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PLASMA HEARTH PROCESS VITRIFICATION OF DOE LOW-LEVEL MIXED WASTE[1]

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Abstract

The Plasma Hearth Process (PHP) demonstration project is one of the key technology projects in the Department of Energy (DOE) Office of Technology Development Mixed Waste Focus Area. The PHP is recognized as one of the more promising solutions to DOE's mixed waste treatment needs, with potential application in the treatment of a wide variety of DOE mixed wastes. The PHP is a high temperature vitrification process using a plasma arc torch in a stationary, refractory lined chamber that destroys organics and stabilizes the residuals in a nonleaching, vitrified waste form. This technology will be equally applicable to low-level mixed wastes generated by nuclear utilities. The final waste form will be volume reduced to the maximum extent practical, because all organics will have been destroyed and the inorganics will be in a high-density, low void-space form and little or no volume-increasing glass makers will have been added. Low volume and high integrity waste forms result in low disposal costs. This project is structured to ensure that the plasma technology can be successfully employed in radioactive service. The PHP technology will be developed into a production system through a sequence of tests on several test units, both non-radioactive and radioactive. As the final step, a prototype PHP system will be constructed for full-scale radioactive waste treatment demonstration

Plasma Hearth Process Technology Description

The PHP falls into a general category of waste treatment technologies known as vitrification. Vitrification is the process of converting a material into a glass-like form. In the case of the PHP, the waste materials are converted into a very stable vitrified slag form, significantly reducing volume and hazards and greatly improving the disposability of the waste.

The term "plasma" refers to a highly-ionized electrically conductive gas. Plasmas can be generated by a variety of techniques, over a wide range of pressures and energy levels. The type of plasma produced in the PHP application is a dc arc-generated thermal plasma and is created by a device known as a "plasma torch." The plasma torch used in the PHP technology operates in the transferred arc mode. Basically, the transferred arc torch uses a

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flow of gas to stabilize an electrical discharge (arc) between a high voltage electrode (inside the torch) and a molten pool of waste (maintained at ground potential). Because of the very high resistance to electrical current flow through a gas, electrical energy is converted to heat. Plasma gas temperatures are estimated to reach as high as 10,000°C. Even more energy is converted as the electrical current passes through the melt, creating a Joule-heating effect in the molten pool. The resulting molten product can form two phases: 1) a high integrity, leach-resistant slag is produced in any operating mode; and 2) a separate reduced metal phase is produced when the process is operated in a reducing (oxygen deficient) mode. The two phases segregate naturally due to density differences and can be recovered separately[1].

Plasma arc technology is an existing, well understood, and commercially available technology. Industry has been using plasma arc torches in various applications for many years. Some of the commercial applications of plasma currently used around the world include the following:

- metal and ceramic powder production,
- composites production (metal on metal, metal on ceramic, etc.),
- titanium dioxide pigment production,
- chemical production (acetylene, ethylene, etc.),
- metal ore smelting,
- metal and refractory recycling,
- metal refining, and
- metal cutting and welding.

The PHP Project involves adapting commercial plasma torch metal refining technology to the vitrification of waste materials. Because of the maturity of plasma torch technology and the similarity of the applications, the development is expected to be rapid.

The PHP technology is chiefly applicable to solid or sludge wastes where a stabilized byproduct is required for disposal. The technology is ideally suited for heterogeneous wastes of nearly any type that are difficult to treat by conventional thermal technologies. The application for which it is currently being developed is DOE solid mixed wastes, both low-level and transuranic (TRU). These wastes are found at most DOE sites and many of the waste streams have no identified treatment option. One of the key advantages of the PHP technology is the ability to process a wide variety of waste materials, often without regard to physical or chemical nature. This minimizes the number of different treatment processes that would otherwise be needed to treat a variety of wastes. Whole drums of waste, including heterogeneous matrices, may be fed into the process chamber, which minimizes pretreatment characterization, sorting, sizing, and other handling and potential exposure to toxic and radioactive contaminants.

PHP System Description

The primary functional units of the PHP system are the feed system, plasma chamber, slag/metal removal system, secondary combustion chamber, and air pollution control system (APCS). Processing begins as complete drums of waste are fed to the fixed hearth plasma chamber, where heat from the plasma torch initiates a variety of chemical and physical changes. Complex organic compounds break down into non-complex gases that are drawn from the chamber, while the remaining inorganic material materials are "drip melted" slowly into a crucible. The molten material separates into two phases: slag and metal. The molten materials are poured into waste containers by a simple hearth tilting mechanism to avoid tap hole plugging problems. This high-integrity final waste form, similar to that selected for high-level radioactive wastes, has repeatedly shown the ability to meet or exceed disposal requirements instituted by the EPA.

Induced draft fans pull gases from the plasma chamber to a secondary combustion chamber. Once there, excess oxygen and the product gases are mixed in a very hot and turbulent environment for a sufficient residence time to complete the conversion of the gaseous organic compounds to CO_2 and H_2O. This secondary chamber guarantees the hazardous organics are treated completely to achieve the high-destruction-efficiency required by the EPA. The offgas is then scrubbed by state-of-the-art air pollution control technologies capable of removing a high degree of pollutants, producing very clean process emissions[1]. Offgas volumes are much smaller than for conventional incinerators since the plasma gas volumes are very small and no fossil fuel burning occurs in the plasma chamber. SAIC is working on development of an electrically-fired secondary combustion chamber to replace the fossil fuel burner in the secondary and further reduce offgas emissions.

Completed PHP Testing

The first PHP hardware installation, referred to as the Proof of Principle System, was constructed at Retech, Inc., a supplier of plasma torch equipment. The final testing on this unit is now complete and the data is very promising. The Proof of Principle System, illustrated in Figure 1, was constructed to conduct tests involving the demonstration of treatment of a wide variety of nonradioactive surrogate DOE waste forms. The tests proved that a fixed hearth plasma process can treat extremely difficult-to-process wastes contained within their original containers, the containers can be fed whole into the process chamber without opening, sorting, and/or pretreatment, and the waste can be converted directly into a vitrified, high integrity final waste form without the need for additives. The PHP easily treats mixtures of combustibles, noncombustibles, and metals[2].

This final proof of principle test series served a dual function. The first function was to demonstrate PHP treatability of the waste types selected by the DOE as being representative of a majority of DOE wastes nationwide. The treatability assessment included potential for reasonable waste processing rates and the environmental performance measurements of product TCLP leachability, particulate emissions, and destruction and removal efficiency (DRE). The second function was to provide baseline data for process development. The baseline data obtained from these tests involved product and offgas characterization, including waste volume reduction[3].

Test Results to Date

Tests performed to date demonstrate that the PHP addresses DOE mixed waste final waste form requirements, in that the residual from the PHP provides a very stable vitrified final product of high integrity, often without the need for glass formers. The chemistry of the

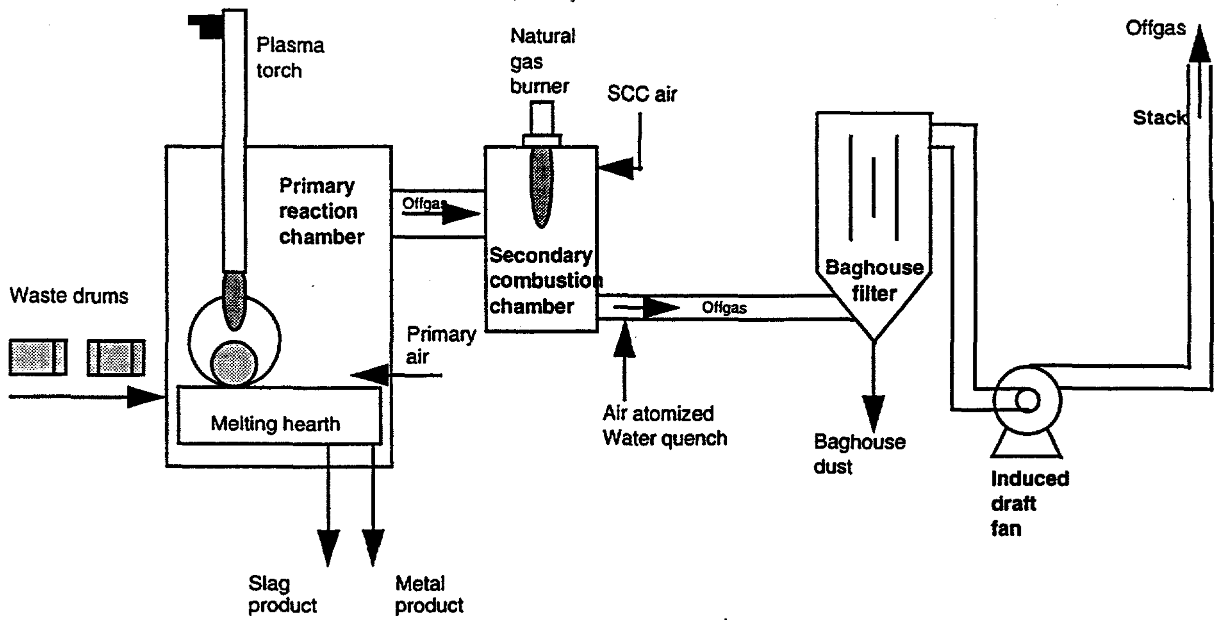

Figure 1. Proof of Principle PHP Facility

molten slag can be controlled, if necessary (through additives), to optimize properties for disposal. Test results to date have yielded slags that vary widely in appearance and composition. Given the varied characteristics of the waste feed for any given test and the lack of any mechanical agitation, the PHP slag is surprisingly homogeneous. Analysis indicates the presence of large amounts of crystallinity in many slags. Although the slag from this process is not a true glass, it was directly compared with glasses from vitrification processes which, due to the lower operating temperatures of these systems, require strict chemistry control to achieve final forms with acceptable leaching characteristics.

Analyses performed on the PHP slag consistently exceeded EPA's requirements for leachability using the Toxic Characteristic Leaching Procedure (TCLP) to meet the Land Disposal Restrictions and compared favorably with the DOE's Waste Acceptance Product Specifications for high-level waste glass. The metal concentrations in the TCLP leachate for all the slags were consistently at least two orders of magnitude below the RCRA limits. The slag crystallinity appears to have no adverse affect on the slag integrity with respect to TCLP results.

Product Consistency Tests (PCT) were performed on the slag to assess waste form durability and to compare it to high-level waste glass performance. The PCT results are compared to SRL 200, a typical borosilicate glass proposed for high-level waste, and EA glass, the benchmark glass composition for high-level waste glass. DOE's Waste Acceptance Product Specifications require all high-level waste glass to demonstrate PCT leach resistance greater than or equal to that of EA glass. With respect to SRL 200 glass, PHP slags have similar or superior leach resistance for all common analytes (Al,Fe,Mg,K,Si and Na). The PCT was developed for assessing high level waste, which results from reprocessing nuclear fuel and has an essentially constant composition. The PCT is different from the TCLP in that it addresses matrix leachability (degradation) rather than the leachability of toxic metals. The PCT was selected because it is the only yardstick applied to radioactive wastes, even though it currently applies only to high level waste (which is treated by standard vitrification methods). Tight control of product composition is not achievable for any large scale process treating a wide range of waste materials. However, this analysis indicates that strict compositional control is not required to produce a final waste form that exhibits outstanding leachability and durability characteristics[4].

PHP emission characteristics were compared with EPA's current and proposed regulatory limits. The Proof of Principle System, having only a rudimentary air pollution control system consisting of a partial quench spray and a fabric filter baghouse, had total particulate matter emission characteristics that were consistently an order of magnitude below these limits. The baghouse, which used conventional filtration media, consistently achieved 99.8% capture efficiency even though particle size distribution measurements indicated a large fraction of submicron particulate at the baghouse inlet (Table I). As illustrated in Table II, destruction and removal efficiency (DRE) for organics consistently exceeded 99.99 and were in excess of 99.9999 for some constituents[3].

TABLE I
Particulate Emissions

	INORGANIC SLUDGE		HETEROGEN. DEBRIS		ORGANIC SLUDGE		RCRA LIMIT	EPA COMBUSTION STRATEGY
	M-1	M-2	M-3	M-4	M-5	M-6		
Baghouse Outlet, gr/dscf @ 7% O_2	0.0022	0.0010	0.0026	0.0018	0.0040	0.0044	0.08	0.015
Capture Efficiency, percent	99.88	99.76	99.85	99.87	99.81	99.82		

TABLE II
Destruction and Removal Efficiencies, %

POHC	M-5	M-6
Naphthalene	99.9998	99.9961
1,2-Dichlorobenzene	>99.9999	>99.9999

Treatment Volume Reduction

One of the parameters of interest is the volume reduction factor. Minimizing the volume of the treated waste form minimizes disposal costs. SAIC selected formulations for three waste categories that represent a range of mixed waste streams that pose significant treatment problems for DOE. The selected waste categories include inorganic sludge, heterogeneous debris, and organic sludge, which also represent low, medium, and high heating value wastes, respectively. Table III summarizes the resulting volume reduction factors. First, the volume reduction was determined in comparison to the volume of the waste itself. The fill fraction of the waste container has no impact on this determination. Second, the volume reduction was determined in comparison to the volume of the waste containers processed. On average, the drums of surrogate waste were filled to about 80% of capacity. Potential for volume reduction for a waste increases with organic content and decreases with bulk density. As expected, the inorganic sludge exhibited the lowest reduction factors because it had the highest bulk density (1300 kg/m^3) and little organic content. The heterogeneous debris yielded the highest volume reduction factors. It had the lowest bulk density (600 kg/m^3) and organic content comparable with the organic sludge. The bulk density of the product was relatively insensitive to the feed composition; it was consistently around 3000 kg/m^3 [3].

TABLE III
Volume Reduction Ratios

	INORGANIC SLUDGE	HETEROGENEOUS DEBRIS	ORGANIC SLUDGE
Waste Only	5:1	9:1	7:1
Waste Drums	8:1	11:1	9:1

PHP Treatment Advantages and Disadvantages

The features that make the PHP particularly attractive for waste treatment include:

- the ability to treat a very wide range of waste types;
- the ability of the process chamber to accept whole drums of waste;
- little or no front-end handling, characterization, feed preparation, or pretreatment;
- the ability to destroy organic compounds, including hazardous organics;
- generation of a stable, nonleaching end-product that complies fully with all disposal regulations, and;
- maximum waste volume reduction, because little or no waste-form-enhancing additives are required.

On the down side, the PHP is a high temperature thermal process, and has been designated an incinerator by the EPA for purposes of permitting. This technology faces many of the same objections from the public and environmental groups as incinerators, and the resulting obstacles for permitting. However, the characteristics of the technology in terms of low offgas volumes and a disposable residual will help in this regard. The PHP technology is one of a limited number that has been selected by the Western Governors Association (WGA) to follow through the development and demonstration phase in their activities to accelerate technology implementation for cleanups. Within the WGA activities, stakeholders have expressed support for the technology.

PHP Technology Status

The DOE PHP demonstration project is a comprehensive multi-year demonstration that involves many different pieces of laboratory and pilot system hardware, and involves the demonstration of treatment of both surrogate radioactive materials and actual DOE mixed waste materials. The initial thrust of the project was to demonstrate the general applicability of the PHP to the treatment of DOE solid mixed wastes and to evaluate the potential to achieve successful implementation. Current development and demonstration activities include fabrication of two PHP test systems for testing in calendar year 1996. Surrogate studies will be conducted on a full-scale nonradioactive unit to verify expected system performance for waste forms being targeted for treatment. This will be paralleled by testing of a bench-scale system using radioactive materials to confirm that the nonradioactive surrogate studies properly model the behavior of radionuclides during treatment. As the final step, a prototype PHP system will be constructed for full-scale radioactive waste treatment demonstration[5].

References

1. R. L. Gillins, S. D. Poling, "Plasma Hearth Waste Treatment Demonstration for Radioactive Mixed Waste," , presented at the 1994 International Incineration Conference, Houston, TX (May, 1994).

2. R. L. Gillins, "The Plasma Hearth Process: A Versatile Solid Mixed Waste Treatment Technology", presented at the Executive Enterprises Conference on Mixed Waste, Charleston, SC (February 1995).

3. G. R. Hassel, R. M. Geimer, J. A. Batdorf, and G.L. Leatherman, "Evaluation of the Plasma Hearth Process for Mixed Waste Treatment Applications," presented at the 1994 International Incineration Conference, Houston, TX (May 1994).

4. G. L. Leatherman, R. Geimer,J. Batdorf, G. Hassel, P. Wolfe, "The Plasma Hearth Process: Process Residuals Characterization," presented at the 96th Annual Meeting of the American Ceramic Society, Indianapolis, IN (April 1994).

5. R. L. Gillins, R. Geimer, C. Bonzon, "The Plasma Hearth Process Demonstration Project for U.S. Department of Energy Waste Treatment," presented at Metatechnies "94, Bordeaux, FR (September 1994).