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INTEGRATION OF PNEUMATIC FRACTURING AND IN SITU VITRIFICATION IN THE SOIL SUBSURFACE

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ABSTRACT

Pacific Northwest Laboratory is evaluating ways to increase the applicability of the in situ vitrification (ISV) process at hazardous and radioactive waste sites. One innovation is the placement of a conductive material that will facilitate initiating the ISV process at a target depth.

A series of laboratory tests performed at the New Jersey Institute of Technology (NJIT) assessed the feasibility of pneumatic fracturing (PF) in the highly permeable soils of the Hanford Site. The NJIT tests included an analysis of Hanford soils, a series of PF injection tests, and a parametric analysis to determine how soil properties affect the PF process. Results suggest that the PF process can be applied to Hanford soils and that dry medium (e.g., conductive material such as graphite flake) can be injected into the fracture.

This paper describes the laboratory testing performed at NJIT, its results, and the application of those results to plans for a field demonstration at Hanford.

INTRODUCTION

ISV is a thermal treatment technology, developed by the Pacific Northwest Laboratory for the U.S. Department of Energy, to treat soils contaminated with transuranic elements. The process is traditionally initiated at the soil surface through the use of conductive material placed within an array of electrodes. Heat generated in the conductive material melts the soil. Molten soil conducts electricity and is the heat source for downward and outward propagation of the process. Propagation continues until a target volume has been treated. Operating temperatures in excess of 1400°C destroy or pyrolyze organic and inorganic molecules. Heavy metals and radionuclides are immobilized in the final ISV product, a glass and crystalline material that has excellent leach resistance.

Initiation of the ISV process in the soil subsurface: 1) has the potential to increase the applicable treatment depth of the process (demonstrated to 6 m), 2) permits the creation of subsurface vitrified structures, and 3) permits the selective treatment of contamination located at depth. A key step for this ISV application is the placement of a conductive material in the electrode array to initiate the process at a target depth. Murphy et al. [1] identified horizontal drilling, direct injection, and subsurface fracturing technologies as methods to initiate the process underground. In laboratory experiments, Luey and Seiler [2] showed that the ISV electrode array can be connected either by linear paths of conductive material or by a plane of such material. Successful initiation by a plane of conductive material provides the basis for investigating pneumatic fracturing for placement of conductive material at a target depth (fractures typically are horizontal in the soil subsurface).

PNEUMATIC FRACTURING

Pneumatic fracturing enhances the in situ removal and treatment of contaminants in low-permeability soil and rock formations. It was developed at the Hazardous Substance Management Research Center (HSMRC) at the New Jersey Institute of Technology (NJIT). The process generally involves injecting air into a contaminated geologic formation at a pressure that exceeds the natural in situ stresses and a flow rate that exceeds the permeability of the formation. The resultant failure of the medium creates a fracture network radiating from the injection point. The established fractures increase the permeability of the formation, thereby enhancing the flow rate of vapors or liquids for more efficient removal or treatment of contaminants.

The principle objectives of pneumatic fracturing are reduction of treatment time and extension of available technologies to more difficult geologic conditions. It is designed to be integrated with other in situ treatment technologies, such as vapor extraction, bioremediation, and pump and treat. Initial applications focused on enhancing treatment of the vadose zone, but recently the technology has been extended into the saturated zone. The PF system has also been modified to deliver biological supplements (e.g., nutrients, buffers, and microorganisms) directly into the fractured formation to enhance bioremediation.

To date, pilot tests of pneumatic fracturing have been conducted at 10 sites in a variety of geologic formations, including a U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Demonstration at a contaminated industrial site in Hillsborough, New Jersey [3]. Pisciotta et al. [4], Schuring and Chan [5] and Schuring, Valdis, and Chan [6] have published on PF applications.

Pneumatic fracturing is a patented process [7] and is commercially available from Accutech Remedial Systems of Keyport, New Jersey. Accutech offers a fully mobile, production version called Pneumatic Fracturing Extraction (PFE). PFE is an integrated remedial system for removing and treating volatile organic carbon molecules from geologic formations of low to moderate permeability.

LABORATORY STUDIES

To support PNL's ISV technology, a series of laboratory tests were performed at NJIT to assess the feasibility of pneumatic fracturing in the highly permeable soils of the Hanford Site. The NJIT tests included an analysis of Hanford soils, a series of PF injection tests, and a parametric analysis to determine how soil properties affect the PF process.

Analysis of Hanford Soils

For a field demonstration of ISV initiated in the soil subsurface, PNL selected a test site on the Hanford Site in south-eastern Washington. The underlying geologic unit is the Hanford Formation, which consists of coarse-grained sands and gravel deposited in a matter of days during cataclysmic floods at the end of the last ice age. The rapid deposition preserved a high ratio of void space between particles. The nature of the Hanford Formation results in high porosity (>30%) and high saturated hydraulic conductivity (0.35 to 3.5 cm/s) [8,9].

Investigators at NJIT tested soil from the PNL test site to determine physical properties of the Hanford Formation. Testing included grain size analysis, Unified Soil Classification System (USCS) classification, Atterburg limit tests, organic content, specific gravity, and the standard Proctor density test. All testing was performed in accordance with the standard methods of the American Society of Testing and Materials (ASTM). The investigators then prepared a surrogate test soil at NJIT to support a series of bench-scale PF injection tests. Table I compares the physical data for the Hanford soils with the surrogate test soil; the surrogate test soil compared well with the Hanford soil and was deemed suitable for bench-scale PF injection tests.

Bench-Scale PF Injection Tests

Bench-scale PF injection tests addressed the application of an integrated PF/ISV system in Hanford-type soils. Bench-scale tests physically simulate the integrated process and thereby permit study of critical soil parameters and their effect on fracture injection behavior. Figure 1 illustrates the key components of the bench-scale system: a test tank with plexiglass walls, an air supply system, a flow-directing injector-nozzle, a venting system, and a dry-media injection system. The plexiglass walls of the test tank permit direct viewing of the results of each injection and permit real-time adjustment of injection pressures and flow rates.

Of the 38 PF injection tests performed, 28 tests were with air alone, 6 with air and silica sand, and 4 with air and ISV conductive material. Soil density for the sessions varied between 1.65 and 1.80 g/cm^3; the moisture content was 0.8% to 7.8% by weight. Seven nozzle designs were used during the initial 10 fracture sessions with air alone. A nozzle previously designed for clays and other fine-grained soils (the traditional application of PF) allowed air to escape along the injection pipe. Subsequent designs using discs to isolate the nozzle from the injection pipe provided limited success but erratic results. A design using a disc that provided directional flow was the most effective and was used in most sessions.

Results from the bench-scale tests show that dry density and moisture content of the soils are critical factors in creating and controlling fractures and injecting dry media. The most important factor was dry density. Fractures at a density of 1.7 g/cm^3 were successful; inconsistencies were observed at lower densities. A density of 1.7 g/cm^3 represents the lower range for Hanford soils. As density increased, the pressure required to initiate fracturing tended to decrease. This effect was accentuated through the use of a surcharge on the soil surface to simulate soil overburden pressure.

Fracturing was generally successful when moisture content exceeded 2 wt%. Fracturing at lower moisture contents was successful if density exceeded 1.7 g/cm^3. At densities at or below 1.65 g/cm^3 and moisture content below 1wt%, discrete fractures were unattainable. This is attributed to a reduction of interstitial surface tension and the corresponding loss of apparent soil cohesion. The initial pressure required to fracture was not affected by the moisture content, contrary to expectations that the required pressure would decrease with increasing moisture content as apparent cohesion reduced the escape of air.

Results from bench-scale tests involving the injection of dry media (silica sand or ISV conductive material) showed a significant difference in lens geometry for different materials. Excavation was performed after injection of sand or ISV conductive material. For the sand injection, the lens was nearly continuous from the nozzle throughout the plane of fracture. Injection of sand, which is denser and less viscous than the ISV material, probably enhanced displacement or "cutting" of the Hanford surrogate soils. In contrast, excavation after injection of ISV material revealed a continuous layer at the fracture level, but the lens was not traceable to the nozzle. The ISV material appeared to have traveled upward along the injector pipe to the fracture. The ISV material is less dense than sand and has self-lubricating properties, which may have allowed it to travel along the small annular space between the injector and the soil.

The four tests involving the injection of ISV material were modeled to simulate the integrated PF/ISV process, in which conductivity is measured across the filled fracture and through the graphite electrodes of the ISV process. Results show that pneumatic fracturing can establish a conductive link in the soil subsurface between electrodes. The key to successfully establishing this link will be the formation of the fracture in the Hanford soil.

<u>Parametric Analysis</u>

A modelling study was performed to investigate selected physical processes of the integrated PF/ISV system. This was necessary because there was no previous experience with injecting granular media into a coarse-grain soil formation. The results provided insight into the critical mechanisms of the PF/ISV system and allowed estimates to be made of key design parameters for a field-scale system.

In a radial flow model for pneumatic fracturing, the velocity of the injected air decreased rapidly. Calculations suggest that the effective radius of the PF/ISV system may be limited to several feet in Hanford soil at standard injection flow rates and pressures. This distance is significantly less than the radius of influence typically observed in fine-grained soil and rock formations. The difference is attributable to the high permeability of the Hanford soil and corresponding rapid leak-off. Results underscore the need for proper nozzle design for the field, as well as maximization of system flow rates and pressures.

The critical suspension velocities for transport of the ISV conductive material in the fractures were determined by two different methods: Shields diagram method [10] and dust transport method [11]. The suspension velocity determined from these methods was generally less than 0.4 m/s. This relatively low velocity indicates that transport of the ISV conductive material should not be an issue in open fractures; rather, the limiting condition will be the ability to propagate the fractures.

The ability to transport ISV conductive material through the interstices of the Hanford soil was also analyzed with standard published filtration criteria. The results show that interstitial penetration of the conductive material will not be a significant mechanism in the Hanford soil; most of the particles are predicted to strain or cake at the fracture interface. A benefit from this caking may be the extension of the radius of the fracture as caking reduces the permeability of the upper and lower boundaries of the fracture. The reduced permeability extends the fracture by minimizing leak-off from the upper and lower boundaries.

CONCLUSION

Results of bench scale tests suggest that pneumatic fracturing and in situ vitrification can be successfully integrated to expand the applicability of both technologies. The establishment of fractures in Hanford surrogate soils shows that pneumatic fracturing is applicable in soils other than clays and fine-grained soils. Successful injection of ISV conductive material in the soil subsurface to provide a conductive link between ISV electrodes provides a means for initiating the ISV process at a target depth. The consequent increased ISV capability enhances the applicability of the technology beyond current demonstrated depths.

We are integrating the results of the laboratory results into plans for a field demonstration of pneumatic fracturing at Hanford to be performed in the first quarter of 1995 on an uncontaminated soil site. If a suitable conductive path is created, then the field demonstration will continue the ISV process initiated in the soil subsurface.

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REFERENCES

1. Murphy, M.T., J.L. Buelt, J.A. Stottlemyre, and J.S. Tixier. May 1992. "Vitrified Underground Structures." U.S. Patent 5,114,277.
2. Luey, J. and D.K. Seiler. 1994. "Evaluation of New Starter Path Geometries for In Situ Vitrification." PNL-10122, Pacific Northwest Laboratory, Richland, Washington.
3. U.S. Environmental Protection Agency. July 1993. "Applications Analysis Report: SITE Demonstration test; Accutech Pneumatic Fracturing Extraction and Hot Gas Injection, Phase 1." EPA/540/AR-93/509, U.S. Environmental Protection Agency, Cincinnati, Ohio.
4. Pisciotta, T., D. Pry, J.R. Schuring, P. Chan, and J. Chang. 1991. "Enhancement of Volatile Organic Extraction in Soil at an Industrial Site." Proceedings of FOCUS Conference on Eastern Regional Groundwater Issues, National Water Well Association, Portland, Maine.
5. Schuring, J. and C. Chan. 1992. "Removal of Contaminants from the Vadose Zone by Pneumatic Fracturing." U.S. Geological Survey, Department of Interior, U.S.G.S. Award 14-08-0001-G1739.
6. Schuring, J. , J. Valdis, and P. Chan. 1991. "Pneumatic Fracturing of a Clay Formation to Enhance Removal of VOC's." Proceedings of Fourteenth Annual Madison Waste Conference, University of Wisconsin, Madison, Wisconsin.
7. Schuring, J.R., P.C. Chan, J.W. Liskowitz, P. Papanicolaou, and C.T. Bruening. July 1991. "Method and Apparatus for Eliminating Non-Naturally Occurring Subsurface, Liquid Toxic Contaminants from Soil." U.S. Patent 5,032,042.
8. Graham, M.J., M.D. Hall, S.R. Strait, and W.R. Brown. 1981. "Hydrology of the Separations Area." RHO-ST-42. Rockwell Hanford Operations, Richland, Washington.
9. Last, G.V. and V.J. Rohay. 1993. "Refined Conceptual Model for the Volatile Organic Compounds Arid Integrated Demonstration and 200 Area West Area Carbon Tetrachloride Expedited Response Action." PNL-8597, Pacific Northwest Laboratory, Richland, Washington.
10. Boggs, S. Jr. 1987. "Principles of Sedimentology and Stratigraphy." Merrill Publishing Company, Columbus, Ohio.
11. Tsoar, H. and K. Pye. 1987. "Dust Transport and the Question of Desert Loess Formation." *Sedimentology*, 34: 139-153.

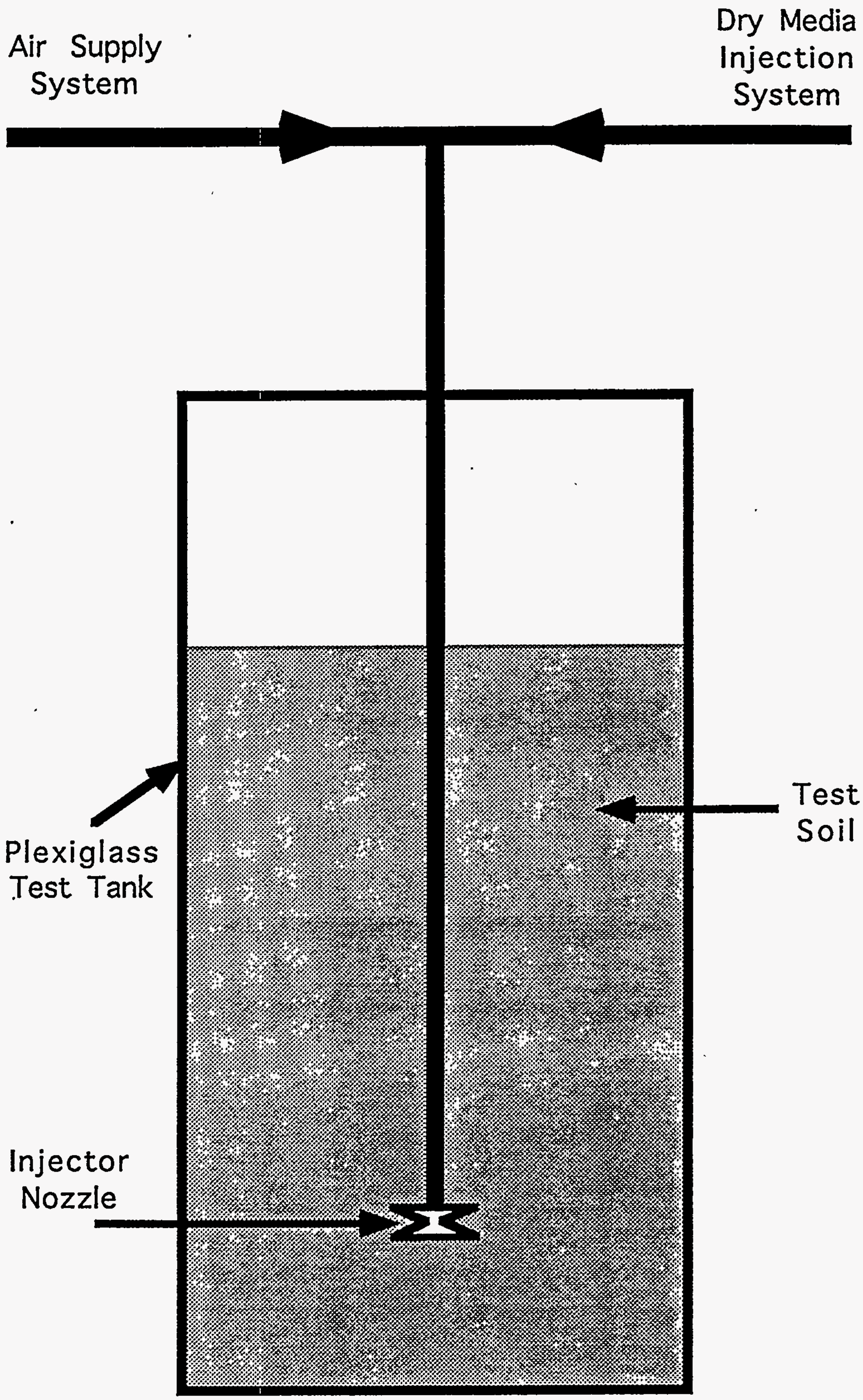
Air Supply System
Dry Media Injection System
Plexiglass Test Tank
Test Soil
Injector Nozzle

FIGURE 1

TABLE 4-1

Comparison of Physical Data-Hanford Soils and Surrogate Soils

Test	Method	Parameter	Hanford Soils	Surrogate Soils*
Grain Size Analysis:	ASTM D 2217-85	cobbles	22.3 wt%	25 wt%
Washing (No. 200 sieve),	ASTM D 1140-92	gravels	27.6 wt%	30.7 wt%
Manual Separation,	ASTM D 422-63	sand	46.7 wt%	40.9 wt%
Mechanical Sieve,		silt	3.3 wt%	2.7 wt%
and Hydrometer Test		clay	0.1 wt%	0.7 wt%
Liquid and Plastic Limits	ASTM D 2217-85 ASTM D 4318-84		Non-plastic	Non-plastic
Organic Content	ASTM D 854-92		0.12 wt%	0.28 wt%
Specific Gravity	ASTM D 854-92		2.82	2.66
USCS Classification	ASTM D 2487-93		GP	GP
Color	Munsell® Soil Color Charts (air dry soil)		Batch 1--10YR 5/6: Yellowish Brown Batch 2--10YR 4/2: Dark Grayish Brown	2.5Y 6/4: Light Yellowish Brown

* Sample for grain size analysis was collected after 12 fracture sessions; sample is not 100% representative of original blend.

TABLE 1 - TO BE REFORMATTED FOR CONFERENCE PAPER.