Vitrification of Residue (ASH) From Municipal Waste Combustion Systems

ABSTRACT

The American Society of Mechanical Engineers (ASME) and the U.S. Bureau of Mines (the Bureau), through cooperative agreements that included over 30 government and industry sponsors, conducted over 200 hours of melting tests to vitrify residues from five municipal solid waste combustion facilities. These tests, conducted in response to public concern regarding the potential leachability of combustion residues, confirmed that vitrification by electric furnace arc melting is technically viable among the available options for managing MWC residues. The residues included dry combined grate and baghouse residues from three state-of-the-art mass burning waste-to-energy (WTE) plants, dry combined ash from a multiple-hearth wastewater treatment plant (WWTP) sludge combustor, and dry acid gas absorber baghouse residue from a WTE plant burning refuse-derived fuel (RDF).

An electric arc melting furnace having water-cooled roof and sidewalls, a modified power supply, and dedicated feeding and emissions control systems was constructed specifically to continuously feed and melt up to one short ton per hour of residue and to allow the vitrified products to be continuously tapped from the furnace within stringent environmental requirements. The melting demonstration began with short tests to define operating procedures and culminated in a 100-hour operation in which over 54,000 pounds of combustor residues were melted.

Upon melting, the combined residue separated into three distinct materials. From 69 to 86 percent (pct) became vitrified products, which satisfied ASTM requirements for aggregate applications. Lesser percentages became metal and metal sulfide (matte) products, which are also potentially useful materials. The vitrified products, metal, and matte materials were tested using the Environmental Protection Agency's (EPA's) Toxicity Characteristic Leaching Procedure (TCLP). The eight metals of concern were found to be below regulatory thresholds. Some of the volatile heavy metals in the feed materials were concentrated in the fume solids and collected. These solids also tested using TCLP may have a potential for metal recovery and reuse. The results of projected generic economic estimates of electric arc furnace vitrification technology also are presented.

SUMMARY

Over six years of planning, organizing, and fundraising by ASME and the U.S. Bureau of Mines (the Bureau), resulted in an agreement signed in September 1990 to conduct vitrification tests of residues from waste-to-energy (WTE) plants processing municipal wastes. An ash vitrification subcommittee was formed by ASME's Research Committee on Industrial and Municipal Wastes in order to plan and conduct the vitrification program. Participants included industry and government researchers, furnace manufacturers and operators, academics, solid waste industry professionals, regulatory agencies, and private engineering consultants.
The Program required the design and construction of a sealed three-phase electric arc melting furnace having a water-cooled shell and roof, modification of an existing power supply to accommodate anticipated higher resistivity in the molten residues, and design and construction of feeding and emissions control systems.

This report describes the collection, processing, and shipping of residues from five state-of-the-art municipal waste combustion (MWC) facilities to the U.S. Bureau of Mines Research Center in Albany, Oregon, (ALRC) and the installation and operation of the feed system, electric arc melting furnace, and emissions control system. The technical information obtained during 100-hour (hr) of continuous operation processing more than 54,000 pounds of residues is presented and discussed. The results of generic economic estimates of electric arc furnace vitrification technology are provided.

PROGRAM IMPLEMENTATION

- Combined grate and baghouse residues from three WTE plants burning municipal waste were collected, screened, dried, bagged, and shipped to the melting facility at ALRC. Particulate emissions from the drying operation were collected in a baghouse and combined with the dry residue. Emissions from the baghouse were also monitored.

- Combined dry residue from a regional WWTP sludge combustor and residue from a dry acid gas absorber of a WTE plant burning RDF were shipped directly to the Bureau's melting facility.

- The residues were extensively characterized to determine physical properties and chemical composition.

- A melting facility comprised of a feed system, electric arc melting furnace, emissions control system, and water-cooling tower was constructed. The feed residue conveying system provided continuous feeding to the furnace of minus 1-inch (in) residues with densities approximating 80 pounds per cubic feet (lb/cu ft) at rates up to 2,000 lb/hr.

- A stationary, sealed, refractory-lined arc melting furnace with a 5-cu ft hearth, water-cooled walls and roof, and air-cooled bottom, was constructed, and an existing three-phase 800 kilovolt ampere (kV A) power supply was modified to provide the higher voltage anticipated for effectively melting the combustor residues. The furnace was fitted with a water-cooled copper tapping fixture, for continuous tapping of vitrified product at rates up to 1,500 lb/hr. The furnace was emptied through a lower taphole of the furnace hearth.

- The emissions control system was designed to accommodate 125 to 250 standard cubic feet per minute (scfm) of furnace exhaust. It consisted of a cleanable six-inch duct, a 123,000 British thermal units/hr (BTU/hr) heat exchanger, baghouse,
lime injector for acid gas control, and a thermal oxidizer providing one second residence time at 1,800° F.

- For safety reasons during this demonstration, nitrogen gas was injected into the emissions control system to limit oxygen concentration below five percent (pct) to prevent a formation of a flammable gas mixture.

- Preliminary melting trials of up to 18 hr duration were conducted to refine operating procedures.

- Five municipal waste combustor residues were melted sequentially over a period of about 100 hr to demonstrate the technical feasibility of arc melting and to provide furnace products for beneficial use evaluations.

- The chemical composition and compound identification of furnace products, including vitrified product, metal, metal sulfide (matte), and fume solids, were determined. A material balance for each residue was also estimated.

- To assess environmental implications, furnace products and fume solids were tested in strict compliance with the U.S. Environmental Protection Agency's (EPA's) Toxicity Characteristic Leaching Procedure (TCLP). Exhaust gas emissions were also monitored for O\textsubscript{2}, CO\textsubscript{2}, VOC, S\textsubscript{0}, HCl, Hg etc. and PCDD/PCDF.

- Generic economic estimates were prepared to project potential commercial applicability of electric arc furnace vitrification technology.

**FINDINGS AND CONCLUSIONS**

- Combined grate and dry scrubber baghouse residues from three different types of state-of-the-art MSW combustors, combined residue from a WWTP sludge combustor, and dry scrubber baghouse residue from a state-of-the-art WTE plant burning RDF were extensively characterized to provide detailed physical descriptions and chemical compositions.

- The combined MWC residues and the sewage sludge combustor residue were consecutively melted in the 100-hr furnace operation so as to provide a new dense environmentally acceptable material for practical economic use. Carbon in MSW combustor residues may cause operational difficulties during arc melting, and further research is needed to define the acceptable range for residue carbon content.

- During early trials, baghouse residue from a WTE plant burning RDF was successfully melted as received. It was subsequently pelletized to simplify material handling and with iron oxide and silica sand added to better control thermochemical reactions.
• Chloride and sulphur salts in the residues decomposed into acid gases in the furnace thereby requiring provisions for acid gas emission control.

• Melting of MWC residues, the WWTP sludge combustor residue, as well as the RDF baghouse residue resulted in 69-86% vitreous product. For further details see Table 6-3.

| Vitreous Product
| Metallic Product
| Matte Product
| Fume Solids
| Baghouse and Gas Solids

• The MWC residues and the baghouse residue with iron oxide and silica additions produced black glassy vitrified products similar in appearance to obsidian. The WWTP sludge combustor residue melted at a lower temperature and produced a predominately crystalline product.

• Continuous feeding of residues to the furnace and continuous tapping of vitrified product at rates up to 1,500 lb/hr were successfully demonstrated during the 100-hr furnace operation. Metal was tapped intermittently from the furnace hearth.

• As is common in such demonstrations, steady state test runs on each residue were quite short, and were intruded upon by unscheduled interruptions which occurred frequently. Therefore establishing and maintaining furnace equilibrium for more than short periods was very difficult. Nevertheless the furnace was forgiving, yielding relatively uniform melt products despite of the erratic conditions encountered.

• The power required to melt the residues was influenced significantly by operational factors. Periods of furnace down time, slower charge rates, and thermochemical reactions within the furnace increased power consumption. During periods of uninterrupted (though not necessarily steady-state) operations, the operating power ranged from 616 to 1040 kWh per hort ton. (This variation is believed to result largely from intermittent furnace operation and non-equilibrium thermal conditions prior to the measurement.) The Project's furnace designer estimated that a residue feed rate of 1300 lbs/hr to an optimally designed furnace of this type could, for some types of residue, reduce power consumption to as low as 500 kWh/st under normal, continuous operating conditions. This power usage could range from one-fifth to one-third of that which can be produced from the energy recovered from burning the corresponding amount of municipal waste.

• To assess environmental implications, the products from the electric furnace were testing in accordance with EPA’s Toxicity Characteristic Leaching Procedure (TCLP). The leaching potential of the vitrified products and metals was below the PEA limit for each of the eight regulated metals. The fume solids exceeded
the limit for lead (Pb) and/or cadmium (Cd). If metals in the fume solids are further concentrated, they may have the potential to provide a source of raw material for recovery of Pb and Cd and possibly zinc (Zn) and tin (Sn). No oxides into the products, nor was the cost of disposal considered in the economic analysis.

- Thermal oxidizer stack emissions were monitored for acid gases, metals, and dioxins and controlled to meet current regulatory levels. Mercury emissions were measured (a) at the dryer baghouse exhaust, (b) in the dried residue furnace feed, (c) at the furnace-fume baghouse outlet and (d) in all resulting furnace products. The environmental significance of the measured values must ultimately be determined by the appropriate regulatory agency.

- The vitrified products satisfied American Society for Testing and Materials (ASTM) testing requirements for aggregate in Portland cement or asphaltic concretes as conducted by the Oregon DOT. Other potential uses include grit for air blast cleaning, aggregate for walkway or garden tiles, roofing granules, mineral wool insulation, and flowable construction fill. The metal may be acceptable for recycling to steel mills or iron foundries. The matte may be a feed .material for metal refiners and smelters by virtue of its copper and precious metal content.

- Projections in the Bureau's estimate for 20 percent moisture residues are based on adjacent stand alone electric furnace equipment systems each having independent air quality controls. Assuming an electric power cost of five cents/kWh, then, the calculated operating costs range from $98/short ton for a plant processing 350 short tons per day (st/d) of MWC residue to $175/short ton for a plant processing 60 short tons per day of residue. The extent of front end and back end recycling as well as other methods for calculating the cost of capital may alter these figures significantly. Additional tipping fee costs for vitrification of resulting residue could range from $10 per ton to $45 per ton of municipal waste delivered to the WTE plant.

- For commercial implementation it would be prudent to conduct at least a five-day, twenty-four hour per day melting test program on the specific residues to obtain sufficient definitive reproducible information for establishing the parametric data basis for design, operation, regulatory requirements, and realistic cost projections.

- The ASME/BuMines Investigative Program, conducted in response to public concern regarding the potential leachability of combustion residues, demonstrated that vitrification by electric arc furnace melting is technically feasible for decreasing the volume and leachability of MWC residues and may provide products having potential beneficial use in lieu of burial.