.94	30.1	10.9	0.0229	0.0716
546.3	1.85	30.0	11.0	0.0219	0.0676
552.1	1.72	30.0	11.0	0.0204	0.0629

Test #64. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
*560.0	1.69	30.0	11.0	0.0200	0.0618
564.2	1.88	30.2	10.8	0.0221	0.0700
570.1	1.69	30.2	10.8	0.0199	0.0629
576.0	1.69	30.2	10.8	0.0199	0.0629
582.0	1.67	30.2	10.8	0.0196	0.0622
588.0	1.67	30.2	10.8	0.0196	0.0622
594.0	1.67	30.6	10.9	0.0194	0.0616
600.0	1.67	30.9	11.1	0.0192	0.0605
*606.6	1.77	30.1	10.4	0.0209	0.0684
612.0	1.85	30.3	10.2	0.0217	0.0729
618.0	1.39	31.1	10.4	0.0159	0.0537
624.0	1.39	31.1	10.9	0.0159	0.0513
†624.5		START SIMULATED GROUND WATER			
630.1	1.64	32.0	10.0	0.0182	0.0659
636.0	1.41	32.5	9.5	0.0154	0.0597
642.0	1.39	32.4	10.1	0.0152	0.0553
*648.0	1.67	29.7	12.3	0.0200	0.0546
654.1	2.46	27.9	13.1	0.0313	0.0755
660.1	2.78	27.2	13.8	0.0363	0.0810
666.0	2.54	27.3	14.2	0.0330	0.0719
*672.0	2.78	26.4	15.1	0.0374	0.0740
678.3	2.91	25.8	15.2	0.0401	0.770

Test #64. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
684.0	3.22	25.5	15.5	0.0448	0.0835
690.0	3.06	25.0	16.0	0.0435	0.0769
696.0	3.06	24.5	16.0	0.0444	0.0769
*702.1	3.01	24.5	16.0	0.0436	0.0756
708.2	2.73	24.3	16.2	0.0399	0.0678
714.1	2.82	23.7	16.8	0.0423	0.0675
720.0	3.11	23.4	17.1	0.0472	0.0731
726.2	3.23	23.0	17.2	0.0499	0.0755
732.3	2.73	22.8	17.2	0.0425	0.0638
*738.0	2.92	22.5	17.5	0.0461	0.0671
744.0	2.78	22.2	17.8	0.0447	0.0628
750.2	2.69	22.2	17.8	0.0430	0.0608
*755.6	2.78	22.2	17.8	0.0447	0.0628
762.0	2.86	22.1	17.9	0.0460	0.0642
762.5		RUN STOPPED FOR 1 WEEK			
930.0		RUN RESTARTED			
937.3	6.62	21.8	19.2	0.108	0.139
942.4	6.86	20.5	20.0	0.119	0.138
*947.8	5.56	20.3	20.2	0.0973	0.111
954.0	4.84	20.3	21.2	0.0847	0.0918
961.5	6.22	18.7	21.8	0.118	0.115
966.0	6.30	18.5	21.5	0.121	0.118

Test #64. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
972.0	4.44	18.8	21.2	0.0839	0.0842
978.0	5.00	18.2	21.6	0.0976	0.0931
984.0	4.72	17.5	21.8	0.0958	0.0871
990.2	4.30	17.0	22.5	0.0898	0.0768
996.0	4.60	17.8	21.2	0.0918	0.0872
*1002.0	4.72	18.0	21.5	0.0931	0.0883
1008.0	4.17	17.0	21.5	0.0871	0.0780
1008.0	RUN STOPPED FOR 1 WEEK				
†1176.0	RUN RESTARTED				
1182.3	6.35	21.3	19.2	0.106	0.133
*1188.0	6.73	19.0	21.5	0.126	0.126
1194.0	6.11	19.0	21.5	0.114	0.114
1200.0	6.67	17.9	22.1	0.132	0.121
1206.4	6.51	17.4	22.6	0.133	0.116
1211.8	6.17	17.1	22.9	0.128	0.108
1218.0	5.65	17.0	23.0	0.118	0.0988
*1224.0	5.55	17.0	23.0	0.116	0.0970
1229.9	5.08	17.0	23.0	0.106	0.0888
1236.1	5.11	17.0	23.0	0.107	0.0893
1242.0	5.37	17.0	23.0	0.112	0.0939
1248.0	5.28	17.0	23.0	0.110	0.0923
*1254.2	5.38	17.2	22.6	0.111	0.0957

Test #64. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
1260.2	4.72	17.4	22.6	0.0963	0.0840
1266.0	5.17	17.2	22.8	0.107	0.0912
*1272.0	5.28	18.0	24.0	0.104	0.0885
RUN TERMINATED					

Observations from the Simulation Leach Test #65

Ore used = Wyoming
Solution used = 1.0 g/l KHCO_3 - Sat'd O_2 at 45 psig
Inlet section packing material = -80 AFS Subangular Sand
Inlet section packing length = 10.0 in.
Length of the front ore section = 47.00 in.
Length of the middle ore section = 50.25 in.
Length of the end ore section = 44.25 in.
Outlet section packing material = -80 AFS Subangular Sand
Outlet section packing length = 5.00 in.
Ore packing bed density = 1.71 kg/l

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = tamps/8 in. of ore. Column position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.
† indicates introduction of fresh feed solution(s).

Test #65

Ore - Wyoming

Sol - 1.0 g/l KHCO_3
Sat'd O_2 (45 psig)

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
30.1	3.52	1.00	2.05	2.05	1.270	0.662	0.583
36.0	3.15	0.80	1.35	2.15	1.421	0.900	0.498
42.0	3.06	0.60	1.35	1.55	1.840	0.874	0.671
48.0	5.56	1.30	1.90	2.10	1.543	1.129	0.899
54.2	5.38	1.30	1.80	1.20	1.493	1.153	1.523
*59.8	5.65	1.20	1.75	1.00	1.699	1.246	1.919
66.1	5.82	1.30	1.90	0.85	1.615	1.182	2.326
72.0	5.93	1.25	1.95	0.90	1.712	1.173	2.238
78.0	5.28	1.20	1.70	0.80	1.588	1.198	2.242
*84.0	5.28	1.15	1.60	0.90	1.657	1.273	1.993
90.0	5.28	1.00	1.50	0.80	1.905	1.358	2.242
96.0	4.44	0.80	1.40	0.75	2.002	1.224	2.011
102.0	5.00	1.00	1.40	0.90	1.804	1.378	1.887
*107.9	4.52	0.85	1.25	0.85	1.919	1.395	1.806
114.0	4.64	0.90	1.35	1.00	1.860	1.326	1.576
120.2	4.57	0.80	1.25	1.20	2.061	1.410	1.294
126.0	4.31	0.75	1.25	1.00	2.073	1.330	1.464
132.1	4.37	0.80	1.25	1.05	1.971	1.349	1.414
138.0	5.08	0.90	1.35	1.10	2.037	1.452	1.569
*144.2	4.57	0.90	1.20	1.25	1.832	1.469	1.242
150.0	3.74	0.35	0.75	1.00	3.855	1.924	1.270
156.0	3.89	0.55	0.75	1.00	2.552	2.001	1.321

Test #65. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
162.0	4.72	1.05	1.20	1.20	1.622	1.517	1.336
168.0	4.17	1.20	1.05	1.20	1.254	1.532	1.180
168.0		RUN STOPPED 24 HOURS					
+192.0		CHEMICAL LEACH STARTED					
198.0	8.61	3.25	2.75	2.00	0.956	1.208	1.462
204.1	10.38	2.85	3.10	2.50	1.314	1.292	1.410
*210.0	8.76	2.80	3.00	2.50	1.129	1.127	1.190
217.2	10.65	3.35	3.40	2.70	1.147	1.208	1.340
221.6	10.61	3.70	3.75	2.90	1.035	1.092	1.243
228.0	9.64	3.70	3.90	2.75	0.940	0.954	1.191
234.0	9.44	3.45	4.15	2.80	0.987	0.878	1.145
240.1	10.38	4.05	3.65	3.10	0.925	1.097	1.137
*246.0	9.60	3.70	4.30	3.00	0.936	0.861	1.087
252.0	9.72	3.50	4.20	3.15	1.002	0.893	1.048
258.2	9.14	3.65	4.00	2.85	0.903	0.882	1.089
264.1	8.76	3.50	4.00	2.80	0.903	0.845	1.063
269.9	10.92	4.20	5.00	3.25	0.938	0.843	1.141
276.0	10.38	4.05	4.45	3.00	0.925	0.900	1.175
*282.0	10.00	3.90	4.20	2.80	0.925	0.919	1.213
288.0	8.61	3.95	3.80	2.90	0.786	0.874	1.008
294.1	11.48	5.40	4.55	3.20	0.767	0.973	1.219
300.7	9.60	5.00	3.75	2.65	0.693	0.988	1.231

Test #65. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*306.0	9.75	5.00	3.70	2.70	0.704	1.017	1.227
312.0	10.55	5.70	3.85	2.75	0.668	1.057	1.303
318.4	10.42	6.40	3.90	2.55	0.587	1.031	1.388
323.9	9.39	6.80	3.95	2.50	0.498	0.917	1.276
330.0	9.29	7.25	3.85	2.80	0.462	0.931	1.127
336.0	8.61	8.00	3.70	2.45	0.388	0.898	1.194
*342.0	10.00	11.2	3.90	2.70	0.322	0.989	1.258
347.9	9.60	13.7	3.85	2.45	0.253	0.962	1.331
354.0	9.29	16.5	3.80	2.45	0.203	0.943	1.288
+360.0	9.44	21.0	3.85	2.35	0.162	0.946	1.365
366.0	9.44	25.5	4.05	2.45	0.134	0.900	1.309
*372.4	8.59	26.0	3.45	2.30	0.119	0.961	1.269
378.0	8.04	28.0	3.35	2.20	0.104	0.926	1.241
384.0	8.33	29.1	3.40	2.35	0.103	0.945	1.204
390.0	7.78	28.5	2.55	2.20	0.0985	1.177	1.201
396.0	6.11	28.5	2.45	1.75	0.0774	0.962	1.186
402.3	5.82	27.0	2.10	1.65	0.0778	1.069	1.204
408.1	7.76	30.5	2.95	2.10	0.0918	1.015	1.255
416.0	7.06	29.9	2.65	1.70	0.0852	1.028	1.410
*420.2	6.45	29.0	2.60	1.65	0.0802	0.957	1.328
426.1	5.93	28.6	2.20	1.50	0.0748	1.040	1.343
432.0	5.65	28.6	2.25	1.95	0.0713	0.969	0.984

Test #65. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
438.0	5.56	28.5	2.30	1.65	0.0704	0.933	1.145
444.0	5.00	28.6	2.30	1.70	0.0631	0.839	0.999
450.0	5.83	29.5	2.45	1.85	0.0713	0.918	1.070
456.0	7.78	32.0	3.25	2.05	0.0877	0.924	1.289
462.6	8.33	33.5	3.20	1.80	0.0897	1.004	1.572
468.0	6.17	32.0	2.95	1.45	0.0696	0.807	1.445
474.0	6.11	31.5	2.75	1.65	0.0700	0.857	1.258
480.0	7.78	33.5	3.10	1.70	0.0838	0.968	1.555
486.1	10.66	38.4	4.20	2.20	0.100	0.979	1.646
*492.0	8.76	38.5	4.20	2.40	0.0821	0.805	1.240
498.0	8.33	38.3	4.15	2.40	0.0785	0.774	1.179
504.0	8.33	38.9	3.80	2.25	0.0773	0.846	1.258
510.1	7.92	38.9	4.05	2.20	0.0735	0.754	1.223
516.0	7.63	38.8	3.85	2.25	0.0710	0.765	1.152
522.0	7.50	38.6	3.85	2.35	0.0701	0.752	1.084
*528.0	7.22	38.9	3.55	2.20	0.0670	0.785	1.115
534.3	6.88	38.1	3.30	2.15	0.0652	0.804	1.087
540.0	7.31	38.5	3.50	2.10	0.0685	0.806	1.182
+546.0	6.67	39.1	3.55	1.70	0.0615	0.725	1.333
552.0	7.22	38.3	3.65	1.90	0.0680	0.763	1.291
558.1	6.56	38.5	3.50	2.00	0.0615	0.723	1.114
564.2	6.28	39.2	3.70	2.05	0.0578	0.655	1.041

Test #65. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
570.1	7.91	37.2	4.20	2.20	0.0767	0.727	1.221
576.0	8.19	36.6	4.20	2.45	0.0807	0.752	1.136
582.2	8.33	37.6	4.40	1.90	0.0799	0.730	1.489
*588.3	8.47	36.7	5.20	2.60	0.0833	0.628	1.107
594.0	10.82	34.7	5.75	2.80	0.113	0.726	1.313
600.0	11.10	34.5	5.90	2.95	0.116	0.726	1.278
606.2	11.02	33.9	6.80	3.15	0.117	0.625	1.188
611.6	12.65	32.5	7.70	3.45	0.140	0.634	1.246
618.0	13.80	30.1	8.40	3.95	0.165	0.634	1.187
624.0	9.44	29.3	6.45	2.95	0.116	0.565	1.087
630.0	9.17	31.3	6.25	2.85	0.106	0.566	1.093
*636.2	9.14	31.7	6.05	2.80	0.104	0.583	1.109
642.0	8.91	32.2	5.75	2.75	0.0998	0.598	1.101
648.0	9.44	33.9	6.20	2.90	0.100	0.587	1.106
654.0	10.28	32.5	7.45	3.00	0.114	0.532	1.164
660.1	10.38	32.7	8.00	3.30	0.115	0.501	1.069
666.0	11.58	32.0	8.40	3.40	0.131	0.532	1.157
672.0	10.83	32.0	7.40	3.20	0.122	0.565	1.150
678.1	9.02	32.0	7.60	3.10	0.102	0.458	0.988
684.0	10.17	32.4	8.05	3.10	0.113	0.487	1.114
690.0	10.00	32.0	7.75	3.40	0.113	0.498	0.999
*696.0	10.00	32.7	7.40	3.10	0.110	0.521	1.096

Test #65. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
701.9	9.89	32.1	7.45	2.95	0.111	0.512	1.139
708.2	10.32	32.6	8.00	3.15	0.114	0.498	1.113
+714.0	9.77	30.7	8.70	3.50	0.115	0.433	0.948
720.0	10.56	31.4	8.55	3.30	0.121	0.476	1.087
725.9	9.89	31.5	8.55	3.10	0.113	0.446	1.084
732.0	9.84	31.5	8.60	3.10	0.113	0.441	1.039
738.1	9.84	32.0	8.85	2.75	0.111	0.429	1.216
743.9	10.05	32.1	8.70	3.15	0.113	0.446	1.084
*749.9	9.17	30.2	9.00	3.20	0.110	0.393	0.973
756.0	10.66	29.2	9.75	3.20	0.132	0.422	1.132
762.1	10.38	29.3	9.70	3.20	0.128	0.413	1.102
768.0	10.17	27.0	10.50	3.50	0.136	0.374	0.987
773.0	11.33	24.5	10.30	3.20	0.167	0.424	1.203
780.0	6.91	25.5	8.80	2.95	0.098	0.303	0.796
785.4	6.48	26.2	8.15	2.70	0.089	0.307	0.815
793.0	7.68	28.2	8.10	3.15	0.0982	0.366	0.828
798.4	7.72	28.5	8.40	2.70	0.0977	0.355	0.971
803.8	7.72	29.3	8.55	2.65	0.0951	0.348	0.990
810.0	7.26	28.8	8.50	2.80	0.0910	0.330	0.881
816.0	8.33	29.3	8.35	2.90	0.103	0.385	0.976
*822.0	9.44	31.1	9.20	2.75	0.110	0.396	1.166
828.0	9.44	30.5	9.90	3.15	0.112	0.368	1.018

Test #65. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
834.0	9.72	28.0	10.70	3.50	0.125	0.350	0.943
840.0	10.05	29.1	10.05	2.70	0.125	0.386	1.264
846.2	9.14	29.0	10.50	3.25	0.114	0.336	0.955
852.0	10.63	29.0	10.30	3.35	0.132	0.398	1.078
858.0	10.00	28.4	10.40	3.25	0.127	0.371	1.045
864.0	9.44	29.3	9.65	3.00	0.116	0.377	1.069
870.0	9.44	29.0	10.00	2.90	0.117	0.364	1.106
876.6	9.34	29.2	10.30	3.15	0.115	0.350	1.007
+882.0	9.88	28.9	10.70	3.15	0.123	0.356	1.065
*888.0	9.72	29.6	10.30	2.45	0.118	0.364	1.348
894.0	8.89	28.5	9.65	2.80	0.113	0.355	1.079
900.0	8.06	28.5	10.20	2.80	0.102	0.305	0.978
905.7	9.06	26.2	11.1	3.40	0.125	0.315	0.905
912.1	9.90	24.9	11.1	3.20	0.143	0.344	1.051
918.0	8.76	27.0	9.75	2.70	0.117	0.343	1.102
924.0	8.06	28.3	9.10	2.55	0.103	0.342	1.074
929.8	6.90	29.0	8.95	2.50	0.0858	0.297	0.938
936.0	7.26	29.0	8.75	2.60	0.0903	0.320	0.949
942.0	6.94	29.5	8.20	2.40	0.0849	0.327	0.982
948.2	7.26	29.7	8.10	2.25	0.0882	0.346	1.096
954.0	7.47	30.1	8.25	2.35	0.0895	0.349	1.080
*960.0	8.61	30.8	8.35	2.45	0.101	0.398	1.194

Test #65. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
+960.0		START SIMULATED GROUND WATER					
965.7	8.19	31.0	9.30	2.60	0.0953	0.340	1.070
972.1	14.58	25.5	12.5	3.90	0.206	0.450	1.270
978.0	10.73	27.6	11.3	3.30	0.140	0.366	1.105
984.0	8.33	30.2	9.90	2.60	0.0995	0.325	1.088
*990.1	6.83	31.4	8.00	2.30	0.0785	0.329	1.009
996.0	6.21	32.5	7.35	2.05	0.0689	0.326	1.029
1002.0	5.56	33.1	6.80	1.50	0.0606	0.315	1.259
1008.0	5.00	34.0	5.90	1.90	0.0531	0.327	0.894
1014.7	4.48	36.0	4.45	1.50	0.0449	0.388	1.015
1020.0	3.77	36.2	4.20	1.30	0.0376	0.346	0.985
*1026.0	3.33	37.0	3.90	1.40	0.0325	0.329	0.808
1026.0		RUN STOPPED FOR 1 WEEK					
+1194.0		RUN RESTARTED					
1200.0	2.78	39.5	2.95	1.25	0.0254	0.364	0.755
1206.6	3.79	39.0	2.75	1.25	0.0351	0.532	1.030
*1212.3	3.45	39.2	2.70	1.20	0.0318	0.493	0.977
1218.0	3.16	39.4	2.55	1.10	0.0289	0.478	0.976
1224.0	3.33	39.5	2.45	1.15	0.0304	0.524	0.984
1230.6	3.28	38.5	2.35	1.10	0.0307	0.538	1.013
1236.0	3.40	38.8	2.25	1.00	0.0316	0.583	1.155
1242.2	3.23	39.0	2.20	1.00	0.0299	0.569	1.097

Test #65. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1248.0	3.45	39.1	2.05	0.65	0.0318	0.649	1.803
*1253.8	3.45	39.0	2.05	0.80	0.0319	0.649	1.465
1260.0	2.96	38.5	2.05	0.70	0.0277	0.557	1.436
1266.1	2.73	39.2	2.05	0.70	0.0251	0.514	1.325
1272.0	2.54	39.1	2.00	0.70	0.0234	0.490	1.233
1277.9	2.54	38.7	2.00	0.70	0.0237	0.490	1.233
*1284.0	2.73	38.5	2.05	0.75	0.0256	0.514	1.237
1290.0	2.50	39.0	2.05	0.75	0.0231	0.470	1.132
1296.0	2.50	40.0	1.95	0.85	0.0226	0.495	0.999
1302.0	2.22	38.8	1.80	0.70	0.0206	0.476	1.077
1308.0	1.94	38.6	1.80	0.60	0.0181	0.416	1.098
1314.0	1.94	38.5	1.75	0.50	0.0182	0.428	1.318
1320.9	1.93	39.0	1.80	0.60	0.0179	0.414	1.093
*1326.0	1.96	38.6	1.75	0.60	0.0183	0.432	1.110
1332.5	2.05	39.0	1.70	0.55	0.0190	0.465	1.266
1338.0	2.12	39.3	1.70	0.60	0.0194	0.481	1.200
1344.0	1.67	39.6	1.75	0.60	0.0152	0.368	0.945
1350.0	1.67	39.0	1.75	0.50	0.0154	0.368	1.135
*1356.7	1.74	39.0	1.80	0.40	0.0161	0.373	1.478
1362.0	1.57	40.0	1.80	0.55	0.0142	0.337	0.970
1362.0			RUN STOPPED 1 WEEK				
+1530.0			RUN RESTARTED				

Test #65. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1536.0	2.22	40.2	2.10	0.65	0.0199	0.408	1.160
1542.2	2.15	40.2	2.10	0.65	0.0193	0.395	1.124
1548.0	2.01	40.1	2.05	0.55	0.0181	0.378	1.241
1554.0	1.67	40.0	2.05	0.50	0.0151	0.314	1.135
*1560.0	1.67	40.2	2.05	0.50	0.0150	0.314	1.135
1566.0	1.67	40.2	2.10	0.45	0.0150	0.307	1.261
1572.4	1.67	40.2	2.05	0.35	0.0150	0.314	1.621
1578.0	1.67	40.0	2.05	0.30	0.0151	0.314	1.891
1584.0	1.67	40.0	2.05	0.40	0.0151	0.314	1.418
1590.5	1.79	39.6	2.05	0.35	0.0163	0.337	1.737
1596.7	1.79	40.0	2.05	0.35	0.0161	0.337	1.737
1602.0	1.67	39.6	2.05	0.30	0.0152	0.314	1.891
1608.0	1.67	39.6	2.10	0.30	0.0152	0.307	1.891
*1614.0	1.67	39.7	2.10	0.30	0.0152	0.307	1.891
1619.9	1.40	39.7	2.05	0.25	0.0127	0.263	1.902
1626.0	1.37	40.0	2.15	0.35	0.0124	0.246	1.330
1632.0	1.39	40.2	1.90	0.55	0.0125	0.282	0.859
1638.2	1.34	40.2	1.90	0.50	0.0120	0.272	0.910
1643.1	1.36	40.2	1.90	0.50	0.0122	0.276	0.924
1650.0	1.45	40.6	1.95	0.55	0.0129	0.287	0.896
*1656.0	1.39	41.1	2.10	0.85	0.0122	0.255	0.556
1661.7	1.46	40.9	2.00	0.65	0.0129	0.282	0.763

Test #65. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1668.3	1.26	40.5	2.05	0.60	0.0112	0.237	0.713
1674.0	1.17	41.5	2.05	0.70	0.0102	0.220	0.568
1680.0	1.11	40.9	2.10	0.75	0.0098	0.204	0.503
1686.4	1.11	41.0	2.05	0.70	0.0098	0.209	0.539
1692.2	1.11	40.4	2.00	0.65	0.0099	0.214	0.580
1698.0	1.11	41.2	2.10	0.80	0.0097	0.204	0.471
1704.0	1.11	40.7	2.15	0.80	0.0098	0.199	0.471
1710.2	1.11	40.3	2.15	0.80	0.0099	0.199	0.471
*1716.2	1.11	40.3	2.20	0.75	0.0099	0.195	0.503
1722.0	1.11	39.8	2.20	0.70	0.0101	0.195	0.539
1728.0	1.11	40.7	2.20	0.85	0.0098	0.195	0.444
1734.1	0.97	40.7	2.25	0.80	0.0086	0.166	0.412
1740.0	0.97	39.7	2.30	0.75	0.0088	0.163	0.439
1746.3	0.97	40.0	2.10	0.80	0.0087	0.178	0.412
1752.2	0.97	39.7	2.25	0.90	0.0088	0.166	0.366
1757.9	0.97	39.7	2.25	0.70	0.0088	0.166	0.470
1764.0	0.97	39.5	2.30	0.60	0.0089	0.163	0.549
1770.2	0.97	39.5	2.30	0.65	0.0089	0.163	0.507
1776.1	0.97	39.5	2.35	0.65	0.0089	0.159	0.507
1781.6	0.97	39.5	2.35	0.65	0.0089	0.159	0.507
*1788.0	0.97	39.5	2.25	0.70	0.0089	0.166	0.470
1794.0	0.83	39.5	2.25	0.65	0.0076	0.142	0.434

Test #65. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1800.0	0.83	39.5	2.35	0.65	0.0076	0.136	0.434
1806.0	0.83	39.5	2.40	0.65	0.0076	0.133	0.434
1813.1	0.83	39.5	2.40	0.60	0.0076	0.133	0.470
1818.0	0.83	39.4	2.45	0.55	0.0076	0.131	0.513
1824.0	0.83	39.2	2.50	0.65	0.0076	0.128	0.434
1830.1	0.83	39.3	2.30	0.70	0.0076	0.139	0.403
1836.0	0.83	39.3	2.40	0.60	0.0076	0.133	0.470
1842.0	0.83	39.3	2.50	0.60	0.0076	0.128	0.470
*1848.0	0.83	39.6	2.50	0.75	0.0076	0.128	0.376
1854.0	0.72	39.0	2.50	0.55	0.0067	0.111	0.445
1861.2	0.72	39.3	2.55	0.65	0.0066	0.109	0.376
1866.0	0.72	39.2	2.60	0.60	0.0066	0.107	0.408
1872.0	0.72	39.1	2.55	0.60	0.0066	0.109	0.408
1878.0	0.72	39.2	2.50	0.55	0.0066	0.111	0.445
1883.7	0.72	39.3	2.60	0.55	0.0066	0.107	0.445
1890.0	0.72	39.3	2.60	0.50	0.0066	0.107	0.489
*1896.5	0.72	39.3	2.50	0.60	0.0066	0.111	0.408
1902.0	0.64	39.3	2.55	0.55	0.0059	0.0968	0.395
1907.8	0.64	39.3	2.50	0.60	0.0059	0.0988	0.362
1913.9	0.64	39.3	2.55	0.60	0.0059	0.0968	0.362
1920.0	0.64	39.3	2.65	0.60	0.0059	0.0932	0.362
1920.0			RUN TERMINATED				

Observations from the Simulation Leach Test #66

Ore used = New Wyoming
Solution used = 1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2
Inlet section packing material = -80 AFS Subangular Sand
Inlet section packing length = 10.0 in.
Length of the front ore section = 47.00 in.
Length of the middle ore section = 50.25 in.
Length of the end ore section = 44.25 in.
Outlet section packing material = -80 AFS Subangular Sand
Outlet section packing length = 5.00 in.
Ore packing bed density = 1.59 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = 10 tamps/8 in. of ore. Column position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.

† indicates introduction of fresh feed solution(s).

Test #66

Ore - New Wyoming

Sol - 1.0 g/l NH_4HCO_3
0.5 g/l H_2O_2

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
36.0	3.85	0.8	2.2	0.5	1.736	0.675	2.616
*42.0	4.44	0.7	2.0	0.5	2.289	0.856	3.017
48.1	9.84	1.2	3.0	1.7	2.959	1.265	1.966
53.9	9.20	1.3	2.8	1.5	2.553	1.268	2.083
60.0	9.84	1.2	3.0	1.7	2.959	1.265	1.966
66.3	9.26	1.4	3.4	1.7	2.386	1.051	1.850
*72.1	10.06	1.7	3.2	1.9	2.135	1.213	1.799
77.8	9.65	1.5	3.2	1.9	2.321	1.163	1.725
84.0	8.60	1.5	3.2	1.9	2.069	1.037	1.538
90.0	10.00	1.6	3.6	2.5	2.255	1.072	1.359
+96.0	8.61	1.7	3.6	2.1	1.827	0.923	1.393
102.2	10.22	1.6	3.8	2.5	2.305	1.038	1.389
108.6	8.59	1.3	3.8	2.3	2.384	0.872	1.269
114.0	9.57	1.5	4.0	2.5	2.302	0.923	1.300
120.0	8.33	1.6	4.2	3.1	1.878	0.765	0.913
*126.4	9.90	1.6	4.4	2.9	2.232	0.868	1.160
131.9	10.30	1.7	4.4	3.1	2.186	0.903	1.129
138.0	9.29	1.4	4.6	3.1	2.394	0.779	1.018
144.0	8.61	1.3	4.6	2.7	2.390	0.722	1.083
150.1	8.74	1.4	4.4	2.5	2.252	0.766	1.188
155.9	8.91	1.3	4.6	2.7	2.473	0.747	1.121

Test #66. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*162.0	9.02	1.3	4.4	2.9	2.503	0.791	1.057
†168.0	8.06	1.3	4.0	2.7	2.237	0.777	1.014
174.0	6.67	0.9	3.8	2.1	2.674	0.677	1.079
180.3	7.67	1.0	4.2	2.5	2.767	0.705	1.042
186.0	7.31	0.8	4.0	2.9	3.297	0.705	0.856
*192.0	6.39	0.9	4.0	2.5	2.562	0.616	0.868
198.0	7.50	1.0	4.0	2.7	2.706	0.723	0.944
204.0	6.39	0.8	4.2	2.7	2.882	0.587	0.804
210.3	7.41	0.8	4.4	2.5	3.342	0.650	1.007
†213.0		START CHEMICAL LEACH					
216.1	7.53	0.9	4.6	3.1	3.019	0.632	0.825
*222.0	7.34	1.7	4.0	2.9	1.557	0.708	0.860
228.6	5.81	1.9	3.8	2.3	1.103	0.590	0.858
234.0	5.86	3.7	3.4	2.7	0.571	0.665	0.737
240.0	6.67	4.0	3.6	2.5	0.602	0.715	0.906
*246.0	6.67	4.3	3.6	2.5	0.560	0.715	0.906
252.0	6.11	5.3	4.2	2.7	0.416	0.561	0.769
258.0	7.78	6.1	3.8	2.9	0.460	0.790	0.911
*264.0	8.89	9.0	5.2	3.7	0.356	0.660	0.816
270.6	10.10	9.8	4.8	3.9	0.372	0.812	0.880
276.0	9.26	10.8	4.6	3.7	0.309	0.777	0.850
*282.0	9.17	12.5	4.2	3.3	0.265	0.842	0.944

Test #66. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
288.0	10.00	22.2	4.6	3.7	0.163	0.839	0.918
*294.0	11.11	26.4	4.4	3.3	0.152	0.974	1.144
300.1	7.92	28.0	3.8	2.9	0.102	0.804	0.928
306.0	7.91	31.3	3.8	2.9	0.0912	0.803	0.927
*312.0	7.50	37.6	3.4	2.1	0.0720	0.851	1.213
318.1	4.92	38.0	2.8	1.7	0.0467	0.678	0.983
324.0	4.80	38.2	2.8	1.5	0.0453	0.661	1.088
330.0	4.44	38.7	2.6	1.5	0.0414	0.659	1.006
*336.0	4.44	39.0	2.6	1.5	0.0411	0.659	1.006
342.3	4.23	38.6	2.6	1.3	0.0395	0.628	1.105
348.0	4.97	38.8	2.4	1.3	0.0462	0.680	1.299
354.0	3.61	39.3	2.2	1.3	0.0331	0.633	0.943
360.0	3.33	39.5	2.2	1.1	0.0304	0.584	1.028
366.2	3.49	39.2	2.2	1.1	0.0321	0.612	1.078
*372.1	3.39	39.2	2.2	1.1	0.0312	0.594	1.047
+378.1	3.33	39.7	2.0	1.1	0.303	0.642	1.028
384.0	3.39	40.9	2.0	1.1	0.0299	0.654	1.047
390.3	3.17	39.9	2.2	1.3	0.0287	0.556	0.828
396.2	5.93	39.2	2.4	1.5	0.0545	0.953	1.343
402.0	5.75	39.0	2.6	1.5	0.0532	0.853	1.302
408.0	5.55	39.2	2.4	1.5	0.0511	0.892	1.257
414.2	4.84	39.8	2.2	1.1	0.0439	0.849	1.495

Test #66. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
419.6	4.63	40.0	2.0	1.1	0.0418	0.893	1.430
426.0	3.65	40.4	2.0	1.3	0.0326	0.704	0.954
432.0	3.61	40.7	1.8	0.9	0.0320	0.774	1.363
*438.0	3.61	40.7	1.8	0.9	0.0320	0.774	1.363
444.2	3.23	40.9	1.8	0.7	0.0285	0.692	1.567
450.0	3.16	40.9	1.6	0.9	0.0279	0.762	1.193
456.0	3.06	41.2	1.6	0.9	0.0268	0.738	1.155
462.1	2.73	40.8	1.4	0.9	0.0241	0.752	1.030
468.1	2.22	40.8	1.6	0.7	0.0196	0.535	1.077
474.0	2.26	41.2	1.6	0.9	0.0198	0.545	0.853
480.0	2.78	41.7	1.6	0.7	0.0241	0.670	1.349
485.9	1.98	41.3	1.4	0.7	0.0173	0.546	0.961
492.1	2.15	41.0	1.6	0.5	0.0189	0.518	1.401
*498.0	2.26	41.3	1.4	0.7	0.0197	0.623	1.097
504.0	2.22	41.6	1.4	0.7	0.0193	0.612	1.077
510.0	1.94	41.5	1.2	0.7	0.0169	0.624	0.941
516.2	1.88	40.9	1.4	0.5	0.0166	0.518	1.277
522.0	2.59	41.1	1.4	0.9	0.0227	0.714	0.978
528.0	2.50	41.6	1.4	0.7	0.0217	0.689	1.213
534.0	2.50	41.3	1.4	0.7	0.0218	0.689	1.213
540.0	1.94	41.2	1.4	0.5	0.0170	0.535	1.318
†546.2	1.88	41.2	1.4	0.5	0.0165	0.518	1.277

Test #66. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
552.0	2.30	41.3	1.6	0.5	0.0201	0.555	1.563
557.8	2.01	41.5	1.4	0.5	0.0175	0.554	1.366
*564.0	2.42	41.3	1.4	0.7	0.0211	0.667	1.174
570.1	2.73	40.9	1.8	0.7	0.0241	0.585	1.325
576.1	3.33	39.9	2.4	1.1	0.0301	0.535	1.028
581.0	7.14	38.6	2.8	1.7	0.0667	0.984	1.427
588.0	5.48	39.7	2.4	1.9	0.0498	0.881	0.980
593.5	5.15	41.1	1.8	1.1	0.0452	1.104	1.590
601.4	2.53	42.5	1.4	0.7	0.0215	0.697	1.228
*606.4	2.33	41.6	1.4	0.7	0.0202	0.642	1.131
611.7	1.89	41.3	1.6	0.5	0.0165	0.456	1.284
618.0	1.59	41.9	1.4	0.7	0.0137	0.438	0.772
624.0	1.94	42.0	1.2	1.1	0.0167	0.624	0.599
630.1	1.64	42.0	1.4	0.5	0.0141	0.452	1.114
635.9	1.72	41.9	1.2	0.3	0.0148	0.553	1.948
*642.0	1.64	42.0	1.2	0.5	0.0141	0.527	1.114
648.0	1.39	42.0	1.2	0.5	0.0119	0.447	0.944
654.2	1.61	41.7	1.2	0.5	0.0139	0.518	1.094
660.0	1.44	41.4	1.2	0.5	0.0125	0.463	0.978
666.0	1.94	41.3	1.4	0.7	0.0169	0.535	0.941
672.0	1.39	41.9	1.2	0.9	0.0120	0.447	0.525
678.0	1.39	41.5	1.2	0.7	0.0121	0.447	0.675

Test #66. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
684.6	1.01	41.2	1.2	0.7	0.0088	0.325	0.490
690.0	1.54	41.8	1.2	0.7	0.0133	0.495	0.747
696.0	0.83	42.1	1.2	0.7	0.0071	0.267	0.403
702.0	1.11	41.8	1.2	0.7	0.0096	0.357	0.539
*708.0	1.39	41.2	1.4	0.5	0.0122	0.383	0.944
713.7	1.75	41.9	1.2	0.7	0.0151	0.563	0.849
720.0	1.32	42.4	1.4	0.5	0.0112	0.364	0.897
726.0	1.11	42.6	1.0	0.7	0.0085	0.428	0.539
732.1	1.09	42.3	1.2	0.5	0.0093	0.350	0.741
737.8	1.17	41.8	1.2	0.7	0.0101	0.376	0.568
744.0	1.61	42.1	1.2	0.7	0.0138	0.518	0.781
750.0	1.67	42.3	1.2	0.5	0.0142	0.537	1.135
*756.2	1.34	42.0	1.2	0.5	0.0115	0.431	0.910
762.0	1.15	42.3	1.2	0.5	0.0098	0.370	0.781
†768.0	1.11	42.6	1.0	0.7	0.0094	0.428	0.539
773.6	1.49	42.2	1.0	0.5	0.0127	0.575	1.012
780.1	1.54	41.9	1.2	0.3	0.0133	0.495	1.744
786.0	1.13	42.2	1.0	0.5	0.0097	0.436	0.768
792.0	1.67	42.6	1.2	0.5	0.0141	0.537	1.135
798.0	1.67	42.5	1.0	0.5	0.0142	0.644	1.135
804.0	1.39	41.9	1.2	0.3	0.0120	0.447	1.574
810.0	1.11	41.7	1.2	0.5	0.0096	0.357	0.754

Test #66. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
816.0	1.67	42.0	1.2	0.5	0.0143	0.537	1.135
822.7	1.24	42.2	1.0	0.5	0.0106	0.478	0.842
828.0	1.57	41.9	1.0	0.5	0.0135	0.606	1.067
834.0	1.39	41.4	1.2	0.5	0.0121	0.447	0.944
*840.0	1.39	42.3	1.2	0.5	0.0119	0.447	0.944
846.3	1.32	42.2	1.2	0.3	0.0113	0.424	1.495
852.0	1.46	42.1	1.2	0.1	0.0125	0.469	4.960
858.0	1.39	42.1	1.2	0.1	0.0119	0.447	4.722
864.0	1.39	42.2	1.2	0.3	0.0119	0.447	1.574
870.4	1.30	42.3	1.0	0.1	0.0111	0.502	4.416
875.7	1.26	42.0	1.0	0.1	0.0108	0.486	4.280
882.0	1.32	42.0	1.2	0.1	0.0113	0.424	4.484
888.0	1.39	42.0	1.2	0.1	0.0119	0.447	4.722
893.9	1.13	41.7	1.2	0.1	0.0098	0.363	3.839
900.0	1.09	41.7	1.2	0.1	0.0094	0.350	3.703
*906.0	1.11	41.7	1.2	0.1	0.0096	0.357	3.771
912.0	1.11	41.8	1.0	0.3	0.0096	0.428	1.257
918.2	1.08	41.6	1.2	0.3	0.0094	0.347	1.223
924.1	1.13	41.5	1.0	0.3	0.0098	0.436	1.280
930.0	1.13	41.4	1.4	0.3	0.0098	0.311	1.280
936.0	1.11	42.9	1.2	0.5	0.0093	0.357	0.754
942.0	1.11	41.9	1.2	0.3	0.0096	0.357	1.257

Test #66. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
948.0	1.11	41.6	1.2	0.3	0.0096	0.357	1.257
954.0	1.11	42.0	1.0	0.7	0.0095	0.428	0.539
960.0	1.11	42.3	1.0	0.7	0.0095	0.428	0.539
966.0	1.11	42.2	1.2	0.5	0.0095	0.357	0.754
972.2	1.08	41.7	1.2	0.5	0.0093	0.347	0.734
*978.0	1.15	42.0	1.0	0.7	0.0099	0.444	0.558
†978.0		START SIMULATED GROUND WATER					
984.0	1.11	42.6	1.2	0.5	0.0094	0.357	0.754
989.9	1.13	42.5	1.2	0.3	0.0096	0.363	1.280
995.9	1.11	42.5	1.2	0.3	0.0094	0.357	1.257
*1002.0	1.37	41.9	1.4	0.7	0.0118	0.377	0.665
1008.0	2.78	41.9	1.4	0.7	0.0239	0.766	1.349
1014.5	2.82	41.5	1.2	0.7	0.0245	0.907	1.369
1020.2	3.51	39.3	2.0	1.5	0.0322	0.677	0.795
1026.0	6.03	40.4	1.8	0.9	0.0539	1.292	2.276
1032.0	4.17	41.1	1.6	0.7	0.0366	1.005	2.024
1038.6	3.03	40.9	1.4	0.5	0.0267	0.835	2.059
*1044.0	2.16	40.9	1.4	0.5	0.0191	0.595	1.468
1050.2	2.15	41.1	1.2	0.5	0.0189	0.691	1.461
1056.0	2.30	41.2	1.2	0.1	0.0201	0.739	7.813
1061.7	2.34	41.5	1.2	0.1	0.0203	0.752	7.949
1068.0	1.85	41.0	1.0	0.5	0.0163	0.714	1.257

Test #66. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1074.1	1.91	40.8	1.2	0.5	0.0169	0.614	1.298
1080.0	2.26	40.8	1.2	0.5	0.0200	0.727	1.535
1085.8	2.01	40.5	1.4	0.3	0.0179	0.554	2.276
*1092.0	1.88	40.8	1.4	0.3	0.0166	0.518	2.129
1098.0	1.67	41.6	1.2	0.3	0.0145	0.537	1.891
1104.0	1.67	41.6	1.2	0.3	0.0145	0.537	1.891
1110.3	1.59	40.9	1.0	0.3	0.0140	0.613	1.800
1116.0	1.46	40.4	1.2	0.3	0.0130	0.469	1.653
*1122.9	1.69	40.4	1.2	0.3	0.0151	0.543	1.914
1128.8	1.69	40.8	1.2	0.5	0.0149	0.543	1.148
1134.1	1.57	40.4	0.8	0.7	0.0140	0.757	0.762
1140.5	1.56	40.1	1.2	0.3	0.0140	0.502	1.766
1146.0	1.52	42.2	1.2	0.3	0.0130	0.489	1.721
1152.0	1.67	43.3	1.0	0.3	0.0139	0.644	1.891
1158.0	1.39	42.0	1.0	0.1	0.0119	0.536	4.722
1164.6	1.52	40.9	1.2	0.1	0.0134	0.489	5.163
*1170.0	1.54	42.7	1.2	0.1	0.0130	0.495	5.231
1170.0			RUN STOPPED 1 WEEK				
+1338.0			RUN RESTARTED				
1344.0	1.94	43.2	0.2	0.9	0.0162	3.742	0.732
1350.2	1.61	42.5	0.4	0.5	0.0137	1.553	1.094
*1356.0	1.44	42.4	0.2	0.5	0.0122	2.778	0.978

Test #66. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1362.0	1.39	42.5	0.2	0.7	0.0118	2.681	0.675
1368.0	1.39	41.7	0.4	0.7	0.0120	1.341	0.675
1374.1	1.37	41.4	0.4	0.7	0.0119	1.321	0.665
1380.3	1.61	41.1	0.4	0.7	0.0141	1.553	0.781
1386.0	1.75	41.2	0.6	0.7	0.0153	1.125	0.849
1392.0	1.67	42.4	0.6	0.7	0.0142	1.074	0.810
1398.5	1.79	41.8	0.6	0.7	0.0155	1.151	0.869
*1404.6	1.91	41.5	0.8	0.5	0.0166	0.921	1.298
1410.0	1.85	41.5	0.8	0.5	0.0161	0.892	1.257
1416.0	1.94	41.3	0.8	0.7	0.0169	0.936	0.941
1422.0	1.94	41.3	0.4	1.1	0.0169	1.871	0.599
1427.8	2.01	41.3	0.4	1.1	0.0176	1.939	0.621
1434.0	2.15	41.9	0.4	1.1	0.0185	2.074	0.664
1440.0	2.22	41.6	0.4	1.1	0.0193	2.141	0.686
1446.2	2.42	41.3	0.4	1.1	0.0211	2.334	0.747
*1452.1	2.26	41.3	0.4	1.1	0.0197	2.180	0.698
1458.0	2.26	41.5	0.6	1.3	0.0196	1.453	0.591
1464.0	2.50	42.8	0.4	0.5	0.0211	2.411	1.699
1469.6	2.38	41.6	0.4	0.5	0.0206	2.296	1.617
1476.3	2.15	41.7	0.4	0.7	0.0186	2.074	1.043
1482.0	2.15	42.1	0.6	0.7	0.0184	1.382	1.043
1488.0	2.22	41.7	0.4	1.3	0.0192	2.141	0.580

Test #66. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1494.3	2.38	41.1	0.4	1.3	0.0209	2.296	0.622
1500.2	2.26	41.0	0.4	1.1	0.0199	2.180	0.698
1506.0	2.30	42.1	0.4	0.9	0.0197	2.218	0.868
1512.0	1.94	41.8	0.4	0.9	0.0167	1.871	0.732
1518.1	1.91	41.3	0.4	1.1	0.0167	1.842	0.590
*1524.2	1.91	41.0	0.4	1.1	0.0168	1.842	0.590
1530.0	1.72	41.3	0.4	1.3	0.0150	1.659	0.449
1536.0	1.67	42.1	0.4	1.1	0.0143	1.611	0.516
1540.9	1.70	41.5	0.4	1.1	0.0148	1.640	0.525
1548.0	1.64	40.9	0.4	1.1	0.0145	1.582	0.506
1554.3	1.59	40.9	0.4	1.1	0.0140	1.534	0.491
1560.2	1.41	41.5	0.4	1.1	0.0123	1.360	0.435
1565.7	1.32	41.2	0.2	1.3	0.0116	2.546	0.345
*1572.0	1.39	40.9	0.2	1.3	0.0123	2.681	0.363
1578.2	1.39	40.9	0.4	1.1	0.0123	1.341	0.429
1584.2	1.39	41.2	0.4	1.1	0.0122	1.341	0.429
1589.5	1.39	40.9	0.4	1.1	0.0123	1.341	0.429
*1596.0	1.39	40.9	0.2	1.3	0.0123	2.681	0.363
1602.0	1.11	41.3	0.4	1.3	0.0097	1.071	0.290
1602.0			RUN STOPPED 1 WEEK				
†1769.0			RUN RESTARTED				
1775.0	1.39	42.8	0.4	1.3	0.0117	1.341	0.363

Test #66. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*1781.1	1.37	42.0	0.4	0.9	0.0118	1.321	0.517
1787.0	1.41	42.0	0.4	0.7	0.0121	1.360	0.684
1793.0	1.11	42.0	0.4	0.9	0.0095	1.071	0.419
1799.0	1.11	42.0	0.4	0.9	0.0095	1.071	0.419
1804.9	1.13	41.4	0.4	0.9	0.0098	1.090	0.427
1811.0	1.37	41.5	0.4	0.9	0.0119	1.321	0.517
1817.0	1.94	41.0	0.6	1.5	0.0171	1.247	0.439
1823.0	3.06	40.4	0.6	1.5	0.0273	1.968	0.693
*1829.1	3.28	39.7	1.0	1.5	0.0298	1.265	0.743
1835.0	4.24	39.7	0.8	1.7	0.0385	2.045	0.847
1841.0	4.44	39.7	0.8	1.7	0.0404	2.141	0.887
1847.0	4.44	39.7	1.0	1.5	0.0404	1.713	1.006
1853.2	4.30	39.4	1.0	1.5	0.0394	1.659	0.974
1859.0	4.31	39.7	1.0	1.5	0.0392	1.663	0.976
1865.0	4.44	39.7	0.8	1.7	0.0404	2.141	0.887
1871.0	4.17	39.3	0.8	1.5	0.0383	2.011	0.944
1877.2	4.30	39.1	1.0	1.5	0.0397	1.659	0.974
1883.4	4.03	39.7	1.0	1.5	0.0366	1.555	0.913
*1889.2	4.02	39.4	0.8	1.7	0.0368	1.939	0.803
1895.0	3.74	39.1	1.0	1.5	0.0345	1.443	0.847
1900.9	3.67	39.3	0.8	1.5	0.0337	1.770	0.831
1906.6	3.80	39.3	0.8	1.5	0.0349	1.833	0.861

Test #66. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1913.0	3.91	39.1	0.8	1.7	0.0361	1.886	0.781
1919.0	3.89	39.3	0.6	1.7	0.0357	2.501	0.777
1925.2	3.49	39.0	0.8	1.5	0.0323	1.683	0.790
*1930.7	3.64	39.0	0.8	1.5	0.0337	1.755	0.824
1937.0	3.44	38.8	0.8	1.7	0.0320	1.659	0.687
1943.0	3.33	39.0	0.8	1.5	0.0308	1.606	0.754
1949.0	3.33	39.2	0.6	1.5	0.0306	2.141	0.754
1955.0	3.33	39.0	0.8	1.5	0.0308	1.606	0.754
1961.0	3.33	39.0	0.8	1.5	0.0308	1.606	0.754
1961.0			RUN TERMINATED				

Observations from the Simulation Leach Test #67

Ore used = Wyoming

Solution used = 1.0 g/l NH_4HCO_3 - Sat'd O_2 at 120 psig

Inlet section packing material = -80 AFS Subangular Sand

Inlet section packing length = 10.0 in.

Length of the front ore section = 35.50 in.

Length of the middle ore section = 52.00 in.

Length of the end ore section = 52.00 in.

Outlet section packing material = -80 AFS Subangular Sand

Outlet section packing length = 5.00 in.

Ore packing bed density = 1.67 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = 10 tamps/8 in. of ore. Column position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.

† indicates introduction of fresh feed solution(s).

Test #67

Ore - Wyoming

Sol - 1.0 g/l NH_4HCO_3
+ Sat'd O_2 @ 120 psig

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
43.2		PROBES INSTALLED IN COLUMN					
49.4	5.11	1.20	1.75	1.60	1.16	1.21	1.32
54.0	6.88	0.55	0.90	0.75	3.41	3.17	3.80
60.0	5.83	0.50	0.70	0.65	3.18	3.45	3.72
66.0	6.11	0.45	0.65	0.65	3.70	3.90	3.90
*72.0	10.56	1.05	1.55	1.50	2.74	2.82	2.92
78.1	11.75	1.00	1.60	1.80	3.20	3.04	2.71
84.0	10.17	1.00	1.65	1.85	2.77	2.56	2.28
89.9	9.60	0.95	1.50	1.70	2.75	2.65	2.34
95.9	10.56	1.10	1.70	1.90	2.62	2.58	2.30
*102.0	10.93	1.10	1.70	1.90	2.71	2.67	2.39
108.3	8.47	1.00	1.60	1.70	2.31	2.19	2.07
+113.9	9.52	0.95	1.50	1.60	2.73	2.63	2.47
120.0	10.38	1.00	1.60	1.70	2.83	2.69	2.53
126.4	9.90	1.10	1.90	2.00	2.45	2.16	2.05
132.6	10.75	1.15	1.85	1.95	2.55	2.41	2.29
*137.9	9.75	1.10	1.80	1.90	2.42	2.25	2.13
143.9	10.00	1.20	1.95	2.05	2.27	2.13	2.02
149.9	11.11	1.20	2.00	2.05	2.52	2.30	2.25
155.8	9.08	1.30	2.00	2.15	1.90	1.88	1.75
162.0	10.22	1.45	2.30	2.40	1.92	1.84	1.77
168.0	11.67	1.30	2.15	2.25	2.45	2.25	2.15

Test #67. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
174.1	10.38	1.10	1.95	2.05	2.57	2.21	2.10
*180.0	9.89	1.20	1.95	2.05	2.25	2.10	2.00
186.0	9.72	1.30	2.05	2.15	2.04	1.97	1.87
192.0	10.28	1.30	2.10	2.20	2.15	2.03	1.94
+192.0		START CHEMICAL LEACH					
197.6	8.93	1.15	1.85	1.95	2.12	2.00	1.90
*204.2	10.10	1.70	1.90	2.05	1.62	2.20	2.04
210.0	10.63	2.00	2.05	2.25	1.45	2.15	1.96
216.0	10.28	2.05	1.85	2.00	1.37	2.30	2.13
222.2	10.75	2.60	1.45	0.90	1.13	3.07	4.95
228.1	10.73	2.85	1.45	1.00	1.03	3.07	4.45
234.1	10.28	3.20	1.55	1.15	0.875	2.75	3.71
240.0	10.45	2.80	1.70	1.00	1.02	2.55	4.33
*246.1	9.56	2.80	1.30	0.70	0.930	3.05	5.66
252.1	9.44	3.00	1.30	0.70	0.857	3.01	5.59
258.0	9.89	3.50	1.45	0.90	0.770	2.83	4.56
264.0	11.11	3.40	1.75	1.15	0.890	2.63	4.01
269.9	10.17	3.45	1.60	0.70	0.803	2.64	6.02
276.0	9.56	3.55	1.30	0.70	0.734	3.05	5.66
+282.2	9.14	4.00	1.55	0.70	0.623	2.44	5.41
288.1	9.32	4.20	1.70	0.70	0.605	2.27	5.52
*293.8	10.53	4.30	1.65	0.70	0.667	2.65	6.24

Test #67. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
299.9	10.93	4.45	1.70	0.80	0.669	2.67	5.66
306.1	9.95	4.70	1.90	0.90	0.577	2.17	4.58
312.2	10.11	4.85	1.90	0.90	0.568	2.21	4.66
317.5	11.01	5.20	2.05	0.95	0.577	2.23	4.80
324.0	11.03	5.50	2.05	0.95	0.546	2.23	4.81
330.0	10.83	5.90	2.30	1.00	0.500	1.95	4.49
336.0	10.56	6.00	2.40	1.00	0.480	1.82	4.38
341.9	10.17	4.90	2.40	1.00	0.566	1.76	4.22
*349.0	11.03	5.60	2.40	1.20	0.537	1.91	3.81
354.0	11.00	5.90	2.40	1.20	0.508	1.73	3.46
360.0	10.83	6.05	2.40	1.20	0.488	1.87	3.74
366.0	10.56	5.55	2.30	0.70	0.518	1.90	6.25
371.9	11.02	6.20	2.30	0.70	0.484	1.99	6.53
378.0	10.11	6.55	2.25	0.75	0.421	1.86	5.59
384.0	11.11	6.80	2.20	0.70	0.445	2.09	6.58
*390.0	10.28	6.90	2.45	0.70	0.406	1.74	6.09
397.1	10.56	7.30	2.70	0.70	0.394	1.62	6.25
†402.0	10.54	7.65	2.20	1.25	0.375	1.99	3.50
407.9	8.76	20.0	2.00	1.10	0.119	1.82	3.30
413.9	8.61	23.0	2.00	1.10	0.102	1.78	3.25
419.6	7.60	24.5	1.90	1.10	0.0845	1.66	2.86
426.0	7.29	26.5	1.95	1.10	0.0750	1.55	2.75

Test #67. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
432.7	6.72	26.0	1.90	1.05	0.0704	1.47	2.65
*437.9	9.62	23.0	2.20	1.75	0.114	1.81	2.28
444.1	8.60	24.7	2.15	1.65	0.0949	1.66	2.16
449.8	9.94	29.0	2.15	1.65	0.0934	1.92	2.50
455.9	9.56	11.5	2.00	2.10	0.227	1.98	1.89
461.9	7.78	14.5	1.40	1.60	0.146	2.30	2.02
467.7	7.76	19.5	1.50	1.65	0.108	2.14	1.95
473.2	8.18	23.5	1.70	1.75	0.0949	1.99	1.94
*478.9	7.89	26.5	1.80	1.80	0.0811	1.82	1.82
484.9	7.78	29.0	1.80	1.80	0.0731	1.79	1.79
491.1	7.80	30.5	2.30	1.90	0.0697	1.41	1.70
497.0	7.63	32.0	2.35	1.95	0.0650	1.35	1.62
503.0	9.72	34.0	2.65	2.25	0.0779	1.52	1.79
509.2	9.68	34.5	2.60	2.15	0.0765	1.54	1.87
515.0	9.77	35.0	2.60	2.35	0.0761	1.56	1.72
521.0	9.17	37.5	2.85	2.20	0.0666	1.33	1.73
527.0	9.44	37.5	2.60	2.10	0.0686	1.51	1.86
532.9	9.60	37.5	2.70	1.75	0.0698	1.47	2.27
539.0	8.74	39.0	2.75	1.75	0.0611	1.32	2.07
*545.0	10.00	39.0	3.05	2.05	0.0699	1.36	2.02
551.0	10.56	36.5	3.00	2.10	0.0788	1.46	2.08
556.9	9.32	41.5	2.95	1.75	0.0612	1.31	2.21

Test #67. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
562.9	10.00	41.5	3.05	1.85	0.0657	1.36	2.24
569.0	10.11	42.0	3.10	1.90	0.0656	1.35	2.21
575.0	10.00	42.0	3.10	1.95	0.0649	1.34	2.13
581.1	10.66	39.0	3.40	2.30	0.0745	1.30	1.92
586.9	10.06	40.0	3.45	2.00	0.0685	1.21	2.09
*593.0	9.56	39.5	3.20	1.90	0.0660	1.24	2.09
599.0	9.44	42.5	3.10	1.90	0.0605	1.26	2.06
605.1	9.56	43.0	3.15	1.85	0.0606	1.26	2.14
611.3	9.41	43.0	3.30	1.90	0.0596	1.18	2.05
617.1	9.48	43.5	3.15	1.90	0.0594	1.25	2.07
623.0	9.32	43.5	3.10	1.90	0.0584	1.25	2.03
628.9	9.32	43.5	3.20	1.95	0.0584	1.21	1.98
634.6	9.36	43.5	3.25	1.90	0.0586	1.19	2.04
640.9	9.26	45.5	3.25	1.80	0.0555	1.18	2.13
646.9	9.17	45.0	3.15	2.00	0.0555	1.21	1.90
653.0	9.29	47.5	3.35	1.95	0.0533	1.15	1.98
658.7	9.65	47.0	3.30	2.05	0.0559	1.21	1.95
665.0	9.52	47.5	3.30	2.00	0.0546	1.20	1.97
671.0	9.72	48.0	3.40	1.95	0.0552	1.19	2.07
676.9	10.73	49.0	3.50	2.15	0.0597	1.27	2.07
682.9	10.56	49.0	3.45	2.15	0.0587	1.27	2.04
*689.0	10.38	50.0	3.45	2.10	0.0566	1.25	2.05

Test #67. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
695.0	10.00	50.0	3.45	2.00	0.0545	1.20	2.07
700.9	9.89	49.0	3.50	2.00	0.0550	1.17	2.05
706.9	10.00	49.0	3.40	1.95	0.0556	1.22	2.13
713.0	10.11	50.5	3.40	1.85	0.0546	1.23	2.27
719.0	10.00	52.0	3.40	1.90	0.0524	1.22	2.18
725.1	10.66	52.0	3.70	2.15	0.0559	1.19	2.06
730.6	10.61	51.0	3.70	2.15	0.0567	1.19	2.05
738.5	10.55	52.0	3.60	2.00	0.0553	1.22	2.19
743.0	10.37	52.5	3.35	2.00	0.0538	1.28	2.15
748.9	10.73	54.0	4.00	2.20	0.0541	1.11	2.02
754.9	10.56	53.0	3.80	2.15	0.0543	1.15	2.04
761.0	10.11	55.5	3.70	2.10	0.0496	1.13	2.00
+767.0	10.00	55.5	3.85	2.05	0.0491	1.08	2.02
773.5	9.74	38.5	3.35	1.80	0.0689	1.20	2.24
778.9	9.57	42.0	3.10	1.60	0.0621	1.28	2.48
785.0	9.02	44.0	3.35	1.70	0.0559	1.12	2.20
*790.9	9.32	45.0	3.60	2.05	0.0564	1.07	1.88
796.7	9.77	45.0	3.40	1.90	0.0592	1.19	2.13
803.0	9.26	47.0	3.40	2.00	0.0537	1.13	1.92
809.1	9.02	49.0	3.55	1.90	0.0502	1.05	1.97
814.9	8.91	49.5	3.70	1.90	0.0491	0.998	1.94
820.7	8.91	48.5	3.70	1.95	0.0501	0.998	1.89

Test #67. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*827.0	8.47	50.0	3.65	2.00	0.0462	0.962	1.76
833.0	8.61	52.0	3.65	1.95	0.0451	0.978	1.83
839.0	10.00	55.0	5.00	2.75	0.0495	0.829	1.51
845.2	9.68	52.0	4.00	2.15	0.0507	1.00	1.87
851.5	9.26	53.0	3.80	2.05	0.0476	1.01	1.87
857.0	8.79	54.0	3.90	21.0	0.0444	0.934	1.74
863.0	10.56	55.0	4.40	2.45	0.0523	0.995	1.79
869.1	9.29	55.0	4.30	2.20	0.0460	0.896	1.75
875.9	9.56	56.0	4.00	2.25	0.0465	0.991	1.76
881.0	9.48	56.0	3.95	2.10	0.0461	0.995	1.87
887.0	9.72	57.5	4.70	2.60	0.0461	0.857	1.55
893.0	10.28	59.0	4.55	2.55	0.0475	0.937	1.67
*899.3	9.79	57.5	4.40	2.25	0.0464	0.922	1.80
905.5	9.41	58.5	4.20	2.30	0.0438	0.929	1.70
†905.5			START 1 g/l Na ₂ SO ₃ FLOW				
911.0	10.00	59.0	4.40	2.45	0.0462	0.942	1.69
917.0	8.61	43.5	3.90	2.05	0.0539	0.915	1.74
922.6	9.52	35.0	4.05	2.30	0.0741	0.975	1.72
*929.0	8.59	27.0	4.05	2.25	0.0867	0.879	1.58
935.0	10.00	32.0	3.90	2.45	0.0852	1.06	1.69
941.0	7.78	36.0	2.90	1.80	0.0589	1.11	1.79
*947.0	7.50	42.0	2.60	1.70	0.0487	1.20	1.83

Test #67. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
952.9	6.80	43.5	2.40	1.60	0.0426	1.17	1.76
959.0	8.89	55.0	2.75	1.60	0.0440	1.34	2.30
965.0	6.67	56.0	2.90	1.15	0.0325	0.954	2.40
971.0	6.11	57.0	3.10	1.15	0.0292	0.817	2.20
976.9	6.21	59.5	3.20	0.90	0.0284	0.804	2.86
*982.9	5.83	57.0	3.50	0.80	0.0279	0.691	3.02
989.0	4.64	55.5	3.85	0.60	0.0228	0.450	3.21
994.8	5.17	54.5	4.20	0.60	0.0259	0.510	3.57
1001.0	4.57	60.0	6.20	0.70	0.0208	0.306	2.71
+1007.0	5.00	58.0	6.85	0.65	0.0235	0.303	3.19
1013.0	4.72	59.5	7.60	0.60	0.0216	0.257	3.26
*1019.0	4.72	60.0	8.40	0.55	0.0214	0.233	3.56
1025.0	4.17	61.0	8.85	0.60	0.0186	0.195	2.88
1030.5	4.24	60.0	8.70	0.50	0.0193	0.202	3.52
+1032.0		START SIMULATED GROUND H ₂ O					
1036.9	3.91	61.0	8.00	0.30	0.0175	0.203	5.40
1043.0	3.83	62.0	9.00	0.30	0.0168	0.176	5.29
*1049.0	3.61	62.0	9.30	0.30	0.0159	0.161	4.99
1055.0	3.06	60.0	9.50	0.30	0.0139	0.134	4.23
1061.0	2.78	60.0	10.00	0.30	0.0126	0.115	3.84
1067.0	2.50	60.0	11.00	0.30	0.0114	0.0942	3.46
1073.0	2.78	61.0	11.00	0.35	0.0124	0.105	3.29

Test #67. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1079.0	2.78	57.0	11.0	0.25	0.0133	0.105	4.61
1084.9	2.54	56.5	11.0	0.25	0.0123	0.0957	4.21
1091.0	2.19	57.5	11.5	0.30	0.0104	0.0790	3.03
1097.0	2.22	57.5	12.0	0.30	0.0105	0.0767	3.07
1103.0	2.50	56.5	12.0	0.30	0.0121	0.0864	3.46
*1109.0	2.50	56.0	13.0	0.30	0.0122	0.0797	3.46
1115.0	2.50	57.0	13.0	0.30	0.0120	0.0797	3.46
1121.0	2.78	57.5	13.0	0.40	0.0132	0.0887	2.88
1127.0	2.50	55.0	13.5	0.35	0.0124	0.0768	2.96
1133.4	2.34	54.5	13.5	0.35	0.0117	0.0719	2.77
1139.3	2.26	54.0	14.0	0.32	0.0114	0.0669	2.93
1145.0	2.34	54.0	14.0	0.30	0.0118	0.0693	3.23
1151.0	2.22	54.0	14.0	0.30	0.0112	0.0657	3.07
1156.8	2.01	53.5	14.0	0.30	0.0102	0.0595	2.78
1163.0	2.15	54.0	14.0	0.30	0.0108	0.0637	2.97
1169.0	1.94	53.5	14.0	0.30	0.0099	0.0575	2.68
*1174.9	2.26	55.5	12.0	0.30	0.0111	0.0781	3.12
1181.0	2.19	54.0	14.0	0.35	0.0111	0.0649	2.59
1186.7	2.05	54.0	14.5	0.35	0.0103	0.0586	2.43
1193.0	2.38	55.0	16.0	0.35	0.0118	0.0617	2.82
1199.0	2.50	55.0	15.0	0.45	0.0124	0.0691	2.30

Test #67. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1205.0	2.22	52.0	15.5	0.45	0.0116	0.0594	2.05
1211.0	2.50	51.0	16.5	0.40	0.0134	0.0628	2.59
1217.0	2.50	50.5	16.5	0.40	0.0135	0.0628	2.59
1223.0	2.50	50.0	17.0	0.40	0.0136	0.0610	2.59
1228.9	2.54	50.0	17.0	0.40	0.0138	0.0619	2.63
1235.5	2.53	50.0	17.5	0.40	0.0138	0.0599	2.26
1241.0	2.42	50.0	17.5	0.40	0.0132	0.0573	2.51
1247.0	2.22	49.5	17.5	0.40	0.0122	0.0526	2.30
1253.2	2.15	49.5	17.0	0.40	0.0118	0.0524	2.23
*1259.2	2.22	49.5	17.5	0.40	0.0122	0.0526	2.30
1265.0	2.01	49.0	18.0	0.40	0.0112	0.0463	2.08
1271.0	2.22	48.0	18.5	0.40	0.0126	0.0498	2.30
1276.9	1.98	48.0	18.5	0.40	0.0112	0.0444	2.05
1283.0	2.19	48.0	18.5	0.40	0.0124	0.0491	2.27
1289.0	2.22	48.0	19.0	0.40	0.0126	0.0487	2.30
1301.0	2.22	48.0	18.5	0.40	0.0126	0.0498	2.30
1307.0	2.22	48.0	18.5	0.40	0.0126	0.0498	2.30
1313.9	2.17	47.5	19.0	0.40	0.0124	0.0474	2.25
1319.0	2.29	48.0	19.0	0.40	0.0130	0.0500	2.37
*1324.9	2.26	48.0	18.5	0.40	0.0128	0.0506	2.34
1331.0	1.91	47.5	19.0	0.40	0.0110	0.0417	1.98
1337.0	1.94	48.0	19.5	0.40	0.0110	0.0412	2.01

Test #67. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1343.0	1.94	47.5	19.5	0.45	0.0111	0.0412	1.79
+1343.0		RESTART 1 g/l Na ₂ SO ₃					
1348.9	2.82	44.0	20.0	0.50	0.0175	0.0585	2.34
1361.2	2.30	42.0	21.0	0.41	0.0149	0.0454	2.33
1368.2	2.14	41.0	22.0	0.42	0.0142	0.0403	2.11
1373.2	2.00	42.0	22.0	0.45	0.0130	0.0377	1.84
*1379.4	1.88	41.5	21.0	0.45	0.0123	0.0371	1.73
1385.0	1.79	42.0	21.0	0.45	0.0116	0.0353	1.65
1391.0	1.94	44.0	22.5	0.50	0.0120	0.0357	1.61
1397.0	1.94	45.5	21.0	0.50	0.0116	0.0383	1.61
1402.8	2.01	46.0	20.5	0.50	0.0119	0.0407	1.67
1409.0	2.15	45.0	20.5	0.50	0.0130	0.0435	1.78
1415.0	1.94	44.5	20.0	0.55	0.0119	0.0402	1.46
*1421.0	1.94	45.5	19.0	0.55	0.0116	0.0423	1.46
1426.6	1.79	45.5	19.0	0.55	0.0107	0.0391	1.35
1433.0	2.08	45.5	19.5	0.55	0.0125	0.0442	1.57
1438.9	1.98	45.0	20.5	0.55	0.0120	0.0400	1.49
1445.0	1.91	45.5	19.5	0.55	0.0114	0.0406	1.44
1450.9	1.98	46.0	19.0	0.55	0.0117	0.0432	1.49
1457.0	2.19	46.5	20.0	0.55	0.0128	0.0453	1.65
*1463.0	1.94	45.0	19.0	0.55	0.0117	0.0423	1.46
+1463.0		RESTART SIMULATED GROUND H ₂ O					

Test #67. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1469.0	2.22	46.0	19.5	0.55	0.0132	0.0472	1.67
1474.9	2.26	46.0	20.0	0.55	0.0134	0.0468	1.70
1480.9	2.22	45.0	21.0	0.52	0.0134	0.0438	1.77
1487.0	2.19	45.0	20.5	0.52	0.0133	0.0443	1.75
1493.0	2.22	44.5	20.0	0.55	0.0136	0.0460	1.67
*1498.8	2.01	45.0	20.0	0.55	0.0122	0.0417	1.52
1505.0	1.88	44.5	21.0	0.55	0.0115	0.0371	1.42
1510.7	1.81	44.0	21.0	0.55	0.0112	0.0357	1.36
1516.9	1.81	44.0	21.0	0.55	0.0112	0.0357	1.36
1522.9	1.81	45.0	21.5	0.55	0.0110	0.0349	1.36
1529.0	1.81	45.0	21.5	0.55	0.0110	0.0349	1.36
1535.0	1.94	45.0	21.0	0.60	0.0117	0.0383	1.34
1540.7	1.94	45.0	21.0	0.60	0.0117	0.0383	1.34
1547.0	1.94	45.0	21.0	0.60	0.0117	0.0383	1.34
*1553.0	1.94	45.0	21.5	0.60	0.0117	0.0374	1.34
1559.0	1.81	45.0	21.0	0.60	0.0110	0.0357	1.25
1565.3	1.81	45.0	21.0	0.60	0.0110	0.0357	1.25
1571.0	1.81	45.0	21.5	0.65	0.0110	0.0349	1.15
1577.0	1.81	44.5	21.5	0.65	0.0111	0.0349	1.15
1583.0	1.88	44.0	21.5	0.70	0.0116	0.0363	1.11
1589.0	1.88	43.5	21.0	0.70	0.0118	0.0371	1.11
1595.0	1.88	43.5	21.0	0.70	0.0118	0.0371	1.11

Test #67. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1601.0	1.88	43.0	21.5	0.70	0.0119	0.0363	1.11
*1607.0	1.88	43.5	21.5	0.75	0.0118	0.0363	1.03
1613.0	1.88	44.0	21.0	0.80	0.0116	0.0371	0.974
1618.9	1.88	44.0	21.5	0.80	0.0116	0.0363	0.974
1625.0	1.88	43.5	22.0	0.80	0.0118	0.0354	0.974
1631.0	1.88	43.5	22.0	0.80	0.0118	0.0354	0.974
1637.3	1.88	43.5	22.0	0.80	0.0118	0.0354	0.974
1643.1	1.88	44.0	21.5	0.85	0.0116	0.0363	0.917
1649.0	1.88	43.5	22.0	0.85	0.0118	0.0354	0.917
1655.0	1.81	43.0	22.5	0.90	0.0115	0.0334	0.834
1661.0	1.81	43.0	22.5	0.90	0.0115	0.0334	0.834
1666.8	1.81	43.0	23.0	0.90	0.0115	0.0326	0.834
*1673.0	1.81	43.0	23.0	0.90	0.0115	0.0326	0.834
1673.0			RUN TERMINATED				

Observations from the Simulation Leach Test #68

Ore used = Texas

Solution used = H_2SO_4 , pH = 1.0

Inlet section packing material = -80 AFS Subangular Sand

Inlet section packing length = 10.0 in.

Length of the front ore section = 46.38 in.

Length of the middle ore section = (Not used in 8 ft ore bed)

Length of the end ore section = 52.50 in.

Outlet section packing material = -80 AFS Subangular Sand

Outlet section packing length = 5.00 in.

Ore packing bed density = 1.47 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = 15 tamps/8 in. of ore. Column position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.

† indicates introduction of fresh feed solution(s).

Test #68

Ore - Texas

Sol - H_2SO_4 , pH 1.00

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
36.2	5.83	4.40	6.75	0.478	0.348
42.2	5.83	4.40	6.75	0.478	0.348
48.0	5.75	5.05	8.45	0.411	0.274
*54.0	11.11	5.60	10.9	0.716	0.411
60.0	11.11	5.20	10.9	0.771	0.411
66.0	9.72	5.00	11.3	0.701	0.347
†72.3	9.52	4.55	11.3	0.755	0.340
78.2	9.89	4.00	10.3	0.892	0.387
83.9	6.14	3.10	7.75	0.715	0.319
90.0	8.47	3.60	8.90	0.849	0.384
96.2	8.33	4.30	10.4	0.699	0.323
*102.2	8.61	4.50	11.1	0.690	0.313
107.6	9.26	4.60	11.7	0.726	0.319
114.0	9.64	4.55	13.7	0.764	0.284
120.0	9.17	4.65	12.5	0.712	0.296
*126.0	9.17	4.60	12.7	0.719	0.291
†126.0		START CHEMICAL LEACH			
*132.0	6.11	4.45	8.50	0.495	0.290
*139.0	4.29	8.55	6.50	0.181	0.266
*144.0	3.33	13.0	5.50	0.0900	0.244
*150.0	4.72	33.9	6.60	0.0489	0.288

Test #68. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
156.0	2.50	35.0	5.50	0.0251	0.183
162.0	2.50	35.5	5.00	0.0247	0.202
168.0	2.22	35.8	4.75	0.0218	0.188
174.0	2.22	36.0	4.95	0.0217	0.181
*180.0	1.88	35.7	4.80	0.0185	0.158
187.2	1.88	34.8	4.70	0.0190	0.161
192.0	1.88	35.4	4.65	0.0187	0.163
198.0	1.88	35.3	4.75	0.0187	0.160
204.0	1.63	35.8	4.75	0.0160	0.138
209.7	1.63	35.7	4.80	0.0160	0.137
216.0	1.63	35.7	4.80	0.0160	0.137
222.5	1.63	35.1	5.40	0.0163	0.122
228.0	1.50	35.3	5.25	0.0149	0.115
*234.1	1.50	35.3	5.25	0.0149	0.115
239.9	1.50	35.3	5.25	0.0149	0.115
245.9	1.50	35.1	5.40	0.0150	0.112
252.0	1.30	34.8	5.20	0.0131	0.101
257.8	1.30	35.3	5.20	0.0129	0.101
263.3	1.30	35.3	5.20	0.0129	0.101
269.0	1.30	35.3	5.20	0.0129	0.101
275.0	1.18	34.8	5.15	0.0119	0.0923
281.2	1.18	35.0	5.05	0.0118	0.0942

Test #68. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
*287.0	1.18	35.8	5.25	0.0116	0.0906
293.0	1.18	36.2	5.35	0.0114	0.0889
299.2	1.18	35.0	5.00	0.0118	0.0951
305.1	1.18	35.7	4.80	0.0116	0.0991
311.0	1.18	34.7	4.80	0.0119	0.0991
317.0	1.18	34.3	5.25	0.0121	0.0906
322.9	1.18	35.0	5.00	0.0118	0.0951
329.0	1.18	35.2	4.80	0.0118	0.0991
335.0	1.18	34.7	4.80	0.0119	0.0991
*341.0	1.18	35.2	4.85	0.0118	0.0980
347.0	1.04	35.1	4.90	0.0104	0.0873
353.0	1.04	35.3	4.75	0.0103	0.0882
359.0	1.04	35.4	4.65	0.0103	0.0901
365.0	1.04	35.4	4.65	0.0103	0.0901
371.2	0.90	35.5	4.55	0.0089	0.0797
377.0	0.90	35.6	4.45	0.0089	0.0815
383.0	0.90	36.1	4.40	0.0088	0.0824
389.0	0.90	35.5	4.50	0.0089	0.0806
395.2	0.83	35.7	4.35	0.0082	0.0769
*401.4	0.83	36.3	4.25	0.0080	0.0787
407.2	0.83	36.3	4.20	0.0080	0.0796
413.0	0.83	36.2	4.35	0.0081	0.0769

Test #68. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
418.9	0.83	36.2	4.35	0.0081	0.0769
424.6	0.83	36.3	4.25	0.0080	0.0787
431.0	0.83	36.4	4.15	0.0080	0.0806
437.0	0.83	36.3	4.25	0.0080	0.0787
443.1	0.90	35.8	4.25	0.0088	0.0853
448.7	0.90	36.3	4.20	0.0087	0.0864
455.0	0.90	35.8	4.25	0.0088	0.0853
461.0	0.90	34.6	5.45	0.0091	0.0666
467.0	0.83	35.0	5.00	0.0083	0.0669
472.9	0.83	35.2	4.85	0.0083	0.0690
479.0	0.83	35.4	4.65	0.0082	0.0719
485.0	0.83	35.2	4.80	0.0083	0.0697
*491.0	0.76	35.3	4.75	0.0076	0.0645
497.1	0.76	35.5	4.50	0.0075	0.0681
503.0	0.76	36.0	4.00	0.0074	0.0766
509.0	0.76	35.7	4.30	0.0075	0.0712
515.2	0.76	35.6	4.40	0.0075	0.0696
520.7	0.76	36.3	4.25	0.0074	0.0721
528.6	0.76	36.4	4.10	0.0073	0.0747
533.0	0.76	36.4	4.10	0.0073	0.0747
539.0	0.72	36.5	4.00	0.0069	0.0725
544.9	0.72	36.6	3.90	0.0069	0.0744

Test #68. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
551.0	0.72	36.7	3.80	0.0069	0.0764
558.5	0.72	35.9	4.10	0.0070	0.0708
563.6	0.66	36.2	4.35	0.0064	0.0611
569.0	0.66	36.6	3.95	0.0063	0.0673
575.0	0.66	36.2	4.30	0.0064	0.0619
581.0	0.66	35.7	4.30	0.0065	0.0619
586.8	0.63	35.5	4.45	0.0062	0.0571
593.0	0.63	36.5	4.05	0.0061	0.0627
599.2	0.63	36.3	3.75	0.0061	0.0677
604.9	0.63	35.9	4.10	0.0062	0.0619
*610.8	0.62	36.4	4.15	0.0060	0.0602
617.0	0.62	35.9	4.10	0.0061	0.0609
623.0	0.62	36.3	3.70	0.0060	0.0675
629.0	0.62	36.1	3.95	0.0060	0.0632
635.3	0.56	36.5	3.55	0.0054	0.0636
641.6	0.56	36.7	3.80	0.0054	0.0594
647.0	0.56	36.3	3.75	0.0054	0.0602
653.0	0.56	36.2	3.85	0.0054	0.0586
659.2	0.56	36.2	3.80	0.0054	0.0594
666.0	0.56	36.8	3.70	0.0053	0.0610
671.0	0.56	37.2	3.30	0.0053	0.0684
677.0	0.56	37.4	3.65	0.0053	0.0618

Test #68. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
683.0	0.49	37.7	3.80	0.0046	0.0520
689.4	0.49	38.4	3.60	0.0045	0.0549
695.0	0.49	38.4	3.60	0.0045	0.0549
701.0	0.49	38.7	3.85	0.0044	0.0513
707.0	0.46	38.8	3.70	0.0042	0.0501
712.7	0.46	39.0	3.55	0.0041	0.0522
*719.0	0.46	38.6	3.45	0.0042	0.0537
719.0		STOP RUN FOR 72 HOURS			
+791.0		RESTART RUN			
797.0	1.06	36.5	4.00	0.0102	0.107
803.1	1.06	35.6	4.95	0.0105	0.0863
*809.0	1.06	36.4	4.60	0.0102	0.0929
815.0	1.06	36.0	4.55	0.0103	0.0939
821.0	1.06	35.4	5.10	0.0105	0.0838
826.9	1.46	35.1	5.45	0.0146	0.108
833.0	1.46	34.6	5.90	0.0146	0.0997
839.0	1.46	34.1	6.40	0.0148	0.0919
845.0	1.46	33.7	6.85	0.0152	0.0859
851.5	1.88	34.0	7.00	0.0194	0.108
857.0	1.88	33.4	7.10	0.0198	0.107
*863.0	1.88	33.3	7.20	0.0198	0.105
869.0	1.88	33.7	7.30	0.0196	0.104

Test #68. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
875.0	1.94	33.7	7.30	0.0202	0.107
881.0	1.94	33.7	7.30	0.0202	0.107
887.0	1.94	33.2	7.35	0.0205	0.106
893.0	1.94	32.9	7.60	0.0207	0.103
899.0	1.81	33.0	7.50	0.0193	0.0973
905.0	1.81	33.1	7.45	0.0192	0.0979
911.0	1.81	33.6	7.40	0.0189	0.0986
*916.0	1.81	32.4	8.15	0.0196	0.0895
†916.0		START 1 g/ℓ NaHSO ₃ (pH = 3.6)			
923.5	1.75	33.4	7.65	0.0184	0.0922
929.4	1.75	33.2	7.30	0.0185	0.0966
*935.0	1.75	35.2	5.85	0.0175	0.121
*941.0	0.83	36.6	4.40	0.0080	0.0760
946.8	0.35	37.4	3.65	0.0033	0.0386
953.1	0.35	37.4	3.10	0.0033	0.0455
959.1	0.35	37.7	3.35	0.0033	0.0421
965.0	0.35	38.0	3.00	0.0032	0.0470
*971.0	0.09	38.2	2.80	0.0008	0.0130
976.5	0.09	38.4	2.65	0.0008	0.0137
983.0	0.09	38.5	2.55	0.0008	0.0142
983.0		STOP RUN FOR 24 HOURS			
1007.0		RESTART RUN			

Test #68. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
1013.0	0.14	38.6	1.90	0.0013	0.0297
1019.1	0.14	38.6	1.90	0.0013	0.0297
*1025.6	0.14	38.6	1.95	0.0013	0.0289
1031.0	0.14	38.6	1.95	0.0013	0.0289
1031.0	STOP RUN TO REVERSE FLOW				
1035.0	RESTART FLOW IN REVERSE DIRECTION				
1037.0	--	2.10	7.65	--	--
1043.3	--	13.5	0.75	--	--
1054.0	--	PRESSURE INCREASED TO NORMAL			
1055.0	--	22.0	2.60	--	--
*1061.0	0.18	44.0	0.15	0.0014	0.484
1066.9	0.18	44.0	0.15	0.0014	0.484
1073.0	0.18	44.0	0.15	0.0014	0.484
1079.1	0.18	44.0	0.10	0.0014	0.725
1091.0	0.18	44.0	0.10	0.0014	0.725
1097.0	0.18	44.0	0.10	0.0014	0.725
1104.0	0.18	44.0	0.15	0.0014	0.484
1109.1	0.18	44.0	0.15	0.0014	0.484
1115.0	0.18	44.0	0.15	0.0014	0.484
*1121.0	0.18	44.0	0.15	0.0014	0.484
1127.0	0.28	44.0	0.15	0.0022	0.752
1132.0	0.28	44.5	0.10	0.0022	1.128

Test #68. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
1139.9	0.28	44.5	0.10	0.0022	1.128
1151.2	0.28	44.0	0.15	0.0022	0.752
1158.2	0.28	44.0	0.15	0.0022	0.752
1163.3	0.28	44.0	0.20	0.0022	0.564
1169.5	0.28	43.5	0.20	0.0022	0.564
1175.0	0.28	43.0	0.25	0.0023	0.451
1181.0	0.28	43.5	0.20	0.0022	0.564
1187.0	0.28	43.5	0.30	0.0022	0.376
*1192.9	0.28	43.0	0.30	0.0023	0.376
1199.0	0.28	42.5	0.25	0.0023	0.564
1199.0	STOP FLOW 24 HOURS - ACIDIFY FEED TO pH 2.00				
+1223.0	RESTART FLOW IN ORIGINAL DIRECTION				
1229.0	2.08	33.7	9.25	0.0217	0.0906
*1235.0	2.08	31.0	12.0	0.0236	0.0698
1240.9	3.67	29.0	14.0	0.0444	0.106
*1247.0	5.19	29.0	14.5	0.0629	0.144
1253.0	5.00	27.0	16.0	0.0650	0.126
1259.0	5.28	24.0	19.0	0.0773	0.112
*1265.0	5.28	20.9	22.1	0.0887	0.0963
1271.0	5.56	17.5	25.5	0.112	0.0879
1277.1	5.19	14.5	28.5	0.126	0.0734
*1283.0	4.5]	12.5	30.5	0.127	0.0597

Test #68. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
1288.9	3.39	11.0	32.0	0.108	0.0427
1295.0	3.28	10.10	33.0	0.114	0.0401
1300.7	2.78	9.78	33.5	0.0998	0.0334
1307.0	2.78	9.30	34.0	0.105	0.0330
1313.0	2.78	9.15	34.0	0.107	0.0330
1319.0	2.78	8.90	34.5	0.110	0.0325
1325.0	2.54	8.60	35.0	0.104	0.0292
1330.8	2.54	8.25	35.5	0.108	0.0288
*1337.0	2.32	8.15	35.0	0.100	0.0267
1343.0	2.32	8.20	35.0	0.0994	0.0267
1349.0	2.31	8.00	35.5	0.101	0.0262
1355.3	2.31	7.80	35.5	0.104	0.0262
1361.0	2.42	7.75	34.5	0.110	0.0283
1367.0	2.42	7.80	35.5	0.109	0.0275
1373.0	2.36	7.75	36.0	0.107	0.0264
1379.0	2.36	7.55	36.0	0.110	0.0264
1385.0	2.36	7.45	35.5	0.111	0.0268
1391.0	2.36	7.65	35.5	0.108	0.0268
1397.0	2.34	7.55	36.0	0.109	0.0262
*1403.1	2.34	7.45	36.0	0.110	0.0262
1408.9	2.38	7.30	35.0	0.115	0.0274
1415.0	2.38	7.45	35.5	0.112	0.0270

Test #68. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
†1419.0		START SIMULATED GROUND H ₂ O			
1421.0	1.76	8.40	35.0	0.0736	0.0203
1427.3	1.76	7.30	36.0	0.0847	0.0197
1433.1	2.14	7.20	36.0	0.104	0.0240
1439.0	2.14	7.20	36.0	0.104	0.0240
*1445.0	2.22	7.10	36.0	0.110	0.0249
1451.0	2.22	7.00	36.0	0.111	0.0249
1456.9	2.22	7.05	36.0	0.111	0.0249
1463.0	2.22	7.35	36.0	0.106	0.0249
1469.0	2.36	7.25	36.0	0.114	0.0264
*1475.0	2.36	7.30	36.0	0.114	0.0264
1481.2	2.36	7.35	36.0	0.113	0.0264
1487.0	2.36	7.35	36.0	0.113	0.0264
1493.0	2.36	7.35	36.0	0.113	0.0264
1499.0	2.36	7.30	36.0	0.114	0.0264
1505.3	2.40	7.35	36.0	0.115	0.0269
1510.8	2.40	7.40	36.0	0.114	0.0269
1517.0	2.34	7.35	35.8	0.112	0.0263
1522.9	2.34	7.30	36.0	0.113	0.0262
1529.2	2.38	7.50	35.5	0.111	0.0270
*1535.0	2.38	7.75	35.5	0.108	0.0270
1541.0	2.50	9.25	34.0	0.0949	0.0296

Test #68. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
1546.8	2.87	10.00	33.0	0.101	0.0350
1553.4	3.28	10.5	32.0	0.110	0.0413
1559.0	3.57	11.0	31.5	0.114	0.0457
1565.0	4.17	12.0	30.5	0.122	0.0551
1571.0	4.17	12.0	30.5	0.122	0.0551
*1577.0	3.89	13.0	29.5	0.105	0.0531
1588.7	3.98	13.5	29.0	0.104	0.0553
1589.0	4.40	14.0	28.5	0.110	0.0622
1595.0	4.72	14.0	28.2	0.118	0.0675
1601.0	4.72	15.0	27.5	0.111	0.0692
1607.3	4.50	16.0	26.5	0.0988	0.0684
1613.1	4.31	16.0	26.5	0.0946	0.0655
1619.1	4.17	15.6	26.5	0.0939	0.0634
1625.0	4.24	16.0	26.5	0.0931	0.0645
*1631.0	4.17	15.5	26.5	0.0945	0.0634
1631.0		RUN TERMINATED			

Observations from the Simulation Leach Test #69

Ore used = Wyoming

Solution used = H_2SO_4 , pH = 1.0

Inlet section packing material = -80 AFS Subangular Sand

Inlet section packing length = 10.0 in.

Length of the front ore section = 47.13 in.

Length of the middle ore section = (Not used in 8 ft ore bed)

Length of the end ore section = 52.25 in.

Outlet section packing material = -80 AFS Subangular Sand

Outlet section packing length = 5.00 in.

Ore packing bed density = 1.69 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = 10 tamps/8 in. of ore. Column position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.

† indicates introduction of fresh feed solution(s).

Test #69

Ore - Wyoming

Sol - H₂SO₄, pH 1.00

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
24.0	2.82	1.20	3.30	0.850	0.343
30.0	8.06	2.55	2.50	1.14	1.29
36.0	10.56	2.65	2.15	1.44	1.97
*42.1	9.56	2.50	1.90	1.38	2.02
48.0	8.47	2.50	1.80	1.23	1.89
54.0	9.72	2.70	1.90	1.30	2.05
60.1	9.84	2.85	2.05	1.25	1.93
66.0	10.45	2.80	1.95	1.35	2.15
72.0	8.89	2.70	1.80	1.19	1.98
+77.0	9.00	2.80	1.90	1.16	1.90
84.2	7.41	1.95	1.40	1.37	2.12
90.0	6.61	2.40	1.65	0.996	1.61
*96.0	8.06	2.40	1.70	1.22	1.90
102.0	7.78	2.20	1.55	1.28	2.01
108.3	9.52	2.50	2.00	1.37	1.91
114.5	8.06	2.55	1.95	1.14	1.66
120.2	8.77	2.55	1.95	1.24	1.80
126.1	7.63	2.35	1.90	1.17	1.61
132.0	8.47	2.50	2.00	1.23	1.70
137.7	8.77	2.45	2.00	1.30	1.76
144.1	8.33	2.30	1.90	1.31	1.76
150.1	7.78	2.20	1.80	1.28	1.73

Test #69. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
156.2	7.92	2.10	1.80	1.36	1.76
161.8	8.04	2.25	1.95	1.29	1.65
*168.0	7.80	2.15	1.90	1.31	1.65
174.0	8.06	2.20	2.05	1.33	1.58
†174.0		START CHEMICAL LEACH			
180.1	6.28	1.90	1.75	1.20	1.44
186.0	6.58	2.20	1.85	1.08	1.43
*192.0	6.58	2.05	1.60	1.16	1.65
198.0	8.06	3.20	3.65	0.911	0.886
*204.0	10.56	4.00	5.10	0.955	0.831
210.0	9.44	4.00	4.80	0.854	0.789
*216.0	8.89	4.25	4.15	0.757	0.859
222.0	10.00	5.35	4.85	0.676	0.827
228.2	10.48	6.05	5.45	0.627	0.771
233.8	10.12	6.20	5.55	0.591	0.731
241.7	11.70	6.50	5.40	0.651	0.869
*†245.5	11.70	6.85	5.70	0.618	0.823
252.1	9.85	7.20	5.60	0.495	0.706
258.0	8.76	6.90	5.00	0.459	0.703
264.0	8.89	7.65	5.40	0.420	0.660
*271.5	9.56	8.85	6.05	0.391	0.634
276.7	9.62	9.60	6.65	0.363	0.580

Test #69. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
282.0	10.06	9.70	6.60	0.375	0.611
288.1	10.66	10.4	6.65	0.371	0.643
294.4	9.26	10.0	6.50	0.335	0.571
299.8	10.19	10.5	6.60	0.351	0.619
*306.1	9.26	10.5	6.40	0.319	0.580
312.3	8.60	10.6	6.20	0.294	0.556
318.0	8.48	11.6	6.55	0.264	0.519
323.8	8.91	11.6	6.40	0.278	0.558
330.1	8.20	12.5	6.30	0.237	0.522
+336.0	8.47	13.2	6.55	0.232	0.519
342.0	7.78	10.0	5.60	0.281	0.557
348.4	8.59	13.3	6.45	0.234	0.534
*354.6	7.80	12.6	5.75	0.224	0.544
360.0	7.72	14.6	6.65	0.191	0.466
366.0	9.17	15.7	6.85	0.211	0.537
372.2	10.22	16.7	6.80	0.221	0.603
379.0	9.77	17.0	6.60	0.208	0.594
384.0	8.33	17.8	6.40	0.169	0.522
390.0	9.17	19.3	6.70	0.172	0.549
396.0	8.61	19.5	6.50	0.160	0.531
*402.4	8.85	19.9	6.15	0.161	0.577
408.0	8.04	21.0	6.00	0.139	0.537

Test #69. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
414.0	8.06	23.1	6.30	0.126	0.513
420.0	9.17	25.5	6.40	0.130	0.575
425.8	8.33	26.0	6.25	0.116	0.535
†432.0	8.33	26.3	6.00	0.115	0.557
438.0	8.06	23.4	5.50	0.125	0.588
*444.0	9.17	28.7	6.15	0.116	0.598
450.2	9.14	28.1	5.80	0.118	0.632
456.0	7.18	27.9	5.55	0.093	0.519
462.1	8.20	31.6	5.95	0.094	0.553
468.0	8.47	33.5	5.60	0.091	0.607
474.0	9.44	34.5	5.70	0.099	0.664
*480.0	8.33	35.0	5.45	0.086	0.613
486.0	8.06	35.0	5.15	0.083	0.628
492.0	7.50	35.2	4.90	0.077	0.614
497.8	7.76	35.4	4.80	0.079	0.648
504.0	7.26	37.3	4.85	0.070	0.600
510.0	7.50	37.5	4.75	0.072	0.633
516.1	7.38	37.5	4.65	0.071	0.637
522.0	7.34	37.5	4.65	0.071	0.633
†528.0	6.94	37.7	4.55	0.067	0.612
534.0	6.39	38.9	4.70	0.059	0.545
*540.0	7.22	38.5	4.60	0.068	0.630

Test #69. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
546.0	6.94	38.0	4.5	0.066	0.619
552.0	6.94	38.2	4.35	0.066	0.640
558.0	6.11	37.7	4.10	0.059	0.598
564.1	6.83	38.0	4.00	0.065	0.685
570.0	6.50	38.0	3.90	0.062	0.669
576.0	5.56	38.1	3.80	0.053	0.587
*582.0	6.11	38.2	3.75	0.058	0.654
588.1	6.01	38.5	3.75	0.056	0.643
594.0	5.65	38.3	3.80	0.053	0.596
600.0	5.83	38.5	3.65	0.055	0.641
606.0	5.28	38.6	3.50	0.049	0.605
612.2	5.65	38.5	3.50	0.053	0.647
618.1	4.80	38.5	3.45	0.045	0.558
*624.0	5.65	38.6	3.35	0.053	0.676
628.0	4.17	38.7	3.25	0.039	0.515
+628.0		START SIMULATED GROUND H ₂ O			
636.0	3.75	41.2	1.50	0.033	1.00
642.5	0.88	42.0	0.95	0.0076	0.372
648.0	0.88	42.1	0.85	0.0076	0.415
*654.0	0.88	41.7	0.70	0.0076	0.504
659.9	0.88	42.2	0.70	0.0075	0.504
666.1	0.88	42.5	0.65	0.0075	0.543

Test #69. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
672.1	0.88	42.5	0.60	0.0075	0.588
678.0	0.62	42.7	0.60	0.0053	0.414
684.0	0.62	43.0	0.60	0.0052	0.414
689.8	0.62	43.0	0.60	0.0052	0.414
696.0	0.62	42.8	0.70	0.0052	0.355
702.0	0.62	42.7	0.65	0.0053	0.383
708.0	0.62	42.7	0.60	0.0053	0.414
*714.0	0.62	42.5	0.60	0.0053	0.414
720.0	0.62	42.6	0.70	0.0053	0.355
726.0	0.62	42.6	0.70	0.0053	0.355
732.1	0.62	42.6	0.65	0.0053	0.383
738.6	0.62	42.0	0.60	0.0053	0.414
744.0	0.62	42.8	0.55	0.0052	0.452
750.0	0.62	43.2	0.60	0.0052	0.414
756.4	0.62	43.0	0.60	0.0052	0.414
762.3	0.62	42.7	0.60	0.0053	0.414
768.0	0.62	42.7	0.60	0.0053	0.414
774.0	0.62	43.1	0.70	0.0052	0.355
780.0	0.62	43.0	0.60	0.0052	0.414
786.0	0.62	43.0	0.55	0.0052	0.452
*792.1	0.62	42.5	0.60	0.0053	0.414
804.1	0.62	43.0	0.70	0.0052	0.355

Test #69. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
809.0	0.62	43.0	0.60	0.0052	0.414
817.1	0.62	43.0	0.50	0.0052	0.497
822.1	0.62	43.0	0.60	0.0052	0.414
828.0	0.62	43.0	0.60	0.0052	0.414
*834.0	0.62	43.0	0.60	0.0052	0.414
840.0	0.62	42.3	0.55	0.0053	0.452
846.0	0.62	42.2	0.75	0.0053	0.332
846.0		STOP RUN FOR 1 WEEK			
1008.0		RESTART RUN			
1013.7	0.97	42.2	0.95	0.0083	0.410
1020.0	0.97	42.0	0.95	0.0083	0.410
1026.0	0.97	42.0	0.90	0.0083	0.432
1032.0	0.97	41.6	0.90	0.0084	0.432
*1038.0	0.97	42.1	0.90	0.0083	0.432
1043.8	0.97	42.0	0.90	0.0083	0.432
1050.0	0.97	41.2	0.80	0.0085	0.486
1056.0	0.97	41.1	0.85	0.0085	0.458
1062.0	0.97	41.6	0.85	0.0084	0.458
1068.4	0.83	41.5	0.80	0.0072	0.416
1074.0	0.83	41.1	0.80	0.0073	0.416
1080.0	0.83	41.1	0.75	0.0073	0.444
1086.0	0.83	41.5	0.85	0.0072	0.392

Test #69. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
1092.1	0.83	41.5	0.85	0.0072	0.392
1098.0	0.83	41.0	0.80	0.0073	0.416
1104.0	0.83	41.0	0.80	0.0073	0.416
1110.0	0.83	41.0	0.85	0.0073	0.392
1116.1	0.83	41.0	0.80	0.0073	0.416
1122.0	0.83	40.5	0.85	0.0074	0.392
1128.0	0.83	40.5	0.80	0.0074	0.416
1134.0	0.83	40.9	0.85	0.0073	0.392
1140.4	0.83	41.0	0.85	0.0073	0.392
1146.2	0.81	40.4	0.85	0.0073	0.382
*1152.0	0.81	40.5	0.80	0.0072	0.406
1158.0	0.81	40.5	0.80	0.0072	0.406
1164.1	0.81	40.5	0.80	0.0072	0.406
1169.9	0.81	40.5	0.80	0.0072	0.406
1176.0	0.81	40.5	0.75	0.0072	0.433
1187.0	0.81	40.5	0.80	0.0072	0.406
1188.0	0.81	40.5	0.75	0.0072	0.433
1194.3	0.81	40.5	0.75	0.0072	0.433
1200.0	0.81	40.5	0.70	0.0072	0.464
1206.0	0.81	41.0	0.70	0.0071	0.464
1212.0	0.73	41.7	0.80	0.0063	0.366
1218.3	0.73	41.5	0.70	0.0064	0.418

Test #69. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
1225.8	0.73	40.5	0.70	0.0065	0.418
1230.0	0.73	41.0	0.75	0.0064	0.390
1236.0	0.73	42.0	0.80	0.0063	0.366
*1242.2	0.73	41.5	0.75	0.0064	0.390
1248.0	0.73	40.9	0.70	0.0065	0.418
1254.0	0.73	41.2	0.75	0.0064	0.390
1259.9	0.73	42.0	0.75	0.0063	0.390
1266.5	0.73	41.0	0.75	0.0064	0.390
1272.0	0.73	40.7	0.70	0.0065	0.418
1278.0	0.73	41.2	0.80	0.0064	0.366
1284.1	0.73	41.5	0.80	0.0064	0.366
1290.0	0.73	40.7	0.70	0.0065	0.418
1296.8	0.73	41.0	0.70	0.0064	0.418
1302.1	0.62	40.7	0.60	0.0055	0.414
1308.0	0.62	41.2	0.70	0.0054	0.355
1314.0	0.62	41.5	0.65	0.0054	0.383
1320.4	0.62	42.0	0.65	0.0053	0.383
1326.2	0.62	41.5	0.65	0.0054	0.383
*1332.2	0.62	41.4	0.85	0.0054	0.293
1338.0	0.62	41.0	0.85	0.0055	0.293
1344.0	0.62	41.1	0.85	0.0055	0.293
1356.6	0.62	42.0	1.00	0.0053	0.249

Test #69. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
1361.9	0.62	42.5	0.95	0.0053	0.262
1368.0	0.62	41.1	0.65	0.0055	0.383
1374.0	0.62	41.2	0.85	0.0054	0.293
1380.2	0.62	41.7	1.0	0.0054	0.249
1385.8	0.62	42.5	1.0	0.0053	0.249
1392.0	0.62	41.2	0.95	0.0054	0.262
1398.0	0.62	41.2	0.90	0.0054	0.276
1404.0	0.62	41.5	1.10	0.0054	0.226
1409.9	0.62	41.0	1.20	0.0055	0.207
1416.0	0.62	40.5	1.15	0.0055	0.216
1422.0	0.62	41.3	0.90	0.0054	0.276
1428.0	0.62	42.0	0.75	0.0053	0.332
1433.6	0.62	41.5	0.75	0.0054	0.332
1440.0	0.62	41.1	0.65	0.0055	0.383
*1445.8	0.62	40.9	0.75	0.0055	0.332
1452.0	0.62	41.5	0.80	0.0054	0.311
1458.2	0.62	42.5	0.80	0.0053	0.311
1464.0	0.62	41.5	0.75	0.0054	0.332
1469.9	0.62	41.5	0.70	0.0054	0.355
1476.0	0.51	41.5	0.80	0.0044	0.256
1482.0	0.51	41.5	0.90	0.0044	0.227
1488.0	0.51	41.5	0.85	0.0044	0.241

Test #69. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
1494.0	0.51	41.5	0.85	0.0044	0.241
1500.0	0.51	41.5	0.80	0.0044	0.256
1506.2	0.51	41.5	0.85	0.0044	0.241
1512.0	0.51	41.5	0.80	0.0044	0.256
*1518.0	0.51	41.5	0.85	0.0044	0.241
1524.2	0.51	41.5	0.95	0.0044	0.215
1530.0	0.51	41.0	0.95	0.0045	0.215
1536.0	0.51	40.7	0.95	0.0045	0.215
1542.0	0.51	41.3	0.90	0.0045	0.227
1548.2	0.51	41.5	0.85	0.0044	0.241
1554.0	0.51	42.0	0.80	0.0044	0.246
1560.0	0.51	40.8	0.90	0.0045	0.227
1566.1	0.51	41.5	0.90	0.0044	0.227
1572.2	0.51	41.5	0.90	0.0044	0.227
1578.0	0.51	41.0	0.90	0.0045	0.227
1584.0	0.51	41.1	0.90	0.0045	0.227
1590.0	0.51	41.6	0.95	0.0044	0.215
*1596.1	0.51	42.0	0.95	0.0044	0.215
1602.0	0.51	41.2	0.85	0.0045	0.241
1608.0	0.51	41.2	0.85	0.0045	0.241
1614.0	0.47	41.7	0.90	0.0041	0.209
1620.0	0.47	41.7	1.00	0.0041	0.189

Test #69. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
1627.0	0.47	42.0	0.95	0.0040	0.198
1632.0	0.47	41.5	0.95	0.0041	0.198
1638.0	0.47	41.2	1.05	0.0041	0.180
1644.0	0.47	42.5	0.75	0.0040	0.251
1649.9	0.47	42.5	0.80	0.0040	0.236
1656.0	0.47	42.0	0.80	0.0040	0.236
1662.0	0.47	41.2	1.00	0.0041	0.189
1668.5	0.47	41.2	1.00	0.0041	0.189
1674.4	0.47	42.0	0.95	0.0040	0.198
1680.0	0.47	41.3	0.80	0.0041	0.236
1686.0	0.47	40.8	0.80	0.0042	0.236
*1692.0	0.47	41.5	0.80	0.0041	0.236
1698.2	0.47	41.5	0.80	0.0041	0.236
1704.0	0.47	40.8	0.80	0.0042	0.236
1710.0	0.47	41.2	0.80	0.0041	0.236
1716.0	0.47	41.2	0.80	0.0041	0.236
1722.7	0.47	41.5	0.85	0.0041	0.222
1728.0	0.47	41.3	0.90	0.0041	0.209
1734.0	0.47	41.3	0.90	0.0041	0.209
1740.3	0.47	42.0	0.70	0.0040	0.269
1746.4	0.47	41.2	0.70	0.0041	0.269
1752.0	0.47	40.6	0.70	0.0042	0.269

Test #69. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
1758.0	0.47	41.1	0.70	0.0041	0.269
1764.0	0.47	42.0	1.00	0.0040	0.189
1770.3	0.42	42.0	0.60	0.0036	0.281
1776.0	0.42	41.1	0.70	0.0037	0.241
1782.0	0.42	41.5	0.75	0.0037	0.225
1788.0	0.42	42.0	0.80	0.0036	0.211
1794.0	0.42	42.0	0.75	0.0036	0.225
*1800.4	0.42	42.0	0.75	0.0036	0.225
1806.0	0.42	42.5	0.85	0.0036	0.198
1812.0	0.42	42.5	0.80	0.0036	0.211
1818.0	0.42	42.5	0.80	0.0036	0.211
1824.3	0.42	42.5	0.75	0.0036	0.225
1830.1	0.42	42.5	0.80	0.0036	0.211
1835.9	0.42	42.5	0.80	0.0036	0.211
1842.0	0.42	42.5	0.75	0.0036	0.225
†1848.0	0.42	41.5	0.60	0.0037	0.281
1854.0	0.54	44.4	0.75	0.0044	0.289
1860.2	0.54	44.5	0.70	0.0044	0.309
1866.0	0.54	43.5	0.70	0.0045	0.309
1872.0	0.54	43.3	0.65	0.0045	0.333
1878.0	0.54	43.7	0.70	0.0045	0.309
1884.1	0.54	43.8	0.75	0.0045	0.289

Test #69. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
1890.0	0.54	43.0	0.75	0.0045	0.289
1896.0	0.54	43.4	0.80	0.0045	0.271
1902.0	0.54	43.3	0.90	0.0045	0.241
1908.0	0.54	44.0	0.80	0.0044	0.271
*1914.0	0.54	43.0	0.80	0.0045	0.271
1920.0	0.54	43.0	0.80	0.0045	0.271
1926.0	0.54	43.0	0.85	0.0045	0.255
1932.0	0.54	42.7	1.00	0.0046	0.217
1938.0	0.54	43.0	0.80	0.0045	0.271
1944.0	0.54	42.5	0.75	0.0046	0.289
1950.0	0.54	43.0	0.80	0.0045	0.271
1956.0	0.88	43.0	0.95	0.0074	0.372
1962.1	0.88	42.8	0.90	0.0074	0.392
1968.0	0.88	43.0	0.90	0.0074	0.392
1974.1	0.88	42.5	1.00	0.0075	0.353
1980.0	0.88	42.2	0.95	0.0075	0.372
1986.0	0.88	42.0	0.90	0.0076	0.392
1992.2	0.88	42.5	0.85	0.0075	0.415
1997.8	0.88	42.5	0.90	0.0075	0.392
2004.0	0.88	41.5	0.90	0.0077	0.392
*2010.4	0.88	41.5	0.90	0.0077	0.392
2016.0	0.88	41.9	0.90	0.0076	0.392

Test #69. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
2022.0	0.88	42.2	0.85	0.0075	0.415
2027.9	0.88	42.2	1.05	0.0075	0.336
2034.0	0.88	41.1	1.00	0.0077	0.353
2040.0	0.88	41.2	0.90	0.0077	0.392
2046.0	0.88	41.2	0.90	0.0077	0.392
2052.0	0.88	42.0	1.10	0.0076	0.321
2058.0	0.88	41.0	1.10	0.0077	0.321
2064.0	0.88	41.0	1.05	0.0077	0.336
2070.0	0.88	41.0	1.15	0.0077	0.307
2076.3	0.88	41.0	1.15	0.0077	0.307
2082.0	0.88	40.5	1.10	0.0079	0.321
2088.0	0.88	41.5	1.10	0.0077	0.321
2094.0	0.88	41.7	0.95	0.0076	0.372
2100.1	0.83	42.0	0.80	0.0071	0.416
2106.0	0.83	42.0	0.75	0.0071	0.444
2112.0	0.83	41.5	0.70	0.0072	0.476
2118.0	0.83	41.5	0.75	0.0072	0.444
*2124.2	0.83	42.0	0.75	0.0071	0.444
2131.2	0.83	41.5	0.70	0.0072	0.476
2136.0	0.83	41.5	0.70	0.0072	0.476
2142.0	0.83	41.5	0.75	0.0072	0.444
2148.0	0.83	41.5	0.75	0.0072	0.444

Test #69. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
2154.0	0.83	41.5	0.70	0.0072	0.476
2160.0	0.83	41.5	0.70	0.0072	0.476
2166.0	0.83	41.5	0.70	0.0072	0.476
2172.1	0.83	41.3	0.70	0.0073	0.476
2178.1	0.83	41.3	0.90	0.0073	0.370
2184.0	0.83	41.2	0.95	0.0073	0.350
2190.0	0.83	41.1	1.00	0.0073	0.333
*2196.0	0.83	41.2	0.85	0.0073	0.392
2201.9	0.83	42.0	0.70	0.0071	0.476
2208.0	0.83	41.1	0.65	0.0073	0.512
2208.0		RUN TERMINATED			

Observations from the Simulation Leach Test #70

Ore used	= Wyoming
Solution used	= 1.0 g/l NH_4HCO_3
Inlet section packing material	= -80 AFS Subangular Sand
Inlet section packing length	= 10.0 in.
Length of the front ore section	= 47.38 in.
Length of the middle ore section	= 50.25 in.
Length of the end ore section	= 44.38 in.
Outlet section packing material	= -80 AFS Subangular Sand
Outlet section packing length	= 5.00 in.
Ore packing bed density	= 1.69 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = 10 tamps/8 in. of ore. Column position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.
† indicates introduction of fresh feed solution(s).

Test #70

Ore - Wyoming

Sol - 0.5 g/l H_2O_2
1.0 g/l NH_4HCO_3

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
30.0	11.11	3.3	2.6	2.7	1.22	1.65	1.40
36.0	12.22	3.4	2.2	1.5	1.31	2.14	2.78
42.0	11.94	3.2	2.2	1.7	1.36	2.09	2.39
49.5	8.89	2.9	1.8	1.5	1.11	1.90	2.02
*54.5	11.00	3.0	2.0	1.5	1.33	2.12	2.50
60.0	11.21	3.0	2.0	1.5	1.36	2.16	2.55
†66.2	10.75	2.9	1.8	1.5	1.35	2.30	2.44
72.1	10.45	3.6	2.2	1.3	1.06	1.83	2.74
77.7	10.12	3.2	2.2	1.1	1.15	1.79	3.13
84.0	10.32	3.9	3.0	1.7	0.962	1.33	2.07
*90.3	10.32	3.7	2.8	1.5	1.01	1.42	2.34
96.0	10.32	4.0	2.8	1.5	0.930	1.41	2.32
101.7	9.94	3.9	2.6	1.5	0.927	1.47	2.26
108.0	10.32	4.4	2.8	1.7	0.853	1.42	2.07
114.0	10.56	5.1	2.8	1.9	0.753	1.46	1.89
*120.0	10.56	5.2	2.8	2.1	0.739	1.46	1.71
126.4	10.16	5.3	2.6	1.9	0.697	1.51	1.82
132.5	8.74	5.3	2.6	1.9	0.600	1.30	1.57
138.0	9.09	5.3	2.6	1.9	0.624	1.35	1.63
*144.0	9.17	5.0	2.8	2.3	0.667	1.26	1.36
†144.0			START CHEMICAL LEACH				
150.2	8.33	4.4	2.6	1.3	0.689	1.236	2.18

Test #70. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*156.9	5.22	3.4	2.0	1.7	0.558	1.01	1.05
162.0	5.00	6.7	3.2	2.9	0.271	0.603	0.587
168.0	8.89	9.2	4.4	3.7	0.351	0.779	0.819
174.0	11.11	11.3	4.2	3.9	0.358	1.02	0.971
*180.4	8.85	12.2	4.0	3.5	0.264	0.854	0.861
186.0	7.74	13.5	3.6	3.5	0.209	0.829	0.753
*192.0	8.61	17.8	3.4	3.9	0.176	0.977	0.752
198.0	9.44	23.0	3.4	3.5	0.149	1.07	0.919
203.8	7.18	25.1	2.8	2.9	0.104	0.989	0.843
210.0	7.53	24.0	3.4	3.7	0.114	0.854	0.693
*216.0	9.44	32.2	3.2	3.5	0.107	1.14	0.919
222.0	8.33	39.0	2.6	2.7	0.0777	1.24	1.05
*228.1	7.38	39.7	2.0	2.3	0.0676	1.42	1.09
233.9	4.31	39.9	2.0	2.1	0.0393	0.831	0.699
240.0	4.10	40.3	1.6	2.1	0.0370	0.989	0.665
246.0	5.00	40.2	1.6	1.9	0.0452	1.21	0.897
252.0	5.00	40.4	1.6	1.7	0.0450	1.21	1.00
258.0	3.89	40.4	1.6	1.7	0.0350	0.938	0.780
263.9	4.24	40.4	1.4	1.9	0.0382	1.17	0.760
*270.1	4.30	40.1	1.6	1.7	0.0390	1.04	0.862
276.1	4.17	40.3	1.4	1.7	0.0376	1.15	0.836
282.0	4.80	40.7	1.6	1.7	0.0429	1.16	0.962

Test #70. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
†283.0			START 1 g/l NH_4HSO_3				
*288.0	6.00	26.3	3.0	2.7	0.0830	0.772	0.757
*294.0	10.56	7.3	3.0	2.5	0.526	1.358	1.44
300.0	10.00	4.9	2.6	2.3	0.742	1.48	1.48
*306.0	10.00	4.5	2.4	2.3	0.808	1.61	1.48
309.0	8.89	4.8	2.2	2.5	0.674	1.56	1.21
†309.0			RESTART LEACH				
*312.0	10.00	8.1	1.6	1.9	0.449	2.41	1.79
317.9	9.08	36.2	1.8	1.5	0.0912	1.95	2.06
324.0	6.18	36.6	1.8	1.7	0.0614	1.32	1.24
*330.0	5.28	36.8	1.6	1.7	0.0522	1.27	1.06
336.0	6.39	41.1	1.6	1.9	0.0565	1.54	1.15
342.1	4.92	41.2	1.4	1.7	0.0434	1.36	0.986
348.0	4.80	41.2	1.4	1.7	0.0424	1.32	0.962
354.0	4.72	41.5	1.6	1.5	0.0414	1.14	1.07
360.0	4.44	42.0	1.4	1.5	0.0384	1.22	1.01
366.1	4.64	41.7	1.4	1.5	0.0405	1.28	1.05
372.0	4.80	41.4	1.4	1.5	0.0422	1.32	1.09
*378.0	4.64	41.4	1.4	1.5	0.0408	1.28	1.05
384.0	4.17	42.0	1.4	1.5	0.0361	1.15	0.947
390.2	4.17	41.4	1.4	1.5	0.0366	1.15	0.947
396.0	3.89	41.4	1.4	1.5	0.0342	1.07	0.884

Test #70. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
402.0	4.17	41.4	1.4	1.5	0.0366	1.15	0.947
408.0	3.89	41.7	1.4	1.5	0.0339	1.07	0.884
414.6	3.79	41.4	1.4	1.5	0.0333	1.04	0.861
420.4	3.74	41.7	1.4	1.5	0.0326	1.03	0.849
426.1	3.80	42.2	1.2	1.5	0.0328	1.22	0.863
*432.0	3.67	42.2	1.2	1.5	0.0316	1.18	0.834
437.9	3.39	42.3	1.4	1.5	0.0291	0.934	0.770
444.0	3.55	42.3	1.4	1.5	0.0305	0.978	0.806
450.0	3.61	42.0	1.4	1.5	0.0313	0.995	0.820
456.0	3.61	42.3	1.2	1.7	0.0310	1.16	0.723
462.0	3.61	42.3	1.4	1.5	0.0310	0.995	0.820
467.8	3.74	42.2	1.2	1.5	0.0322	1.20	0.849
*474.0	3.49	42.6	1.2	1.7	0.0298	1.12	0.699
†476.0		RESTART 1 g/ℓ NH ₄ HSO ₃					
480.0	4.72	41.1	1.2	1.7	0.0418	1.52	0.946
*486.0	8.61	8.5	1.6	2.1	0.368	2.08	1.40
492.2	6.99	5.9	1.4	1.9	0.431	1.93	1.25
498.0	7.76	7.0	2.0	2.3	0.403	1.50	1.15
*501.0	10.00	6.6	1.8	2.3	0.551	2.14	1.48
†501.0		RESTART LEACH (H ₂ O ₂ at 0.25 g/ℓ)					
504.0	9.44	12.9	1.4	1.5	0.266	2.60	2.14
509.9	7.91	30.9	1.8	1.1	0.0931	1.70	2.45
*516.6	7.46	31.3	1.6	0.9	0.0867	1.80	2.82

Test #70. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
522.0	7.72	32.9	1.6	1.1	0.0853	1.86	2.39
528.0	8.06	38.1	2.6	2.7	0.0769	1.20	1.02
534.3	9.52	38.2	2.2	2.7	0.0906	1.67	1.20
540.3	9.44	38.2	2.4	2.5	0.0899	1.52	1.29
546.0	8.48	38.5	2.4	2.5	0.0801	1.36	1.16
552.2	7.80	38.9	2.2	2.3	0.0729	1.37	1.16
*557.9	7.60	39.0	2.0	2.1	0.0709	1.47	1.23
564.0	7.38	39.2	1.8	2.1	0.0685	1.58	1.20
570.3	7.04	39.0	2.0	2.1	0.0657	1.36	1.14
582.0	7.04	39.0	2.0	2.1	0.0657	1.36	1.14
588.0	7.04	39.2	1.8	2.1	0.0653	1.51	1.14
595.1	6.57	38.8	2.0	2.3	0.0616	1.27	0.973
600.1	6.67	39.5	1.8	2.1	0.0614	1.43	1.08
606.0	5.46	39.5	1.8	2.1	0.0503	1.17	0.886
612.0	5.83	39.2	1.8	2.1	0.0541	1.25	0.946
618.0	5.56	39.0	2.0	2.1	0.0519	1.07	0.902
*624.0	5.83	39.8	2.0	1.9	0.0533	1.12	1.05
630.0	5.83	40.1	1.6	1.7	0.0529	1.41	1.17
642.3	5.28	39.7	1.4	1.7	0.0484	1.46	1.06
649.3	5.47	40.5	1.2	1.7	0.0491	1.76	1.10
654.3	4.67	40.4	1.2	1.5	0.0420	1.50	1.06
660.5	4.30	40.1	1.0	1.7	0.0390	1.66	0.862

Test #70. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
666.0	4.24	40.2	1.2	1.7	0.0384	1.36	0.850
672.0	4.17	40.5	1.2	1.7	0.0374	1.34	0.836
678.0	4.17	40.5	1.2	1.7	0.0374	1.34	0.836
683.8	4.02	40.7	1.0	1.7	0.0359	1.55	0.806
690.0	4.30	40.4	1.0	1.7	0.0387	1.66	0.862
696.0	4.17	41.0	1.2	1.5	0.0370	1.34	0.947
*702.0	4.17	41.0	1.2	1.5	0.0370	1.34	0.947
707.7	4.09	40.9	1.0	1.5	0.0364	1.58	0.929
714.0	3.97	40.4	1.0	1.7	0.0357	1.53	0.796
+720.0	3.61	40.7	1.0	1.7	0.0323	1.39	0.723
726.0	3.61	41.3	1.0	1.7	0.0318	1.39	0.723
731.9	5.08	40.4	1.4	1.9	0.0457	1.40	0.911
738.0	5.56	39.8	1.8	2.1	0.0508	1.19	0.902
744.0	7.78	39.2	2.0	2.5	0.0722	1.50	1.06
750.0	7.78	39.5	1.8	2.1	0.0716	1.67	1.26
756.0	6.39	39.6	1.6	1.9	0.0587	1.54	1.15
762.0	5.56	39.9	1.6	1.9	0.0507	1.34	0.997
768.1	5.74	40.2	1.6	1.9	0.0519	1.38	1.03
774.0	5.65	40.1	1.4	1.9	0.0512	1.56	1.01
779.8	5.46	39.8	1.4	1.9	0.0499	1.50	0.979
*786.0	5.38	39.9	1.6	1.9	0.0490	1.30	0.965
791.8	5.17	39.9	1.6	1.9	0.0471	1.25	0.927

Test #70. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
798.0	5.11	40.1	1.4	1.9	0.0463	1.41	0.916
804.0	5.00	39.9	1.6	1.9	0.0456	1.21	0.897
810.0	5.00	39.5	1.8	2.1	0.0460	1.07	0.811
816.0	6.39	39.6	2.0	2.1	0.0587	1.23	1.04
821.8	5.75	40.2	1.6	1.9	0.0520	1.39	1.03
828.0	4.84	39.9	1.6	1.9	0.0441	1.17	0.868
834.0	5.56	39.1	2.0	2.3	0.0517	1.07	0.824
*840.0	5.28	40.5	1.4	2.1	0.0474	1.46	0.857
846.4	4.69	40.7	1.4	1.9	0.0419	1.29	0.841
852.0	4.46	40.1	1.4	1.9	0.0405	1.23	0.800
858.0	3.89	40.3	1.2	1.9	0.0351	1.25	0.698
864.0	4.17	40.9	1.2	1.9	0.0371	1.34	0.748
870.0	4.17	40.8	1.2	1.7	0.0372	1.34	0.836
876.0	4.17	40.5	1.2	1.7	0.0374	1.34	0.836
*882.0	4.17	40.1	1.4	1.9	0.0378	1.15	0.748
†882.0		RESTART NH_4HSO_3					
888.0	4.17	40.3	1.8	1.9	0.0376	0.894	0.748
894.1	12.30	25.2	4.4	3.3	0.178	1.08	1.27
*899.0	13.67	10.0	2.6	2.3	0.497	2.03	2.02
906.0	9.52	8.7	2.0	2.1	0.398	1.84	1.54
912.0	10.56	6.2	2.2	1.1	0.619	1.85	3.27
*918.4	9.64	5.6	2.0	0.7	0.626	1.86	4.69

Test #70. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
924.5	9.29	5.9	2.0	0.7	0.573	1.79	4.52
930.0	10.61	6.7	2.2	0.9	0.576	1.86	4.02
936.0	9.44	7.0	2.0	1.1	0.490	1.82	2.92
942.1	9.29	7.2	2.4	1.1	0.469	1.49	2.88
*947.8	9.65	8.0	2.8	1.1	0.439	1.33	2.99
954.0	9.95	8.8	3.0	1.3	0.411	1.28	2.61
959.0	10.00	9.5	2.6	1.9	0.383	1.48	1.79
+960.0	START SIMULATED GROUND WATER						
966.0	5.56	3.6	0.8	0.9	0.562	2.68	2.10
972.3	2.65	0.4	0.2	0.5	2.41	5.11	1.81
*978.0	9.65	9.0	2.0	1.5	0.390	1.86	2.19
984.0	9.72	12.5	2.6	2.5	0.283	1.44	1.32
990.0	8.89	12.5	2.2	2.3	0.259	1.56	1.32
996.4	7.81	12.3	2.0	2.1	0.231	1.51	1.27
1001.9	6.06	11.3	1.8	1.5	0.195	1.30	1.38
1008.0	4.10	11.0	1.2	1.5	0.136	1.32	0.931
*1013.9	4.24	11.2	1.2	1.3	0.138	1.36	1.11
1020.2	3.17	10.7	1.0	1.1	0.108	1.22	0.982
1026.0	4.60	16.0	2.2	1.5	0.105	0.807	1.04
1032.0	5.83	17.0	2.0	1.9	0.125	1.12	1.05
1037.8	6.03	16.7	1.6	1.7	0.131	1.45	1.21
1044.5	4.98	15.8	1.2	1.5	0.115	1.60	1.13

Test #70. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1050.0	3.94	16.4	1.2	1.5	0.0874	1.27	0.895
1056.0	3.33	18.8	1.4	1.3	0.0644	0.918	0.873
1062.0	8.33	35.3	2.0	1.9	0.0858	1.61	1.49
1068.0	7.78	38.8	1.8	1.9	0.0729	1.67	1.40
†1074.8	7.60	38.9	2.4	2.1	0.0711	1.22	1.23
1080.1	6.29	39.3	2.4	2.3	0.0582	1.01	0.932
*1086.0	9.60	38.6	2.6	2.5	0.0905	1.42	1.31
1092.0	9.44	38.0	3.2	2.5	0.0904	1.14	1.27
1098.4	9.38	37.6	3.6	2.5	0.0907	1.01	1.28
1104.2	10.06	37.4	3.6	2.7	0.0978	1.08	1.27
1110.1	9.89	37.1	3.6	2.7	0.0970	1.06	1.25
1116.0	10.17	37.2	3.8	2.7	0.0994	1.03	1.28
1122.0	9.44	37.0	3.8	2.9	0.0928	0.958	1.11
1128.0	10.00	36.6	3.6	2.9	0.0994	1.07	1.17
1134.6	9.34	36.2	3.8	2.5	0.0938	0.948	1.27
*1139.9	8.81	36.5	3.8	2.5	0.0878	0.894	1.20
1146.0	8.74	36.6	4.0	2.5	0.0869	0.843	1.19
1152.0	8.61	36.3	4.0	2.5	0.0863	0.830	1.17
1158.2	4.35	23.8	2.4	1.9	0.0665	0.699	0.780
1163.8	4.35	22.1	2.4	1.5	0.0716	0.699	0.988
*1170.0	4.35	20.1	2.0	1.5	0.0787	0.839	0.988
†1170.0			RESTART NH_4HSO_3 FLOW				

Test #70. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1176.0	7.50	38.6	4.0	2.3	0.0707	0.723	1.11
1182.0	7.78	37.1	5.2	2.3	0.0763	0.577	1.15
*1187.9	9.08	35.5	6.6	2.5	0.0930	0.531	1.24
1194.0	9.02	34.7	7.0	2.9	0.0945	0.497	1.06
1200.0	8.89	34.3	7.2	3.1	0.0943	0.476	0.977
1206.0	9.72	33.2	8.0	3.1	0.106	0.469	1.07
1211.6	9.52	32.6	8.4	3.3	0.106	0.437	0.983
1218.0	10.16	32.2	9.2	2.9	0.115	0.426	1.19
*1223.8	5.98	19.2	5.6	2.1	0.113	0.412	0.970
1230.0	5.98	18.0	5.2	1.9	0.121	0.444	1.07
1236.1	5.56	19.3	5.2	2.1	0.105	0.413	0.902
1242.0	5.65	19.0	5.2	2.1	0.108	0.419	0.917
1247.8	5.46	18.7	5.2	2.1	0.106	0.405	0.886
1254.0	5.65	18.0	5.2	1.9	0.114	0.419	1.01
1259.9	5.65	20.3	5.6	1.9	0.101	0.389	1.01
1266.0	5.46	20.1	5.6	2.1	0.0988	0.376	0.886
1271.9	5.37	20.1	5.6	2.1	0.0972	0.370	0.871
1278.0	5.46	20.4	5.6	2.1	0.0973	0.376	0.886
1284.1	5.74	21.8	6.0	2.1	0.0957	0.369	0.931
*1290.0	5.65	19.7	5.4	2.1	0.104	0.397	0.917
†1290.0	RESTART SIMULATED GROUND WATER						
1296.0	8.06	33.5	7.6	2.9	0.0875	0.409	0.947

Test #70. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1302.1	8.20	33.6	7.4	2.7	0.0888	0.428	1.03
*1308.0	7.34	33.8	7.2	2.7	0.0790	0.393	0.926
1314.0	7.22	34.1	7.2	2.7	0.0770	0.387	0.911
1320.0	7.50	34.2	6.8	2.7	0.0798	0.426	0.946
1326.1	7.10	33.5	6.8	2.5	0.0771	0.403	0.968
*1332.0	6.80	33.7	6.6	2.5	0.0734	0.397	0.927
1338.0	6.39	33.4	6.6	2.5	0.0696	0.374	0.871
1344.2	6.45	33.6	6.4	2.5	0.0698	0.389	0.879
1350.3	6.28	33.3	6.6	2.3	0.0686	0.367	0.930
1356.0	6.32	33.2	6.2	2.5	0.0692	0.393	0.861
*1362.0	6.39	34.7	6.8	2.5	0.0670	0.363	0.871
1362.0			RUN TERMINATED				

Observations from the Simulation Leach Test #71

Ore used = Wyoming

Solution used = H_2SO_4 , pH = 1.0

Inlet section packing material = -80 AFS Subangular Sand

Inlet section packing length = 10.0 in.

Length of the front ore section = 47.00 in.

Length of the middle ore section = (Not used in 8 ft ore bed)

Length of the end ore section = 52.00 in.

Outlet section packing material = -80 AFS Subangular Sand

Outlet section packing length = 5.00 in.

Ore packing bed density = 1.71 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = 10 tamps/8 in. of ore. Column position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.

† indicates introduction of fresh feed solution(s).

Test #71

Ore - Wyoming

Sol - H_2SO_4 , pH = 1.0

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
30.0	5.46	2.25	1.50	0.876	1.45
35.9	7.63	2.25	1.40	1.22	2.18
42.1	7.80	2.25	1.40	1.25	2.22
48.0	7.34	2.55	1.40	1.04	2.09
*54.0	8.61	2.85	1.75	1.09	1.96
59.8	8.05	2.85	1.75	1.02	1.84
66.4	6.57	2.50	1.50	0.948	1.75
72.0	7.74	2.50	1.25	1.12	2.47
78.0	5.00	2.45	1.20	0.736	1.67
84.0	6.67	1.95	1.65	1.23	1.61
90.0	7.78	2.85	1.50	0.985	2.07
*96.7	7.96	3.05	1.60	0.942	1.99
+102.0	5.97	3.65	2.00	0.590	1.19
108.0	10.97	3.30	1.85	1.20	2.37
114.0	8.06	3.25	1.70	0.895	1.89
120.3	7.41	2.60	1.90	1.03	1.56
126.1	7.76	3.10	2.60	0.903	1.19
132.1	9.17	3.00	2.55	1.10	1.44
138.0	8.76	3.40	2.80	0.930	1.25
144.0	8.61	3.30	2.80	0.941	1.23
*150.0	8.06	3.10	2.65	0.938	1.21
+150.0		START CHEMICAL LEACH			

Test #71. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
156.6	7.32	2.85	2.20	0.927	1.33
*161.9	4.40	3.30	2.00	0.481	0.878
168.0	7.10	6.80	3.25	0.377	0.872
174.0	8.61	9.35	5.80	0.332	0.593
180.1	9.56	11.7	5.75	0.295	0.664
*185.8	9.36	13.4	5.25	0.252	0.712
192.0	8.60	14.0	5.05	0.222	0.680
198.0	8.33	13.7	5.15	0.219	0.646
204.0	9.17	14.1	5.55	0.235	0.660
209.9	10.17	13.7	5.85	0.268	0.694
216.0	10.66	14.2	6.10	0.271	0.698
222.0	10.00	14.0	6.30	0.258	0.634
*228.0	9.44	14.2	6.60	0.239	0.571
233.6	9.23	14.8	6.45	0.225	0.571
†240.0	8.59	14.8	6.40	0.209	0.536
245.8	7.18	11.1	3.90	0.233	0.735
252.0	4.57	5.7	3.05	0.289	0.598
258.1	4.92	13.0	4.40	0.137	0.446
263.9	6.61	10.7	4.75	0.223	0.556
269.8	7.63	15.2	6.00	0.181	0.508
*276.0	8.33	16.6	6.05	0.181	0.550
281.9	8.19	20.2	6.90	0.146	0.474

Test #71. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
288.0	8.74	20.7	6.85	0.152	0.509
293.9	8.19	21.6	6.95	0.137	0.470
300.0	8.74	22.8	7.10	0.138	0.491
306.1	9.02	25.7	7.30	0.127	0.493
312.0	8.47	26.7	7.30	0.114	0.463
318.0	8.33	31.1	7.70	0.097	0.432
*324.1	8.47	31.8	7.50	0.096	0.451
330.0	9.08	31.9	7.30	0.103	0.497
†336.0	7.50	33.0	7.20	0.082	0.416
342.0	8.61	36.2	7.45	0.086	0.461
348.2	7.80	35.7	7.40	0.079	0.421
354.0	5.75	35.8	7.20	0.058	0.319
360.0	10.28	36.0	7.00	0.103	0.586
366.1	6.83	36.5	7.00	0.068	0.390
372.2	7.38	36.6	6.80	0.073	0.433
378.0	8.33	36.2	6.75	0.083	0.493
384.0	6.11	37.0	6.60	0.060	0.370
*390.0	6.67	37.0	6.55	0.065	0.410
396.0	6.94	37.0	6.55	0.068	0.423
402.0	6.67	36.8	6.35	0.065	0.419
408.0	6.39	37.1	6.10	0.062	0.418
414.0	6.11	37.6	6.05	0.059	0.403

Test #71. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
419.9	5.93	37.7	5.80	0.057	0.408
427.0	6.10	37.5	5.55	0.059	0.439
†432.0	5.67	37.4	5.20	0.055	0.435
438.0	5.56	38.3	5.40	0.052	0.411
444.0	5.56	38.3	5.50	0.052	0.404
449.9	5.65	37.3	5.55	0.055	0.406
*456.0	5.74	37.2	5.65	0.056	0.406
462.0	6.11	37.5	5.80	0.059	0.421
468.4	5.99	37.6	5.60	0.057	0.427
474.3	6.21	37.2	5.60	0.060	0.443
480.0	5.85	37.3	5.55	0.057	0.421
486.0	5.56	37.8	5.50	0.053	0.404
492.0	5.83	37.8	5.50	0.056	0.423
498.1	5.74	37.8	5.45	0.055	0.420
504.0	5.08	37.3	5.50	0.049	0.369
510.0	5.28	37.9	5.45	0.050	0.387
516.0	5.56	37.9	5.35	0.053	0.415
522.7	5.47	37.5	5.30	0.053	0.412
528.0	5.66	37.5	5.35	0.054	0.422
*534.0	5.56	38.0	5.35	0.053	0.415
540.2	5.65	38.0	5.25	0.054	0.430
546.2	5.28	38.1	5.10	0.050	0.413

Test #71. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
552.0	5.75	37.7	5.10	0.055	0.450
558.0	5.28	38.3	4.95	0.050	0.426
564.0	5.28	38.5	4.80	0.049	0.439
570.2	5.11	38.7	4.70	0.048	0.434
576.0	4.89	38.0	4.70	0.046	0.415
582.0	4.72	38.7	4.60	0.044	0.410
*588.0	5.00	38.7	4.60	0.047	0.434
594.0	4.47	38.3	4.45	0.042	0.401
+600.3	4.47	38.3	4.45	0.042	0.401
605.9	5.06	39.8	4.45	0.046	0.454
612.0	3.83	39.2	4.55	0.035	0.336
618.0	5.28	38.1	5.00	0.050	0.422
624.2	5.38	38.1	5.10	0.051	0.421
630.0	6.90	38.0	5.25	0.066	0.525
635.9	5.93	38.1	5.10	0.056	0.464
642.0	5.74	38.1	5.15	0.054	0.445
648.0	5.83	38.1	5.10	0.055	0.456
*654.0	5.56	38.7	5.00	0.052	0.444
+654.0		START 2 g/l NaHSO ₃ AT pH 2.00			
660.1	5.19	40.3	4.00	0.046	0.518
666.0	2.54	41.0	3.30	0.022	0.307
*672.0	3.61	41.0	3.30	0.032	0.437

Test #71. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
678.0	3.33	41.4	3.40	0.029	0.391
684.0	3.33	41.4	3.50	0.029	0.380
690.0	3.89	40.3	3.45	0.035	0.450
696.0	3.06	40.3	3.45	0.027	0.354
708.0	3.89	40.8	3.50	0.034	0.444
713.9	3.39	40.8	3.50	0.030	0.387
720.0	3.28	40.8	3.45	0.029	0.380
726.0	3.89	40.8	3.50	0.034	0.444
732.0	3.61	40.6	3.60	0.032	0.400
737.9	3.39	40.2	3.55	0.030	0.381
*744.0	3.55	40.3	3.50	0.032	0.405
750.0	3.33	40.9	3.50	0.029	0.380
756.0	3.61	40.6	3.60	0.032	0.400
762.0	3.89	40.3	3.55	0.035	0.437
767.9	3.67	40.3	3.40	0.033	0.431
774.0	3.83	40.7	3.50	0.034	0.437
780.0	3.61	40.8	3.45	0.032	0.418
786.0	3.33	40.4	3.30	0.030	0.403
792.1	4.10	40.5	3.20	0.037	0.511
*797.8	3.51	41.1	3.20	0.031	0.438
804.0	3.22	41.1	3.20	0.028	0.402
810.4	3.39	41.3	3.10	0.030	0.437

Test #71. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
816.0	3.27	41.1	3.20	0.029	0.408
822.0	2.78	41.8	3.00	0.024	0.370
827.9	2.82	42.0	2.95	0.024	0.382
834.0	3.28	41.4	2.90	0.029	0.452
840.0	2.78	41.0	2.85	0.024	0.389
846.0	3.06	41.9	2.90	0.026	0.421
851.9	3.11	42.0	2.90	0.026	0.428
858.0	2.73	41.5	2.85	0.024	0.382
*864.0	3.33	41.5	2.85	0.029	0.466
870.0	3.33	41.8	3.00	0.029	0.443
876.2	3.22	41.5	2.85	0.028	0.451
882.0	2.59	40.9	2.90	0.023	0.357
888.0	3.06	41.1	2.75	0.027	0.444
894.0	2.78	41.5	2.85	0.024	0.389
900.0	2.78	41.5	2.85	0.024	0.389
906.0	3.89	41.0	2.80	0.034	0.555
912.0	2.78	41.0	2.80	0.024	0.396
918.0	2.78	41.3	2.95	0.024	0.376
924.1	3.55	41.4	2.95	0.031	0.480
*931.1	3.10	41.5	2.95	0.027	0.419
936.0	2.38	41.5	2.85	0.021	0.333
†940.0		START SIMULATED GROUND WATER			

Test #71. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
942.0	2.22	42.7	2.65	0.019	0.334
948.1	2.73	42.5	2.60	0.023	0.419
954.0	2.82	42.0	2.40	0.024	0.470
960.0	2.50	42.0	2.80	0.021	0.356
966.0	3.06	41.6	3.20	0.027	0.382
972.0	3.89	41.5	3.25	0.034	0.478
*978.0	3.61	41.5	3.25	0.031	0.443
984.0	3.33	41.3	3.45	0.038	0.385
990.0	3.61	41.4	3.40	0.031	0.424
996.0	3.89	41.5	3.30	0.034	0.471
1001.8	3.45	41.5	3.30	0.030	0.417
1008.0	3.49	41.5	3.25	0.030	0.429
1014.0	3.06	42.0	3.35	0.026	0.365
1020.0	3.89	41.5	3.25	0.034	0.478
1026.0	3.33	41.6	3.10	0.029	0.429
*1032.0	3.33	41.8	3.05	0.029	0.436
1038.0	3.06	41.7	3.15	0.026	0.388
1044.0	3.06	42.0	2.80	0.026	0.436
1050.0	3.33	41.0	2.80	0.029	0.475
1056.0	2.78	40.4	2.50	0.025	0.444
1062.0	2.50	39.9	2.50	0.023	0.399
1067.8	2.59	40.2	2.55	0.023	0.405

Test #71. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
1074.2	2.60	40.7	2.40	0.023	0.432
1080.0	2.30	40.9	2.35	0.020	0.391
*1086.0	2.50	41.5	2.40	0.022	0.416
1091.8	2.47	41.0	2.40	0.022	0.411
1098.2	2.47	41.0	2.40	0.022	0.411
1104.1	2.47	40.7	2.35	0.022	0.420
1110.0	2.47	41.2	2.25	0.022	0.438
1116.2	2.47	41.1	2.20	0.022	0.448
1122.0	2.47	40.6	2.20	0.022	0.448
1128.3	2.47	40.7	2.05	0.022	0.481
1134.1	2.11	40.8	2.20	0.019	0.383
1140.1	2.11	40.7	2.00	0.019	0.421
1146.0	2.11	40.6	2.20	0.019	0.383
*1152.0	2.11	40.7	2.05	0.019	0.411
+1152.0	RESTART 2 g/l NaHSO ₃ (NO pH ADJUSTMENT)				
1158.0	2.22	42.6	2.20	0.019	0.403
1164.1	2.22	42.1	2.25	0.019	0.394
1170.0	2.22	41.1	2.70	0.019	0.328
1176.0	3.89	41.0	3.30	0.034	0.471
*1182.0	4.17	40.4	3.45	0.037	0.483
1188.0	4.72	40.4	3.30	0.042	0.571
1194.0	4.17	40.0	3.20	0.038	0.520

Test #71. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
1200.0	3.89	40.0	3.25	0.035	0.478
1206.0	4.72	41.6	3.25	0.041	0.580
1212.0	3.89	40.5	3.25	0.035	0.478
1212.9	4.80	41.0	3.30	0.042	0.581
1224.0	4.37	41.0	3.30	0.038	0.529
*1230.0	4.44	40.9	3.40	0.039	0.521
1236.0	3.61	41.1	3.20	0.032	0.450
1241.9	4.52	40.7	3.10	0.040	0.582
1248.0	3.55	40.8	3.00	0.031	0.472
1254.0	3.61	40.9	2.90	0.032	0.497
1260.0	3.61	41.0	2.80	0.032	0.515
1266.0	3.33	41.5	2.80	0.029	0.475
1272.0	2.78	41.5	2.75	0.024	0.404
1277.9	3.39	41.6	2.70	0.029	0.501
1284.0	3.28	41.5	2.70	0.029	0.485
1290.0	3.06	41.5	2.70	0.027	0.452
1296.1	3.28	42.1	2.70	0.028	0.485
1302.0	3.39	42.2	2.65	0.029	0.511
1308.0	3.06	42.2	2.60	0.026	0.470
1314.0	2.78	42.2	2.65	0.024	0.419
1320.0	2.78	41.6	2.70	0.024	0.411
1326.0	2.78	42.2	2.65	0.024	0.419

Test #71. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
1331.9	2.82	42.1	2.70	0.024	0.417
1338.0	3.28	42.2	2.60	0.028	0.504
1344.0	2.78	42.3	2.50	0.024	0.444
1350.0	2.78	41.8	2.55	0.024	0.435
1356.0	2.22	42.3	2.50	0.019	0.354
1362.0	2.78	42.0	2.30	0.024	0.483
*1368.0	2.78	41.8	2.50	0.024	0.444
1374.0	2.78	42.4	2.45	0.024	0.453
1380.1	2.73	42.5	2.40	0.023	0.454
1386.0	2.54	42.0	2.40	0.022	0.422
1392.0	2.50	42.0	2.35	0.021	0.425
1398.0	2.22	42.4	2.40	0.019	0.370
1404.0	2.50	43.0	2.35	0.021	0.425
1410.0	2.50	42.5	2.25	0.021	0.444
1416.0	2.50	42.0	2.25	0.021	0.444
*1420.0	2.34	42.6	2.20	0.020	0.425
1428.1	2.34	42.5	2.30	0.020	0.406
1433.5	2.24	42.1	2.20	0.019	0.406
1440.0	2.24	42.1	2.10	0.019	0.426
†1443.0		RESTART GROUND H ₂ O			
1446.0	1.82	42.7	2.00	0.015	0.363
1452.0	1.82	42.8	1.85	0.015	0.393

Test #71. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
1457.9	1.82	43.0	1.70	0.015	0.427
1464.1	1.82	42.5	2.20	0.015	0.330
*1470.0	2.85	42.2	2.60	0.024	0.438
1476.2	2.85	41.7	2.60	0.025	0.438
1481.9	2.85	40.9	2.45	0.025	0.464
1488.0	2.85	41.9	2.50	0.025	0.455
1494.3	2.85	42.2	2.60	0.024	0.438
1500.0	2.85	42.2	2.60	0.024	0.438
1506.2	2.85	41.7	2.50	0.025	0.455
1512.0	2.97	41.4	2.50	0.026	0.474
1518.0	2.97	41.4	2.45	0.026	0.484
*1524.0	2.63	41.3	2.55	0.023	0.412
1530.1	2.63	41.3	2.60	0.023	0.404
1536.0	2.63	41.0	2.40	0.023	0.437
1542.0	2.63	41.8	2.55	0.023	0.412
1547.7	2.63	41.3	2.50	0.023	0.420
1554.1	2.63	41.5	2.40	0.023	0.437
1560.0	2.09	42.1	2.20	0.018	0.379
1566.0	2.09	42.6	2.20	0.018	0.379
1571.8	2.09	42.2	2.10	0.018	0.397
1578.0	2.09	42.2	2.05	0.018	0.407
1584.0	2.09	41.6	2.20	0.018	0.379

Test #71. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
1590.0	2.09	42.0	2.35	0.018	0.355
*1596.2	2.09	41.7	2.00	0.018	0.417
1602.0	2.09	41.7	2.00	0.018	0.417
1608.0	2.09	41.8	2.00	0.018	0.417
1614.0	2.09	41.9	1.85	0.018	0.451
1619.8	1.76	41.7	2.10	0.015	0.335
1626.0	1.76	41.9	1.90	0.015	0.370
1632.0	1.76	41.9	1.85	0.015	0.380
1638.1	1.76	41.9	1.85	0.015	0.380
1644.1	1.76	41.9	1.95	0.015	0.360
*1650.0	1.76	43.0	1.75	0.015	0.401
1656.0	1.76	43.1	1.75	0.015	0.401
1662.0	1.76	43.0	1.75	0.015	0.401
1668.2	1.76	43.0	1.85	0.015	0.401
1680.0	1.76	42.6	1.65	0.015	0.426
1686.0	1.76	41.8	1.90	0.015	0.370
1692.3	1.76	43.0	1.80	0.015	0.390
1698.3	1.42	43.1	1.65	0.012	0.344
1704.0	1.42	42.3	1.50	0.012	0.378
1710.0	1.42	42.8	1.55	0.012	0.366
*1716.0	1.42	43.3	1.50	0.012	0.378
1722.0	1.42	42.6	1.65	0.012	0.344

Test #71. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi		Permeability, Darcy	
		Front Sec.	End Sec.	Front Sec.	End Sec.
1728.0	1.42	42.7	1.60	0.012	0.354
1734.0	1.42	42.8	1.50	0.012	0.378
1740.0	1.42	42.8	1.52	0.012	0.378
1746.0	1.42	42.8	1.55	0.012	0.366
1752.0	1.42	42.3	1.50	0.012	0.378
1758.0	1.42	43.2	1.60	0.012	0.354
1764.0	1.42	43.3	1.50	0.012	0.378
1770.3	1.42	43.3	1.55	0.012	0.366
1776.0	1.42	42.9	1.40	0.012	0.405
*1779.0	1.42	42.9	1.40	0.012	0.405
RUN TERMINATED					

Observations from the Simulation Leach Test #72

Ore used = Wyoming

Solution used = 1.0 g/l NH_4HCO_3 - 0.5 g/l CaCl_2 -
0.5 g/l mgSO_4 - Sat'd O_2 at 45 psig

Inlet section packing material = -80 AFS Subangular Sand

Inlet section packing length = 10.0 in.

Length of the front ore section = 47.00 in.

Length of the middle ore section = 50.13 in.

Length of the end ore section = 44.13 in.

Outlet section packing material = -80 AFS Subangular Sand

Outlet section packing length = 5.00 in.

Ore packing bed density = 1.69 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = 10 tamps/8 in. of ore. Column position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.

† indicates introduction of fresh feed solution(s).

Test #72

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
30.0	2.78	2.40	2.20	6.10	0.418	0.486	0.154
36.0	8.06	3.00	2.15	3.20	0.969	1.44	0.853
42.0	8.33	3.15	2.05	2.15	0.954	1.56	1.31
*48.0	8.33	3.00	2.00	1.75	1.00	1.60	1.61
54.0	8.89	3.20	2.35	1.80	1.00	1.46	1.67
60.0	8.61	3.30	2.45	1.80	0.941	1.35	1.62
65.6	8.89	3.30	2.45	1.75	0.972	1.40	1.72
+72.0	9.72	3.25	2.50	1.80	1.08	1.50	1.83
77.8	8.91	3.21	2.50	1.70	1.00	1.37	1.78
84.0	8.87	3.30	2.50	1.65	0.970	1.37	1.82
*90.2	9.41	3.55	2.70	1.80	0.956	1.34	1.77
95.9	9.06	3.60	2.75	1.80	0.908	1.27	1.70
101.9	8.89	3.50	2.70	1.80	0.916	1.53	1.67
108.0	9.29	3.50	2.70	1.80	0.958	1.32	1.75
113.9	8.76	3.65	2.80	2.00	0.866	1.20	1.48
120.0	9.02	3.65	2.80	1.95	0.892	1.24	1.57
125.9	8.47	3.60	2.80	1.95	0.849	1.16	1.47
132.0	8.20	3.55	2.70	2.00	0.833	1.17	1.39
138.0	8.06	3.70	2.85	2.20	0.786	1.09	1.24
*144.0	9.48	3.65	3.00	2.65	0.937	1.22	1.21
+144.0	START CHEMICAL LEACH, SAT'D O ₂ AT 45 PSIG						
150.0	8.89	4.40	3.25	2.75	0.729	1.05	1.09

Test #72. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
156.2	9.68	4.60	3.20	2.20	0.759	1.16	1.49
162.0	6.90	3.80	3.15	1.80	0.711	0.843	1.30
168.0	3.33	3.85	2.95	1.65	0.312	0.434	0.684
*174.0	7.78	4.35	3.40	2.15	0.645	0.881	1.23
180.2	9.95	4.85	4.00	2.85	0.740	0.957	1.18
186.0	8.33	4.50	3.85	2.50	0.668	0.833	1.13
192.0	6.94	4.10	3.70	2.30	0.611	0.722	1.02
198.1	4.64	2.90	2.75	1.55	0.577	0.649	1.01
204.2	3.55	2.10	2.25	1.20	0.610	0.607	1.00
*210.0	4.31	2.25	2.20	1.10	0.691	0.754	1.33
216.0	2.22	1.05	1.40	0.55	0.763	0.610	1.37
222.0	6.67	2.70	2.50	1.65	0.891	1.03	1.37
228.0	5.00	2.85	2.70	1.80	0.633	0.713	0.941
234.0	8.33	3.60	3.45	2.80	0.835	0.929	1.01
*240.0	6.94	3.45	3.00	2.20	0.726	0.890	1.07
†246.0	6.39	3.95	3.55	2.95	0.584	0.693	0.734
251.9	8.76	3.80	3.45	2.70	0.832	0.977	1.10
259.0	8.69	3.55	3.20	2.30	0.883	1.04	1.28
264.0	3.00	1.45	1.55	0.80	0.746	0.745	1.27
270.0	10.00	4.40	3.90	3.05	0.820	0.987	1.11
276.0	11.67	4.40	3.85	3.15	0.957	1.17	1.25
281.9	10.17	3.40	3.10	2.30	1.08	1.26	1.50

Test #72. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
288.0	1.64	0.15	0.80	0.10	3.94	0.789	5.55
294.0	6.39	3.35	2.95	2.00	0.747	0.834	1.08
300.4	8.59	3.35	2.90	1.95	0.925	1.14	1.49
306.4	1.11	0.05	0.90	0.10	8.01	0.475	3.76
312.0	4.76	0.65	1.30	0.55	2.64	1.41	2.93
*318.0	7.78	3.40	3.00	1.85	0.826	0.998	1.42
324.0	12.22	4.30	3.95	2.60	1.03	1.19	1.59
330.2	12.63	4.40	4.05	2.70	1.04	1.20	1.58
336.0	10.92	4.40	4.15	2.70	0.895	1.01	1.37
342.0	10.83	4.25	3.85	2.50	0.919	1.08	1.47
348.0	10.28	4.00	3.80	2.40	0.927	1.04	1.45
354.7	11.19	4.10	3.80	2.35	0.985	1.13	1.61
360.0	9.12	4.10	3.80	2.35	0.803	0.924	1.31
*366.0	10.00	4.10	3.85	2.45	0.880	0.999	1.38
372.3	10.85	4.15	3.90	2.40	0.943	1.07	1.53
378.3	10.83	3.90	4.00	2.40	1.00	1.04	1.53
384.0	9.65	3.60	3.80	2.35	0.967	0.977	1.39
390.0	8.89	3.55	3.75	2.15	0.904	0.912	1.40
396.0	10.56	3.95	4.00	2.45	0.965	1.02	1.46
402.2	10.75	3.95	4.00	2.50	0.982	1.03	1.46
408.0	9.77	4.05	4.00	2.45	0.870	0.940	1.35
414.0	10.28	4.00	3.95	2.50	0.927	1.00	1.39

Test #72. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
420.0	10.83	4.00	4.00	2.45	0.977	1.04	1.50
*426.0	8.89	3.65	3.80	2.20	0.879	0.900	1.37
433.4	9.46	4.00	3.65	2.30	0.853	0.997	1.39
†435.0	CHANGE OXIDANT TO 0.5 g/l H ₂ O ₂						
438.0	10.00	4.10	3.75	2.30	0.880	1.03	1.47
444.0	6.11	2.25	2.50	1.20	0.980	0.940	1.72
450.0	3.33	1.80	2.00	0.80	0.667	0.641	1.41
456.2	4.30	1.55	2.00	0.75	1.00	0.827	1.94
*462.1	3.39	1.45	2.00	0.60	0.844	0.652	1.91
467.9	3.16	1.55	2.00	0.75	0.736	0.608	1.43
474.0	3.83	1.55	2.00	0.70	0.892	0.737	1.85
480.0	4.44	3.55	3.25	1.55	0.451	0.526	0.970
486.0	9.17	4.60	3.80	2.00	0.719	0.929	1.55
*492.1	9.84	4.80	3.70	2.00	0.740	1.02	1.67
498.0	8.47	4.05	3.25	1.55	0.755	1.00	1.85
504.0	8.33	4.50	3.45	1.65	0.668	0.929	1.71
510.0	7.78	4.00	3.20	1.50	0.702	0.936	1.76
516.0	8.33	4.40	3.50	1.75	0.683	0.916	1.61
522.0	8.06	4.30	3.35	1.60	0.676	0.926	1.71
528.0	8.61	4.85	3.30	1.75	0.641	1.00	1.67
†534.0	7.22	4.35	3.15	1.60	0.599	0.882	1.53
540.0	7.22	3.20	2.70	1.15	0.814	1.03	2.13

Test #72. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
545.9	7.06	3.60	2.95	1.35	0.708	0.921	1.77
552.0	8.20	5.50	3.90	2.20	0.538	0.809	1.26
558.0	10.83	6.40	4.20	2.60	0.611	0.992	1.41
*564.0	11.11	6.35	4.10	2.50	0.631	1.04	1.51
570.0	11.39	6.55	4.25	2.65	0.627	1.03	1.46
576.0	10.56	6.30	3.95	2.40	0.605	1.03	1.49
582.0	10.56	6.60	4.25	2.70	0.577	0.956	1.32
588.0	10.00	6.45	4.05	2.60	0.559	0.950	1.30
594.1	12.57	7.20	4.45	2.90	0.630	1.09	1.47
+600.0	11.30	7.35	4.40	2.90	0.555	0.988	1.32
*606.0	11.11	6.50	4.15	2.50	0.617	1.03	1.51
612.0	7.50	3.85	2.95	1.65	0.703	0.978	1.54
618.0	6.39	3.20	2.75	1.50	0.720	0.894	1.44
624.1	3.83	2.50	2.20	1.05	0.553	0.670	1.24
629.8	5.26	3.10	2.75	1.40	0.612	0.736	1.27
636.0	5.65	3.05	2.70	1.30	0.668	0.805	1.47
642.4	6.51	3.80	3.10	1.55	0.618	0.808	1.42
648.0	5.65	6.00	4.10	2.50	0.340	0.530	0.765
654.0	10.00	5.40	3.75	2.15	0.668	1.03	1.58
*659.9	11.58	6.95	4.50	2.90	0.601	0.990	1.35
666.0	10.92	6.80	4.20	2.60	0.579	1.00	1.42
+672.0	11.94	7.70	4.65	3.00	0.559	0.988	1.35

Test #72. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
678.0	10.83	7.80	4.80	3.40	0.501	0.868	1.08
683.9	10.17	5.95	3.95	2.40	0.617	0.991	1.44
690.0	9.02	5.85	3.90	2.35	0.556	0.890	1.30
696.0	8.89	5.80	3.90	2.30	0.553	0.877	1.31
702.0	10.28	6.25	4.15	2.70	0.593	0.953	1.29
708.3	9.26	7.10	4.45	3.00	0.471	0.801	1.05
714.0	11.11	6.80	4.35	2.85	0.589	0.983	1.32
*720.0	11.11	7.45	4.60	3.10	0.538	0.929	1.21
†726.0	10.56	7.50	4.65	2.95	0.508	0.874	1.21
732.0	9.72	5.70	4.10	2.50	0.615	0.912	1.32
738.0	8.06	5.45	3.60	2.10	0.534	0.862	1.30
744.0	8.33	6.90	3.95	2.25	0.436	0.811	1.25
750.0	9.17	6.00	3.80	2.40	0.551	0.929	1.29
756.1	9.02	6.75	4.05	2.70	0.482	0.857	1.13
763.2	9.39	6.25	3.80	2.40	0.542	0.951	1.33
768.0	8.68	5.95	3.65	2.25	0.526	0.915	1.31
†773.5	8.79	6.50	3.90	2.55	0.488	0.867	1.17
780.1	8.20	3.95	2.80	1.55	0.749	1.13	1.79
786.1	5.56	3.40	2.70	1.40	0.590	0.792	1.35
*792.0	5.08	3.10	2.60	1.30	0.591	0.752	1.32
804.1	6.11	4.95	3.45	2.05	0.445	0.681	1.01
810.1	8.20	4.70	3.30	1.90	0.629	0.956	1.46

Test #72. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
816.0	6.80	7.00	4.50	2.75	0.350	0.581	0.838
822.0	10.56	7.00	4.50	3.05	0.544	0.903	1.17
828.0	11.11	7.00	4.55	3.10	0.573	0.940	1.21
833.8	12.07	7.50	4.70	3.30	0.581	0.988	1.24
+840.0	10.22	5.15	3.45	1.95	0.716	1.14	1.78
846.0	8.06	4.85	3.35	2.05	0.600	0.926	1.33
*852.0	10.56	6.85	4.35	3.00	0.556	0.934	1.19
858.0	10.28	6.75	4.15	2.80	0.549	0.953	1.24
864.0	9.72	6.80	4.30	2.80	0.516	0.870	1.18
870.0	10.83	7.35	4.55	3.15	0.532	0.916	1.16
876.0	10.56	7.10	4.40	3.00	0.537	0.924	1.19
882.0	10.00	7.05	4.30	2.95	0.512	0.895	1.15
*888.0	10.28	7.10	4.30	2.90	0.522	0.920	1.20
894.0	9.72	7.75	4.65	3.00	0.453	0.804	1.10
+894.0	START SIMULATED GROUND WATER						
899.9	9.89	5.70	3.90	3.05	0.626	0.976	1.10
906.2	10.05	4.75	3.90	3.10	0.763	0.992	1.10
912.2	9.77	4.00	3.55	2.75	0.881	1.06	1.20
*918.0	8.61	3.45	3.40	2.65	0.900	0.974	1.10
923.8	8.91	3.10	3.25	2.50	1.04	1.05	1.21
930.2	6.25	2.30	2.65	1.80	0.980	0.908	1.18
+936.1	4.80	1.60	2.10	1.20	1.08	0.880	1.35

Test #72. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
942.0	8.89	2.30	2.35	1.30	1.39	1.46	2.32
948.2	7.53	2.20	1.75	0.95	1.23	1.66	2.68
954.0	7.47	2.15	1.60	0.85	1.25	1.80	2.98
960.3	8.47	2.30	1.70	0.90	1.32	1.92	3.19
966.0	8.18	2.25	1.65	0.90	1.31	1.91	3.08
972.1	5.74	1.85	1.30	0.70	1.12	1.70	2.78
978.0	6.21	2.05	1.40	0.70	1.09	1.71	3.00
984.0	5.56	1.90	1.25	0.60	1.06	1.71	3.14
*990.0	2.78	1.15	0.75	0.40	0.872	1.43	2.35
996.1	7.10	--	--	--	--	--	--
1002.0	5.65	2.15	1.30	0.65	0.948	1.67	2.94
1008.0	5.28	2.10	1.25	0.60	0.907	1.63	2.98
1014.0	6.11	2.80	1.45	0.60	0.787	1.62	3.45
1020.0	5.83	2.25	1.25	0.70	0.935	1.79	2.82
*1026.0	5.28	2.20	1.25	0.70	0.866	1.63	2.55
1032.0	6.11	3.35	2.10	1.15	0.658	1.12	1.80
1038.0	9.44	3.15	1.85	1.10	1.08	1.96	2.91
+1038.0			START 1 g/l NaHSO ₃				
1044.0	7.78	2.00	1.20	0.60	1.40	2.49	4.39
1049.9	3.11	0.30	0.20	0.05	3.74	5.98	--
1056.0	0.57	0.65	0.40	0.15	0.316	0.548	1.29
1062.0	6.94	3.74	2.45	1.35	0.668	1.09	1.74

Test #72. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1068.0	10.28	3.20	2.10	1.15	1.16	1.88	3.03
*1073.9	7.63	2.50	1.60	0.85	1.10	1.84	3.04
1080.0	6.56	2.15	1.30	0.65	1.10	1.94	3.42
1086.0	3.33	1.10	0.65	0.35	1.09	1.97	3.22
1092.0	2.22	0.90	0.55	0.20	0.890	1.55	3.76
1098.0	2.22	1.10	0.80	0.30	0.728	1.07	2.51
1104.0	1.94	0.65	0.55	0.15	1.08	1.36	4.38
1109.9	1.94	0.80	0.70	0.20	0.875	1.07	3.29
1116.0	1.94	0.90	0.80	0.20	0.778	0.933	3.29
1122.0	2.50	0.95	0.85	0.20	0.949	1.13	4.23
1128.1	2.73	1.30	1.10	0.30	0.758	0.955	3.08
1134.0	2.82	1.05	0.95	0.30	0.969	1.14	3.18
1140.0	2.78	1.25	1.05	0.35	0.802	1.02	2.69
*1146.0	3.61	1.45	1.20	0.40	0.898	1.16	3.06
1152.0	3.61	1.40	1.15	0.35	0.930	1.21	3.49
1158.0	6.94	2.90	2.25	1.10	0.863	1.19	2.14
1163.9	8.19	2.85	2.20	1.10	1.04	1.43	2.52
1170.0	7.92	2.90	2.20	1.05	0.985	1.39	2.55
1176.0	8.33	2.90	2.20	1.05	1.04	1.46	2.69
1182.0	7.78	2.95	2.25	1.05	0.952	1.33	2.51
1188.0	7.50	2.75	2.20	1.05	0.984	1.31	2.42
1194.0	6.94	2.80	2.20	1.00	0.894	1.21	2.35

Test #72. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1200.0	7.78	2.75	2.35	1.05	1.02	1.27	2.51
*1206.0	6.67	2.60	2.20	1.00	0.926	1.17	2.26
1212.1	7.65	2.80	2.40	1.10	0.986	1.23	2.36
1218.0	6.80	2.40	2.05	0.80	1.02	1.28	2.88
1224.0	5.83	2.40	2.15	0.85	0.876	1.04	2.32
†1230.0	5.28	2.05	1.85	0.80	0.929	1.10	2.24
1236.0	5.56	1.50	1.50	0.65	1.34	1.43	2.90
1242.0	3.06	0.95	1.15	0.35	1.16	1.02	2.96
1248.0	1.67	0.10	0.60	--	6.03	1.07	--
1254.0	3.33	3.20	2.80	1.35	0.375	0.458	0.835
1260.1	12.84	3.90	4.00	2.30	1.19	1.24	1.89
1265.6	13.33	3.80	4.05	2.30	1.27	1.27	1.96
*1272.0	12.50	3.75	4.10	2.40	1.20	1.17	1.76
†1276.0		RESTART GROUND H ₂ O					
1278.0	--	0.40	1.55	0.55	--	--	--
1284.0	2.78	0	0.85	0.15	--	1.26	6.28
1289.9	1.69	0	1.10	0.25	--	0.592	2.29
1296.1	1.34	0	1.05	0.20	--	0.491	2.27
*1302.0	3.39	0.80	1.75	0.70	1.53	0.745	1.64
1308.3	4.50	0.85	1.90	0.75	1.91	0.911	2.03
1313.9	3.57	1.15	1.95	0.85	1.12	0.704	1.42
1320.0	4.64	1.05	1.85	0.75	1.59	0.965	2.10

Test #72. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1326.3	5.03	1.15	1.95	0.90	1.58	0.993	1.89
1332.0	3.22	0.80	1.85	0.75	1.45	0.670	1.45
1338.2	4.30	1.15	2.00	0.90	1.35	0.827	1.62
1344.0	4.89	0.90	1.85	0.75	1.96	1.02	2.21
1350.0	4.17	1.00	1.90	0.80	1.50	0.845	1.77
*1356.0	5.28	1.35	2.35	1.05	1.41	0.865	1.70
1362.0	5.00	1.40	2.40	1.10	1.29	0.802	1.54
1368.0	5.00	1.25	2.35	1.00	1.44	0.819	1.69
1374.0	5.28	1.20	2.25	1.10	1.59	0.903	1.63
1379.7	5.26	1.00	1.95	0.95	1.90	1.04	1.88
1386.1	3.91	0.85	1.80	0.80	1.66	0.836	1.66
*1392.0	4.24	1.10	2.10	1.00	1.39	0.777	1.44
1398.0	5.28	1.30	2.40	1.20	1.47	0.847	1.49
1403.8	5.17	1.35	2.50	1.25	1.38	0.796	1.40
1410.1	5.56	1.35	2.50	1.20	1.49	0.856	1.57
1416.1	5.28	1.30	2.45	1.20	1.47	0.829	1.49
1422.0	4.92	1.20	2.30	1.15	1.48	0.823	1.45
1428.2	5.38	1.30	2.45	1.20	1.49	0.845	1.52
*1434.0	5.17	1.30	2.50	1.20	1.43	0.796	1.46
1440.1	4.92	1.30	2.50	1.10	1.37	0.757	1.51
1446.0	5.37	1.20	2.35	1.15	1.61	0.879	1.58
RUN TERMINATED							

Observations from the Simulation Leach Test #73

Ore used = Wyoming

Solution used = 1.0 g/l NH_4HCO_3 - 1.0 g/l Na_2SiO_3 -
0.5 g/l H_2O_2

Inlet section packing material = -80 AFS Subangular Sand

Inlet section packing length = 10.0 in.

Length of the front ore section = 47.00

Length of the middle ore section = 50.25 in.

Length of the end ore section = 44.00 in.

Outlet section packing material = -80 AFS Subangular Sand

Outlet section packing length = 5.00 in.

Ore packing bed density = 1.70 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = 10 tamps/8 in. of ore. Column position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.

† indicates introduction of fresh feed solution(s).

Test #73

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
30.0	8.89	4.0	3.6	3.1	0.802	0.953	0.969
36.0	9.72	3.9	3.4	2.5	0.899	1.10	1.31
41.9	10.17	4.0	3.6	2.5	0.917	1.09	1.37
48.0	9.56	3.6	3.4	2.5	0.958	1.08	1.29
*54.0	8.61	3.5	3.2	2.5	0.888	1.04	1.16
60.4	9.11	4.0	3.4	2.5	0.822	1.03	1.23
66.3	9.08	3.7	3.4	2.5	0.885	1.03	1.23
+72.0	9.48	3.7	3.4	2.7	0.924	1.08	1.19
78.0	9.44	3.8	3.8	2.5	0.896	0.958	1.28
84.0	10.83	4.6	4.2	3.1	0.849	0.995	1.18
90.2	9.95	4.3	4.2	3.1	0.835	0.914	1.08
96.0	9.77	4.5	4.4	3.3	0.783	0.857	1.00
*102.0	10.56	4.3	4.6	3.3	0.886	0.886	1.08
108.0	10.00	4.0	4.6	3.3	0.902	0.839	1.02
114.8	9.80	3.8	4.6	3.5	0.930	0.822	0.946
120.0	9.62	3.6	4.8	3.5	0.964	0.773	0.928
125.7	9.36	3.4	4.8	3.7	0.993	0.752	0.855
132.2	10.26	3.8	5.2	4.1	0.974	0.783	0.845
*138.4	10.48	3.6	5.4	4.1	1.05	0.749	0.863
144.0	9.52	3.4	5.4	4.3	1.01	0.680	0.748
150.0	10.00	3.5	5.4	4.5	1.03	0.714	0.751
+150.0			START CHEMICAL LEACH				

Test #73. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
156.0	11.11	4.1	6.0	3.9	0.978	0.714	0.962
162.3	10.05	4.0	5.8	5.1	0.906	0.668	0.666
*168.0	8.77	4.1	6.6	5.1	0.772	0.513	0.581
174.0	10.00	4.9	8.0	6.5	0.736	0.482	0.520
180.0	9.72	3.8	6.2	6.1	0.923	0.605	0.538
186.0	6.39	3.2	5.2	5.3	0.720	0.474	0.407
192.4	4.69	2.5	4.0	3.9	0.677	0.452	0.406
198.0	8.93	5.9	8.2	7.7	0.546	0.420	0.392
204.0	8.61	4.4	6.8	6.7	0.706	0.488	0.434
210.0	8.06	4.1	5.8	5.9	0.709	0.536	0.461
*216.3	7.94	4.5	6.6	6.5	0.637	0.464	0.413
222.1	8.62	5.1	7.0	6.7	0.610	0.475	0.435
227.9	9.20	4.8	7.4	6.9	0.692	0.480	0.450
234.0	8.47	4.8	7.0	6.7	0.637	0.467	0.427
240.0	8.61	6.4	9.0	7.9	0.485	0.369	0.368
*246.0	10.00	6.8	9.0	8.1	0.531	0.429	0.417
252.2	10.75	7.2	9.4	8.5	0.539	0.441	0.427
257.9	11.11	7.4	9.2	8.5	0.542	0.466	0.442
264.0	10.11	7.5	9.6	8.3	0.486	0.406	0.411
270.0	10.00	7.9	10.0	8.7	0.457	0.386	0.388
276.1	10.11	8.5	10.4	8.9	0.429	0.375	0.384
282.0	10.17	8.5	10.0	8.7	0.432	0.392	0.395

Test #73. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
288.0	9.72	9.0	10.0	8.5	0.390	0.375	0.386
+294.0	9.72	10.2	11.2	9.1	0.344	0.335	0.361
*300.0	10.00	10.2	11.2	8.5	0.354	0.344	0.397
305.9	9.08	10.0	10.8	7.9	0.328	0.324	0.388
312.0	8.74	11.4	11.6	8.7	0.277	0.291	0.339
318.0	10.83	11.4	13.4	10.5	0.343	0.312	0.348
324.0	11.94	11.2	14.2	11.1	0.385	0.324	0.363
329.9	11.30	11.8	14.0	11.3	0.346	0.311	0.338
336.0	11.20	12.1	14.4	10.9	0.334	0.300	0.347
342.0	10.00	12.7	14.2	11.1	0.284	0.272	0.304
348.0	10.56	12.5	14.2	11.3	0.305	0.287	0.316
*354.1	10.93	13.5	14.2	10.9	0.292	0.297	0.339
359.9	10.34	14.1	14.6	11.1	0.265	0.273	0.315
366.0	10.93	14.8	16.0	12.9	0.266	0.264	0.286
372.0	12.22	15.1	15.8	12.5	0.292	0.298	0.330
378.0	11.67	15.9	15.6	11.9	0.265	0.289	0.331
384.1	10.66	16.4	15.4	11.9	0.235	0.267	0.303
389.8	9.94	16.6	15.4	11.7	0.216	0.249	0.287
396.0	9.84	17.0	15.4	11.3	0.209	0.247	0.294
402.5	9.74	17.2	15.2	11.3	0.204	0.247	0.291
*408.0	10.00	17.5	15.2	11.3	0.206	0.254	0.299
414.0	9.72	18.0	15.0	11.3	0.195	0.250	0.291

Test #73. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
419.8	9.77	17.9	15.2	10.9	0.197	0.248	0.303
426.0	9.14	18.2	15.0	10.5	0.181	0.235	0.294
+432.0	8.89	18.4	15.0	10.3	0.174	0.229	0.292
438.0	8.89	18.9	15.0	10.7	0.170	0.229	0.281
443.9	9.32	15.7	16.2	12.1	0.214	0.222	0.260
450.0	10.66	15.5	16.4	12.1	0.248	0.251	0.298
456.0	10.56	15.1	16.8	12.1	0.252	0.243	0.295
462.0	9.72	15.4	17.0	11.9	0.228	0.221	0.276
468.3	10.85	15.8	15.6	12.3	0.248	0.268	0.298
474.0	10.53	16.5	15.8	11.7	0.230	0.257	0.304
*480.0	9.17	17.3	15.6	11.1	0.191	0.227	0.279
486.0	8.33	18.0	15.4	10.9	0.170	0.209	0.258
492.1	8.20	17.9	15.4	10.7	0.165	0.205	0.259
498.0	8.47	18.3	15.0	10.7	0.170	0.218	0.267
504.0	8.33	18.3	15.2	10.5	0.164	0.211	0.268
510.0	8.06	18.8	15.0	10.5	0.155	0.207	0.259
516.2	7.80	18.7	15.0	10.3	0.150	0.201	0.256
523.1	7.73	18.9	14.8	10.3	0.148	0.202	0.254
528.0	7.82	19.1	14.8	10.1	0.148	0.204	0.262
532.0	7.50	19.4	14.8	10.1	0.139	0.196	0.251
540.1	7.82	20.1	13.8	10.1	0.140	0.219	0.262
*546.0	7.34	20.5	13.8	9.7	0.129	0.205	0.256

Test #73. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
552.0	7.22	20.7	14.0	9.3	0.126	0.199	0.262
558.0	6.67	20.9	13.8	9.3	0.115	0.186	0.242
564.0	6.39	21.9	13.8	9.3	0.105	0.179	0.232
570.0	6.94	21.1	13.8	9.1	0.119	0.194	0.258
576.0	6.94	21.2	14.0	9.1	0.118	0.191	0.258
582.0	6.67	21.3	14.0	9.3	0.113	0.184	0.242
588.0	6.94	21.3	14.0	9.3	0.118	0.191	0.252
593.8	6.61	21.1	14.2	8.7	0.113	0.180	0.257
+600.0	6.72	21.2	13.8	8.7	0.114	0.188	0.261
*606.0	7.50	22.4	13.4	9.1	0.121	0.216	0.278
612.0	7.78	21.5	14.0	9.1	0.131	0.214	0.289
618.0	8.33	18.9	15.0	10.1	0.159	0.214	0.279
624.0	8.61	17.9	15.8	10.3	0.174	0.210	0.282
630.0	9.17	17.4	16.2	10.7	0.190	0.218	0.289
636.0	9.17	16.8	16.4	10.5	0.197	0.216	0.295
642.0	8.33	16.7	16.4	10.3	0.180	0.196	0.273
648.0	8.33	16.8	16.6	10.3	0.179	0.194	0.273
654.0	8.06	17.0	16.6	10.1	0.171	0.187	0.270
*659.8	8.33	17.4	15.8	10.5	0.173	0.203	0.268
666.3	7.95	17.8	16.0	9.9	0.161	0.192	0.271
672.0	7.89	18.1	16.0	9.9	0.157	0.190	0.269
678.0	7.22	18.8	15.8	9.7	0.139	0.176	0.251

Test #73. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
683.8	7.47	19.1	15.6	9.3	0.141	0.185	0.271
690.2	6.77	19.7	15.2	9.1	0.124	0.172	0.251
696.2	6.67	19.7	15.4	8.9	0.122	0.167	0.253
702.0	8.05	18.9	14.8	10.3	0.154	0.210	0.264
708.2	7.26	19.9	15.0	9.1	0.132	0.187	0.269
714.0	6.90	19.8	15.2	8.7	0.126	0.175	0.268
720.4	6.77	19.8	15.0	8.9	0.123	0.174	0.257
726.1	7.02	19.9	15.0	9.1	0.127	0.181	0.261
732.1	6.39	19.7	15.4	8.9	0.117	0.160	0.243
738.0	6.80	19.4	15.4	8.9	0.126	0.170	0.258
*744.0	6.94	19.7	15.4	8.9	0.127	0.174	0.263
750.0	6.67	19.8	15.6	8.9	0.122	0.165	0.253
756.2	6.72	20.1	15.4	8.5	0.121	0.168	0.267
762.0	6.03	20.5	15.2	8.3	0.106	0.153	0.245
768.0	5.56	20.7	15.4	7.9	0.097	0.139	0.238
†774.0	5.83	21.0	14.6	8.7	0.100	0.154	0.226
780.1	6.01	21.6	15.0	8.3	0.100	0.155	0.245
786.0	7.06	21.3	15.4	7.9	0.120	0.177	0.302
792.0	6.39	18.9	16.6	8.5	0.122	0.149	0.254
798.0	7.22	19.0	16.8	9.1	0.137	0.166	0.268
*804.0	6.94	19.4	16.6	8.3	0.129	0.161	0.282
809.9	6.21	19.9	16.6	8.1	0.113	0.144	0.259

Test #73. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
816.0	6.28	20.4	16.6	7.9	0.111	0.146	0.269
822.0	5.56	20.7	16.6	7.9	0.097	0.129	0.238
828.0	5.83	20.6	16.4	7.9	0.102	0.137	0.249
833.9	5.65	20.5	16.2	7.9	0.099	0.135	0.242
840.0	5.46	20.5	16.2	7.9	0.096	0.130	0.233
846.1	6.01	20.7	15.6	8.3	0.105	0.149	0.245
*852.0	5.65	20.8	15.6	7.9	0.098	0.140	0.242
857.9	5.46	20.6	15.8	7.9	0.096	0.133	0.233
864.0	5.19	21.1	15.8	7.7	0.089	0.127	0.228
869.9	5.65	21.5	15.6	7.5	0.095	0.140	0.254
876.0	4.92	21.3	15.8	7.5	0.083	0.120	0.222
882.0	5.28	21.3	15.8	7.5	0.089	0.129	0.238
888.1	4.37	21.3	15.8	7.5	0.074	0.107	0.197
894.0	4.80	21.4	15.8	7.7	0.081	0.117	0.211
*900.0	5.28	21.6	15.6	7.7	0.088	0.131	0.232
906.0	4.72	21.6	15.8	7.5	0.079	0.115	0.213
912.0	4.44	21.4	15.8	7.7	0.075	0.108	0.195
+912.0			START GROUND H ₂ O				
918.0	5.56	21.3	15.6	8.3	0.094	0.138	0.226
*923.9	7.63	15.8	18.0	10.5	0.174	0.164	0.245
930.0	8.20	14.6	19.0	10.7	0.203	0.167	0.259
936.0	7.78	13.8	19.8	10.7	0.203	0.152	0.246

Test #73. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
942.0	8.33	12.9	20.2	10.9	0.233	0.159	0.258
*947.9	8.19	12.5	20.6	10.9	0.236	0.153	0.254
954.0	7.10	12.1	21.0	10.9	0.212	0.130	0.220
960.0	7.50	12.0	21.2	11.1	0.226	0.136	0.228
966.0	7.78	11.6	21.2	11.5	0.242	0.142	0.229
972.1	8.20	11.2	21.0	11.5	0.264	0.151	0.241
978.0	8.47	10.7	20.8	11.9	0.286	0.157	0.240
984.0	8.06	11.6	20.4	12.3	0.251	0.152	0.221
990.0	8.33	11.4	19.4	12.9	0.264	0.166	0.218
*996.1	6.56	9.5	17.0	10.3	0.249	0.149	0.215
1002.0	6.80	8.8	15.4	8.7	0.279	0.170	0.264
1008.0	5.28	8.5	14.2	8.1	0.216	0.143	0.220
†1008.0			START 2.0 g/l NaHSO ₃				
1014.0	8.06	11.1	16.0	10.3	0.262	0.194	0.264
1020.1	9.84	12.8	17.2	13.7	0.277	0.221	0.243
1025.5	11.11	13.4	17.6	12.7	0.299	0.244	0.296
1032.0	16.67	13.6	22.4	7.7	0.442	0.287	0.731
1038.0	7.92	5.4	12.6	2.9	0.529	0.243	0.923
1044.1	3.55	4.7	11.0	2.5	0.273	0.125	0.480
*1049.9	5.17	4.5	10.6	2.5	0.415	0.188	0.699
1056.1	4.92	4.3	10.2	2.5	0.413	0.186	0.664
1062.0	4.80	4.8	10.8	2.9	0.361	0.171	0.559

Test #73. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1068.4	5.21	5.1	11.2	3.1	0.369	0.179	0.568
1073.9	4.55	4.9	10.8	3.1	0.335	0.163	0.496
1080.0	5.19	4.8	10.6	3.1	0.390	0.189	0.566
1086.3	5.03	5.0	10.8	3.3	0.363	0.180	0.515
1092.0	4.50	4.9	10.6	3.3	0.331	0.164	0.461
*1098.3	5.29	5.3	11.2	3.5	0.360	0.182	0.511
1104.0	5.26	5.2	11.0	3.5	0.365	0.184	0.508
1110.0	5.83	5.1	11.0	3.3	0.412	0.204	0.597
1116.0	5.83	5.5	12.2	3.5	0.382	0.184	0.563
1122.2	5.38	5.7	12.4	3.7	0.341	0.167	0.491
1128.0	5.46	6.1	12.6	3.7	0.323	0.167	0.498
+1134.0	6.67	6.0	12.8	3.9	0.401	0.201	0.578
1139.6	3.87	5.0	10.4	3.1	0.279	0.143	0.422
1146.2	4.80	3.9	9.2	2.7	0.444	0.201	0.601
1152.0	2.59	3.5	8.0	2.5	0.267	0.125	0.350
1158.0	5.56	6.2	11.2	4.1	0.324	0.192	0.458
*1163.8	5.82	5.6	11.6	3.7	0.375	0.194	0.531
1170.1	5.03	5.2	11.0	3.5	0.349	0.176	0.485
1176.0	5.93	5.8	11.6	4.1	0.369	0.197	0.489
1182.0	7.78	7.3	13.4	5.3	0.385	0.224	0.496
1188.2	7.80	6.8	13.4	4.9	0.414	0.225	0.538
1194.0	6.90	6.3	13.0	4.9	0.395	0.205	0.476

Test #73. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1200.0	7.22	6.4	12.4	5.1	0.407	0.225	0.478
*1206.0	7.22	6.8	13.2	5.7	0.383	0.211	0.428
†1206.0			START GROUND H ₂ O				
1211.7	4.68	1.5	4.0	1.9	1.13	0.451	0.832
1218.0	1.85	0.9	1.6	1.1	0.742	0.446	0.568
*1224.2	1.01	1.0	1.8	0.7	0.364	0.216	0.487
1230.1	1.01	1.1	2.2	1.1	0.331	0.177	0.310
1236.1	1.01	1.0	2.2	0.9	0.364	0.177	0.379
1242.0	1.98	1.5	2.8	1.3	0.476	0.273	0.514
1248.0	2.22	5.5	6.8	2.9	0.146	0.126	0.259
1254.0	3.61	3.0	5.2	2.5	0.434	0.268	0.488
1260.3	4.50	3.2	5.6	2.5	0.507	0.310	0.608
1271.0	4.39	1.8	3.0	1.1	0.880	0.565	1.35
1278.0	4.52	6.0	7.8	4.1	0.272	0.224	0.372
1284.3	5.82	5.6	7.6	3.5	0.375	0.295	0.562
*1290.3	4.72	4.6	7.0	2.7	0.370	0.260	0.591
1296.0	3.22	3.2	5.6	1.9	0.363	0.222	0.572
1302.0	2.78	5.3	7.2	3.3	0.189	0.149	0.285
1308.0	5.00	5.3	7.6	3.5	0.340	0.254	0.483
1313.9	3.95	5.3	7.2	3.3	0.269	0.212	0.404
1320.0	3.83	4.0	6.4	2.7	0.345	0.231	0.479
*1326.0	3.06	3.9	5.8	2.5	0.283	0.204	0.413

Test #73. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1332.2	3.49	3.7	5.6	2.3	0.340	0.240	0.513
1338.0	2.59	4.1	5.8	2.3	0.228	0.172	0.380
1344.0	2.78	3.5	5.4	2.1	0.287	0.199	0.447
1350.0	3.33	4.7	6.4	2.9	0.256	0.201	0.388
1356.0	3.61	4.6	6.4	2.7	0.283	0.218	0.452
1362.4	3.13	2.8	6.2	2.3	0.403	0.195	0.460
1368.0	2.68	4.0	5.6	2.3	0.242	0.185	0.394
1374.0	3.06	6.2	7.6	3.5	0.178	0.155	0.295
*1380.0	4.44	5.9	7.6	3.5	0.272	0.225	0.429
1386.1	4.10	5.6	7.2	3.3	0.264	0.220	0.420
1392.0	4.24	5.1	7.0	3.1	0.300	0.234	0.462
1398.0	3.61	4.6	6.4	2.7	0.283	0.218	0.452
1405.0	2.38	4.2	5.8	2.5	0.204	0.158	0.322
1410.2	3.53	3.5	5.2	2.3	0.364	0.262	0.518
1416.2	1.67	3.4	5.6	2.1	0.177	0.115	0.269
1422.1	2.54	3.7	5.0	2.3	0.248	0.196	0.373
1427.8	1.75	3.4	4.6	2.1	0.186	0.147	0.282
1434.0	3.49	4.6	5.8	2.7	0.274	0.232	0.437
*1440.0	3.89	5.0	6.4	2.9	0.281	0.234	0.453
RUN TERMINATED							

Observations from the Simulation Leach Test #74

Ore used = Wyoming

Solution used = 1.0 g/l NH_4HCO_3 - Sat'd O_2 at 45 psig

Inlet section packing material = -80 AFS Subangular Sand

Inlet section packing length = 10.0 in.

Length of the front ore section = 47.00 in.

Length of the middle ore section = 50.13 in.

Length of the end ore section = 44.38 in.

Outlet section packing material = -80 AFS Subangular Sand

Outlet section packing length = 5.00 in.

Ore packing bed density = 1.70 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = 10 tamps/8 in. of ore. Column position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.

† indicates introduction of fresh feed solution(s).

Test #74

Ore - Wyoming

Sol - 1.0 g/l NH_4HCO_3 -
sat'd O_2 (45 psig)
followed by 3.0 g/l AlCl_3

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
36.0	6.11	1.65	1.15	4.25	1.34	2.04	0.490
42.0	6.67	2.00	1.35	1.90	1.20	1.90	1.20
*48.0	9.17	2.55	1.95	1.50	1.30	1.81	2.08
53.9	10.73	2.60	1.90	1.50	1.49	2.17	2.44
60.2	9.26	2.60	1.85	1.50	1.29	1.93	2.10
66.0	10.34	2.60	1.85	1.50	1.43	2.15	2.35
72.0	9.44	2.60	1.80	1.50	1.31	2.02	2.14
77.8	10.34	2.60	1.90	1.50	1.43	2.09	2.35
84.2	9.64	2.60	2.00	1.45	1.34	1.85	2.27
*+90.2	9.72	2.55	2.00	1.55	1.38	1.87	2.14
96.0	10.34	2.70	1.95	1.30	1.38	2.04	2.71
102.2	8.87	2.50	1.80	1.20	1.28	1.90	2.52
108.0	9.48	2.70	2.10	1.25	1.27	1.74	2.58
114.3	10.58	2.75	2.30	1.30	1.39	1.77	2.77
120.1	9.77	2.75	2.30	1.40	1.28	1.63	2.38
126.1	10.00	2.70	2.30	1.40	1.34	1.67	2.43
132.0	10.17	2.65	2.40	1.35	1.38	1.63	2.57
138.0	8.89	2.55	2.40	1.35	1.26	1.43	2.24
144.0	8.89	2.50	2.35	1.40	1.28	1.46	2.16
*150.2	10.22	2.75	2.80	1.60	1.34	1.40	2.18
156.2	10.56	2.75	2.90	1.60	1.39	1.40	2.25
162.0	10.63	2.70	3.05	1.70	1.42	1.34	2.13

Test #74. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
168.0	9.44	2.70	3.10	2.00	1.26	1.17	1.61
*168.0			START CHEMICAL LEACH				
174.1	10.93	3.10	3.35	2.20	1.27	1.26	1.69
*180.1	10.83	3.70	3.30	2.20	1.06	1.26	1.68
186.0	10.45	3.65	4.20	2.15	1.03	0.957	1.66
192.0	8.33	3.05	3.85	2.05	0.985	0.833	1.38
198.0	10.00	3.60	4.80	2.70	1.00	0.802	1.26
203.9	10.45	3.60	5.05	2.75	1.05	0.796	1.29
210.0	9.56	3.90	5.35	3.20	0.884	0.688	1.02
216.0	10.00	3.80	5.20	3.40	0.949	0.740	1.00
*222.0	9.44	3.75	5.00	3.40	0.908	0.727	0.946
227.9	10.17	4.05	5.15	3.60	0.906	0.760	0.962
234.0	10.66	4.15	5.05	3.65	0.927	0.812	0.995
240.0	10.00	4.10	4.90	3.50	0.880	0.785	0.973
246.0	9.44	4.10	4.75	3.30	0.831	0.765	0.975
*252.0	10.56	4.60	5.10	3.45	0.828	0.797	1.04
258.0	9.44	4.70	5.10	3.40	0.725	0.712	0.946
*263.9	10.17	4.90	5.20	3.40	0.749	0.753	1.02
270.0	9.56	4.95	5.25	3.30	0.697	0.701	0.987
276.0	10.00	5.10	5.30	3.30	0.707	0.726	1.03
282.1	8.74	5.30	5.35	3.25	0.595	0.629	0.916
*288.0	9.32	5.35	5.45	3.25	0.629	0.658	0.977

Test #74. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
294.0	9.72	5.50	5.50	3.25	0.638	0.680	1.02
300.0	9.17	5.90	5.60	3.30	0.561	0.630	0.947
306.0	9.17	6.05	5.75	3.35	0.547	0.614	0.933
312.0	9.44	6.00	5.80	3.40	0.568	0.626	0.946
317.9	8.76	6.50	6.00	3.50	0.486	0.562	0.853
*324.6	9.20	6.70	6.05	3.45	0.495	0.585	0.909
330.0	10.19	7.00	6.00	3.45	0.525	0.654	1.01
336.0	8.89	6.90	6.20	3.45	0.465	0.552	0.878
342.0	10.00	7.50	6.35	3.65	0.481	0.606	0.933
348.0	9.44	7.50	6.40	3.55	0.454	0.568	0.906
354.0	9.44	7.60	6.30	3.45	0.448	0.577	0.932
360.0	8.61	7.65	6.30	3.50	0.406	0.526	0.838
366.1	8.74	8.30	6.50	3.60	0.380	0.517	0.827
372.0	9.32	8.25	6.40	3.45	0.408	0.560	0.920
378.0	8.06	8.40	6.35	3.40	0.346	0.488	0.808
384.0	7.22	8.25	6.35	3.45	0.316	0.438	0.713
*390.1	8.74	9.10	6.60	3.65	0.347	0.510	0.816
396.0	9.60	9.30	6.60	3.55	0.372	0.560	0.921
402.0	9.17	10.20	6.90	3.80	0.324	0.511	0.822
408.0	8.61	10.40	6.95	3.90	0.299	0.477	0.752
414.1	8.74	10.40	6.75	3.80	0.303	0.498	0.784
419.6	8.48	10.40	6.70	3.70	0.294	0.487	0.781

Test #74. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
426.0	9.11	11.5	7.00	3.80	0.286	0.501	0.817
432.0	9.44	12.5	7.05	3.90	0.272	0.515	0.825
438.1	7.38	13.1	7.00	3.80	0.203	0.406	0.662
443.9	8.62	13.2	6.90	3.75	0.236	0.481	0.783
*450.1	8.87	14.8	7.00	3.75	0.216	0.488	0.806
456.0	9.32	15.7	7.15	3.90	0.214	0.502	0.814
462.3	8.99	17.0	7.30	4.00	0.191	0.474	0.766
*467.9	8.63	18.2	7.20	3.85	0.171	0.461	0.764
474.0	8.20	18.7	7.05	3.75	0.158	0.448	0.745
480.4	8.07	20.0	6.85	3.72	0.146	0.453	0.739
486.0	8.63	21.5	7.00	3.75	0.145	0.474	0.784
492.2	8.33	23.8	7.20	3.80	0.126	0.445	0.747
498.0	8.91	24.8	7.20	3.80	0.130	0.476	0.799
504.0	8.33	25.2	7.05	3.65	0.119	0.455	0.778
510.0	8.89	27.2	7.30	3.85	0.118	0.469	0.787
516.2	7.80	27.7	7.35	3.80	0.102	0.408	0.699
522.0	8.91	28.5	7.30	3.70	0.113	0.470	0.820
528.0	8.06	29.2	7.30	3.85	0.100	0.425	0.713
*533.7	8.48	30.5	7.40	3.90	0.100	0.441	0.741
540.1	8.33	30.7	7.25	3.80	0.098	0.442	0.747
546.0	8.19	31.0	7.20	3.70	0.095	0.438	0.754
552.0	8.61	31.5	6.50	4.00	0.099	0.510	0.733

Test #74. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
557.8	8.05	32.5	6.60	4.00	0.089	0.469	0.686
564.1	6.61	32.4	6.00	3.70	0.074	0.424	0.609
570.0	6.50	32.5	6.10	3.65	0.072	0.410	0.607
576.0	6.11	32.6	5.90	3.65	0.068	0.398	0.570
582.2	6.99	33.0	5.70	3.50	0.076	0.472	0.680
588.0	6.03	33.5	5.75	3.40	0.065	0.404	0.604
*594.0	6.39	33.5	5.75	3.35	0.069	0.428	0.650
600.0	5.28	33.4	5.55	3.30	0.057	0.366	0.545
605.8	6.32	33.7	5.45	3.25	0.068	0.446	0.663
612.0	5.65	33.7	5.25	3.10	0.060	0.414	0.621
618.2	5.38	34.3	5.35	3.10	0.057	0.387	0.591
624.1	5.65	34.3	5.35	3.15	0.059	0.406	0.611
630.1	5.56	34.0	5.25	3.10	0.059	0.408	0.611
636.0	5.65	33.7	5.35	3.05	0.060	0.406	0.631
642.0	5.28	34.4	5.25	3.05	0.055	0.387	0.590
648.0	5.56	34.8	5.10	3.05	0.058	0.420	0.621
654.3	5.56	34.8	5.10	3.00	0.058	0.420	0.631
666.0	5.41	35.0	4.95	2.95	0.056	0.421	0.625
672.0	5.00	35.0	4.85	2.95	0.052	0.397	0.577
678.3	5.29	35.1	4.80	2.90	0.054	0.424	0.621
*684.3	5.00	34.7	4.70	2.75	0.052	0.409	0.619
690.0	4.68	35.0	4.75	2.70	0.048	0.379	0.591

Test #74. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
696.0	5.56	34.9	4.80	2.75	0.057	0.446	0.689
702.0	5.28	35.0	4.60	2.70	0.054	0.442	0.666
708.0	5.28	35.1	4.70	2.65	0.054	0.432	0.679
714.0	4.44	35.2	4.60	2.60	0.046	0.371	0.582
720.0	4.72	35.1	4.70	2.65	0.049	0.386	0.607
726.2	5.11	35.0	4.50	2.60	0.053	0.437	0.670
732.0	5.46	35.5	4.45	2.55	0.055	0.472	0.729
738.0	4.44	35.5	4.50	2.45	0.045	0.380	0.617
*744.0	5.00	35.3	4.60	2.60	0.051	0.418	0.655
750.0	4.72	35.3	4.45	2.60	0.048	0.408	0.619
756.4	5.21	35.5	4.40	2.45	0.053	0.456	0.725
†762.1	4.97	35.5	4.45	2.40	0.051	0.430	0.706
768.1	5.00	35.5	4.40	2.50	0.051	0.437	0.681
774.0	4.52	34.7	4.20	2.40	0.047	0.414	0.642
780.0	3.89	34.9	4.15	2.30	0.040	0.361	0.576
786.0	5.28	34.9	4.30	2.30	0.055	0.472	0.782
792.0	4.44	35.0	4.25	2.40	0.046	0.402	0.630
798.0	4.17	34.7	4.15	2.35	0.043	0.387	0.605
804.1	4.37	35.0	4.10	2.30	0.045	0.410	0.647
810.2	4.37	35.5	4.15	2.25	0.044	0.405	0.662
816.2	5.28	35.5	4.30	2.30	0.054	0.472	0.782
*821.9	4.97	35.0	4.25	2.30	0.051	0.450	0.736

Test #74. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
828.0	4.37	35.0	4.10	2.25	0.045	0.410	0.662
834.0	4.44	34.9	4.25	2.20	0.046	0.402	0.688
840.0	4.72	35.2	4.30	2.35	0.048	0.422	0.684
846.1	4.64	35.2	4.20	2.30	0.048	0.425	0.687
852.0	4.80	35.0	4.15	2.15	0.049	0.445	0.761
858.0	4.44	34.8	4.20	2.25	0.046	0.407	0.672
864.0	5.28	36.3	4.65	2.45	0.052	0.437	0.734
870.1	5.56	36.5	4.50	2.35	0.055	0.475	0.806
876.0	4.80	36.0	4.75	2.40	0.048	0.389	0.681
882.0	5.00	36.2	4.75	2.40	0.050	0.405	0.710
888.0	5.00	36.3	4.60	2.45	0.050	0.418	0.695
894.2	4.84	36.4	4.50	2.35	0.048	0.414	0.702
900.0	4.89	36.0	4.35	2.30	0.049	0.433	0.724
*906.0	5.00	36.0	4.55	2.30	0.050	0.423	0.741
912.0	4.44	36.5	4.50	2.35	0.044	0.380	0.644
918.3	5.03	36.0	4.40	2.25	0.050	0.440	0.762
925.0	4.98	36.0	4.70	2.25	0.050	0.408	0.754
†930.0	4.67	35.5	4.90	2.35	0.047	0.367	0.677
936.0	5.28	36.0	4.65	2.30	0.053	0.437	0.782
942.0	4.44	35.9	4.55	2.25	0.045	0.375	0.672
947.9	4.24	36.0	4.70	2.25	0.042	0.347	0.642
954.0	4.92	35.5	5.05	2.30	0.050	0.344	0.729

Test #74. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
960.0	4.72	35.7	5.00	2.40	0.048	0.363	0.670
966.1	4.37	35.5	4.75	2.35	0.044	0.354	0.634
972.0	5.08	35.9	4.65	2.20	0.051	0.420	0.787
978.0	4.44	35.8	4.90	2.20	0.045	0.349	0.688
984.2	4.57	36.0	4.90	2.40	0.046	0.359	0.649
*990.0	4.60	35.8	4.70	2.30	0.046	0.377	0.681
996.1	4.37	35.9	4.60	2.25	0.044	0.366	0.662
1002.0	4.52	36.0	4.70	2.20	0.053	0.370	0.700
†1002.0			START 3.0 g/l AlCl ₃				
1008.0	5.00	35.0	5.15	2.45	0.052	0.374	0.695
1014.0	5.83	29.0	9.20	5.05	0.073	0.244	0.393
*1020.1	11.75	16.0	9.40	5.05	0.265	0.481	0.793
1026.0	9.89	8.20	7.60	3.65	0.435	0.501	0.923
1032.0	7.72	7.25	7.75	3.85	0.384	0.383	0.683
*1037.9	9.89	5.95	7.80	3.90	0.600	0.488	0.864
1044.3	8.33	4.85	7.50	3.65	0.620	0.427	0.778
1050.0	8.77	4.40	7.55	3.70	0.719	0.447	0.808
*1056.0	8.33	4.25	7.45	3.85	0.707	0.430	0.737
1061.8	8.91	4.10	7.15	3.55	0.784	0.480	0.855
1068.3	7.69	3.95	6.70	3.30	0.702	0.442	0.794
1074.0	8.18	3.75	6.15	2.95	0.787	0.512	0.945
†1080.0	7.50	3.60	5.70	2.60	0.752	0.506	0.983

Test #74. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1085.8	8.33	3.55	5.60	2.40	0.847	0.573	1.18
*1092.0	6.45	2.80	4.80	1.85	0.831	0.517	1.19
1098.1	6.83	2.75	4.40	1.65	0.896	0.597	1.41
1104.2	5.46	1.85	3.30	1.20	1.06	0.637	1.55
1109.5	3.46	1.55	2.95	0.95	0.805	0.451	1.24
1116.0	3.59	1.60	2.90	0.80	0.810	0.476	1.53
1122.3	4.23	1.85	3.10	0.85	0.825	0.525	1.70
1127.7	3.40	1.75	2.85	0.85	0.701	0.459	1.36
*1134.0	3.97	1.80	3.05	0.90	0.796	0.501	1.50
1140.0	4.17	1.80	3.00	0.80	0.836	0.535	1.78
1146.0	3.61	1.70	2.80	0.75	0.766	0.496	1.64
1152.1	8.33	3.45	4.65	1.45	0.871	0.689	1.96
1158.2	7.92	3.25	4.55	1.45	0.879	0.670	1.86
1164.2	7.50	3.15	4.55	1.40	0.859	0.634	1.83
1170.0	7.76	3.00	4.50	1.30	0.933	0.664	2.03
1176.0	7.50	2.75	4.30	1.30	0.984	0.671	1.97
1181.9	7.91	2.70	4.30	1.30	1.06	0.708	2.07
1188.0	6.01	2.80	4.45	1.30	0.774	0.520	1.58
1194.0	6.94	2.70	4.45	1.25	0.927	0.600	1.89
*1200.0	6.39	2.65	4.40	1.30	0.870	0.559	1.67
1206.0	6.67	2.40	4.10	1.20	1.00	0.626	1.89
1212.4	5.73	2.30	4.10	1.10	0.899	0.538	1.77

Test #74. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1218.0	5.65	2.25	4.00	1.15	0.906	0.544	1.67
1223.9	3.67	1.80	3.50	1.10	0.736	0.403	1.14
1230.0	1.91	0.30	1.45	0.50	2.30	0.507	1.30
1235.9	2.54	0.90	1.35	0.40	1.02	0.724	2.16
1242.0	4.10	3.30	6.75	2.55	0.448	0.234	0.548
†1248.0		START WYOMING GROUND H ₂ O					
1254.0	5.56	5.50	4.85	2.50	0.365	0.441	0.758
1260.5	8.97	6.00	5.10	2.60	0.539	0.677	1.18
*1266.3	7.18	6.25	5.35	2.65	0.414	0.516	0.923
1272.0	9.65	7.30	6.60	3.35	0.477	0.563	0.981
1278.0	4.44	1.95	1.70	1.30	0.822	1.01	1.16
1284.3	1.04	1.30	1.30	0.90	0.289	0.308	0.394
1290.3	1.94	1.75	1.95	1.15	0.400	0.383	0.575
1295.9	2.08	1.50	1.90	1.25	0.500	0.421	0.567
1302.0	2.19	1.85	2.05	1.30	0.427	0.411	0.574
1308.3	2.12	1.90	2.20	1.30	0.403	0.371	0.556
1314.0	2.63	1.95	2.40	1.35	0.487	0.422	0.664
1320.0	5.00	3.75	4.10	2.45	0.481	0.469	0.695
1326.1	6.01	3.55	4.00	2.30	0.610	0.578	0.890
*1332.1	4.17	2.95	3.45	1.95	0.510	0.465	0.729
1338.0	4.80	3.15	3.70	2.00	0.550	0.499	0.818
1344.0	5.56	3.35	3.90	2.30	0.599	0.549	0.824

Test #74. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1349.8	5.46	3.30	4.40	2.20	0.597	0.478	0.846
1356.0	4.84	3.10	4.25	1.95	0.563	0.438	0.846
1362.0	4.72	2.75	3.90	1.95	0.619	0.466	0.825
*1368.0	4.17	2.70	3.75	2.05	0.557	0.428	0.693
1374.3	5.03	2.50	3.60	1.85	0.726	0.538	0.926
1380.0	3.22	2.40	3.55	1.75	0.484	0.349	0.627
1386.0	3.89	2.35	3.55	1.80	0.597	0.422	0.736
1392.0	4.17	2.40	3.50	1.90	0.626	0.458	0.748
*1398.5	3.59	2.30	3.40	1.70	0.563	0.406	0.719
1404.0	3.33	2.25	3.40	1.70	0.534	0.377	0.667
1410.0	3.61	2.30	3.10	1.65	0.566	0.448	0.745
1416.0	3.06	2.20	3.05	1.60	0.502	0.386	0.652
*1422.5	4.62	2.75	4.00	2.00	0.606	0.444	0.787
1428.2	4.97	2.15	3.55	1.80	0.834	0.539	0.941
1433.4	1.92	0.20	0.65	0.70	3.46	1.14	0.934
RUN TERMINATED							

Observations from the Simulation Leach Test #75

Ore used = Wyoming

Solution used = 1.0 g/l NH_4HCO_3 - Sat'd O_2 at 45 psig

Inlet section packing material = -80 AFS Subangular Sand

Inlet section packing length = 10.0 in.

Length of the front ore section = 35.50 in.

Length of the middle ore section = 52.00 in.

Length of the end ore section = 52.00 in.

Outlet section packing material = -80 AFS Subangular Sand

Outlet section packing length = 5.00 in.

Ore packing bed density = 1.69 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = 10 tamps/8 in. of ore. Column position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.

† indicates introduction of fresh feed solution(s).

Test #75

Ore - Wyoming

Sol - High Pressure -
1.0 g/l NH_4HCO_3
sat'd O_2 (45 psig)

Time Hrs	Flow mL/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
48.0	5.00	1.25	2.10	2.00	1.09	0.950	0.998
54.0	10.56	1.20	2.00	1.90	2.40	2.11	2.22
60.0	11.94	1.30	2.10	1.95	2.51	2.27	2.44
*66.0	11.11	1.35	2.10	2.00	2.25	2.11	2.22
72.0	11.11	1.30	2.05	1.95	2.33	2.16	2.27
78.2	10.75	1.20	1.90	1.80	2.45	2.26	2.38
84.0	12.36	1.35	2.15	2.00	2.50	2.29	2.47
90.0	11.67	1.25	1.95	1.80	2.55	2.39	2.59
+*96.0	11.11	1.20	1.90	1.75	2.53	2.33	2.53
102.0	6.94	0.65	0.95	0.95	2.91	2.91	2.91
108.3	8.73	0.90	1.40	1.30	2.65	2.49	2.68
114.0	10.53	1.10	1.70	1.55	2.61	2.47	2.71
120.1	9.56	1.20	1.85	1.70	2.17	2.06	2.24
126.0	8.76	0.90	1.40	1.30	2.66	2.50	2.69
132.1	10.93	1.20	1.85	1.70	2.49	2.36	2.57
*138.0	10.73	1.20	1.85	1.70	2.44	2.31	2.52
144.1	9.56	1.20	1.80	1.65	2.17	2.12	2.31
150.0	10.73	1.25	1.90	1.75	2.34	2.25	2.45
156.1	11.20	1.30	2.00	1.85	2.35	2.23	2.42
162.2	11.48	1.35	2.05	1.90	2.32	2.23	2.41
168.2	10.83	1.30	2.00	1.80	2.27	2.16	2.40
173.9	10.53	1.25	1.90	1.75	2.30	2.21	2.40

Test #75. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
180.0	10.38	1.25	1.90	1.75	2.27	2.18	2.37
*186.0	11.67	1.40	2.05	1.85	2.28	2.27	2.52
192.0	10.00	1.30	1.85	1.70	2.10	2.16	2.35
†192.0		START CHEMICAL LEACH					
198.1	7.38	0.45	0.60	0.60	4.48	4.91	4.91
204.0	2.54	0.20	0.25	0.30	3.47	4.05	3.38
210.0	5.83	0.95	1.35	1.25	1.68	1.72	1.86
215.0	10.00	1.40	2.00	1.80	1.95	2.00	2.22
222.1	12.21	1.50	2.05	2.00	2.22	2.38	2.44
228.1	10.83	1.70	1.90	1.90	1.74	2.27	2.27
*234.0	12.71	1.80	2.15	2.10	1.93	2.36	2.41
240.0	11.94	1.70	1.95	1.90	1.92	2.44	2.51
246.2	--	1.70	1.90	1.80	--	--	--
252.0	--	1.80	1.85	1.80	--	--	--
258.0	--	1.85	1.85	1.85	--	--	--
264.0	11.11	2.00	1.95	1.90	1.52	2.27	2.33
*270.3	11.38	1.90	1.75	1.60	1.64	2.59	2.84
277.0	11.69	2.00	1.75	1.65	1.60	2.67	2.83
282.0	11.00	2.10	1.80	1.70	1.43	2.44	2.58
288.0	10.28	1.85	1.50	1.50	1.52	2.73	2.73
294.0	8.89	1.85	1.50	1.45	1.31	2.36	2.45
299.9	10.17	1.95	1.50	1.45	1.42	2.71	2.80

Test #75. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*306.0	8.47	2.00	1.50	1.45	1.16	2.25	2.33
312.0	8.61	2.05	1.50	1.45	1.15	2.29	2.37
318.1	8.47	2.40	1.45	1.40	0.963	2.33	2.41
*324.0	8.76	2.55	1.45	1.40	0.938	2.41	2.50
†330.0	9.17	2.65	1.40	1.40	0.945	2.61	2.61
336.2	8.87	3.00	1.60	1.50	0.807	2.21	2.36
342.0	9.14	2.95	1.50	1.45	0.846	2.43	2.52
348.1	9.29	3.00	1.50	1.50	0.845	2.47	2.47
354.0	10.17	3.05	1.55	1.50	0.910	2.62	2.71
360.0	9.17	3.15	1.55	1.50	0.794	2.36	2.44
366.0	9.44	3.20	1.50	1.15	0.805	2.51	3.28
372.1	9.84	3.30	1.50	1.15	0.814	2.62	3.41
378.0	10.45	3.45	1.55	1.15	0.827	2.69	3.63
384.0	9.17	3.55	1.55	1.15	0.705	2.36	3.18
339.9	6.21	3.55	1.50	1.15	0.478	1.65	2.15
*396.3	9.90	3.60	1.50	1.15	0.751	2.63	3.43
402.0	9.65	3.75	1.50	1.15	0.703	2.57	3.35
408.0	10.00	4.00	1.55	1.20	0.683	2.57	3.33
413.8	10.06	4.00	1.55	1.20	0.687	2.59	3.34
420.3	8.97	4.20	1.55	1.20	0.583	2.31	2.98
426.0	9.65	4.25	1.55	1.20	0.620	2.48	3.21
†432.0	10.00	4.30	1.55	1.20	0.635	2.57	3.33

Test #75. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*437.8	9.20	4.60	1.65	1.30	0.546	2.22	2.82
444.0	10.22	4.75	1.65	1.30	0.587	2.47	3.14
450.1	9.84	4.90	1.70	1.30	0.548	2.31	3.02
456.2	9.29	4.90	1.65	1.30	0.518	2.25	2.85
461.5	9.43	4.90	1.65	1.30	0.525	2.28	2.89
468.0	8.46	5.15	1.60	1.30	0.448	2.11	2.60
474.3	9.52	5.50	1.65	1.30	0.473	2.30	2.92
*479.7	8.95	5.75	1.65	1.30	0.425	2.16	2.75
486.0	8.99	6.15	1.70	1.30	0.399	2.11	2.76
492.0	9.44	6.65	1.65	1.30	0.388	2.28	2.90
498.0	8.89	7.25	1.65	1.30	0.335	2.15	2.73
*504.0	9.17	8.10	1.65	1.30	0.309	2.22	2.81
510.2	9.95	9.15	1.70	1.35	0.297	2.34	2.94
516.2	10.00	10.00	1.75	1.35	0.273	2.28	2.96
522.0	9.48	10.05	1.70	1.35	0.258	2.23	2.80
528.0	9.44	11.0	1.75	1.30	0.234	2.15	2.90
534.9	8.70	11.5	1.80	1.30	0.207	1.93	2.67
540.0	10.13	12.5	1.80	1.30	0.221	2.25	3.11
*546.0	9.44	12.5	1.75	1.25	0.206	2.15	3.01
552.0	7.50	12.5	2.15	1.25	0.164	1.39	2.39
558.0	9.44	13.0	2.20	1.25	0.198	1.71	3.01
564.4	9.11	13.0	2.25	1.25	0.191	1.62	2.91

Test #75. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
570.0	8.93	13.0	2.45	1.30	0.188	1.45	2.74
575.9	8.19	12.5	2.50	1.30	0.179	1.31	2.51
582.0	9.56	12.0	2.45	1.25	0.217	1.56	3.05
587.9	10.17	11.5	2.50	1.25	0.241	1.62	3.25
*594.0	8.47	10.5	2.40	1.20	0.220	1.41	2.82
600.0	8.61	11.0	2.40	1.15	0.214	1.43	2.99
606.0	9.17	12.0	2.65	1.25	0.209	1.38	2.93
612.5	9.74	11.5	2.80	1.30	0.231	1.39	2.99
618.3	8.91	11.5	2.80	1.30	0.212	1.27	2.73
624.0	8.48	11.0	2.80	1.30	0.210	1.21	2.60
630.0	8.61	11.0	2.80	1.30	0.214	1.23	2.64
636.3	8.99	10.5	2.85	1.30	0.234	1.26	2.76
642.2	7.63	10.0	2.70	1.20	0.208	1.13	2.54
647.9	7.60	11.0	2.70	1.20	0.189	1.12	2.53
*654.0	8.20	12.0	2.65	1.10	0.187	1.23	2.97
660.3	7.67	12.5	2.70	1.10	0.168	1.13	2.78
666.0	6.43	13.5	2.75	1.10	0.130	0.933	2.33
672.0	9.17	14.5	3.60	1.45	0.173	1.02	2.52
678.1	10.66	14.5	3.50	1.40	0.201	1.22	3.04
684.0	8.76	14.5	3.15	2.70	0.165	1.11	1.29
690.0	10.00	14.0	3.30	1.90	0.195	1.21	2.10
696.0	9.44	14.5	3.10	2.15	0.178	1.22	1.75

Test #75. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
701.8	10.63	14.5	3.05	1.90	0.200	1.39	2.23
708.0	8.87	15.5	3.00	2.00	0.156	1.18	1.77
714.0	9.17	16.5	3.15	1.95	0.152	1.16	1.88
*720.0	9.17	16.0	3.05	2.05	0.156	1.20	1.78
726.3	9.52	17.5	3.30	2.25	0.149	1.15	1.69
732.0	10.23	18.0	3.20	2.10	0.155	1.28	1.94
738.0	8.89	18.5	3.40	2.20	0.131	1.04	1.61
744.0	9.72	19.5	3.40	2.25	0.136	1.14	1.72
750.0	10.28	20.0	3.40	2.45	0.140	1.21	1.67
756.0	9.44	20.5	3.50	2.50	0.126	1.08	1.51
*762.0	9.72	21.0	3.35	2.60	0.126	1.16	1.49
†768.0	9.17	21.0	3.35	2.20	0.119	1.09	1.66
774.5	9.23	20.5	3.75	2.75	0.123	0.982	1.34
780.2	11.70	17.0	4.60	3.20	0.188	1.01	1.46
*786.1	12.43	12.0	4.30	3.00	0.283	1.15	1.65
792.0	10.73	10.0	4.05	2.80	0.293	1.06	1.53
798.2	10.48	9.5	4.00	2.75	0.301	1.05	1.52
804.0	10.63	9.5	4.05	2.50	0.305	1.05	1.70
810.0	10.28	8.5	4.00	2.50	0.330	1.03	1.64
816.0	10.83	8.0	4.10	2.50	0.370	1.05	1.73
822.0	10.28	8.5	4.00	2.60	0.330	1.03	1.58
*828.0	10.28	8.5	4.00	2.60	0.330	1.03	1.58

Test #75. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
834.0	10.28	8.0	4.00	2.65	0.351	1.03	1.55
840.0	10.00	5.90	4.35	2.80	0.463	0.917	1.43
846.1	10.38	5.50	4.00	2.25	0.515	1.04	1.84
852.2	10.66	5.75	4.00	2.40	0.506	1.06	1.77
858.0	9.48	5.80	4.20	2.45	0.446	0.901	1.54
864.0	10.28	5.55	4.00	2.35	0.506	1.03	1.75
*870.1	9.02	5.40	3.65	2.20	0.456	0.986	1.64
876.2	9.02	5.70	3.75	2.30	0.432	0.960	1.56
882.0	9.48	5.75	3.90	2.35	0.450	0.970	1.61
888.0	9.17	5.75	3.95	2.40	0.435	0.926	1.52
893.6	8.93	6.00	3.85	2.30	0.406	0.925	1.55
*900.5	9.66	6.20	3.85	2.45	0.425	1.00	1.57
906.0	7.88	6.50	3.90	2.35	0.331	0.806	1.34
912.1	8.92	6.65	3.95	2.40	0.366	0.901	1.48
918.7	8.92	6.85	3.80	2.50	0.355	0.937	1.42
924.2	8.18	7.15	3.75	2.50	0.312	0.870	1.31
930.0	9.20	7.40	3.95	2.60	0.339	0.929	1.41
*936.0	9.17	7.75	3.95	2.65	0.323	0.926	1.38
942.1	8.47	8.80	3.85	2.15	0.263	0.878	1.57
948.1	8.61	9.05	4.20	2.15	0.260	0.818	1.60
954.3	8.06	9.70	4.25	2.65	0.227	0.757	1.21
*959.0	8.51	10.00	4.35	2.65	0.232	0.781	1.28

Test #75. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
965.9	7.73	10.0	4.50	2.55	0.211	0.683	1.21
972.0	7.92	9.5	4.15	2.75	0.228	0.761	1.15
978.4	7.81	9.0	4.40	2.85	0.237	0.708	1.09
984.3	8.47	9.0	4.25	2.95	0.257	0.795	1.15
989.7	7.40	8.5	4.30	2.95	0.238	0.687	1.00
995.8	7.10	9.0	4.00	2.95	0.215	0.708	0.960
*1002.0	7.80	9.0	3.85	2.80	0.237	0.808	1.11
1008.0	7.78	8.5	4.05	2.75	0.250	0.766	1.13
+1008.0		START 0.5 g/l LaCl ₃ + 0.5 g/l La ₂ (SO ₄) ₃					
1014.2	7.53	8.5	4.05	2.40	0.242	0.742	1.25
*1020.1	9.32	7.0	4.10	2.70	0.363	0.907	1.38
1026.0	9.08	7.0	3.40	2.75	0.354	1.07	1.32
1032.0	8.89	5.1	3.30	2.85	0.476	1.07	1.24
1038.4	7.81	4.6	2.60	2.55	0.464	1.20	1.22
1044.3	7.06	4.75	2.50	2.55	0.406	1.13	1.10
1050.0	8.18	4.75	2.40	2.40	0.470	1.36	1.36
*1056.0	7.78	4.70	2.30	1.70	0.452	1.35	1.83
1062.1	6.01	4.00	1.90	1.35	0.410	1.26	1.78
1067.9	6.03	4.15	2.05	1.35	0.397	1.17	1.78
1074.1	7.53	4.20	2.10	1.25	0.489	1.43	2.40
1080.1	6.39	4.00	2.00	1.15	0.436	1.27	2.22
*1086.1	7.50	4.40	2.25	1.20	0.465	1.33	2.49

Test #75. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1091.9	7.47	4.50	2.30	1.20	0.453	1.30	2.48
1098.0	6.83	4.50	2.40	1.20	0.414	1.14	2.27
1104.0	5.83	2.65	1.20	0.80	0.601	1.94	2.91
1110.1	4.10	2.70	1.20	0.80	0.415	1.36	2.04
1116.1	4.17	2.85	1.30	0.85	0.399	1.28	1.96
*1122.0	5.08	2.90	1.35	0.85	0.478	1.50	2.38
†1128.0	3.89	2.70	1.25	0.80	0.393	1.24	1.94
1134.1	4.37	2.65	1.25	0.80	0.450	1.39	2.18
1140.4	3.17	2.70	1.25	0.80	0.321	1.01	1.58
1146.0	5.06	2.70	1.25	0.80	0.512	1.62	2.52
1152.3	3.44	2.70	1.25	0.80	0.348	1.10	1.72
1158.1	4.31	2.45	1.15	0.75	0.480	1.50	2.29
1164.1	3.89	2.60	1.20	0.80	0.408	1.29	1.94
1170.0	3.89	2.60	1.25	0.75	0.408	1.24	2.07
1176.0	4.17	2.35	1.55	0.75	0.484	1.07	2.22
*1181.8	6.03	3.55	2.40	1.05	0.464	1.00	2.29
1188.1	6.35	3.70	2.50	1.10	0.469	1.01	2.30
1194.0	5.93	3.55	2.40	1.10	0.456	0.986	2.15
1200.0	6.39	3.55	2.40	1.10	0.491	1.06	2.32
1205.8	6.61	3.50	2.40	1.10	0.516	1.10	2.40
1212.1	6.08	3.60	2.50	1.10	0.461	0.970	2.21
1218.0	6.50	3.50	2.45	1.10	0.507	1.06	2.36

Test #75. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1224.0	5.56	3.20	2.10	1.05	0.474	1.06	2.11
1230.1	5.46	3.20	2.10	1.00	0.466	1.04	2.18
1236.1	5.56	2.85	1.90	0.95	0.533	1.17	2.34
1242.0	5.93	2.85	1.90	0.95	0.568	1.25	2.49
1248.0	5.28	2.65	1.75	0.90	0.544	1.20	2.34
1254.2	5.65	2.95	2.00	1.00	0.523	1.13	2.25
1260.1	6.21	3.05	2.05	1.00	0.556	1.21	2.48
*1266.0	5.93	3.15	2.15	1.05	0.514	1.10	2.25
1272.0	5.28	2.90	1.95	0.95	0.497	1.08	2.22
†1272.0	START WYOMING GROUND H ₂ O						
1278.4	5.21	2.90	1.90	1.00	0.490	1.09	2.08
1284.5	5.46	2.90	1.90	0.95	0.514	1.15	2.29
1290.3	5.75	3.00	1.95	1.00	0.523	1.18	2.29
*1302.3	3.22	1.70	1.10	0.60	0.517	1.17	2.14
1308.7	2.86	1.45	0.90	0.55	0.538	1.27	2.07
1314.1	3.08	1.55	1.00	0.55	0.542	1.23	2.23
1320.1	2.50	1.20	0.75	0.45	0.569	1.33	2.22
1326.0	3.39	1.80	1.15	0.65	0.514	1.18	2.08
1332.4	3.13	1.60	1.00	0.55	0.534	1.25	2.27
1338.0	3.57	1.50	0.90	0.50	0.650	1.58	2.85
1344.1	5.74	3.30	2.10	1.05	0.475	1.09	2.18
*1350.1	5.83	3.25	2.05	1.00	0.490	1.13	2.33

Test #75. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1356.4	5.29	3.40	2.20	1.05	0.425	0.959	2.01
1362.0	6.55	3.35	2.15	1.05	0.534	1.22	2.49
1368.0	6.39	3.45	2.30	1.05	0.506	1.11	2.43
1374.1	5.74	3.80	2.55	1.10	0.412	0.898	2.08
*1380.6	5.64	3.70	2.55	1.10	0.416	0.882	2.05
1386.0	5.88	3.60	2.55	1.05	0.446	0.920	2.23
1392.0	5.00	3.65	2.70	1.00	0.374	0.739	2.00
1398.4	4.95	3.70	2.80	1.05	0.365	0.705	1.88
1404.3	4.24	3.65	2.85	1.00	0.317	0.594	1.69
1410.0	5.56	3.55	2.90	1.00	0.428	0.765	2.22
1417.6	5.70	4.00	3.40	1.10	0.389	0.669	2.06
1422.4	4.51	4.00	3.45	1.10	0.308	0.522	1.64
1428.2	5.46	4.00	3.55	1.10	0.373	0.614	1.98
*1434.0	5.17	3.95	3.60	1.05	0.357	0.573	1.96
†1440.0	5.28	4.10	4.20	1.15	0.352	0.502	1.83
1446.2	3.49	2.45	2.60	0.75	0.389	0.536	1.86
1452.1	4.24	2.60	2.85	0.80	0.445	0.594	2.11
1458.4	5.03	3.70	4.10	1.10	0.371	0.490	1.82
1464.1	4.09	3.60	4.05	1.10	0.310	0.403	1.48
1469.7	4.46	3.25	3.70	1.00	0.375	0.481	1.78
1476.1	5.47	4.15	4.80	1.25	0.360	0.455	1.75
*1483.3	5.32	4.20	4.90	1.30	0.346	0.433	1.63

Test #75. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1489.0	2.92	2.40	2.75	0.80	0.332	0.424	1.46
1495.3	2.69	2.25	2.60	0.75	0.326	0.413	1.43
1501.1	2.30	1.80	2.10	0.60	0.349	0.437	1.53
1513.0	6.11	4.95	5.70	1.40	0.337	0.428	1.74
1519.4	6.25	4.70	5.60	1.40	0.363	0.445	1.78
1526.0	5.36	4.60	5.65	1.40	0.318	0.379	1.53
1531.0	5.67	4.55	5.75	1.45	0.340	0.393	1.56
*1537.0	5.28	4.50	5.70	1.45	0.320	0.370	1.45
1543.3	5.29	4.55	5.95	1.50	0.317	0.355	1.41
1548.6	5.35	4.65	6.15	1.60	0.314	0.347	1.33
1555.0	4.95	4.75	6.25	1.65	0.284	0.316	1.20
1561.0	5.28	4.80	6.30	2.00	0.300	0.334	1.05
1567.1	4.64	4.80	6.50	2.10	0.264	0.285	0.882
1573.1	4.44	4.60	6.20	2.05	0.264	0.286	0.864
1579.0	5.65	4.65	6.30	2.10	0.332	0.358	1.08
1585.0	5.00	4.60	6.25	2.10	0.297	0.319	0.950
1591.1	4.64	4.35	6.00	2.10	0.291	0.309	0.882
1597.7	5.30	4.50	6.30	2.20	0.322	0.336	0.961
1603.0	4.40	4.50	6.30	2.25	0.267	0.279	0.780
*1609.0	4.72	4.45	6.20	2.25	0.290	0.303	0.837
1615.1	4.92	4.45	6.25	2.30	0.302	0.314	0.854
1621.1	3.89	4.70	6.50	2.40	0.226	0.239	0.647
1627.1	4.72	4.75	6.60	2.50	0.271	0.285	0.753
RUN TERMINATED							

Observations from the Simulation Leach Test #76

Ore used = Wyoming

Solution used = 1.0 g/l NH_4HCO_3 - 1.0 g/l Na_2SiO_3 -
sat'd O_2 at 45 psig

Inlet section packing material = -80 AFS Subangular Sand

Inlet section packing length = 10.0 in.

Length of the front ore section = 47.25 in.

Length of the middle ore section = 50.00 in.

Length of the end ore section = 44.38 in.

Outlet section packing material = -80 AFS Subangular Sand

Outlet section packing length = 5.00 in.

Ore packing bed density = 1.68 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the
peg-bottom drop-weight tamper. Batch size: 8 in. of the column
length. Amplitude of tamping - 2.0 ft. Frequency of tamping =
10 tamps/8 in. of ore. Column position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the
illustrations.

† indicates introduction of fresh feed
solution(s).

Test #76

Ore - Wyoming

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
48.0	10.28	1.95	1.40	4.70	1.91	2.82	0.861
54.0	10.28	1.45	1.60	2.00	2.57	2.47	1.75
60.0	9.17	2.60	1.75	1.10	1.28	2.01	2.84
66.0	10.56	2.10	1.40	0.85	1.82	2.90	4.23
72.0	8.06	1.75	1.10	0.75	1.67	2.81	3.66
78.4	4.43	0.90	0.55	0.40	1.79	3.09	3.77
85.0	6.31	1.35	0.80	0.55	1.70	3.03	3.91
†90.0	3.33	0.40	0.25	0.20	3.02	5.11	5.67
96.0	4.55	2.50	1.30	0.80	0.660	1.34	1.94
101.9	--	0.90	0	0	--	--	--
107.8	--	0.85	0	0	--	--	--
114.0	--	0.80	0	0	--	--	--
120.0	--	1.00	0	0.20	--	--	--
126.1	5.46	1.70	0.50	0.55	1.16	2.93	3.38
131.9	5.17	1.50	0.30	0.50	1.25	6.62	3.52
138.0	3.55	2.45	1.95	1.00	0.526	0.699	1.21
*144.0	8.61	2.30	1.80	1.00	1.36	1.84	2.93
150.0	6.39	1.60	1.30	0.10	1.45	1.89	21.77
156.1	7.38	1.70	1.20	0.10	1.57	2.36	25.14
162.0	5.37	1.45	0.90	0.10	1.34	2.29	18.30
168.0	9.72	2.40	1.80	1.00	1.47	2.07	3.31
*174.0	7.22	1.90	1.30	0.75	1.38	2.13	3.28

Test #76. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End sec.	Front sec.	Middle Sec.	End Sec.
180.1	6.01	1.90	1.20	0.80	1.15	1.92	2.56
186.0	5.37	1.80	1.05	0.70	1.08	1.96	2.61
*192.0	10.00	2.40	1.60	1.15	1.51	2.40	2.96
†192.0		START CHEMICAL LEACH WITH Na_2SiO_3					
197.8	12.07	3.65	2.85	0.35	1.20	1.63	11.75
204.2	9.90	3.75	2.75	0.80	0.958	1.38	4.22
*210.0	9.77	4.10	3.20	1.90	0.864	1.17	1.75
216.0	10.00	4.35	3.25	2.05	0.834	1.18	1.66
221.8	9.77	4.50	3.20	2.10	0.787	1.17	1.59
228.2	9.38	4.55	3.25	2.20	0.748	1.11	1.45
*234.0	9.77	4.65	3.35	2.30	0.762	1.12	1.45
†236.0		START CHEMICAL LEACH WITHOUT Na_2SiO_3					
240.0	10.42	4.20	3.35	1.95	0.900	1.19	1.82
245.7	10.23	4.15	3.40	1.95	0.894	1.16	1.79
252.0	8.99	4.15	3.35	1.95	0.786	1.03	1.57
*258.0	8.33	4.35	3.30	2.00	0.695	0.969	1.42
264.1	9.29	4.00	3.10	1.90	0.842	1.15	1.67
269.5	7.09	4.15	2.95	1.90	0.620	0.923	1.27
276.0	5.76	4.05	2.85	1.80	0.516	0.776	1.09
282.2	7.80	4.30	2.90	1.90	0.658	1.03	1.40
287.7	6.36	4.25	2.90	2.00	0.543	0.842	1.08
*293.9	8.06	4.40	2.90	2.00	0.664	1.07	1.37

Test #76. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
300.0	7.92	4.35	2.80	2.00	0.660	1.09	1.35
306.0	7.22	4.60	3.05	1.65	0.569	0.909	1.49
312.0	10.00	5.65	3.55	1.75	0.642	1.08	1.95
*318.1	9.29	5.65	3.40	1.60	0.596	1.05	1.98
324.1	10.56	6.00	3.40	1.70	0.638	1.19	2.12
330.0	9.08	6.25	3.40	1.70	0.527	1.03	1.82
336.0	10.28	6.40	3.55	1.80	0.583	1.11	1.95
341.9	11.02	7.00	3.20	1.50	0.571	1.32	2.50
347.9	9.17	7.25	3.20	1.45	0.459	1.10	2.15
354.0	8.74	7.40	3.20	1.50	0.428	1.05	1.99
360.0	10.28	7.55	3.15	1.55	0.494	1.25	2.26
*366.0	9.44	7.80	3.35	1.25	0.439	1.08	2.57
372.3	9.52	8.05	3.25	1.30	0.429	1.12	2.49
+378.0	9.65	8.35	3.35	1.45	0.419	1.11	2.27
383.8	9.20	8.15	3.25	1.45	0.409	1.09	2.16
390.0	9.41	8.40	3.10	1.45	0.406	1.17	2.21
395.9	10.17	9.10	3.40	1.40	0.405	1.15	2.47
402.0	9.84	9.45	3.45	1.45	0.378	1.09	2.31
408.0	9.72	9.50	3.35	1.50	0.371	1.11	2.21
414.0	9.17	9.75	3.30	1.50	0.341	1.07	2.08
420.4	9.90	9.95	3.30	1.50	0.361	1.15	2.25
426.2	8.91	11.0	3.40	1.60	0.294	1.01	1.90

Test #76. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*431.9	9.65	11.3	3.70	1.20	0.310	1.00	2.74
438.0	8.74	11.4	3.65	1.30	0.278	0.919	2.29
444.2	9.41	12.0	3.60	1.30	0.284	1.00	2.47
450.1	8.47	12.0	3.55	1.40	0.256	0.916	2.06
455.9	8.91	12.3	3.70	1.45	0.263	0.924	2.09
462.0	9.29	11.9	3.50	1.40	0.283	1.02	2.26
468.0	9.72	13.0	3.75	1.40	0.271	0.995	2.37
474.0	8.89	13.6	3.75	1.45	0.237	0.910	2.09
480.0	9.44	13.9	3.95	1.45	0.246	0.917	2.22
486.0	10.56	14.4	3.90	1.30	0.266	1.04	2.77
492.0	8.89	14.9	3.75	1.20	0.216	0.910	2.52
+498.0	8.89	15.0	3.75	1.15	0.215	0.910	2.63
*504.0	9.44	15.1	3.85	1.40	0.227	0.941	2.30
509.8	9.77	15.6	3.70	1.35	0.227	1.01	2.47
516.0	9.68	17.0	3.80	1.45	0.207	0.978	2.27
522.0	9.44	17.4	3.95	1.45	0.197	0.917	2.22
528.0	9.44	17.5	3.85	1.45	0.196	0.941	2.28
534.2	9.68	17.9	3.85	1.50	0.196	0.965	2.20
540.0	9.77	18.8	3.75	1.50	0.188	1.00	2.22
546.0	9.44	19.3	3.95	1.40	0.177	0.917	2.30
552.0	9.72	19.7	3.90	1.25	0.179	0.957	2.65
*558.4	9.11	20.0	3.65	1.10	0.165	0.958	2.82

Test #76. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
564.0	8.93	21.7	3.90	1.25	0.149	0.879	2.43
570.0	10.00	21.7	3.95	1.20	0.167	0.972	2.84
+575.0	9.00	22.3	3.85	1.25	0.146	0.897	2.45
582.4	8.56	22.3	3.80	1.25	0.139	0.865	2.33
*588.2	9.20	23.6	4.05	1.30	0.141	0.872	2.41
594.1	9.89	24.7	3.80	1.30	0.145	0.999	2.59
600.0	8.47	26.5	4.30	1.30	0.116	0.756	2.22
606.2	9.41	25.4	4.15	1.20	0.134	0.870	2.67
612.0	9.20	25.4	3.80	1.15	0.131	0.929	2.73
618.0	8.06	25.9	3.70	1.20	0.113	0.836	2.29
624.0	9.44	26.9	3.75	1.25	0.127	0.966	2.57
630.0	7.78	26.9	3.80	1.20	0.105	0.786	2.21
636.0	8.61	27.9	3.85	1.20	0.112	0.859	2.44
642.0	8.33	30.6	4.25	1.35	0.099	0.752	2.10
*648.0	9.44	31.3	4.45	1.55	0.109	0.814	2.07
654.1	9.29	31.6	4.15	1.40	0.107	0.859	2.26
660.2	9.56	33.7	4.10	1.35	0.103	0.895	2.41
666.0	8.62	35.2	4.00	1.55	0.089	0.827	1.89
+672.0	9.44	36.6	4.10	1.20	0.094	0.884	2.68
678.1	8.47	37.5	4.00	1.10	0.082	0.813	2.62
684.1	9.44	38.1	4.15	1.15	0.090	0.873	2.80
690.0	7.91	38.7	4.00	1.15	0.074	0.759	2.34

Test #76. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
696.0	8.61	40.3	4.10	1.35	0.077	0.806	2.17
701.6	9.52	42.2	4.20	1.40	0.082	0.870	2.32
708.4	8.58	42.1	4.10	1.40	0.074	0.803	2.09
714.0	7.44	42.2	3.95	1.50	0.064	0.723	1.69
720.0	8.06	42.5	3.90	1.40	0.069	0.793	1.96
726.6	7.32	42.1	3.70	1.35	0.063	0.759	1.85
732.2	6.55	42.2	3.65	1.40	0.056	0.689	1.59
*738.0	7.76	42.9	3.75	1.30	0.066	0.794	2.03
+744.0	7.78	42.6	3.65	1.20	0.066	0.818	2.21
750.1	6.01	43.0	3.35	1.05	0.051	0.689	1.95
756.1	5.56	42.6	3.45	1.05	0.047	0.619	1.80
762.2	7.10	43.0	3.45	1.00	0.060	0.790	2.42
768.0	5.75	43.2	3.25	1.05	0.048	0.679	1.87
773.9	5.65	43.0	3.30	1.05	0.048	0.657	1.83
779.9	6.39	42.5	3.30	1.10	0.055	0.743	1.98
786.3	5.21	43.2	3.20	1.10	0.044	0.625	1.61
792.2	5.37	42.7	3.15	1.10	0.046	0.654	1.66
797.6	4.63	42.8	3.10	1.05	0.039	0.573	1.50
803.8	4.57	42.3	3.00	1.10	0.039	0.585	1.42
810.0	5.65	42.3	3.05	1.10	0.048	0.711	1.75
816.0	5.28	43.2	3.15	1.20	0.044	0.643	1.50
*822.1	5.46	43.5	3.00	1.00	0.046	0.699	1.98

Test #76. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
828.1	5.56	43.0	2.90	1.00	0.047	0.736	1.89
834.0	5.37	43.0	2.80	1.00	0.046	0.736	1.83
840.0	5.56	42.6	2.80	1.00	0.047	0.762	1.89
846.4	5.47	42.6	2.70	1.00	0.047	0.778	1.86
852.3	4.52	43.2	2.65	1.00	0.038	0.655	1.54
858.0	4.97	43.2	2.70	1.00	0.042	0.707	1.69
864.0	5.00	43.2	2.65	1.00	0.042	0.724	1.70
870.1	5.19	43.2	2.55	1.00	0.044	0.781	1.77
875.8	4.68	42.9	2.60	1.00	0.040	0.691	1.59
882.1	4.50	43.2	2.75	1.00	0.038	0.628	1.53
*888.0	4.80	43.7	2.60	1.15	0.040	0.709	1.42
894.1	5.19	42.7	2.45	1.05	0.044	0.813	1.68
899.9	4.31	43.5	2.45	1.00	0.036	0.675	1.47
906.0	4.37	43.5	2.45	1.05	0.036	0.685	1.42
912.0	5.00	43.6	2.40	0.95	0.042	0.800	1.79
918.1	4.64	43.5	2.45	0.90	0.039	0.727	1.76
924.0	4.24	43.8	2.30	0.90	0.035	0.708	1.61
929.9	4.24	43.1	2.40	0.95	0.036	0.678	1.52
936.0	4.37	43.7	2.35	0.95	0.036	0.714	1.57
942.1	4.92	43.8	2.30	0.90	0.041	0.821	1.86
948.3	4.03	43.8	2.30	0.95	0.033	0.673	1.45
954.0	4.09	43.8	2.35	0.90	0.034	0.668	1.55

Test #76. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*960.2	4.30	43.8	2.30	0.95	0.036	0.718	1.54
966.1	4.24	43.8	2.25	0.95	0.035	0.723	1.52
972.0	3.39	43.8	2.25	0.95	0.028	0.578	1.22
978.0	4.44	43.3	2.25	0.95	0.037	0.758	1.59
984.0	4.17	44.8	2.30	1.10	0.034	0.696	1.29
+984.0			START 1.0 g/l Na_2SiO_3				
989.7	4.68	44.5	2.25	0.80	0.038	0.799	1.99
996.1	3.65	45.0	2.00	0.70	0.029	0.701	1.78
1002.0	3.39	45.1	1.90	0.80	0.027	0.685	1.44
1008.0	4.44	44.5	2.00	0.80	0.036	0.852	1.89
1013.7	3.51	44.5	1.90	0.75	0.029	0.709	1.59
1020.1	3.39	42.5	2.00	0.80	0.029	0.651	1.44
*1026.0	3.67	44.0	2.00	0.80	0.030	0.704	1.56
1032.0	3.33	44.1	1.90	0.80	0.027	0.673	1.42
1038.2	3.22	42.9	2.30	0.85	0.027	0.537	1.29
1044.1	5.65	41.5	3.25	1.20	0.049	0.667	1.60
*1050.0	6.21	43.5	3.25	1.20	0.052	0.734	1.76
1056.0	6.11	42.7	2.80	1.75	0.052	0.838	1.19
1062.2	5.11	42.0	2.50	1.70	0.044	0.785	1.02
1068.1	6.80	41.0	2.90	1.85	0.060	0.900	1.25
1074.0	7.06	41.6	3.20	1.90	0.062	0.847	1.27
1080.0	6.39	41.8	3.10	1.85	0.055	0.791	1.18

Test #76. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1086.3	6.88	42.2	3.20	1.95	0.059	0.825	1.20
1092.5	7.80	40.7	3.50	2.00	0.070	0.856	1.33
*1098.3	7.18	40.6	3.50	2.00	0.064	0.788	1.22
1104.1	6.32	37.0	2.90	1.80	0.062	0.837	1.20
1110.2	6.83	35.5	2.90	1.75	0.070	0.904	1.33
1116.6	6.25	35.1	2.90	1.75	0.065	0.827	1.22
1122.1	6.36	35.0	2.80	1.85	0.066	0.872	1.17
1128.1	6.94	35.5	2.90	1.80	0.071	0.919	1.31
1134.0	6.80	35.5	2.90	1.75	0.069	0.900	1.32
1140.3	5.82	35.5	2.90	1.70	0.059	0.770	1.17
*1146.0	6.73	35.5	3.00	1.75	0.069	0.861	1.31
+1152.1	5.74	28.5	1.80	1.45	0.073	1.22	1.35
1158.1	3.06	20.5	1.10	1.10	0.054	1.07	0.948
1164.3	2.15	14.6	1.60	1.00	0.053	0.516	0.733
1170.0	2.05	11.6	0.80	0.90	0.064	0.987	0.776
1176.0	3.89	25.8	2.40	1.55	0.055	0.622	0.855
1182.1	6.01	27.7	2.80	1.65	0.079	0.824	1.24
1188.5	4.69	25.9	2.10	1.55	0.066	0.857	1.03
1194.0	5.45	25.3	2.40	1.50	0.078	0.872	1.24
1200.0	5.00	26.2	2.90	1.60	0.069	0.666	1.06
*1206.3	5.03	25.2	2.90	1.60	0.072	0.666	1.07
1212.0	4.39	23.9	2.30	1.50	0.067	0.733	0.997

Test #76. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1218.0	4.44	23.3	2.5	1.50	0.069	0.682	1.01
1225.5	4.22	22.0	2.5	1.50	0.070	0.648	0.959
1230.3	4.51	21.9	2.4	1.50	0.075	0.721	1.02
1236.1	3.45	21.1	2.2	1.45	0.059	0.602	0.811
1242.0	3.95	20.1	2.3	1.40	0.071	0.659	0.961
1248.0	3.89	23.2	2.5	1.55	0.061	0.597	0.855
1254.1	7.65	33.5	4.1	2.05	0.083	0.716	1.27
1260.1	7.22	33.8	4.3	2.05	0.077	0.645	1.20
*1266.3	6.99	34.0	4.1	2.10	0.075	0.655	1.13
†1272.1	6.61	33.8	3.9	2.00	0.071	0.651	1.13
1277.6	7.58	33.5	4.2	1.90	0.082	0.693	1.36
1284.1	6.15	32.3	3.9	1.95	0.069	0.605	1.07
1291.3	5.79	32.1	4.2	1.95	0.065	0.529	1.01
1297.0	6.14	31.1	4.5	2.05	0.072	0.524	1.02
1303.2	6.72	30.4	4.7	2.10	0.080	0.549	1.09
1309.1	6.80	29.8	4.7	2.15	0.083	0.555	1.08
1315.0	6.80	29.7	5.3	2.20	0.083	0.493	1.05
1321.0	7.50	28.8	4.8	2.05	0.094	0.600	1.25
1327.3	6.61	29.0	4.7	2.05	0.083	0.540	1.10
*1333.9	7.32	28.8	4.8	2.05	0.092	0.585	1.22
1339.0	7.19	27.8	4.8	2.10	0.094	0.575	1.17
1345.0	6.11	27.9	4.8	1.95	0.079	0.489	1.07

Test #76. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1351.2	6.99	28.0	4.3	1.90	0.091	0.624	1.25
1356.5	5.97	27.8	4.6	1.85	0.078	0.498	1.10
1363.0	5.13	27.7	4.2	1.85	0.067	0.469	0.945
+1369.0		START GROUND H ₂ O					
1375.1	4.92	29.1	3.9	1.70	0.061	0.484	0.986
1381.1	4.72	30.0	4.0	1.80	0.057	0.453	0.893
1387.0	5.08	30.5	4.3	1.90	0.060	0.454	0.911
*1393.0	6.67	28.3	5.3	2.15	0.085	0.483	1.06
1399.0	7.50	26.5	5.5	2.20	0.103	0.524	1.16
1405.7	5.97	16.8	4.0	1.80	0.129	0.573	1.13
1411.0	4.09	15.1	3.5	1.60	0.098	0.449	0.871
1417.0	4.72	14.5	3.1	1.60	0.118	0.585	1.01
1423.1	2.19	4.5	--	1.00	0.117	--	0.746
1429.0	1.13	8.8	--	1.00	0.047	--	0.385
1435.0	1.67	4.5	0.9	1.00	0.135	0.712	0.569
*1441.0	3.61	12.0	2.65	1.45	0.109	0.523	0.848
1447.1	1.09	--	--	--	--	--	--
1452.8	3.39	7.70	2.15	1.25	0.160	0.605	0.924
1459.2	1.67	7.45	2.00	1.20	0.081	0.321	0.474
1465.2	1.41	6.10	1.65	1.15	0.084	0.328	0.418
1471.1	1.44	2.90	0.90	0.85	0.180	0.614	0.577
1476.9	2.69	9.40	2.10	1.25	0.104	0.492	0.733

Test #76. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1483.1	2.69	9.45	2.10	1.22	0.103	0.492	0.751
*1489.1	3.06	13.5	2.40	1.30	0.082	0.489	0.802
1495.1	2.78	12.7	2.20	1.30	0.079	0.485	0.729
1501.1	2.78	11.4	1.80	1.15	0.088	0.593	0.824
1507.3	0.81	6.32	1.20	1.00	0.046	0.259	0.276
1513.0	2.34	12.7	2.00	1.27	0.067	0.449	0.628
1519.2	2.42	12.8	1.85	1.20	0.069	0.502	0.687
1525.1	1.69	9.75	1.50	1.05	0.063	0.433	0.548
1531.0	0.85	6.35	0.95	0.90	0.049	0.343	0.322
*1537.0	2.78	15.8	2.20	1.35	0.064	0.485	0.702
1543.1	3.83	21.2	3.05	1.55	0.066	0.482	0.842
1549.1	4.17	21.1	3.00	1.55	0.072	0.534	0.917
1555.0	3.39	21.3	3.00	1.50	0.058	0.434	0.770
1561.0	5.00	25.0	3.55	1.70	0.072	0.541	1.00
1567.3	4.76	25.0	3.60	1.70	0.069	0.508	0.954
1573.0	4.39	25.0	3.55	1.70	0.064	0.475	0.880
1579.0	4.72	26.1	3.60	1.60	0.066	0.503	1.01
1585.0	4.44	25.4	3.40	1.60	0.063	0.501	0.945
1590.9	3.67	21.0	2.75	1.45	0.063	0.512	0.862
1597.6	2.99	20.9	2.60	1.40	0.052	0.441	0.728
*1603.1	3.33	20.9	2.60	1.40	0.058	0.492	0.810
1609.0	2.82	21.5	2.50	1.35	0.048	0.433	0.712

Test #76. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1615.1	2.73	22.0	2.50	1.35	0.045	0.419	0.689
1621.2	3.01	22.0	2.50	1.40	0.050	0.462	0.733
1627.1	3.39	22.0	2.45	1.35	0.056	0.531	0.856
1633.1	3.06	22.0	2.50	1.30	0.050	0.470	0.802
1639.2	1.91	22.0	2.40	1.35	0.031	0.306	0.482
*1645.4	3.22	22.5	2.40	1.35	0.052	0.515	0.813
1651.0	2.98	22.5	2.55	1.35	0.048	0.449	0.752
1657.0	2.50	23.1	2.45	1.30	0.039	0.392	0.655
1663.1	1.39	17.0	1.50	1.10	0.030	0.356	0.431
1669.2	1.94	16.1	1.30	1.10	0.044	0.573	0.601
+1675.0	2.30	16.2	1.45	1.05	0.051	0.609	0.746
1681.0	3.06	30.6	3.50	1.70	0.036	0.336	0.613
1687.1	5.19	30.2	3.65	1.75	0.062	0.546	1.01
1693.5	4.69	30.5	3.65	1.70	0.056	0.493	0.940
1699.0	4.24	29.5	3.60	1.70	0.052	0.452	0.850
1705.0	4.44	28.8	3.65	1.70	0.056	0.467	0.890
1711.1	4.37	28.9	3.75	1.70	0.055	0.447	0.876
1717.1	4.44	28.3	3.85	1.75	0.057	0.443	0.864
1723.0	5.08	27.9	4.05	1.80	0.066	0.482	0.962
1729.0	5.00	27.9	4.10	1.80	0.065	0.468	0.946
*1735.0	4.72	27.8	4.20	1.80	0.062	0.431	0.893
1741.1	4.64	27.6	4.35	1.95	0.061	0.409	0.811

Test #76. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1747.0	5.65	27.4	4.45	1.90	0.075	0.487	1.01
1753.0	5.56	26.6	4.65	1.95	0.076	0.459	0.971
1759.0	6.11	26.0	4.70	1.95	0.085	0.499	1.07
1765.1	5.19	25.8	4.90	2.10	0.073	0.407	0.842
1771.5	6.51	26.0	5.25	2.15	0.091	0.476	1.03
1777.0	7.58	25.6	5.50	2.15	0.107	0.529	1.20
1783.1	6.01	25.7	5.60	2.05	0.085	0.412	0.999
1789.1	6.11	25.4	5.95	2.10	0.087	0.394	0.991
1795.3	6.18	25.3	6.00	2.10	0.089	0.395	1.00
1801.0	5.85	25.0	6.15	2.05	0.085	0.365	0.972
1806.9	6.50	25.3	6.05	2.00	0.093	0.412	1.11
1813.1	5.38	25.0	6.20	1.95	0.078	0.333	0.940
1819.0	5.08	25.1	6.35	1.90	0.073	0.307	0.911
*1825.0	5.56	25.5	6.45	1.85	0.079	0.331	1.02
RUN TERMINATED							

Observations from the Simulation Leach Test #77

Ore used = Wyoming

Solution used = 1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2

Inlet section packing material = -80 AFS Subangular Sand

Inlet section packing length = 10.0 in.

Length of the front ore section = 47.25 in.

Length of the middle ore section = 50.00 in.

Length of the end ore section = 44.38 in.

Outlet section packing material = -80 AFS Subangular Sand

Outlet section packing length = 5.00 in.

Ore packing bed density = 1.68 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = 10 tamps/8 in. of ore. Column position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.

† indicates introduction of fresh feed solution(s).

Test #77

Ore - Wyoming

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
48.0	9.17	1.9	2.1	2.7	1.75	1.68	1.16
*54.5	8.46	1.8	2.4	1.1	1.70	1.35	2.62
60.1	10.42	1.7	2.2	1.1	2.22	1.82	3.22
66.1	9.89	1.8	2.6	0.6	1.99	1.46	5.62
72.0	8.47	1.6	2.8	--	1.92	1.16	--
78.2	9.41	2.1	3.2	--	1.63	1.13	--
84.0	9.48	2.2	2.7	0.6	1.56	1.92	5.38
90.0	9.44	2.2	2.7	0.6	1.56	1.34	5.36
*96.0	8.61	2.0	2.6	0.9	1.56	1.27	3.26
102.1	9.84	2.1	2.5	1.0	1.70	1.51	3.35
108.0	9.08	2.3	2.6	1.1	1.43	1.34	2.81
†116.0	5.41	2.3	2.4	1.5	0.853	0.865	1.23
120.0	8.75	2.9	2.4	1.5	1.09	1.40	1.99
126.0	10.28	2.7	2.6	0.9	1.38	1.52	3.89
132.2	8.60	2.6	2.4	0.9	1.20	1.38	3.26
137.9	9.36	3.1	2.6	1.1	1.10	1.38	2.90
*144.0	9.29	2.9	2.8	1.1	1.16	1.27	2.88
150.0	9.44	2.9	2.8	1.1	1.18	1.29	2.92
156.1	8.20	2.8	2.6	1.1	1.06	1.21	2.54
161.9	8.91	2.7	3.0	1.1	1.20	1.14	2.76
168.0	7.92	2.7	2.8	1.3	1.06	1.09	2.08
173.5	9.09	2.8	3.0	1.3	1.18	1.16	2.38

Test #77. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*180.4	8.21	2.8	3.0	1.3	1.06	1.05	2.15
186.0	8.04	2.7	3.2	1.5	1.08	0.965	1.83
+186.0			START 3 g/l AlCl ₃				
192.0	8.89	2.3	3.0	0.9	1.40	1.14	3.37
198.6	5.05	1.7	1.8	0.3	1.08	1.08	5.74
204.2	5.36	1.6	2.0	0.5	1.22	1.03	3.65
210.0	5.46	1.6	2.4	0.7	1.24	0.873	2.66
*216.0	5.83	1.9	2.4	0.7	1.11	0.933	2.84
222.0	5.56	1.6	2.2	0.3	1.26	0.970	6.31
228.2	5.38	1.8	2.4	0.5	1.08	0.861	3.67
234.2	4.44	1.6	2.6	0.5	1.01	0.656	3.03
240.0	4.89	1.7	2.4	0.3	1.04	0.782	5.55
*245.8	4.60	1.7	2.4	0.3	0.981	0.736	5.22
251.9	4.10	1.7	2.4	0.3	0.875	0.656	4.66
258.4	5.13	1.9	2.8	0.3	0.979	0.703	5.83
264.3	4.24	1.6	2.8	0.3	0.961	0.581	4.82
269.6	4.72	1.6	2.6	0.5	1.07	0.697	3.22
275.8	4.03	1.6	2.6	0.5	0.914	0.595	2.75
*282.0	4.57	1.7	2.8	0.5	0.975	0.627	3.11
288.0	4.72	1.7	2.8	0.5	1.01	0.647	3.22
294.2	4.03	1.6	2.6	0.5	0.914	0.595	2.75
300.0	5.17	1.5	2.4	0.5	1.25	0.827	3.52

Test #77. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
306.0	4.17	1.9	2.6	0.5	0.796	0.616	2.84
312.0	4.17	1.6	2.4	0.7	0.945	0.667	2.03
318.4	5.21	2.2	3.0	1.3	0.859	0.667	1.37
324.2	5.75	2.1	3.0	1.1	0.993	0.736	1.78
*330.0	5.46	2.2	3.0	1.3	0.900	0.699	1.43
+330.0		START 1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2					
336.0	8.06	3.7	4.3	1.9	0.790	0.720	1.45
*342.0	8.06	4.9	4.4	1.7	0.597	0.703	1.62
347.8	6.90	4.8	4.4	1.5	0.521	0.620	1.57
354.1	6.61	4.4	4.2	1.5	0.545	0.604	1.50
360.0	7.91	6.2	5.4	2.1	0.463	0.562	1.28
*366.0	8.06	6.2	5.4	2.1	0.472	0.573	1.31
371.8	7.47	6.3	5.6	2.1	0.430	0.512	1.21
378.0	8.33	6.2	5.4	2.1	0.487	0.592	1.35
384.0	8.33	7.1	5.8	2.3	0.426	0.551	1.23
390.0	8.33	7.7	5.0	1.9	0.392	0.640	1.49
396.1	8.20	8.0	5.0	1.9	0.372	0.630	1.47
401.9	8.33	8.2	4.8	1.9	0.368	0.666	1.49
407.9	8.33	8.3	5.0	1.9	0.364	0.640	1.49
414.0	7.92	8.4	4.6	1.9	0.342	0.661	1.42
*420.4	7.55	8.4	4.6	1.9	0.326	0.630	1.35
425.9	6.97	8.2	4.8	1.9	0.308	0.557	1.25

Test #77. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
432.2	7.94	8.8	4.8	1.9	0.327	0.635	1.42
438.0	8.33	9.1	4.8	1.9	0.332	0.666	1.49
444.1	7.65	9.1	4.8	1.9	0.305	0.612	1.37
450.0	7.91	9.0	4.6	1.9	0.319	0.660	1.42
456.0	8.06	9.4	5.0	1.7	0.311	0.619	1.61
461.7	8.77	9.7	5.0	1.7	0.328	0.673	1.76
468.1	8.59	10.1	4.6	1.7	0.308	0.717	1.72
*474.0	8.76	10.4	4.6	1.7	0.306	0.731	1.76
480.0	9.17	10.4	4.6	1.7	0.320	0.765	1.84
485.7	7.89	10.1	4.6	1.7	0.283	0.658	1.58
492.1	8.07	10.1	4.6	1.7	0.290	0.673	1.62
498.0	9.08	10.4	4.6	1.7	0.317	0.758	1.82
†504.0	8.33	10.4	4.6	1.7	0.291	0.695	1.67
510.1	8.20	10.4	4.6	1.7	0.286	0.684	1.64
516.1	9.17	10.6	4.4	1.7	0.314	0.800	1.84
522.0	9.89	10.7	5.2	1.7	0.335	0.730	1.98
528.0	8.33	10.7	5.2	1.7	0.282	0.615	1.67
534.2	8.60	11.1	5.4	1.7	0.281	0.611	1.72
540.1	9.60	11.3	5.2	1.7	0.308	0.709	1.92
546.0	9.32	11.6	5.2	1.7	0.291	0.688	1.87
552.0	8.33	11.8	5.6	1.7	0.256	0.571	1.67
*558.4	8.59	12.3	5.4	1.7	0.253	0.611	1.72

Test #77. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
564.4	8.89	12.7	4.8	1.9	0.254	0.711	1.59
570.3	8.76	12.8	5.0	1.9	0.248	0.673	1.57
576.1	8.91	12.8	5.2	1.7	0.252	0.658	1.79
582.3	8.87	12.6	5.6	1.5	0.255	0.608	2.01
588.6	7.94	12.3	5.6	1.5	0.234	0.544	1.80
594.1	8.18	12.1	5.8	1.5	0.245	0.541	1.86
600.1	8.89	12.5	5.8	1.7	0.258	0.588	1.78
606.0	9.32	12.7	6.2	1.7	0.266	0.577	1.87
612.3	8.73	12.6	6.0	1.7	0.251	0.559	1.75
618.0	9.65	12.7	6.2	1.7	0.276	0.598	1.93
*624.0	8.89	12.8	6.4	1.7	0.252	0.533	1.78
630.1	8.47	12.8	6.4	1.7	0.240	0.508	1.70
636.4	8.99	12.7	6.2	1.7	0.257	0.557	1.80
642.0	9.23	12.9	6.4	1.3	0.260	0.554	2.42
648.0	8.33	13.2	6.2	1.5	0.229	0.516	1.89
654.1	8.47	13.1	6.0	1.5	0.235	0.542	1.92
660.6	8.72	13.1	6.0	1.5	0.241	0.558	1.98
666.0	8.64	13.4	6.0	1.5	0.234	0.553	1.96
672.0	8.33	13.7	5.8	1.7	0.221	0.551	1.67
678.3	8.20	13.7	5.8	1.7	0.217	0.543	1.64
684.3	8.06	13.7	5.8	1.7	0.213	0.533	1.62
†690.0	7.89	14.0	5.8	1.7	0.204	0.522	1.58

Test #77. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*697.5	8.00	13.9	6.2	1.7	0.209	0.495	1.60
702.3	7.29	13.6	6.2	1.7	0.194	0.451	1.46
708.2	7.63	13.6	6.2	1.7	0.203	0.472	1.53
714.0	8.33	13.7	6.6	1.5	0.221	0.485	1.89
720.0	8.06	13.7	6.6	1.5	0.213	0.469	1.83
726.1	8.33	14.0	6.6	1.5	0.216	0.485	1.89
732.0	7.34	14.3	6.6	1.5	0.186	0.427	1.67
738.4	7.03	14.1	6.8	1.5	0.181	0.397	1.60
744.2	8.05	13.9	7.0	1.5	0.210	0.441	1.83
749.6	8.33	13.8	7.0	1.3	0.219	0.457	2.18
756.0	8.33	13.8	7.0	1.3	0.219	0.457	2.18
763.4	6.76	13.6	7.2	1.3	0.180	0.360	1.77
*769.0	7.14	13.7	7.2	1.5	0.189	0.381	1.62
775.2	7.26	13.9	7.6	1.5	0.189	0.367	1.65
781.0	7.47	13.9	7.6	1.5	0.195	0.377	1.70
787.0	7.50	14.5	8.2	1.5	0.188	0.351	1.70
793.0	8.33	14.5	8.0	1.7	0.208	0.400	1.67
799.4	8.07	13.9	8.0	1.7	0.211	0.387	1.62
805.9	8.21	13.9	8.2	1.5	0.214	0.384	1.86
811.0	7.84	13.9	8.2	1.5	0.205	0.367	1.78
817.0	8.06	14.1	8.4	1.7	0.207	0.368	1.62
823.3	8.73	13.9	8.8	1.5	0.228	0.381	1.98

Test #77. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
828.5	7.69	14.0	8.8	1.7	0.199	0.335	1.54
*835.0	8.46	14.4	9.0	1.7	0.213	0.361	1.70
841.0	7.50	14.3	9.4	1.7	0.190	0.306	1.50
847.0	8.61	14.7	10.2	1.7	0.212	0.324	1.73
853.0	8.06	14.8	10.4	1.7	0.198	0.298	1.62
859.0	8.61	14.9	11.0	1.3	0.210	0.300	2.26
865.0	8.89	14.5	11.2	1.5	0.222	0.305	2.02
871.1	7.65	14.0	11.4	1.5	0.198	0.258	1.74
877.6	8.97	13.7	11.4	1.5	0.237	0.302	2.04
+883.0	8.02	13.8	11.6	1.5	0.211	0.265	1.82
889.0	7.50	11.3	10.2	1.5	0.241	0.282	1.70
895.1	8.20	11.1	10.6	1.3	0.263	0.297	2.15
*901.0	5.65	9.0	7.8	1.1	0.228	0.278	1.75
907.0	3.33	6.4	6.4	0.9	0.189	0.200	1.26
913.0	4.17	11.8	13.0	2.1	0.128	0.123	0.677
919.1	7.92	11.8	12.2	1.7	0.243	0.249	1.59
924.8	7.60	11.7	12.2	1.5	0.236	0.239	1.73
931.1	5.56	11.3	12.0	1.5	0.178	0.178	1.26
937.2	6.56	11.7	12.6	1.7	0.203	0.200	1.31
943.1	6.50	11.3	12.4	1.7	0.209	0.201	1.30
948.8	6.43	11.7	13.6	1.9	0.199	0.182	1.15
955.0	6.45	12.2	14.0	1.9	0.192	0.177	1.16

Test #77. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*961.1	7.10	12.5	15.0	1.5	0.206	0.182	1.61
967.0	7.91	12.7	16.6	1.5	0.226	0.183	1.80
973.1	7.10	12.4	16.6	1.5	0.208	0.164	1.61
979.3	7.80	12.3	17.0	1.5	0.230	0.176	1.77
985.0	7.02	12.3	16.8	1.7	0.207	0.160	1.41
991.2	7.53	12.5	17.4	1.5	0.218	0.166	1.71
997.1	7.63	12.1	17.8	1.5	0.229	0.165	1.73
1003.0	6.80	12.3	18.0	1.7	0.201	0.145	1.36
*1009.0	6.94	12.3	18.8	1.5	0.205	0.142	1.58
1015.2	6.99	12.7	19.4	1.7	0.200	0.138	1.40
1021.1	7.63	12.5	19.4	1.7	0.221	0.151	1.53
1027.0	7.34	12.3	19.8	1.7	0.216	0.142	1.47
1033.0	8.61	13.4	23.0	1.9	0.233	0.144	1.54
1039.4	8.59	13.2	23.8	1.9	0.236	0.139	1.54
1045.1	8.18	12.8	24.4	1.7	0.232	0.129	1.64
1051.0	8.19	13.0	25.0	1.5	0.229	0.126	1.86
1057.0	9.17	12.7	25.8	1.3	0.262	0.136	2.40
1062.9	8.47	12.4	26.2	1.5	0.248	0.124	1.92
1069.6	7.71	12.1	26.6	1.1	0.231	0.111	2.39
*1075.1	7.88	11.9	26.6	1.3	0.240	0.134	2.07
1081.0	7.91	11.9	26.6	1.3	0.241	0.114	2.07
FRONT SECTION CRACKED; RUN TERMINATED							

Observations from the Simulation Leach Test #78

Ore used = Wyoming

Solution used = 1.0 g/l NH_4HCO_3 - Sat'd O_2 at 45 psig

Inlet section packing material = -80 AFS Subangular Sand

Inlet section packing length = 10.0 in.

Length of the front ore section = 47.00 in.

Length of the middle ore section = 50.00 in.

Length of the end ore section = 44.13 in.

Outlet section packing material = -80 AFS Subangular Sand

Outlet section packing length = 5.00 in.

Ore packing bed density = 1.66 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = 10 tamps/8 in. of ore. Column position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.

† indicates introduction of fresh feed solution(s).

Test #78

Ore - Wyoming

Sol - 1.0 g/l NH_4HCO_3
sat'd O_2 (45 psig)

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
35.9	5.75	1.30	1.70	1.75	1.60	1.30	1.11
42.0	6.28	1.30	1.40	1.10	1.74	1.72	1.93
*48.0	8.33	1.65	1.80	1.25	1.82	1.78	2.26
54.1	9.84	1.70	1.85	1.20	2.09	2.04	2.78
60.1	8.89	1.70	1.80	1.15	1.89	1.90	2.62
†66.0	10.17	1.60	1.80	1.05	2.29	2.17	3.28
72.0	8.89	1.60	1.80	1.05	2.00	1.90	2.87
78.1	7.38	1.30	1.55	0.80	2.05	1.83	3.12
84.4	8.73	1.60	1.80	1.00	1.97	1.86	2.96
90.0	8.33	1.70	1.90	1.00	1.77	1.68	2.82
96.2	8.60	1.60	1.80	0.95	1.94	1.83	3.07
*102.1	8.76	1.70	1.90	1.00	1.86	1.77	2.97
108.1	8.61	1.70	1.90	1.00	1.83	1.74	2.92
114.0	8.76	1.75	1.90	0.90	1.81	1.77	3.30
120.0	9.17	1.70	1.85	0.50	1.95	1.90	6.21
126.0	8.61	1.75	1.95	0.55	1.78	1.79	5.30
132.1	9.72	1.70	1.90	0.50	2.06	1.96	6.58
138.0	9.89	1.70	1.90	0.60	2.10	2.00	5.58
144.0	8.06	1.55	1.85	1.05	1.88	1.67	2.60
149.8	9.77	1.70	2.10	1.15	2.07	1.79	2.88
*156.1	8.73	1.60	2.00	1.00	1.97	1.68	2.96
162.0	9.60	1.60	2.10	1.10	2.16	1.75	2.96

Test #78. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
†162.0		START CHEMICAL LEACH					
168.0	8.89	2.00	2.25	1.15	1.60	1.52	2.62
*174.1	9.84	2.30	2.10	1.50	1.54	1.80	2.22
180.1	8.61	2.55	2.25	1.75	1.22	1.47	1.67
186.0	9.32	2.60	2.25	1.70	1.29	1.59	1.86
192.0	9.17	2.60	2.40	1.80	1.27	1.47	1.73
*198.2	9.41	2.70	2.45	1.80	1.26	1.47	1.77
204.1	8.47	2.65	2.30	1.75	1.15	1.41	1.64
210.0	8.47	2.60	2.20	1.65	1.18	1.48	1.74
216.0	8.89	2.80	2.35	1.90	1.15	1.45	1.58
222.4	8.33	2.70	2.15	1.70	1.11	1.49	1.66
228.6	8.60	2.80	2.00	1.60	1.11	1.65	1.82
234.7	7.92	2.80	1.95	1.65	1.02	1.56	1.63
240.1	9.55	2.80	2.10	1.70	1.23	1.75	1.90
*246.3	8.60	2.85	2.00	1.60	1.09	1.65	1.82
252.7	8.85	2.90	1.90	1.50	1.10	1.79	2.00
258.1	9.25	3.10	1.75	1.50	1.08	2.03	2.09
264.1	8.33	3.10	1.75	1.45	0.970	1.83	1.95
270.0	8.47	3.30	1.75	1.40	0.926	1.86	2.05
*276.4	8.59	3.30	1.70	1.30	0.939	1.94	2.24
†282.0	8.93	3.35	1.65	1.30	0.962	2.08	2.33
288.1	9.02	3.60	1.75	1.45	0.904	1.98	2.11

Test #78. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
294.1	8.89	3.50	1.60	1.25	0.916	2.13	2.41
300.4	9.26	3.90	1.70	1.30	0.857	2.09	2.41
*306.0	8.93	3.80	1.60	1.30	0.848	2.14	2.33
312.0	9.17	4.20	1.80	1.40	0.788	1.96	2.22
318.1	9.29	4.40	1.70	1.30	0.762	2.10	2.42
324.6	8.46	4.50	1.70	1.20	0.678	1.91	2.39
*330.0	8.63	4.65	1.65	1.20	0.670	2.01	2.44
336.0	8.33	5.00	1.75	1.25	0.601	1.83	2.26
342.4	8.33	5.25	1.75	1.20	0.572	1.83	2.35
348.3	8.19	5.40	1.75	1.20	0.547	1.80	2.31
354.0	8.48	5.50	1.70	1.15	0.556	1.91	2.50
*361.6	8.33	5.75	1.80	1.25	0.523	1.78	2.26
366.4	7.29	5.95	1.75	1.20	0.442	1.60	2.06
372.2	7.47	6.05	1.80	1.15	0.445	1.59	2.20
378.0	8.33	6.35	1.85	1.15	0.473	1.73	2.45
384.0	8.33	6.50	1.80	1.20	0.462	1.78	2.35
390.1	9.29	7.05	1.90	1.20	0.475	1.88	2.62
*396.0	8.47	7.30	1.90	1.20	0.419	1.71	2.39
†402.4	8.07	7.45	1.90	1.20	0.391	1.63	2.28
408.1	7.89	7.55	1.95	1.40	0.377	1.55	1.91
413.8	7.60	7.55	1.85	1.40	0.363	1.58	1.84
420.1	8.20	8.20	2.00	1.50	0.361	1.57	1.85

Test #78. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
427.4	8.22	8.15	1.90	1.50	0.364	1.66	1.86
433.0	6.85	8.50	2.00	1.60	0.291	1.31	1.45
439.3	8.20	8.70	1.90	1.50	0.340	1.66	1.85
445.1	7.76	8.95	2.05	1.60	0.313	1.45	1.64
451.0	8.19	9.40	2.15	1.40	0.314	1.46	1.98
*457.0	8.33	9.70	2.00	1.40	0.310	1.60	2.02
463.4	8.07	9.90	2.00	1.15	0.294	1.55	2.38
470.0	8.33	10.05	2.00	1.15	0.299	1.60	2.45
475.0	8.33	10.15	1.95	1.15	0.296	1.64	2.45
481.0	8.61	10.6	2.15	1.30	0.293	1.54	2.24
487.3	9.52	11.1	2.50	1.30	0.309	1.46	2.48
492.6	9.43	11.6	2.45	1.30	0.293	1.48	2.46
499.0	8.33	11.6	2.45	1.30	0.259	1.31	2.17
505.0	8.89	12.2	2.30	1.30	0.263	1.48	2.32
*511.1	8.20	12.1	2.35	1.25	0.245	1.34	2.22
517.1	8.61	12.4	2.35	1.20	0.251	1.41	2.43
523.0	8.19	12.3	2.35	1.20	0.240	1.34	2.31
+529.0	8.33	13.6	2.35	1.30	0.221	1.36	2.17
535.1	8.74	14.1	2.35	1.25	0.224	1.43	2.37
541.7	8.84	13.3	2.30	1.20	0.240	1.48	2.50
547.0	7.86	13.3	2.30	1.20	0.213	1.31	2.22
553.0	9.17	14.2	2.40	1.25	0.233	1.47	2.48

Test #78. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
559.1	9.56	15.0	2.50	1.25	0.230	1.47	2.59
*565.1	8.33	15.0	2.50	1.20	0.200	1.28	2.35
571.1	8.33	15.7	2.55	1.25	0.191	1.25	2.26
577.0	8.19	15.7	2.40	1.30	0.188	1.31	2.13
583.1	8.20	16.0	2.50	1.20	0.185	1.27	2.31
588.9	8.33	16.0	2.60	1.20	0.188	1.23	2.35
595.2	6.88	15.7	2.50	1.10	0.158	1.06	2.12
601.3	7.10	16.2	2.50	1.10	0.158	1.09	2.19
607.1	8.62	17.0	2.60	1.20	0.183	1.27	2.43
612.9	8.62	17.0	2.70	1.20	0.183	1.23	2.43
619.1	7.53	17.8	2.65	1.25	0.153	1.09	2.04
*625.2	7.92	17.7	2.45	1.25	0.161	1.24	2.15
631.1	7.63	18.2	2.50	1.10	0.151	1.17	2.35
637.1	7.22	18.1	2.50	1.10	0.144	1.11	2.22
643.4	7.94	19.1	2.55	1.20	0.150	1.20	2.24
649.0	8.33	19.7	2.45	1.20	0.153	1.31	2.35
655.2	8.06	20.2	2.45	1.20	0.144	1.26	2.27
661.1	7.91	20.6	2.55	1.10	0.139	1.19	2.44
667.0	7.63	21.4	2.35	1.10	0.129	1.25	2.35
*673.0	7.22	22.3	2.50	1.20	0.117	1.11	2.04
679.2	7.80	24.5	2.60	1.20	0.115	1.15	2.20
685.1	8.19	24.1	2.50	1.20	0.123	1.26	2.31

Test #78. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
691.0	7.63	25.2	2.50	1.20	0.109	1.17	2.15
697.0	8.06	26.5	2.55	1.35	0.110	1.21	2.02
703.3	8.47	27.5	2.65	1.30	0.111	1.23	2.21
709.1	7.47	28.0	2.60	1.25	0.096	1.10	2.02
715.0	7.92	29.1	2.55	1.20	0.098	1.19	2.24
*†721.0	8.89	30.5	2.65	1.30	0.105	1.29	2.32
726.9	9.60	32.5	2.70	1.35	0.107	1.36	2.41
733.7	8.09	32.5	2.60	1.30	0.090	1.19	2.11
739.1	8.63	32.5	2.60	1.25	0.096	1.27	2.34
745.0	8.47	34.0	2.75	1.25	0.090	1.18	2.30
751.2	8.87	34.5	2.65	1.20	0.093	1.28	2.50
757.2	8.33	35.0	2.65	1.25	0.086	1.21	2.26
763.1	7.63	35.0	2.60	1.30	0.079	1.13	1.99
769.1	8.33	35.5	2.60	1.20	0.085	1.23	2.35
775.1	8.89	36.8	2.70	1.10	0.087	1.26	2.74
781.4	7.41	37.2	2.70	1.20	0.072	1.05	2.09
787.0	7.44	37.0	2.70	1.20	0.072	1.06	2.10
*793.0	8.06	38.3	2.45	1.15	0.076	1.26	2.37
799.1	7.92	38.1	2.50	1.10	0.075	1.22	2.44
805.2	7.92	38.1	2.50	1.10	0.075	1.22	2.44
811.0	6.61	38.3	2.45	1.15	0.063	1.04	1.95
817.0	7.22	38.5	2.35	1.05	0.068	1.18	2.33

Test #78. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
823.0	6.67	38.5	2.40	1.00	0.063	1.07	2.26
829.5	7.18	39.0	2.45	1.00	0.066	1.13	2.43
835.0	6.97	38.3	2.55	1.05	0.066	1.05	2.25
841.0	6.94	38.9	2.30	0.90	0.064	1.16	2.61
*847.1	6.56	39.3	2.40	0.90	0.060	1.05	2.47
853.0	5.93	39.3	2.35	1.05	0.054	0.969	1.91
859.0	6.94	38.5	2.40	1.00	0.065	1.11	2.35
865.0	6.11	38.8	2.30	0.95	0.057	1.02	2.18
871.1	6.01	38.8	2.35	0.95	0.056	0.982	2.14
877.3	5.38	39.4	2.20	0.95	0.049	0.939	1.92
883.0	6.43	38.8	2.30	0.90	0.060	1.07	2.42
889.0	5.56	39.0	2.20	0.90	0.051	0.970	2.09
895.0	6.39	39.0	2.20	0.80	0.059	1.12	2.71
901.1	5.74	39.0	2.20	0.80	0.053	1.00	2.43
*907.5	5.99	39.0	2.10	0.90	0.055	1.10	2.25
913.0	6.06	39.5	2.15	0.90	0.055	1.08	2.28
919.1	5.19	39.0	2.10	0.70	0.048	0.949	2.51
925.1	5.56	39.0	2.10	0.80	0.051	1.02	2.35
931.4	5.29	39.2	2.15	0.80	0.049	0.945	2.24
937.1	5.85	39.2	2.10	0.80	0.054	1.07	2.20
943.0	5.65	39.2	2.00	0.75	0.052	1.08	2.55
*949.1	5.46	39.1	2.00	0.75	0.050	1.05	2.47

Test #78. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
955.0	5.37	39.2	2.00	0.80	0.049	1.03	2.27
961.0	5.28	39.5	2.00	0.90	0.048	1.01	1.99
†961.0			START GROUND H ₂ O				
967.1	6.83	39.5	2.10	0.85	0.062	1.25	2.72
972.7	5.06	39.5	2.15	0.95	0.046	0.904	1.80
979.0	4.76	39.5	2.20	0.95	0.043	0.831	1.70
985.0	7.22	38.8	2.25	1.00	0.067	1.23	2.45
*991.4	6.77	39.0	2.50	1.10	0.062	1.04	2.09
997.0	8.33	39.1	2.40	1.00	0.077	1.33	2.82
1003.0	7.78	38.8	2.35	0.95	0.072	1.27	2.77
1009.0	5.56	37.1	2.00	0.90	0.054	1.07	2.09
1015.1	6.83	37.0	2.05	0.80	0.067	1.28	2.89
1021.0	6.50	36.5	2.30	0.85	0.064	1.08	2.59
1027.1	6.28	35.5	2.10	0.85	0.064	1.15	2.50
*1033.2	5.19	35.6	2.00	0.80	0.053	0.996	2.20
1039.1	5.93	37.6	2.00	0.70	0.057	1.14	2.87
1045.1	5.28	38.9	2.10	0.60	0.049	0.965	2.98
1051.1	5.28	39.1	1.90	0.65	0.049	1.07	2.75
1057.0	4.80	39.0	1.85	0.65	0.044	0.996	2.50
1063.1	4.10	39.0	2.00	0.50	0.038	0.787	2.78
*1069.1	4.72	39.3	2.00	0.45	0.043	0.906	3.55

Test #78. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1074.9	3.74	39.3	2.10	0.35	0.034	0.684	3.62
1081.1	4.57	39.2	2.20	0.30	0.042	0.797	5.16
1087.1	3.89	38.7	2.30	0.30	0.036	0.649	4.39
1093.3	4.30	39.1	2.45	0.30	0.040	0.674	4.85
*1099.0	4.09	39.0	2.60	0.30	0.038	0.604	4.62
†1105.0	4.44	40.6	2.95	0.45	0.039	0.578	3.34
1111.1	3.83	39.7	3.20	0.35	0.035	0.459	3.70
1118.0	3.86	40.0	3.70	0.50	0.035	0.401	2.61
1123.0	5.00	38.6	4.10	0.60	0.047	0.468	2.82
*1129.0	4.17	38.0	4.75	0.60	0.040	0.337	2.35
1135.0	4.44	37.0	6.05	0.60	0.043	0.282	2.51
1141.1	5.19	35.5	7.30	0.65	0.053	0.273	2.70
1147.0	5.37	34.5	8.10	0.75	0.056	0.255	2.43
1153.0	5.00	32.8	9.45	0.95	0.055	0.203	1.78
1159.2	4.03	28.6	10.9	0.70	0.051	0.142	1.95
1165.1	4.24	27.0	12.5	0.70	0.057	0.130	2.05
1171.0	3.67	27.0	13.0	0.80	0.049	0.108	1.55
1177.0	3.61	26.6	13.0	1.10	0.049	0.107	1.11
1183.1	3.31	26.6	14.0	1.05	0.045	0.091	1.07
*1189.1	3.31	26.0	14.0	1.00	0.046	0.091	1.12
1195.0	3.95	26.7	13.4	1.00	0.053	0.113	1.34
1201.0	3.89	30.5	14.1	1.10	0.046	0.106	1.20

Test #78. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1207.1	4.10	30.0	14.1	1.10	0.049	0.112	1.26
1213.1	3.61	29.7	13.9	1.10	0.044	0.100	1.11
1219.0	4.52	30.5	13.6	1.10	0.053	0.128	1.39
1225.0	3.89	31.0	13.0	1.15	0.045	0.115	1.15
1231.2	4.57	30.6	12.9	1.15	0.054	0.136	1.35
*1236.8	3.87	31.1	13.0	1.15	0.045	0.114	1.14
1243.1	4.76	31.1	12.9	1.20	0.055	0.142	1.34
1249.1	3.33	30.5	13.0	1.15	0.039	0.098	0.981
1255.2	4.10	30.5	13.0	1.10	0.049	0.121	1.26
1260.9	4.97	31.0	13.1	1.10	0.058	0.146	1.53
1267.1	4.03	30.3	13.3	1.05	0.048	0.116	1.30
1273.2	4.10	29.6	14.0	1.10	0.050	0.112	1.26
1279.2	3.33	30.0	13.7	1.05	0.040	0.093	1.07
1285.0	4.02	29.9	14.0	1.05	0.049	0.110	1.30
1291.0	4.17	29.0	14.9	1.00	0.052	0.107	1.41
1297.0	3.89	28.6	15.0	1.05	0.049	0.100	1.25
1303.1	4.17	28.5	15.5	1.00	0.053	0.103	1.41
1309.3	2.96	28.5	15.5	1.00	0.037	0.073	1.00
1315.0	3.22	28.7	15.4	1.10	0.040	0.080	0.991
*1321.0	3.33	27.8	15.8	1.10	0.043	0.081	1.03
1327.0	4.44	27.1	16.0	1.10	0.059	0.107	1.37
1333.4	2.86	27.2	16.1	1.15	0.038	0.068	0.842

Test #78. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1339.0	3.27	26.3	16.9	1.00	0.045	0.074	1.11
1351.4	5.73	25.0	18.2	1.15	0.083	0.121	1.69
1357.2	3.16	24.6	18.6	1.10	0.046	0.065	0.973
1363.0	3.74	24.0	19.1	1.10	0.056	0.075	1.15
+1369.0	3.06	23.6	19.5	1.10	0.047	0.060	0.942
1374.9	3.11	24.7	20.0	1.05	0.045	0.060	1.00
1381.2	2.91	23.5	21.4	1.00	0.045	0.052	0.986
1387.0	3.16	24.0	20.6	1.05	0.048	0.059	1.02
1393.0	2.50	23.7	19.8	1.10	0.038	0.048	0.770
1399.3	3.17	23.7	20.0	1.00	0.048	0.061	1.07
*1405.1	2.87	23.9	17.3	1.00	0.043	0.064	0.972
1411.4	2.91	19.3	15.0	0.85	0.054	0.074	1.16
1417.0	2.98	18.1	13.9	0.80	0.059	0.082	1.26
1423.0	2.22	27.7	16.3	1.00	0.029	0.052	0.752
1429.1	3.28	29.0	14.6	1.00	0.041	0.086	1.11
1435.3	3.49	29.3	13.4	1.10	0.043	0.100	1.07
1441.2	4.24	30.2	13.4	1.15	0.051	0.121	1.25
1447.3	3.83	30.2	13.4	1.15	0.046	0.110	1.13
1453.0	3.80	29.6	13.5	1.30	0.046	0.108	0.990
1459.0	4.17	30.5	13.4	1.35	0.049	0.119	1.05
1465.0	4.17	31.2	12.8	1.45	0.048	0.125	0.974
1471.1	4.10	30.5	12.7	1.50	0.049	0.124	0.926

Test #78. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1477.5	4.17	30.5	12.8	1.45	0.049	0.125	0.974
1483.0	3.94	30.9	12.7	1.60	0.046	0.119	0.834
1489.0	4.72	30.2	12.9	1.60	0.056	0.140	0.999
1495.0	4.72	30.3	12.9	1.50	0.056	0.140	1.07
1501.0	3.61	29.9	12.9	1.40	0.044	0.107	0.873
*1507.0	3.89	30.4	12.8	1.45	0.046	0.117	0.909
1513.0	4.17	30.5	12.7	1.50	0.049	0.126	0.942
1519.0	3.61	30.0	12.7	1.40	0.043	0.109	0.873
1525.2	4.30	30.0	12.8	1.40	0.052	0.129	1.04
1531.0	3.74	30.5	13.2	1.50	0.044	0.109	0.844
1537.0	4.17	29.3	13.4	1.45	0.051	0.119	0.974
1542.8	4.02	29.2	13.5	1.35	0.050	0.114	1.01
1548.8	3.61	29.2	13.7	1.35	0.045	0.101	0.906
1555.0	3.76	29.5	13.8	1.40	0.046	0.105	0.910
1561.0	3.61	28.7	14.0	1.50	0.045	0.099	0.815
1567.0	4.44	28.8	13.9	1.45	0.056	0.123	1.04
1573.4	3.39	28.8	13.9	1.55	0.042	0.094	0.741
†1579.0	3.27	28.7	14.0	1.40	0.041	0.090	0.791
1585.1	4.13	29.4	14.6	1.60	0.051	0.109	0.874
*1590.7	4.13	28.7	14.8	1.50	0.052	0.107	0.933
1597.2	3.08	29.0	15.2	1.50	0.038	0.078	0.695
1603.0	4.31	29.1	15.3	1.50	0.053	0.108	0.973

Test #78. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1608.9	3.67	28.6	15.0	1.60	0.046	0.094	0.777
1615.2	3.44	28.1	14.7	1.55	0.044	0.090	0.752
1621.1	4.80	28.6	14.5	1.55	0.061	0.127	1.05
1627.0	3.67	30.0	13.5	1.70	0.044	0.104	0.731
1633.0	2.50	30.2	13.5	1.50	0.030	0.071	0.565
1639.4	4.95	30.0	13.4	2.00	0.060	0.142	0.838
1645.2	3.74	29.9	13.8	1.50	0.045	0.104	0.844
1651.0	6.03	30.0	13.2	1.95	0.072	0.175	1.05
1657.0	4.44	29.5	13.1	2.05	0.054	0.130	0.734
1663.1	4.64	29.5	13.1	1.95	0.057	0.136	0.806
1669.1	4.44	29.1	13.1	2.00	0.055	0.130	0.752
1675.0	4.52	29.6	13.4	2.20	0.055	0.129	0.696
1681.0	4.72	29.5	13.5	2.20	0.058	0.134	0.727
*1687.0	4.17	28.8	13.5	2.05	0.052	0.119	0.689
1693.0	5.28	28.5	13.6	2.10	0.067	0.149	0.852
1699.0	3.33	29.5	13.0	2.20	0.041	0.098	0.513
1705.0	4.44	29.5	12.9	2.30	0.054	0.132	0.654
1711.3	4.57	29.1	13.0	2.15	0.057	0.135	0.720
1717.0	4.68	29.0	13.0	2.15	0.058	0.138	0.737
1723.0	3.89	28.6	13.3	2.35	0.049	0.112	0.561
1729.0	4.17	28.6	13.3	2.35	0.053	0.120	0.601
1735.2	4.57	28.7	13.3	2.30	0.057	0.132	0.673

Test #78. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1741.0	4.31	28.7	13.1	2.30	0.054	0.126	0.635
1747.1	3.28	28.7	13.1	2.35	0.041	0.096	0.473
1753.0	3.95	27.2	13.7	2.35	0.052	0.111	0.569
1759.3	4.23	27.5	13.3	2.40	0.055	0.122	0.597
1765.2	5.08	27.4	13.5	2.40	0.067	0.144	0.717
1771.0	3.45	27.2	13.3	2.45	0.046	0.100	0.477
1777.0	4.17	27.2	13.5	2.45	0.055	0.119	0.576
*1783.2	3.76	27.5	13.3	2.45	0.049	0.109	0.520
1789.2	3.61	26.7	13.6	2.40	0.049	0.102	0.509
1795.2	4.44	27.2	13.5	2.55	0.059	0.126	0.590
1801.0	3.45	26.1	13.7	2.60	0.048	0.097	0.449
1807.1	3.83	26.1	13.8	2.50	0.053	0.107	0.519
1813.4	2.91	26.4	13.8	2.50	0.040	0.081	0.394
1819.0	3.87	26.4	13.8	2.50	0.053	0.108	0.524
1825.1	4.37	26.4	13.8	2.55	0.060	0.122	0.580
1831.0	3.11	25.5	14.2	2.45	0.044	0.084	0.430
1837.3	4.23	25.6	14.6	2.45	0.060	0.111	0.585
†1843.0	3.80	25.1	15.0	2.55	0.055	0.097	0.505
1855.2	3.42	25.3	15.9	2.50	0.049	0.083	0.463
1861.0	4.31	24.8	15.9	2.55	0.063	0.104	0.572
*1879.3	3.46	24.1	16.0	2.55	0.052	0.083	0.460
1885.1	3.45	24.1	16.1	2.60	0.052	0.082	0.449

Test #78. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1891.0	3.39	24.5	15.5	2.70	0.050	0.084	0.425
1903.2	3.69	24.5	15.6	2.60	0.054	0.091	0.481
1909.1	3.39	24.0	15.6	2.65	0.050	0.083	0.433
1915.4	3.17	24.0	15.6	2.65	0.048	0.078	0.405
1921.0	3.57	25.2	14.7	2.80	0.051	0.093	0.432
1927.0	3.61	24.8	14.7	2.70	0.053	0.094	0.453
1933.0	3.06	24.8	14.6	2.70	0.045	0.080	0.384
1939.2	2.69	24.8	14.7	2.75	0.039	0.070	0.331
1945.0	3.45	25.3	14.7	2.90	0.049	0.090	0.403
1951.1	3.83	24.8	14.6	2.85	0.056	0.101	0.455
1957.0	3.39	24.8	14.9	2.90	0.049	0.087	0.396
1963.0	3.33	24.8	14.3	3.10	0.048	0.089	0.363
1969.0	3.89	25.6	14.0	3.10	0.055	0.107	0.425
1975.2	4.03	25.7	14.0	3.05	0.057	0.111	0.448
1981.4	3.49	25.2	13.9	3.05	0.050	0.100	0.388
*1987.1	3.80	26.0	13.0	3.25	0.053	0.112	0.396
1993.1	3.89	26.0	13.1	3.10	0.054	0.114	0.425
1999.2	3.01	27.6	13.0	3.15	0.039	0.089	0.324
2005.0	4.02	25.1	12.9	3.25	0.058	0.120	0.419
2011.0	3.89	25.5	12.7	3.45	0.055	0.118	0.382
2017.0	3.75	25.4	13.0	3.35	0.053	0.111	0.379
2023.0	3.75	25.0	12.8	3.40	0.054	0.112	0.374

Test #78. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
2029.1	3.52	24.8	13.1	3.40	0.051	0.103	0.351
2035.0	3.52	24.8	13.1	3.40	0.051	0.103	0.351
2041.0	3.52	24.8	13.1	3.40	0.051	0.103	0.351
2047.0	2.69	24.5	13.3	3.45	0.040	0.078	0.264
2053.0	2.69	24.2	13.6	3.45	0.040	0.076	0.264
2059.0	2.69	24.5	13.3	3.45	0.040	0.078	0.264
2065.0	3.68	23.3	13.4	3.40	0.057	0.105	0.367
2071.0	3.68	23.7	13.5	3.45	0.056	0.105	0.361
2077.1	3.68	23.7	13.6	3.40	0.056	0.104	0.367
2083.3	3.64	23.7	13.6	3.45	0.055	0.103	0.357
*2089.0	3.64	23.6	13.8	3.40	0.056	0.101	0.363
2089.0			RUN TERMINATED				

Observations from the Simulation Leach Test #79

Ore used = Wyoming

Solution used = 1.0 g/l NH_4CO_3 - 1.0 MgSO_4 -
Sat'd O_2 at 25 psig

Inlet section packing material = -80 AFS Subangular Sand

Inlet section packing length = 10.0 in.

Length of the front ore section = 47.50 in.

Length of the middle ore section = 50.00 in.

Length of the end ore section = 44.25 in.

Outlet section packing material = -80 AFS Subangular Sand

Outlet section packing length = 5.00 in.

Ore packing bed density = 1.66 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = 10 tamps/8 in. of ore. Column position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.

† indicates introduction of fresh feed solution(s).

Test #79

Ore - Wyoming

Sol - 1.0 g/l NH_4HCO_3 -
1.0 g/l MgSO_4 -
sat'd O_2 (25 psig)

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End sec.
36.0	3.51	0.25	0.65	0.40	5.12	2.07	2.98
42.0	4.17	1.80	1.45	0.70	0.845	1.10	2.02
48.0	8.89	2.25	1.60	0.55	1.44	2.13	5.49
53.8	6.32	0.95	1.00	0.40	2.43	2.43	5.37
60.6	9.31	1.20	1.15	0.40	2.83	3.11	7.91
*66.0	7.09	1.20	1.00	0.40	2.15	2.72	6.02
+72.0	8.33	1.85	1.35	0.50	1.64	2.37	5.66
78.1	8.47	1.00	0.95	0.30	3.09	3.42	9.59
84.2	5.74	1.55	1.20	0.40	1.35	1.84	4.87
90.0	9.48	1.90	1.35	0.45	1.82	2.70	7.16
96.0	9.72	2.00	1.45	0.50	1.77	2.57	6.60
102.1	10.38	2.15	1.55	0.50	1.76	2.57	7.05
108.4	9.26	2.20	1.60	0.50	1.54	2.22	6.29
114.0	9.23	2.10	1.60	0.50	1.60	2.21	6.27
*120.0	10.83	2.35	1.60	0.65	1.68	2.60	5.66
126.0	9.72	2.40	1.65	0.60	1.48	2.26	5.50
132.2	10.06	2.15	1.50	0.55	1.71	2.57	6.21
138.0	10.00	2.35	1.65	0.60	1.55	2.33	5.66
144.0	11.67	2.65	1.85	0.75	1.61	2.42	5.29
150.0	10.93	2.55	1.80	0.65	1.56	2.33	5.71
156.5	9.23	2.45	1.80	0.60	1.37	1.97	5.23
162.0	10.30	2.60	1.90	0.60	1.44	2.00	5.83

Test #79. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*168.0	10.00	2.55	1.85	0.65	1.43	2.08	5.23
*168.0			START LEACH				
174.1	10.46	2.65	2.00	0.60	1.44	2.01	5.92
179.9	10.06	3.15	1.95	0.85	1.16	1.98	4.02
186.0	9.84	3.45	2.00	1.20	1.04	1.89	2.79
*192.0	10.00	3.30	2.25	1.20	1.11	1.71	2.83
198.0	10.83	3.70	2.30	1.25	1.07	1.81	2.94
204.2	9.68	3.60	2.30	1.30	0.981	1.62	2.53
210.0	10.34	3.60	2.35	1.35	1.05	1.69	2.60
216.0	11.11	3.30	2.35	1.50	1.23	1.81	2.52
*222.0	10.28	3.35	2.30	1.35	1.12	1.72	2.59
228.0	9.17	3.35	2.30	1.50	0.998	1.53	2.08
234.5	10.26	3.45	2.45	1.45	1.08	1.61	2.40
240.0	10.30	3.05	2.45	1.45	1.23	1.61	2.41
246.0	10.00	3.05	2.20	1.35	1.20	1.75	2.52
252.1	9.17	3.00	2.10	1.40	1.11	1.68	2.23
258.3	9.95	3.05	2.10	1.25	1.19	1.82	2.70
264.0	9.06	2.80	2.00	1.40	1.18	1.74	2.20
269.9	10.45	2.65	2.05	1.20	1.44	1.96	2.96
276.1	8.60	2.60	2.05	1.15	1.21	1.61	2.54
*282.0	10.17	2.75	2.00	1.10	1.35	1.95	3.14
288.0	10.56	2.75	2.05	1.30	1.40	1.98	2.76

Test #79. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
294.1	10.38	2.65	2.0	1.10	1.43	1.99	3.21
299.6	10.61	2.60	1.95	1.10	1.49	2.09	3.28
306.0	10.16	2.50	1.95	1.15	1.48	2.00	3.00
†312.0	11.11	2.15	1.90	1.20	1.88	2.24	3.15
318.3	10.58	2.35	1.75	1.00	1.64	2.32	3.59
323.9	11.31	2.50	1.85	1.00	1.65	2.35	3.84
*330.0	10.66	2.55	1.90	1.05	1.52	2.15	3.45
336.0	11.11	2.35	1.75	1.00	1.72	2.44	3.77
342.0	10.83	2.40	1.70	0.95	1.65	2.45	3.87
348.0	10.28	2.30	1.70	0.95	1.63	2.32	3.68
354.6	10.35	2.30	1.65	0.95	1.64	2.41	3.70
360.1	10.30	2.30	1.65	0.95	1.63	2.40	3.68
366.0	10.17	2.30	1.70	0.90	1.61	2.30	3.84
372.0	11.39	2.30	1.60	0.95	1.81	2.73	4.07
378.0	10.00	2.35	1.70	1.00	1.55	2.26	3.40
383.8	10.92	2.25	1.60	0.95	1.77	2.62	3.90
390.0	10.22	2.20	1.45	0.90	1.69	2.71	3.86
396.0	10.00	2.05	1.55	0.95	1.78	2.48	3.58
401.9	10.45	2.25	1.50	0.90	1.69	2.67	3.94
*408.0	10.38	2.30	1.40	0.95	1.65	2.85	3.71
414.1	9.84	2.25	1.50	0.90	1.59	2.52	3.71
420.3	10.48	2.20	1.50	0.90	1.74	2.68	3.96

Test #79. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
426.0	10.23	2.10	1.55	0.90	1.78	2.53	3.86
432.0	10.83	2.15	1.40	0.90	1.84	2.97	4.09
438.0	9.72	2.00	1.30	0.85	1.77	2.87	3.88
444.9	10.87	2.15	1.40	0.95	1.84	2.98	3.89
450.0	10.13	2.10	1.40	0.95	1.76	2.78	3.62
†456.0	10.28	2.00	1.20	1.00	1.87	3.29	3.49
462.0	9.44	2.05	1.25	0.90	1.70	2.90	3.56
*468.0	9.44	2.05	1.25	0.85	1.70	2.90	3.77
474.0	9.44	2.20	1.35	0.85	1.56	2.68	3.77
480.0	9.17	1.95	1.20	0.95	1.72	2.93	3.28
486.1	9.84	2.00	1.20	0.80	1.79	3.15	4.18
492.0	9.08	2.05	1.35	0.85	1.62	2.58	3.63
498.0	9.72	2.15	1.35	0.95	1.65	2.76	3.48
504.0	9.72	2.10	1.25	0.85	1.69	2.99	3.88
510.0	9.44	2.05	1.20	0.85	1.68	3.02	3.77
516.0	8.61	2.20	1.30	0.80	1.43	2.54	3.66
522.0	8.33	1.95	1.35	0.80	1.56	2.37	3.54
*528.0	10.83	2.30	1.45	1.05	1.72	2.87	3.50
534.0	11.11	2.25	1.40	1.00	1.80	3.05	3.77
540.1	10.38	2.30	1.40	1.00	1.65	2.85	3.53
546.0	11.58	2.30	1.40	1.00	1.84	3.18	3.93
552.0	10.56	2.25	1.35	1.00	1.71	3.00	3.59

Test #79. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
558.1	11.20	2.20	1.40	0.95	1.86	3.07	4.00
563.7	9.82	2.20	1.35	0.95	1.63	2.79	3.51
570.1	11.46	2.00	1.50	1.00	2.09	2.93	3.89
576.0	10.92	2.05	1.25	0.85	1.94	3.35	4.36
582.1	10.38	1.95	1.30	1.00	1.94	3.07	3.53
587.8	11.11	2.00	1.35	1.00	2.03	3.16	3.77
594.0	11.83	2.10	1.30	1.00	2.05	3.49	4.02
*600.1	10.66	1.90	1.25	1.00	2.05	3.27	3.62
606.2	10.66	1.90	1.30	0.90	2.05	3.15	4.02
612.0	10.92	1.95	1.25	0.95	2.04	3.35	3.90
618.0	10.00	1.90	1.20	0.90	1.92	3.20	3.77
624.0	10.83	1.70	1.10	0.90	2.32	3.78	4.09
630.0	9.72	1.90	1.05	0.75	1.87	3.55	4.40
636.2	8.87	1.80	1.10	0.80	1.80	3.10	3.77
642.0	8.62	1.95	1.15	0.95	1.61	2.88	3.08
648.0	9.72	1.65	1.15	0.80	2.15	3.24	4.13
653.8	10.34	1.85	1.25	0.80	2.04	3.18	4.39
660.3	9.49	1.85	1.25	0.85	1.87	2.91	3.79
†666.0	10.23	1.75	1.25	0.70	2.13	3.14	4.96
678.3	9.62	1.70	1.15	0.75	2.06	3.21	4.36
684.2	10.73	1.90	1.25	0.75	2.06	3.30	4.86
*690.0	10.06	1.85	1.20	0.75	1.98	3.22	4.56

Test #79. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
696.0	10.83	1.90	1.35	0.85	2.08	3.08	4.33
702.0	11.38	2.00	1.30	0.75	2.08	3.36	5.15
708.1	10.66	2.20	1.35	0.70	1.77	3.03	5.17
714.0	10.45	2.10	1.45	0.80	1.82	2.77	4.44
720.0	10.56	1.90	1.25	0.80	2.03	3.24	4.48
726.3	11.11	2.10	1.30	0.70	1.93	3.28	5.39
732.0	9.94	1.90	1.30	0.50	1.91	2.94	6.75
738.3	8.73	2.00	1.25	0.65	1.59	2.68	4.56
†744.0	9.65	1.90	1.30	0.60	1.85	2.85	5.46
*749.9	9.08	2.05	1.25	0.60	1.62	2.79	5.14
756.0	10.66	2.05	1.40	0.60	1.90	2.92	6.04
762.2	8.87	2.10	1.35	0.60	1.54	2.52	5.02
768.1	9.08	2.15	1.40	0.65	1.54	2.49	4.75
774.2	9.84	2.25	1.40	0.60	1.59	2.70	5.57
779.8	9.23	2.10	1.30	0.55	1.60	2.73	5.70
786.0	8.33	1.90	1.30	0.60	1.60	2.46	4.72
792.0	11.11	2.05	1.35	0.70	1.98	3.16	5.39
798.1	10.66	2.05	1.35	0.70	1.90	3.03	5.17
804.5	10.16	2.15	1.35	0.70	1.72	2.89	4.93
†810.0	10.30	1.95	1.40	0.75	1.93	2.82	4.67
816.0	11.11	1.95	1.30	0.75	2.08	3.28	5.03
822.0	11.11	2.15	1.55	0.70	1.88	2.75	5.39

Test #79. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
827.9	11.02	2.25	1.40	0.70	1.79	3.02	5.35
*834.0	10.38	2.05	1.40	0.70	1.85	2.85	5.04
840.0	10.00	2.10	1.35	0.75	1.74	2.84	4.53
845.9	10.45	2.05	1.45	0.60	1.86	2.77	5.92
852.1	10.22	2.05	1.35	0.60	1.82	2.91	5.79
858.0	9.32	2.15	1.40	0.70	1.58	2.56	4.52
864.0	10.28	2.10	1.40	0.65	1.79	2.82	5.37
869.7	9.36	2.10	1.40	0.60	1.63	2.57	5.30
875.7	9.17	2.10	1.35	0.55	1.59	2.61	5.66
882.0	9.52	2.10	1.40	0.60	1.65	2.61	5.39
888.0	9.72	2.00	1.30	0.60	1.77	2.87	5.50
893.9	9.60	2.00	1.35	0.55	1.75	2.73	5.93
900.4	7.95	1.95	1.35	0.55	1.49	2.26	4.91
905.9	8.79	2.05	1.30	0.50	1.56	2.60	5.98
*912.0	8.47	1.95	1.25	0.55	1.58	2.60	5.23
917.7	8.77	2.00	1.25	0.55	1.60	2.69	5.42
924.2	7.69	1.90	1.25	0.45	1.48	2.36	5.81
930.0	7.76	2.00	1.20	0.50	1.42	2.48	5.27
935.8	7.47	1.90	1.20	0.45	1.43	2.39	5.64
942.1	8.06	2.00	1.20	0.40	1.47	2.58	6.84
948.1	7.22	1.80	1.25	0.35	1.46	2.22	7.01
954.0	7.34	1.85	1.30	0.45	1.45	2.17	5.54

Test #79. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*960.0	8.89	1.95	1.40	0.50	1.66	2.44	6.04
+960.0		START GROUND H ₂ O					
966.4	6.77	1.60	1.05	0.40	1.54	2.48	5.75
972.1	7.31	1.60	1.10	0.40	1.67	2.55	6.21
978.0	8.19	1.50	1.10	0.40	1.99	2.86	6.96
*984.0	8.06	1.55	1.00	0.40	1.90	3.09	6.84
990.0	8.06	1.40	1.05	0.25	2.10	2.95	10.95
996.1	6.56	1.40	1.05	0.20	1.71	2.40	11.14
1002.0	7.34	1.25	0.90	0.30	2.14	3.13	8.31
1008.0	7.78	1.20	0.85	0.30	2.36	3.51	8.81
1013.9	5.37	1.25	0.85	0.10	1.57	2.43	18.24
*1020.0	7.10	1.30	0.95	0.10	1.99	2.87	24.12
1026.0	7.22	1.15	0.85	0.05	2.29	3.26	49.1
1032.0	6.39	1.30	0.75	0.05	1.79	3.27	43.4
1038.0	6.99	1.50	0.85	0.05	1.70	3.16	47.5
1043.9	3.22	1.50	0.90	0.05	0.783	1.37	21.9
1050.0	7.65	1.20	0.75	0.05	2.32	3.92	52.0
1056.0	9.17	1.80	1.05	0.15	1.86	3.35	20.8
1062.2	9.41	1.85	1.10	0.05	1.86	3.28	63.9
*1068.0	8.91	1.95	1.15	0.05	1.67	2.97	60.5
+1074.0	5.83	1.85	1.15	0.05	1.15	1.95	39.6
1092.1	5.17	1.45	0.95	0.05	1.30	2.09	35.1

Test #79. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1098.0	5.08	1.30	0.80	0.05	1.43	2.44	34.5
1103.9	4.24	1.35	0.80	0.05	1.15	2.03	28.8
1110.1	5.11	1.30	0.85	0.05	1.43	2.31	34.7
1116.2	4.64	1.30	0.80	0.05	1.30	2.23	31.5
1122.1	3.95	1.25	0.75	0.05	1.15	2.02	26.8
1128.0	5.08	1.50	0.85	0.10	1.24	2.29	17.3
*1134.1	5.74	1.55	0.85	0.05	1.35	2.59	39.0
1140.3	5.65	1.60	0.85	0.05	1.29	2.55	38.4
1145.9	6.55	1.55	0.85	0.10	1.54	2.96	22.3
1152.0	6.83	1.55	0.85	0.10	1.61	3.08	23.2
1158.0	5.28	1.45	0.75	0.05	1.33	2.70	35.9
1164.2	5.38	1.50	0.80	0.05	1.31	2.58	36.6
1170.0	4.02	1.45	0.75	0.05	1.01	2.06	27.3
1182.1	4.82	1.45	0.75	0.05	1.21	2.47	32.7
1188.1	4.17	1.45	0.75	0.05	1.05	2.13	28.3
1206.2	4.42	1.40	0.70	0.05	1.15	2.42	30.0
1212.1	3.39	1.45	0.70	0.05	0.853	1.86	23.0
*1218.0	3.95	1.40	0.70	0.05	1.03	2.17	26.8
1230.1	3.58	1.30	0.55	0.05	1.00	2.50	24.3
1236.1	3.06	1.45	0.55	0.05	0.770	2.14	20.8
1242.3	4.57	1.65	0.55	0.05	1.01	3.19	31.0
1248.0	2.92	1.45	0.50	0.05	0.734	2.24	19.8

Test #79. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1253.8	4.02	1.45	0.50	0.05	1.01	3.09	27.3
1260.0	2.96	1.45	0.55	0.05	0.744	2.07	20.1
1266.1	5.19	1.50	0.55	0.05	1.26	3.62	35.3
1272.0	3.11	1.45	0.55	0.05	0.782	2.17	21.1
1278.0	3.33	1.45	0.55	0.05	0.838	2.32	22.6
*1284.0	3.47	1.35	0.55	0.05	0.937	2.42	23.6
1290.0	3.47	1.55	0.55	0.05	0.816	2.42	23.6
1296.0	3.89	1.60	0.60	0.05	0.887	2.49	26.4
1302.1	3.55	1.55	0.65	0.05	0.835	2.10	24.1
1308.3	3.76	1.65	0.65	0.05	0.831	2.22	25.5
1314.0	3.22	1.65	0.70	0.05	0.712	1.77	21.9
1320.0	3.89	1.55	0.40	0.25	0.915	3.73	5.29
*1326.1	3.83	1.55	0.40	0.15	0.901	3.68	8.67
1332.0	2.82	1.60	0.40	0.10	0.643	2.71	9.58
1338.0	3.06	1.55	0.40	0.05	0.720	2.94	20.8
RUN TERMINATED							

Observations from the Simulation Leach Test #80

Ore used = Wyoming

Solution used = 1.0 g/l NH_4HCO_3 - Sat'd O_2 (45 psig)

Inlet section packing material = -80 AFS Subangular Sand

Inlet section packing length = 10.0 in.

Length of the front ore section = 47.13 in.

Length of the middle ore section = 50.25 in.

Length of the end ore section = 44.38 in.

Outlet section packing material = -80 AFS Subangular Sand

Outlet section packing length = 5.00 in.

Ore packing bed density = 1.66 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = 10 tamps/8 in. of ore. Column position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.

† indicates introduction of fresh feed solution(s).

Test #80

Ore - Wyoming

Sol - 1.0 g/l NH_4HCO_3 -
sat'd O_2 (45 psig)

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
42.0	5.85	1.05	0.50	1.45	2.02	4.51	1.37
54.2	7.92	1.50	0.95	1.35	1.91	3.22	2.00
60.1	8.19	1.90	1.25	1.50	1.56	2.53	1.86
66.0	10.17	2.40	1.60	1.75	1.53	2.45	1.98
72.0	9.17	2.00	1.30	1.55	1.66	2.72	2.02
*77.9	8.76	2.00	1.25	1.50	1.58	2.70	1.99
84.1	7.92	1.85	1.10	1.30	1.55	2.78	2.08
90.0	5.08	2.05	1.25	1.55	0.897	1.57	1.12
96.0	7.50	2.35	1.45	1.65	1.15	2.00	1.55
*102.2	9.68	2.30	1.40	1.45	1.52	2.67	2.27
108.0	5.75	1.50	0.70	1.00	1.39	3.17	1.96
+114.3	6.08	1.85	1.00	1.10	1.19	2.35	1.88
120.0	9.36	2.55	1.85	1.50	1.33	1.95	2.13
125.8	4.60	1.00	0.35	0.70	1.66	5.07	2.24
131.9	4.10	1.20	0.45	0.75	1.24	3.52	1.86
138.2	--	--	--	--	--	--	--
144.0	4.02	1.40	0.45	0.80	1.04	3.45	1.71
150.2	4.57	1.50	0.55	0.80	1.10	3.21	1.95
155.8	2.38	1.10	0.20	0.70	0.783	4.59	1.16
162.0	5.65	2.95	2.00	1.55	0.693	1.09	1.24
*168.0	11.11	2.60	1.45	1.40	1.55	2.96	2.70
+168.0	START 1.0 g/l NH_4HCO_3 SAT'D O_2 (45 psig)						

Test #80. Cont.

Time Hrs.	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End sec.	Front Sec.	Middle Sec.	End Sec.
*174.0	11.11	3.60	2.25	1.60	1.12	1.90	2.37
180.4	10.42	4.00	2.60	1.85	0.942	1.55	1.92
186.0	11.01	4.40	2.85	2.20	0.905	1.49	1.71
192.0	11.39	4.20	2.75	2.10	0.981	1.60	1.85
197.9	9.08	4.25	2.75	1.90	0.773	1.27	1.63
203.9	8.89	4.20	2.75	1.95	0.766	1.25	1.55
210.0	9.56	4.05	2.65	2.05	0.854	1.39	1.59
*216.0	8.89	4.15	2.75	2.05	0.775	1.25	1.48
221.9	8.76	4.05	2.60	1.90	0.783	1.30	1.57
228.1	8.06	4.10	2.50	1.85	0.711	1.24	1.48
234.0	8.19	4.10	2.50	2.05	0.723	1.26	1.36
240.0	9.17	4.10	2.45	2.05	0.809	1.44	1.52
245.7	8.18	4.30	2.45	1.80	0.688	1.29	1.55
251.7	9.17	4.25	2.40	1.70	0.781	1.47	1.84
258.0	8.73	4.20	2.50	1.95	0.752	1.35	1.53
264.0	9.17	4.15	2.20	1.90	0.799	1.61	1.64
*269.9	8.47	4.40	2.30	1.75	0.696	1.42	1.65
276.3	8.33	4.45	2.25	1.60	0.677	1.43	1.77
281.9	9.23	4.55	2.25	1.60	0.734	1.58	1.97
288.0	7.77	4.45	2.05	1.80	0.632	1.46	1.47
293.7	7.77	4.50	2.05	1.55	0.625	1.46	1.71
300.2	8.97	4.65	2.00	1.55	0.698	1.73	1.97

Test #80. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
305.9	8.48	4.70	2.05	1.50	0.653	1.60	1.93
311.8	7.91	4.70	2.00	1.55	0.609	1.53	1.74
*318.1	7.94	4.70	1.95	1.50	0.611	1.57	1.80
324.0	7.91	4.80	2.00	1.40	0.596	1.53	1.92
330.0	8.61	5.25	2.30	1.60	0.593	1.44	1.83
*336.0	10.00	5.15	2.10	1.55	0.703	1.84	2.20
342.3	8.73	5.00	1.90	1.60	0.632	1.77	1.86
348.1	8.91	5.45	1.45	1.55	0.591	2.37	1.96
354.0	9.89	5.65	1.55	1.55	0.633	2.46	2.17
360.0	8.89	5.85	1.25	1.45	0.550	2.74	2.09
*366.0	8.33	6.25	1.55	1.40	0.482	2.07	2.03
372.1	8.20	6.40	1.65	1.35	0.464	1.92	2.07
378.0	9.32	6.65	1.60	1.55	0.507	2.25	2.05
384.0	9.72	7.50	1.70	1.65	0.469	2.21	2.01
389.9	9.08	7.95	1.70	1.50	0.413	2.06	2.06
396.0	9.56	8.40	1.80	1.60	0.412	2.05	2.04
*402.0	8.89	8.60	1.70	1.45	0.374	2.02	2.09
408.0	9.44	9.25	1.45	1.55	0.369	2.51	2.07
414.2	8.33	9.65	1.60	1.25	0.312	2.01	2.27
419.9	8.18	10.00	1.65	1.20	0.296	1.91	2.32
426.0	8.47	11.8	1.65	1.45	0.260	1.98	1.99
432.0	8.61	12.7	1.70	1.55	0.245	1.95	1.89

Test #80. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*438.1	9.29	13.8	1.65	1.30	0.244	2.17	2.43
444.0	7.91	14.9	1.70	1.30	0.192	1.80	2.07
450.0	8.33	15.7	1.90	1.30	0.192	1.69	2.18
456.0	9.72	17.2	1.90	1.40	0.204	1.97	2.37
462.2	8.33	18.2	1.90	1.35	0.166	1.69	2.10
468.1	8.47	18.7	1.90	1.30	0.164	1.72	2.22
*474.0	8.76	19.1	1.80	1.30	0.166	1.88	2.30
479.9	7.91	19.0	1.85	1.35	0.151	1.65	2.00
486.1	7.26	20.4	1.75	1.15	0.129	1.60	2.15
†492.1	8.89	21.1	1.95	1.35	0.152	1.76	2.24
504.0	8.76	22.8	1.80	1.55	0.139	1.88	1.93
510.1	6.83	21.7	1.70	1.35	0.114	1.55	1.72
516.3	8.60	22.8	1.75	1.35	0.136	1.90	2.17
521.9	9.23	23.4	1.85	1.60	0.143	1.92	1.97
528.0	9.29	24.3	1.85	1.60	0.138	1.94	1.98
*534.0	9.17	24.6	1.90	1.30	0.135	1.86	2.40
540.2	8.06	24.8	1.90	1.25	0.118	1.64	2.20
546.0	8.05	25.7	2.10	1.55	0.113	1.48	1.77
558.1	9.09	26.5	2.15	1.25	0.124	1.63	2.48
564.0	7.34	26.7	2.00	1.20	0.099	1.42	2.08
582.2	9.07	28.2	2.05	1.20	0.116	1.71	2.58
588.1	8.19	28.7	2.05	1.20	0.103	1.54	2.33

Test #80. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
594.0	6.80	29.0	1.90	1.35	0.085	1.38	1.72
606.1	8.82	30.4	2.20	1.25	0.105	1.55	2.40
612.0	9.60	30.4	2.25	1.25	0.114	1.65	2.62
618.3	6.08	31.1	2.15	1.20	0.071	1.09	1.73
*624.0	9.36	32.5	2.40	1.55	0.104	1.50	2.06
629.9	8.47	32.7	2.35	1.30	0.094	1.39	2.22
636.0	8.74	32.2	2.30	1.30	0.098	1.47	2.29
642.0	7.22	33.4	2.20	1.20	0.078	1.27	2.05
648.0	8.06	33.7	2.10	1.40	0.087	1.48	1.96
654.0	8.33	34.4	2.20	1.25	0.088	1.46	2.27
660.1	6.83	33.1	2.30	1.25	0.075	1.15	1.86
666.0	7.34	34.0	2.25	1.50	0.078	1.26	1.67
672.0	9.44	36.1	2.10	1.55	0.095	1.73	2.07
678.1	9.02	36.2	2.25	1.30	0.090	1.55	2.36
*684.3	8.06	36.2	2.25	1.25	0.081	1.38	2.20
690.0	7.89	36.5	2.25	1.45	0.078	1.35	1.86
696.0	9.17	37.6	2.10	1.45	0.088	1.68	2.15
702.1	8.20	37.9	2.30	1.25	0.078	1.38	2.23
708.0	7.91	38.4	2.30	1.15	0.075	1.33	2.34
714.0	7.50	38.8	2.15	1.35	0.070	1.35	1.89
720.0	8.89	39.7	2.20	1.40	0.081	1.56	2.16
726.0	7.78	40.0	2.05	1.30	0.070	1.46	2.04

Test #80. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
732.0	8.89	40.1	1.90	1.30	0.080	1.81	2.33
+738.0	7.22	40.3	1.85	1.25	0.065	1.51	1.97
744.0	8.89	42.1	2.35	1.40	0.076	1.46	2.16
*750.0	8.89	42.1	2.30	1.30	0.076	1.49	2.33
756.0	8.89	42.2	2.20	1.30	0.076	1.56	2.33
762.0	8.33	41.8	2.20	1.25	0.072	1.46	2.27
768.0	8.33	41.9	2.05	1.35	0.072	1.57	2.10
774.0	7.78	42.0	2.00	1.30	0.067	1.50	2.04
780.0	7.50	41.7	1.85	1.30	0.065	1.56	1.97
786.3	7.94	41.9	1.80	1.25	0.069	1.70	2.16
791.8	7.88	41.9	1.75	1.25	0.068	1.74	2.15
798.0	6.45	41.9	1.80	1.25	0.056	1.38	1.76
805.0	7.62	41.9	1.80	1.20	0.066	1.63	2.16
*809.8	6.60	41.9	1.80	1.20	0.057	1.41	1.87
814.1	7.38	41.9	1.75	1.20	0.064	1.63	2.10
822.0	7.38	41.5	1.80	1.15	0.064	1.58	2.19
827.7	6.43	41.5	1.65	1.25	0.056	1.50	1.75
834.0	7.41	41.4	1.65	1.25	0.065	1.73	2.02
840.0	7.50	41.5	1.50	1.25	0.065	1.93	2.04
845.8	6.32	41.0	1.60	1.10	0.056	1.52	1.96
852.0	6.72	41.4	1.95	1.15	0.059	1.33	1.99
858.0	7.22	41.5	1.75	1.10	0.063	1.59	2.24

Test #80. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
864.0	7.22	41.6	1.55	1.10	0.063	1.80	2.24
869.8	6.90	40.9	2.20	1.00	0.061	1.21	2.35
876.0	6.45	41.0	1.90	1.00	0.057	1.31	2.20
*882.0	6.67	41.0	1.75	1.10	0.059	1.47	2.07
888.0	6.11	41.4	1.65	1.25	0.053	1.43	1.67
894.0	6.81	41.0	1.60	1.10	0.060	1.64	2.11
900.0	6.81	41.0	1.55	1.05	0.060	1.70	2.21
906.0	5.83	41.1	1.55	1.10	0.051	1.45	1.81
912.0	6.94	41.0	1.50	1.15	0.061	1.78	2.06
918.0	6.67	41.0	1.50	0.95	0.059	1.72	2.39
924.0	5.83	41.0	1.85	1.05	0.051	1.22	1.89
930.0	5.83	41.0	1.75	1.15	0.051	1.29	1.73
*936.0	6.39	41.1	1.45	1.15	0.056	1.70	1.89
†936.0		START 3.0 g/l NaHSO ₃					
942.2	5.91	18.3	4.15	1.95	0.117	0.549	1.04
947.8	7.44	2.5	0.70	0.70	1.08	4.10	3.62
*954.0	1.88	1.0	0.45	0.50	0.680	1.61	1.28
960.0	4.17	2.00	1.20	0.95	0.754	1.34	1.50
966.0	3.89	1.90	1.20	0.85	0.741	1.25	1.56
*971.9	4.52	2.00	1.15	0.80	0.818	1.51	1.92
978.0	4.37	2.45	0.95	0.85	0.645	1.77	1.75
984.0	4.17	2.70	0.60	0.90	0.559	2.68	1.58

Test #80. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*990.2	5.38	3.85	0.75	1.00	0.506	2.77	1.83
996.1	5.65	4.50	0.60	0.85	0.454	3.63	2.26
*1002.0	4.52	5.40	0.50	0.85	0.303	3.49	1.81
1008.0	3.33	6.05	0.60	0.50	0.199	2.14	2.27
1014.0	3.06	7.40	0.75	0.45	0.150	1.57	2.32
*1020.2	4.30	7.70	0.80	0.50	0.202	2.07	2.93
1026.0	3.74	9.10	0.85	0.70	0.149	1.70	1.82
1032.0	5.00	9.95	0.80	0.60	0.182	2.41	2.84
1038.0	5.28	12.2	0.95	0.50	0.157	2.14	3.60
1043.9	3.11	13.0	1.00	0.50	0.087	1.20	2.12
*1050.0	4.64	13.5	1.05	0.75	0.124	1.70	2.11
1056.0	3.61	13.6	0.95	0.55	0.096	1.47	1.89
1061.8	4.02	13.5	0.95	0.55	0.108	1.63	2.49
1068.1	3.70	12.7	1.00	0.50	0.105	1.43	2.52
1074.0	2.82	14.2	0.95	0.55	0.072	1.15	1.75
1080.0	2.78	14.1	1.00	0.60	0.071	1.07	1.58
*1086.0	3.33	14.5	1.00	0.50	0.083	1.28	2.27
1092.0	2.87	14.1	1.05	0.50	0.074	1.16	1.96
1098.0	2.87	14.5	1.15	0.65	0.072	1.27	1.50
1104.0	2.87	14.5	1.05	0.60	0.072	1.16	1.63
1110.0	2.65	14.0	1.10	0.45	0.068	0.929	2.01
1116.0	2.65	14.6	1.15	0.40	0.066	0.896	2.26

Test #80. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
*1122.0	2.65	14.5	1.15	0.40	0.066	0.889	2.26
1128.1	2.65	16.0	1.30	0.55	0.060	0.786	1.64
*1133.9	2.65	15.3	1.35	0.60	0.063	0.757	1.50
1140.0	2.65	15.4	1.35	0.55	0.062	0.757	1.64
1146.2	2.65	14.7	1.45	0.60	0.065	0.705	1.50
1151.8	2.65	14.5	1.50	0.50	0.066	0.682	1.81
1158.1	2.07	14.1	1.55	0.65	0.053	0.515	1.08
1164.0	2.07	14.3	1.60	0.55	0.052	0.499	1.28
1170.0	2.07	14.2	1.55	0.70	0.053	0.515	1.01
1176.0	2.07	19.6	2.15	1.10	0.038	0.371	0.641
*1182.2	4.63	18.4	3.15	0.95	0.091	0.567	1.66
1188.2	4.63	17.8	3.30	0.95	0.094	0.541	1.66
1194.0	4.63	18.8	3.95	1.15	0.089	0.452	1.37
1200.0	5.07	18.3	3.90	1.20	0.100	0.502	1.44
1206.2	5.07	18.7	4.35	1.30	0.098	0.450	1.33
1212.3	5.07	20.0	4.55	1.30	0.092	0.430	1.33
1218.0	5.07	18.6	4.75	1.50	0.099	0.412	1.15
1224.0	5.14	17.2	4.80	1.70	0.108	0.413	1.03
1230.0	5.14	17.2	4.70	1.60	0.108	0.422	1.09
1236.0	5.00	17.0	5.15	1.70	0.106	0.375	1.00
*1242.0	4.31	16.6	5.40	1.80	0.094	0.308	0.816
1248.0	4.31	17.6	5.55	2.00	0.089	0.300	0.734

Test #80. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1254.0	4.31	16.5	5.35	1.85	0.095	0.311	0.794
1260.0	4.31	16.9	5.40	1.90	0.092	0.308	0.773
1266.0	5.18	18.1	6.35	2.15	0.104	0.315	0.821
1272.0	5.18	18.0	6.15	2.15	0.104	0.325	0.821
1278.0	5.18	18.5	6.20	2.05	0.101	0.322	0.861
1284.0	5.18	19.5	6.45	2.10	0.096	0.310	0.840
1290.1	5.18	18.5	6.60	2.15	0.101	0.303	0.821
1295.1	5.18	19.0	6.80	2.25	0.099	0.294	0.784
1302.0	3.44	16.5	5.80	1.80	0.075	0.229	0.651
*1308.0	3.44	16.5	5.70	1.80	0.075	0.233	0.651
1314.0	3.44	17.5	5.90	1.75	0.071	0.225	0.670
1320.0	3.44	17.5	6.00	1.80	0.071	0.221	0.651
1326.0	3.44	17.5	5.85	1.70	0.071	0.227	0.689
1332.1	3.44	18.1	5.80	1.70	0.069	0.229	0.689
1338.0	3.44	19.7	7.10	2.30	0.063	0.187	0.510
1344.0	3.44	19.3	6.05	1.95	0.064	0.219	0.601
†1344.0			START GROUND H ₂ O				
1350.0	3.86	21.9	5.85	2.05	0.064	0.255	0.642
1356.0	3.86	21.2	4.80	1.55	0.066	0.310	0.848
1362.5	3.86	26.0	5.70	1.85	0.054	0.261	0.711
1368.0	3.86	23.6	6.20	1.90	0.059	0.240	0.692
*1374.2	3.86	22.5	6.15	1.70	0.062	0.242	0.774

Test #80. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1380.0	3.86	24.3	7.00	1.90	0.057	0.213	0.692
1386.0	4.72	23.7	8.90	2.55	0.072	0.205	0.631
1392.0	4.72	24.2	9.50	2.85	0.071	0.192	0.564
1398.0	4.72	22.5	9.70	3.35	0.076	0.188	0.480
1404.0	4.72	21.5	9.15	3.60	0.079	0.199	0.447
1410.0	4.72	21.5	8.95	3.85	0.079	0.203	0.418
1416.0	3.09	19.5	7.70	3.55	0.057	0.155	0.297
1422.2	3.09	15.0	6.85	3.00	0.075	0.174	0.351
1428.0	3.09	14.5	6.65	3.00	0.077	0.179	0.351
*1434.0	3.09	18.0	6.85	3.05	0.062	0.174	0.345
1440.0	3.09	18.3	7.55	3.80	0.061	0.158	0.277
1446.0	3.09	13.5	5.85	2.65	0.082	0.204	0.397
1451.8	3.09	13.0	5.95	2.75	0.086	0.200	0.383
1458.0	3.09	15.5	6.70	3.35	0.072	0.178	0.314
1464.0	3.54	17.0	5.70	3.30	0.075	0.240	0.365
1470.1	3.54	19.1	6.60	4.00	0.067	0.207	0.302
1475.8	3.54	21.8	7.35	4.70	0.059	0.186	0.257
1482.0	3.54	21.3	7.35	4.55	0.060	0.186	0.265
1488.0	3.54	20.5	7.50	4.50	0.062	0.182	0.268
1494.0	3.54	19.5	7.50	4.35	0.066	0.182	0.277
1500.0	3.54	20.7	7.70	4.50	0.062	0.177	0.268
*1506.0	3.54	20.2	7.75	4.50	0.063	0.176	0.268

Test #80. Cont.

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1512.0	3.54	20.2	7.95	4.35	0.063	0.172	0.277
1518.0	3.54	20.9	8.30	4.55	0.061	0.165	0.265
1524.1	3.54	21.0	8.20	4.45	0.061	0.167	0.271
1530.0	3.54	23.2	8.70	4.40	0.055	0.157	0.274
1536.0	3.16	22.0	7.75	4.30	0.052	0.157	0.250
*1542.0	3.16	21.5	8.15	4.30	0.053	0.150	0.250
1548.0	3.16	21.3	8.10	4.15	0.054	0.151	0.259
1554.0	3.16	21.4	8.10	4.05	0.053	0.151	0.266
1560.0	3.16	21.5	7.90	3.75	0.053	0.154	0.287
1566.0	3.16	27.0	9.70	4.95	0.042	0.126	0.217
1572.1	3.16	26.0	10.00	4.95	0.044	0.122	0.217
1578.0	3.16	26.0	10.00	4.75	0.044	0.122	0.227
1584.0	3.16	26.1	9.70	4.70	0.044	0.126	0.229
1589.8	3.16	26.0	9.65	4.45	0.044	0.126	0.242
1595.9	3.16	26.3	9.70	4.40	0.043	0.126	0.245
1602.0	3.16	27.4	9.60	4.65	0.042	0.127	0.232
*1608.0	3.16	26.8	9.50	4.35	0.043	0.128	0.247
RUN TERMINATED							

Observations from the Simulation Leach Test #81

Ore used = Wyoming

Solution used = 1.0 g/l NH_4HCO_3 - 0.5 g/l H_2O_2

Inlet section packing material = -80 AFS Subangular Sand

Inlet section packing length = 10.0 in.

Length of the front ore section = 47.38 in.

Length of the middle ore section = 50.25 in.

Length of the end ore section = 44.50 in.

Outlet section packing material = -80 AFS Subangular Sand

Outlet section packing length = 5.00 in.

Ore packing bed density = 1.64 g/ml

Packing Method:

Batch placement of ore in the column followed by tamping using the peg-bottom drop-weight tamper. Batch size: 8 in. of the column length. Amplitude of tamping - 2.0 ft. Frequency of tamping = 10 tamps/8 in. of ore. Column Position - inlet end at the bottom.

NOTE: In the following table: * indicates data points plotted in the illustrations.

† indicates introduction of fresh feed solution(s).

Test #81

Ore - Wyoming

Sol - 1.0 g/l NH_4HCO_3 -
0.5 g/l H_2O_2

Time Hrs	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
36.3	---	1.3	2.2	2.7	---	---	---
42.0	9.06	1.3	2.0	2.3	2.53	1.75	1.35
48.1	9.56	0.9	1.8	2.3	3.86	2.05	1.42
54.0	9.32	1.0	1.8	2.5	3.39	2.00	1.27
60.3	8.99	0.9	1.8	2.3	3.63	1.93	1.36
* 66.0	9.94	1.3	1.8	2.5	2.78	2.13	1.36
72.1	8.74	1.3	1.8	2.5	2.44	1.87	1.19
78.0	6.50	1.1	1.8	2.1	2.15	1.39	1.06
84.3	7.94	0.8	1.4	1.3	3.61	2.19	2.09
90.1	6.32	0.8	1.6	1.7	---	---	---
LEAK IN PRODUCT TANK, SOME SOLUTION LOST							
96.0	---	0.9	1.8	2.3	---	---	---
101.9	---	1.1	1.6	2.3	---	---	---
108.2	---	1.1	1.6	2.3	---	---	---
114.1	---	1.1	1.8	2.7	---	---	---
123.0	---	---	---	---	---	---	---
125.9	---	1.2	1.8	2.3	---	---	---
132.1	11.56	1.1	1.8	2.1	3.82	2.48	1.89
138.4	7.14	0.8	1.8	2.1	3.25	1.53	1.16
143.8	9.26	0.9	1.8	2.3	3.74	1.98	1.38
*150.0	8.06	1.1	1.8	2.7	2.66	1.73	1.01
156.1	8.74	1.1	1.8	2.7	2.88	1.87	1.11

Test #81. Cont.

Time Hrs.	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
162.3	7.80	0.8	1.8	2.7	3.54	1.67	0.987
*168.0	8.48	1.1	2.0	3.7	2.80	1.09	0.783
180.1	6.88	0.4	1.2	1.9	6.26	2.21	1.24
186.1	4.44	0.5	1.2	2.1	3.23	1.43	0.722
204.2	13.16	0.6	1.4	2.7	7.98	3.63	1.66
210.2	8.06	0.9	1.8	3.5	3.26	1.73	0.787
216.0			LEACH INJECTION				
228.1	6.69	0.9	1.4	2.1	2.70	1.84	1.08
*234.1	5.83	1.7	2.0	2.5	1.25	1.12	0.797
240.4	5.03	1.9	2.0	2.9	0.963	0.970	0.592
246.0	8.33	3.5	3.0	5.1	0.865	1.07	0.558
251.9	8.76	3.4	3.0	4.3	0.937	1.13	0.696
258.0	7.38	3.2	2.8	4.1	0.839	1.02	0.615
264.2	6.72	3.6	2.8	4.1	0.679	0.926	0.560
270.0	8.05	3.9	2.6	4.5	0.751	1.19	0.611
*276.0	7.50	4.0	2.8	4.5	0.682	1.03	0.569
282.0	7.22	4.5	2.4	4.7	0.584	1.16	0.524
294.0	4.44	6.7	2.8	6.3	0.241	0.611	0.240
300.2	9.14	7.1	2.8	5.3	0.468	1.26	0.590
306.3	8.74	7.9	2.8	5.1	0.402	1.20	0.585
*312.0	8.77	8.6	2.8	5.3	0.370	1.21	0.565

Test #81. Cont.

Time Hrs.	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
318.0	9.44	9.9	2.6	5.1	0.347	1.40	0.632
324.2	7.80	11.5	2.6	4.7	0.247	1.15	0.567
*330.0	8.33	13.0	2.6	4.7	0.233	0.24	0.605
336.0	8.06	14.8	2.4	4.9	0.198	1.30	0.562
342.0	8.33	18.9	2.4	4.7	0.160	1.34	0.605
348.0	9.17	25.4	2.8	5.3	0.131	1.26	0.501
354.0	8.89	27.6	2.4	4.7	0.117	1.43	0.646
*360.0	7.78	28.4	2.4	4.7	0.0996	1.25	0.565
366.0	8.33	31.9	3.0	5.5	0.095	1.07	0.517
372.0	8.89	34.4	2.6	4.3	0.0940	1.32	0.706
378.0	7.50	35.2	2.2	3.9	0.0775	1.32	0.657
384.0	6.94	36.6	2.4	4.1	0.069	1.12	0.578
390.0	7.92	38.0	2.0	3.7	0.0758	1.53	0.773
396.0	6.56	38.3	2.2	3.5	0.062	1.15	0.640
402.1	6.83	38.4	2.0	3.3	0.0647	1.32	0.707
*408.3	7.26	39.1	2.0	3.3	0.0675	1.40	0.751
413.8	6.97	39.1	2.0	3.3	0.0650	1.34	0.721
420.0	6.72	38.8	2.0	2.9	0.0630	1.29	0.791
427.1	6.33	39.0	1.8	2.9	0.0590	1.36	0.745
431.8	5.32	38.8	2.0	2.9	0.0499	1.02	0.627
438.2	6.51	39.0	1.8	2.9	0.061	1.40	0.767
*444.0	5.75	39.2	1.8	2.7	0.0533	1.23	0.727

Test #81. Cont.

Time Hrs.	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
449.7	4.97	39.4	1.8	2.5	0.046	1.07	0.680
456.0	6.35	39.4	2.0	2.3	0.0586	1.22	0.943
462.0	5.56	40.3	1.6	2.1	0.050	1.34	0.904
467.8	5.46	40.0	1.8	1.9	0.0496	1.17	0.982
474.0	5.91	40.4	2.0	1.9	0.0532	1.14	1.06
440.0	5.28	39.9	2.0	2.1	0.048	1.01	0.860
486.0	6.11	40.3	1.6	2.1	0.055	1.47	0.997
491.8	5.46	40.0	1.8	1.9	0.0496	1.17	0.981
498.0	5.38	40.1	1.8	2.1	0.0488	1.15	0.875
504.0	5.28	41.3	1.8	2.1	0.0465	1.13	0.859
*510.0	5.56	42.7	1.2	1.3	0.047	1.80	1.46
516.3	3.70	41.7	1.4	1.5	0.032	1.02	0.842
522.0	2.92	41.5	1.6	1.5	0.026	0.704	0.664
528.0	4.17	42.2	1.4	1.3	0.036	1.15	1.10
534.0	2.78	42.2	1.4	1.3	0.024	0.766	0.730
540.1	3.28	41.1	1.4	1.5	0.029	0.904	0.747
546.0	3.67	41.6	1.4	1.3	0.032	1.01	0.964
*552.0	3.61	42.4	1.2	1.3	0.030	1.16	0.949
558.0	3.06	41.9	1.4	1.3	0.027	0.843	0.804
564.3	3.51	41.4	1.2	1.1	0.0308	1.13	1.09
569.8	3.03	41.2	1.4	1.1	0.027	0.835	0.941
576.0	3.22	41.1	1.6	1.3	0.0285	0.776	0.846

Test #81. Cont.

Time Hrs.	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
582.0	2.50	42.6	1.6	1.3	0.0213	0.603	0.656
588.0	3.89	42.1	1.4	1.1	0.0336	1.07	1.20
593.9	3.39	41.8	1.4	1.1	0.029	0.934	1.05
600.0	2.46	41.5	1.4	1.1	0.021	0.678	0.764
606.0	3.61	41.8	1.4	1.1	0.031	0.994	1.12
612.3	2.92	41.8	1.6	0.9	0.025	0.704	1.10
*618.1	3.45	41.5	1.6	0.9	0.030	0.832	1.31
624.0	3.95	41.8	1.4	1.1	0.0343	1.09	1.22
630.0	3.33	41.4	1.2	1.1	0.029	1.07	1.03
636.0	3.61	42.4	1.4	1.1	0.031	0.994	1.12
642.2	3.49	42.2	1.6	1.1	0.030	0.841	1.08
648.0	4.02	43.4	1.4	1.3	0.034	0.036	1.06
654.0	3.33	43.3	1.2	1.3	0.028	1.07	0.875
660.0	4.17	42.1	1.4	1.1	0.036	1.15	1.29
666.0	3.06	41.5	1.4	1.1	0.027	0.843	0.950
672.0	3.33	43.0	1.2	1.3	0.028	1.07	0.875
678.0	3.33	42.7	1.2	1.3	0.028	1.07	0.875
683.8	3.45	42.1	1.4	1.1	0.030	0.950	1.07
690.2	3.65	41.5	1.4	1.1	0.032	1.00	1.13
696.0	3.74	41.6	1.4	1.3	0.033	1.03	0.982
*702.0	3.61	42.4	1.4	1.1	0.031	0.994	1.12
708.0	3.33	42.2	1.2	0.9	0.029	1.07	1.26

Test #81. Cont.

Time Hrs.	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
714.1	2.73	41.4	1.2	0.9	0.024	0.878	1.04
720.0	3.67	42.7	1.4	1.1	0.031	1.01	1.14
726.0	3.89	42.6	1.2	0.9	0.033	1.25	1.48
732.0	3.06	42.0	1.2	0.9	0.026	0.983	1.16
738.0	3.06	42.1	1.6	0.9	0.026	0.738	1.16
744.1	3.55	42.4	1.6	0.9	0.030	0.856	1.35
750.2	3.83	43.0	1.4	1.1	0.032	1.05	1.19
755.9	2.92	42.5	1.6	1.1	0.025	0.704	0.907
762.0	2.46	41.9	1.6	1.1	0.021	0.593	0.764
768.3	3.51	41.8	1.4	1.1	0.030	0.967	1.09
*773.9	2.98	42.1	1.4	1.1	0.026	0.821	0.925
780.1	2.96	41.5	1.4	1.1	0.026	0.816	0.919
786.0	3.11	41.7	1.2	1.1	0.027	0.999	0.965
792.0	2.50	42.3	1.2	1.1	0.021	0.803	0.776
798.0	3.06	42.3	1.2	1.1	0.026	0.983	0.950
804.3	3.44	41.4	1.2	1.1	0.030	1.10	1.07
810.2	3.95	41.2	1.4	1.1	0.035	1.09	1.22
816.0	2.87	41.7	1.4	0.9	0.025	0.790	1.08
822.0	3.89	41.2	1.4	1.1	0.034	1.07	1.20
828.3	3.44	41.7	1.4	0.9	0.030	0.948	1.31
834.3	3.89	42.3	1.4	0.9	0.033	1.07	1.48
840.0	3.22	42.3	1.4	0.4	0.028	0.887	1.22

Test #81. Cont.

Time Hrs.	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
846.0	2.78	42.5	1.4	0.7	0.024	0.766	1.36
852.0	3.61	41.7	1.6	0.7	0.031	0.870	1.76
858.0	4.17	41.4	1.8	1.1	0.036	0.894	1.29
*864.0	3.61	42.4	1.6	0.9	0.030	0.870	1.37
870.0	3.33	42.9	1.6	0.7	0.028	0.803	1.62
876.0	3.61	42.8	1.4	0.7	0.031	0.995	1.76
882.0	3.61	42.2	1.4	0.7	0.031	0.995	1.76
888.0	3.06	42.5	1.2	0.9	0.026	0.983	1.16
894.0	3.61	41.9	1.2	1.3	0.031	1.16	0.948
900.0	3.33	41.3	1.4	1.3	0.029	0.917	0.875
906.0	3.89	41.6	1.4	1.3	0.034	1.07	1.02
912.1	3.01	41.4	1.4	1.5	0.026	0.830	0.685
917.8	3.22	41.4	1.4	1.5	0.028	0.887	0.733
924.0	3.49	41.4	1.4	1.5	0.031	0.961	0.794
929.9	3.95	41.5	1.6	1.5	0.034	0.952	0.899
936.0	2.73	41.3	1.6	1.7	0.024	0.658	0.548
942.0	5.83	42.0	1.4	1.5	0.050	1.60	1.33
948.0	0.560	41.5	1.6	1.5	0.0049	0.135	0.128
954.1	3.01	41.7	1.4	1.5	0.026	0.829	0.685
960.0	3.39	43.0	1.4	1.7	0.028	0.934	0.681
966.0	6.67	42.6	1.4	1.5	0.057	1.83	1.51
*972.0	3.33	42.9	1.4	1.5	0.028	0.917	0.758

Test #81. Cont.

Time Hrs.	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
978.0	3.61	42.3	1.4	1.5	0.031	0.994	0.822
984.6	3.78	41.7	1.4	1.5	0.032	1.04	0.860
990.1	3.03	41.7	1.2	1.7	0.026	0.974	0.608
996.2	3.28	41.3	1.2	1.5	0.028	1.05	0.746
*1002.0	3.16	40.9	1.4	1.7	0.028	0.870	0.634
1008.0	3.61	41.7	1.4	1.5	0.031	0.994	0.822
1014.0		START 3.0 g/l LaCl ₃ - La ₂ (SO ₄) ₃					
*1020.1	7.10	37.8	2.6	2.7	0.068	1.05	0.898
1026.0	18.36	24.6	6.0	7.7	0.271	1.18	0.814
1032.0	3.61	2.1	0.8	0.3	0.6252	1.74	4.11
*1038.0	3.61	5.5	1.4	1.1	0.239	0.995	1.12
1044.3	4.23	6.8	1.0	1.1	0.226	1.63	1.31
1050.0	4.09	5.3	0.8	0.7	0.280	1.97	1.99
1056.0	4.17	7.2	1.2	1.1	0.210	1.34	0.29
1062.0	4.17	7.2	1.2	1.1	0.210	1.34	1.29
1068.1	5.46	7.9	1.2	1.3	0.251	1.75	1.43
1073.8	5.26	7.1	1.2	0.9	0.269	1.69	1.99
*1080.0	4.57	7.5	1.0	1.1	0.222	1.76	1.42
1086.0	3.89	7.6	1.0	0.9	0.186	1.50	1.47
1092.2	4.03	5.8	0.8	0.5	0.252	1.94	2.75
1097.8	4.09	5.9	1.0	0.5	0.252	1.58	2.79
1104.0	3.76	4.8	0.8	0.3	0.284	1.81	4.28

Test #81. Cont.

Time Hrs.	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1110.0	3.33	5.5	0.9	0.5	0.220	1.42	2.27
1116.1	3.01	5.2	0.9	0.5	0.210	1.29	2.05
1122.0	3.11	3.8	0.6	0.3	0.297	1.99	3.54
*1128.0	3.33	4.5	0.8	0.3	0.269	1.60	3.79
1134.0	2.22	3.8	0.6	0.3	0.212	1.43	2.53
1140.0	2.22	2.4	0.4	0.1	0.336	2.14	7.58
1146.2	1.34	1.5	0.4	0.1	0.324	1.29	4.58
1152.0	2.59	5.5	0.9	0.5	0.171	1.11	1.77
*1158.0	5.00	6.6	1.0	0.7	0.275	1.93	2.44
1159.0		START 2 g/l NaCl + 1.0 g/l Na ₂ SiO ₃					
1164.0	1.94	5.5	0.6	0.1	0.128	1.25	6.63
1170.0	3.89	5.2	---	---	---	---	---
*1176.0	4.72	7.6	1.0	0.3	0.226	1.82	5.37
1182.0	4.44	7.1	1.2	0.3	0.228	1.43	5.06
1188.0	4.44	7.1	1.2	0.3	0.227	1.43	5.06
1194.2	4.57	7.0	1.2	0.1	0.237	1.47	15.61
1200.0	3.45	7.0	1.0	0.3	0.179	1.33	3.92
1206.0	6.39	11.4	1.4	0.9	0.203	1.76	2.43
*1211.8	5.17	11.7	1.2	0.5	0.160	1.66	3.53
1218.9	4.92	13.3	1.2	0.5	0.135	1.58	3.36
1224.0	6.53	13.1	1.4	0.5	0.181	1.80	4.46
1230.0	5.00	13.1	1.4	0.5	0.139	1.38	3.41

Test #81. Cont.

Time Hrs.	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1235.9	5.37	12.8	1.6	0.5	0.153	1.29	3.66
1242.0	11.92	13.3	1.4	0.5	0.135	1.36	3.36
1248.1	4.37	13.5	1.4	0.3	0.118	1.20	4.98
1251.0	5.17	14.6	1.6	0.5	0.130	1.25	3.532
1254.0	3.88	15.1	1.0	0.9	0.093	1.50	1.47
1259.9	4.24	15.1	1.0	0.9	0.102	1.64	1.60
1266.0	6.11	14.6	1.2	0.9	0.152	1.96	2.32
*1272.3	5.29	14.3	1.4	0.9	0.135	1.46	2.0
1278.0	3.51	14.1	1.4	1.5	0.090	0.967	0.80
1283.8	6.32	13.5	1.4	1.5	0.170	1.74	1.44
1290.0	5.91	13.5	1.4	1.5	0.160	1.63	1.35
1296.0	4.17	13.5	1.4	1.5	0.112	1.15	0.950
1302.0	4.17	13.9	1.6	1.5	0.109	1.0	0.950
1308.1	2.73	14.2	1.6	0.9	0.070	0.660	0.307
1313.9	5.17	14.2	1.4	1.1	0.132	1.42	1.60
1320.0	3.83	15.0	1.6	1.3	0.093	0.923	1.0
1326.0	5.00	15.7	1.8	1.3	0.116	1.07	1.31
1332.1	5.19	15.2	2.0	1.3	0.124	1.0	1.36
1338.1	3.89	14.4	1.8	1.1	0.098	0.834	1.20
*1344.0	3.67	13.3	1.4	1.1	0.100	1.01	1.14
1350.0	2.78	14.1	1.2	1.1	0.071	0.894	0.863
1356.0	3.89	16.8	1.6	1.3	0.084	0.934	1.02

Test #81. Cont.

Time Hrs.	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1361.9	3.95	16.5	1.6	1.3	0.087	0.952	1.04
*1368.0	3.83	17.8	1.8	1.3	0.078	0.820	1.0
1374.0			START GROUND H ₂ O				
1380.0	2.22	14.7	1.0	0.7	0.054	0.856	1.08
1385.9	2.82	11.7	1.2	1.1	0.087	0.90	0.875
1392.0	3.28	11.4	1.8	1.7	0.105	0.703	0.660
1398.0	4.72	7.7	1.4	1.3	0.222	1.30	1.24
*1404.0	3.33	6.1	2.2	0.9	0.198	0.584	1.26
*1410.2	2.96	3.1	8.4	0.7	0.347	0.135	1.44
1416.8	3.53	2.2	15.0	4.3	0.583	0.090	0.280
*1422.0	4.48	3.4	19.0	15.3	0.480	0.091	0.100
1428.0	3.61	2.3	18.4	20.3	0.570	0.076	0.060
1434.4	2.86	2.1	17.6	21.9	0.495	0.062	0.044
1440.1	3.51	2.0	17.2	22.7	0.638	0.0790	0.052
*1446.1	2.22	2.0	16.6	23.3	0.403	0.051	0.032
1452.0	2.26	1.9	16.4	23.3	0.433	0.053	0.033
1458.0	2.22	2.2	16.4	23.3	0.367	0.052	0.033
1464.0	1.94	2.9	15.8	25.9	0.243	0.047	0.026
1470.0	1.94	2.2	16.2	26.5	0.321	0.046	0.025
1475.9	1.94	2.3	16.8	24.9	0.307	0.045	0.027
1482.0	1.94	2.4	16.8	24.5	0.294	0.045	0.027
*1488.0	1.94	2.5	16.4	25.1	0.282	0.046	0.026

Test #81. Cont.

Time Hrs.	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1494.0	1.94	2.2	16.8	24.7	0.321	0.045	0.027
1500.0	1.59	2.2	17.0	24.5	0.263	0.036	0.022
1506.1	1.59	2.1	17.0	24.3	0.275	0.036	0.022
1512.0	1.59	2.6	16.6	25.1	0.222	0.037	0.022
1518.0	1.59	2.9	15.0	26.7	0.199	0.041	0.020
1524.1	1.59	2.7	14.6	26.7	0.214	0.042	0.020
1530.2	1.59	2.6	14.0	27.1	0.222	0.044	0.020
1536.0	1.59	3.1	14.0	27.5	0.187	0.044	0.020
1542.0	1.79	2.8	13.6	27.9	0.233	0.051	0.022
1548.1	1.79	2.8	13.0	27.9	0.233	0.053	0.022
*1554.2	1.79	3.1	11.8	28.5	0.210	0.059	0.021
1560.0	1.79	4.1	11.6	28.9	0.159	0.060	0.021
1566.0	1.79	3.6	10.8	29.9	0.181	0.064	0.020
1572.2	1.79	3.6	10.2	29.9	0.181	0.068	0.020
1577.5	1.79	3.3	10.4	29.7	0.197	0.064	0.020
1584.1	1.79	3.3	10.2	29.9	0.197	0.064	0.020
1590.0	1.86	4.7	7.6	31.7	0.144	0.094	0.020
1596.1	1.86	5.1	6.4	31.9	0.133	0.112	0.020
1602.2	1.86	5.1	6.2	32.1	0.133	0.116	0.020
*1608.0	1.86	5.1	6.2	32.1	0.133	0.116	0.020
1614.0	1.86	5.3	6.0	32.7	0.128	0.120	0.019
1620.1	1.86	5.0	6.0	32.7	0.135	0.120	0.019

Test #81. Cont.

Time Hrs.	Flow ml/min	Pressure Drop, psi			Permeability, Darcy		
		Front Sec.	Middle Sec.	End Sec.	Front Sec.	Middle Sec.	End Sec.
1626.1	1.86	5.1	5.6	32.7	0.133	0.128	0.019
1632.7	1.86	5.7	4.8	33.5	0.119	0.149	0.019
*1638.1	1.87	5.6	4.0	34.1	0.121	0.180	0.019
1644.0	1.87	6.0	3.4	33.7	0.113	0.212	0.019
1650.0	1.87	6.1	3.0	33.7	0.111	0.240	0.019
1656.0	1.87	7.6	3.8	32.9	0.089	0.190	0.019
1662.0	1.87	7.0	2.8	34.5	0.097	0.258	0.019
*1668.0	1.87	6.8	2.8	34.1	0.100	0.258	0.019
1674.2	1.87	7.2	2.8	33.7	0.094	0.258	0.019
1682.0	1.87	7.2	2.6	33.9	0.094	0.277	0.019
1686.1	1.87	7.0	2.6	34.1	0.097	0.277	0.019
1691.9	1.53	7.1	2.4	33.9	0.078	0.246	0.015
1698.4	1.53	7.3	2.6	33.5	0.076	0.227	0.016
1705.1	1.53	7.1	2.6	33.7	0.078	0.227	0.016
*1710.0	1.53	7.5	2.4	33.5	0.074	0.246	0.016
RUN TERMINATED							

APPENDIX C

Ore Pore Volume and System Voidage Volume Determination

It is desirable to know the voidage of the ore bed and the system in order to better relate the laboratory results to those in the field and to better determine when changes in the feed should appear in the product solution. That is, what occurs in a given number of bed pore volumes in the column can perhaps be related to what occurs in the same number of pore volumes in the field. The total voidage of the simulation system is necessary in order to determine after what volume a feed solution change should appear in the product, thus allowing one to measure what initial response has resulted from the feed change. The following presents the method used to calculate these voidages.

Calculation of total and ore bed void volumes:

- (1) True density of the ore and sand (y)
 - (a) Old Wyoming - 2.53 g/ml
 - (b) New Wyoming - 2.47 g/ml
 - (c) Texas - 2.35 g/ml
 - (d) Inlet and Outlet Sand - 2.59 g/ml
- (2) Packing density of ore and sand (x)
- (3) Voidage fraction = z

$$z = \frac{y - x}{y}$$

- (4) Ore bed void (or pore) volumes = vol. of column occupied by
ore $\cdot z$
- (5) Total void volume of system = vol. of column occupied by ore $\cdot z_{(\text{ore})}$
+ vol. of column occupied by sand $\cdot z_{(\text{sand})}$
+ vol. of inlet lines (147.7 ml)

Example A: Test No. 62, Old Wyoming Ore

- (1) Packing density of ore = 1.71 g/ml

Packing density of inlet sand - 1.65 g/ml

Packing density of outlet sand - 1.55 g/ml

Volume of ore bed - 29.09 liters

Volume of inlet sand - 2.06 liters

Volume of outlet sand - 1.03 liters

- (2) Voidage fractions (z):

$$z_{(\text{ore})} = \frac{2.53 - 1.71}{2.53} = 0.324, \quad z_{(\text{sand inlet})} = \frac{2.59 - 1.65}{2.59} = 0.363$$

$$z_{(\text{sand outlet})} = \frac{2.59 - 1.55}{2.59} = 0.400$$

- (3) Ore pore volume = 29.09 liters x 0.324
= 9.4 liters

- (4) Total void volume of system = 9.4 liters + (2.06 liters x 0.363)
+ (1.03 liters x 0.40) + 0.15
= 10.7 liters

Example B: Test No. 64 Texas Ore

- (1) Packing density of ore - 1.48 g/ml

Packing density of inlet sand - 1.65 g/ml

Packing density of outlet sand - 1.56 g/ml

Volume of ore bed - 20.36 liters

Volume of inlet sand - 2.06 liters

Volume of outlet sand - 1.03 liters

Volume of inlet lines - 0.15 liters

- (2) Voidage fractions (z):

$$z_{(\text{ore})} = \frac{2.35 - 1.48}{2.35} = 0.37, \quad z_{(\text{sand inlet})} = \frac{2.59 - 1.65}{2.59} = 0.363,$$

$$z_{(\text{sand outlet})} = \frac{2.59 - 1.56}{2.59} = 0.398$$

(3) Ore pore volume = $20.36 \text{ liters} \times 0.37$
= 7.5 liters

(4) Total void volume of system = $7.5 \text{ liters} + (2.06 \text{ liters} \times 0.363)$
+ $(1.03 \text{ liters} \times 0.398) + 0.15$
= 8.8 liters