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VITRIFICATION: DESTROYING AND IMMOBILIZING HAZARDOUS WASTES

C. C. Chapman
R. D. Peters
J. M. Perez

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Pacific Northwest Laboratory
Richland, Washington 99352

VITRIFICATION: DESTROYING AND IMMOBILIZING HAZARDOUS WASTES

Christopher C. Chapman, Richard D. Peters, and Joseph M. Perez

Pacific Northwest Laboratory
Battelle Memorial Institute
Richland WA 99352

Researchers at the U. S. Department of Energy's Pacific Northwest Laboratory (PNL) have led the development of vitrification a versatile, adaptable process that transforms waste solutions, slurries, moist powders, and/or dry solids into a chemically durable glass form. The glass form can be safely disposed or used for other purposes, such as construction material if non-radioactive. The feed used in the process can be either combustible or non-combustible. Organic compounds are decomposed in the melter's plenum, while the inorganic residue melts into a molten glass pool. The glass produced by this process is a chemically durable material comparable to natural obsidian (Byers, Jercinovic, and Ewing 1986). Its properties typically allow it to pass the EPA Toxicity (TCLP) test as non-hazardous. To date, no glass produced by vitrification has failed the TCLP test. Vitrification is thus an ideal method of treating DOE's mixed waste because of its ability to destroy organic compounds and bind toxic or radioactive elements. This article provides an overview of the technology.

Numerous Benefits Offered

Vitrifying waste offers numerous benefits to industries faced with treatment needs. The process can treat a variety of waste forms, including concentrated slurries or sludges, organics containing heavy metals, combustible wastes, trash, and pesticide-contaminated soils. Vitrification is economical, transforming wastes into a chemically durable glass than can be de-listed and used in construction as an aggregate or clean fill material. If the glass requires disposal, the process minimizes disposal costs by significantly reducing the waste volume. It also provides a glass form that has consistently passed the US Environmental Protection Agency's toxic leach tests.

The scale of operation can be designed for one to hundreds of tons/day (Chapman and Robinson 1993, Robinson, R. A. et al 1992.) A mobile, integrated treatment system has been designed for up to 5 tons/day. A transportable system for 100 tons of soil/day can be assembled from existing operating equipment.

Innovative Treatment Process

Hazardous slurries, solutions, contaminated soils, or miscellaneous solids are fed into the melter using existing technologies. With a suitable off-gas system, the same melter can process all these different types of waste and provide a universal, "one stop" treatment. Figure 1 provides a schematic of the vitrification concept. The process transforms hazardous forms of waste into a durable glass product that resembles obsidian. The obsidian-like product is expected to retain the waste for a million years.

The heart of the process is the melter, a refractory-lined cavity with submerged electrodes. After preheating of the cavity and the initial charge, the melt becomes electrically conductive. With an alternating current placed between pairs of electrodes, the molten glass is self-heated. Molten glass temperature is typically limited only by the extent of corrosion resistance and refractoriness in the lining and the electrodes. Temperatures up to 3000 F are sustainable for hazardous waste processing. At these temperatures almost any material can be melted or dissolved as indicated in Table 1 (Chapman and McElroy 1989).

Small additions of chemicals may be needed to achieve suitable product durability or processability. Local soils can be used as these additives.

Figure 1 Vitrification Process Concept

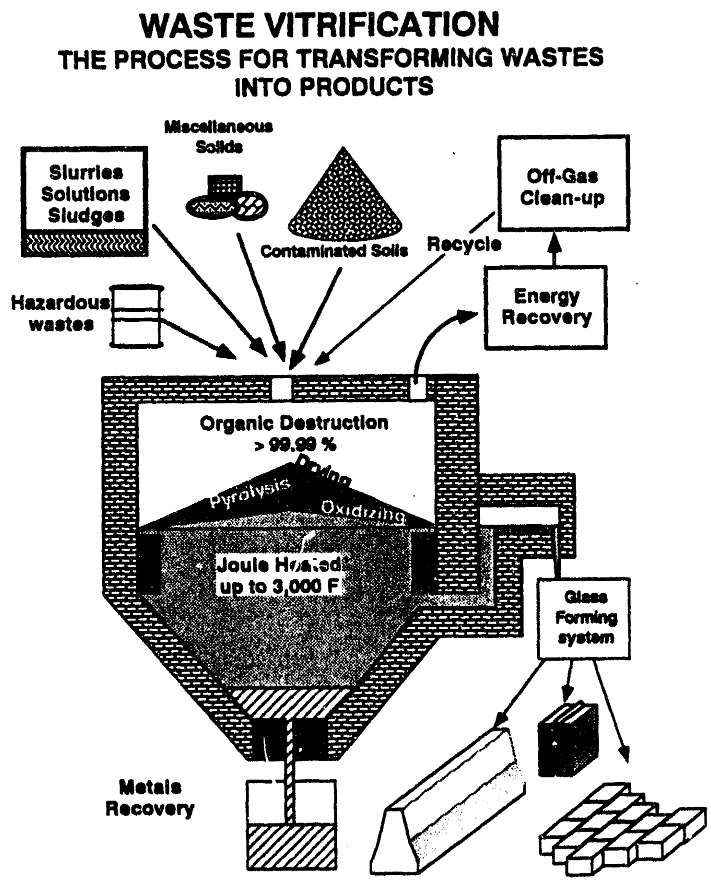

Table 1. Numerous inorganic compounds have been incorporated into glass in PNL's tests of the vitrification process.[(a)]

Oxide	Wt%	Oxide	Wt%
Al_2O_3	28.00	Na_2O	18.10
As_2O_5	0.01 (3.0)	Nd_2O_3	4.00
B_2O_3	12.00	NiO	1.70
BaO	14.90	P_2O_5[(b)]	6.0 (32.0)
Bi_2O_5	0.90	PbO	9.00
CaO	24.00	PuO_2	0.02
CdO	0.60	Rare Earths	5.0
CeO_2	5.00	RuO_2	0.10
Cl-	0.35	Sb_2O_3	0.07
CoO	0.20	SeO_2	0.03
Cr_2O_3	1.60	SiO_2	63.0
Cs_2O	5.80	SO_4-	1.00
CuO	3.00	SrO	2.67
F-	9.00	Tc_2O_7	1.40
Fe_2O_3	20.1	TeO_2	0.40
K_2O	4.00	ThO_2	6.00
La_2O_3	4.00	TiO_2	6.00
Li_2O	9.40	UO_2	6.00
MgO	1.50	ZnO	21.1
MnO_2	3.85	ZrO_2	9.60
MoO_3	4.00		

(a) Highest concentration demonstrated in at least one of several glasses in process equipment at PNL. For some constituents, higher concentrations have been demonstrated using this process outside PNL.
(b) Maximum demonstrated in lab equipment.

A typical limitation for conventional glass melters is the presence of elemental metals in the feed. Although not yet fully demonstrated, an advanced 50-ton/day melter has been designed for processing municipal solid waste (MSW) incinerator ash that contains up to 10 wt% metals (Chapman and Robinson 1993).

Vitrification Process Rates

The process rate depends on several properties of the waste, such as water content, chemical composition, inherent energy content, and particle size. To achieve the desired process capacity, the surface area of the molten pool is adjusted. For solutions and concentrated slurries, and assuming no credit for exothermic reactions in the feed, the specific process rate is between 36 and 60 gal/day/ft^2 (Chapman and McElroy 1989). For contaminated soils and other inorganic feeds, the process rate ranges between 400 and 600 lb/day/ft^2. For primarily combustible wastes such as MSW or medical waste, over 2000 lb/day/ft^2 is the design value.

Energy Requirements

Energy requirements depend mostly upon the water content and the exothermic energy present in the feed. Typically 900 kW-hr/ton of glass produced is required to vitrify inorganics. For contaminated soils, 1600 kW-hr is needed to vitrify each cubic yard (1.76 ton/yd^3). To reduce these costs, innovative energy recovery techniques have been identified for use with the larger processing systems. For ash or waste with more than 10 dry wt% carbon, the electrical power requirements can be less than 100 kw-hr/ton.

Treatment Costs

Treatment costs depend upon various factors, including the type of waste, electricity costs, and treatment location. Estimates for a 100-ton/day system range from $110 to $150/ton to treat contaminated soil, typically the most expensive waste to process from an energy standpoint. Immobilizing bottom ash from a municipal incinerator is estimated at $52/ton of ash. These cost estimates include costs for the melter and off-gas system, labor, maintenance, and capital recovery. Radioactive or designated hazardous waste will be more expensive to treat because of administrative controls driven by regulations.

Experience with Vitrification

This technology was first adapted by the Pacific Northwest Laboratory for the US Department of Energy to transform highly radioactive wastes into a chemically durable glass solid. Reliable equipment and techniques were developed to permit processing of these hazardous wastes essentially without maintenance because the high radiation fields precluded human access to the waste and equipment.

The wastes processed varied from highly acidic nitric acid solutions (2 to 6 molar) to basic slurries (pH~12 to 14). The fission products and chemicals present in the waste encompassed nearly the entire periodic table, the only exceptions being gases, carbon, iodine, and mercury. Vitrification of a high radium-containing material reduced radon release from the original material's value of 52,000 pCi/m^2-s to less than 2 pCi/m^2-s for the vitrified material (Merrill 1993). Many inorganic compounds have been immobilized at PNL using this technology. The process also destroys hazardous organic wastes; in fact, experimentally determined destruction efficiencies for several organic contaminants have been significant as shown in Table 2.

Reducing Waste Volume

Increasing disposal costs make vitrification's volume reduction capability an economical treatment option. The volume of vitrified soils can be as low as 60% of the original volume because the air between the particles is replaced with a continuous solid. For incinerator ash the final volume can be as little as 20% to 30% of the original volume. For some combustible wastes, such as wood or paper, the final volume can be less than 1% of the original volume. Medical wastes are reduced by more than 99.7 volume%.

In contrast to ash from incinerators, the glass product is dense and has a larger size distribution and thus will not form dust that blows away from the treatment or disposal site to any neighbors.

Table 2. High destruction efficiencies have been demonstrated for several organic contaminants in PNL's experimental work. (Balasco 1988)

Compound	Feed Conc., ppm	Percent Destruction
Contaminated soils		
Organochlorine		
Aldrin	3100	99.99994
Dieldrin	1300	99.9995
Endrin	180	>99.998
Isodrin	110	>99.9998
Organophosphorus		
DIMP	<2	>99.8[a]
DMMP	2.26	99.8[a]
Organosulfur		
Dithiane	<1.88	>99.96[a]
Sulfoxide	300	>99.99
Sulfone	670	>99.995
Waste Solutions		
Methylene Chloride	7,300	>99.999
Acetone	3.7-11.0 wt%	>99.999
Ethanol	12.9-38.6 wt%	>99.999
Chlorobenzene		99.99986
Phenol		99.99992
Carbon Tetrachloride		99.99988
Xylenes		99.99817
ACN		99.99996
AN		99.99994

(a) Detection limit in exhaust sample defines these values. None were detected.

Useful Materials Produced

Vitrification can transform many wastes into materials that are highly useful because of the product's excellent chemical durability and high compressive strength. Simple applications, such as using the material as a component in asphalt or concrete aggregate and clean fill, are already possible. More sophisticated products, such as synthetic boulders for erosion control, paving bricks, glass wool insulation and glass tiles, may be economically practical. Small fire-polished pieces of lustrous black glass may be used as jewelry. After further development of applications, sale of the glass will offset the costs of processing the wastes.

Application to Mixed Waste

Vitrification has already been developed for high level waste and other types of radioactive and industrial waste. Based on this experience, development for mixed waste should also be feasible. A vitrification development plan for mixed waste has been prepared which addresses the data needs and associated special requirements for mixed waste treatment (Peters et al 1993). Production of a glass acceptable for land disposal will require some knowledge of the waste composition so that appropriate glass-forming chemicals can be added where necessary. Mixed waste consists of regulated hazardous materials as well as radionuclides. The required product quality is not yet defined beyond certain minimal limits. Through vitrification development, the glass waste form can be tailored to any desired level of quality.

Acknowledgments

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