ASME/U.S. Bureau of Mines Investigative Program On Vitrification of Combustion Ash/Residue

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BACKGROUND

The perception that residues from thermal processes, albeit free of putrescibles, are comprised primarily of inorganic mineral matter, which may leach, however slightly, and eventually contaminate aquifers hasincreased environmental concerns.

Conversion of residues from combustion into useful products which might be absorbed into our economy would relieve these concerns and perhaps provide new economic development opportunities.

Vitrification of these residues into a dense, grainless, amorphous, onyx-like material, is one such processwhich may provide an opportunity to permanently relieve concerns regarding aquifer contamination. If the vitrified products are utilized, this process would conserve those land areas which are suitable fordisposal of those discards for which no practical alternate use has yet been found.

The 1985 proof-of-concept melting trials at the Bureau of Mines Rolla, Missouri Research Center revealed that the vitrified products from the combined combustion residues from the Chicago, NW Waste-to Energy Facility were amorphous, environmentally benign, as much as three times denser than the original residue and had the potential for several beneficial uses, in lieu of burial and potential future liability.

As a consequence, the American Society of Mechanical Engineers Research Committee on Industrial and Municipal Waste began in 1986 to plan and solicit sponsorship for a commercial scale demonstration of vitrificiation technology in an electric arc furnace facility located at the US Bureau of Mines Albany,Oregon Research Center (BuMALRC).

The US Department of Energy (DOE) and the New York State Energy Research & Development Authority(NYSERDA) agreed to provide significant funds for this investigation, but, only on a cost sharing basis... thereby assuring recognition of need for the program by affected users and the technical community.

THE PROGRAM

The American Society of Mechanical Engineers Center for Research & Technology Development and the US Bureau of Mines through cooperative agreements that included more than 30 government and industry sponsors, conducted over 200 hours of melting tests (1990-1991) vitrifying ash residues from five state-of-the-art municipal waste combustion facilities.

Program participants included industry and government researchers, furnace suppliers and operators, academics, solid waste industry professionals, implementing entities, regulatory agencies and privateengineering consultants.

The residues for this melting program included dry combined grate and air quality control equipment residues from three mass burning Waste-to-Energy (WTE) plants, dry combined residue from a multiple hearth wastewater treatment plant (WWTP) sludge combustor and dry acid gas absorber baghouse residues from a modern WTE plant burning refuse derived fuel.

An electric arc melting furnace (having water-cooled roof and sidewalls, a modified power supply, furnace feeding and fume emission control systems) was constructed at BUMALRC specifically to feed and continuously melt up to one ton/hour of combustion residues and permit the vitrified products to be continuously tapped from the furnace all within stringent environmental requirements. The melting program commenced with short test runs to define operating procedures and culminated in a 100 hour operating campaign in which 54,000 pounds of combustor residues were melted.

In addition to the +6000 analyses conducted by the BuMines Laboratories, the ABB-CE Laboratories conducted the many toxicity characteristic leaching procedure (TCLP) analyses on the residue received and the resulting furnace products. Under the direction of Environment Canada, AMTEST extensively characterized the many samples they had taken at various locations in the fume exhaust-system. TheOregon DOT conducted analyses on the vitrified products to assess their potential use as road construction aggregate. This extensive data is assembled and correlated in the ASME/BuMines comprehensive report (CRDT - Vol.24) of this program.

The overview of activity flow is illustrated in Figure 1 - Program Implementation Diagram.

PROGRAM FACILITIES

- Combined grate and air quality control equipment residues from different types of state-of-the-art mass burn MSW WTE plants were collected, screened, dried, bagged and shipped to the melting facility at the BUMALRC. Particulate emissions from drying each residue were collected in a baghouse and combined with the dried residue product prior to bagging and shipment. Exhaust from the baghouse of the dryer was also monitored.

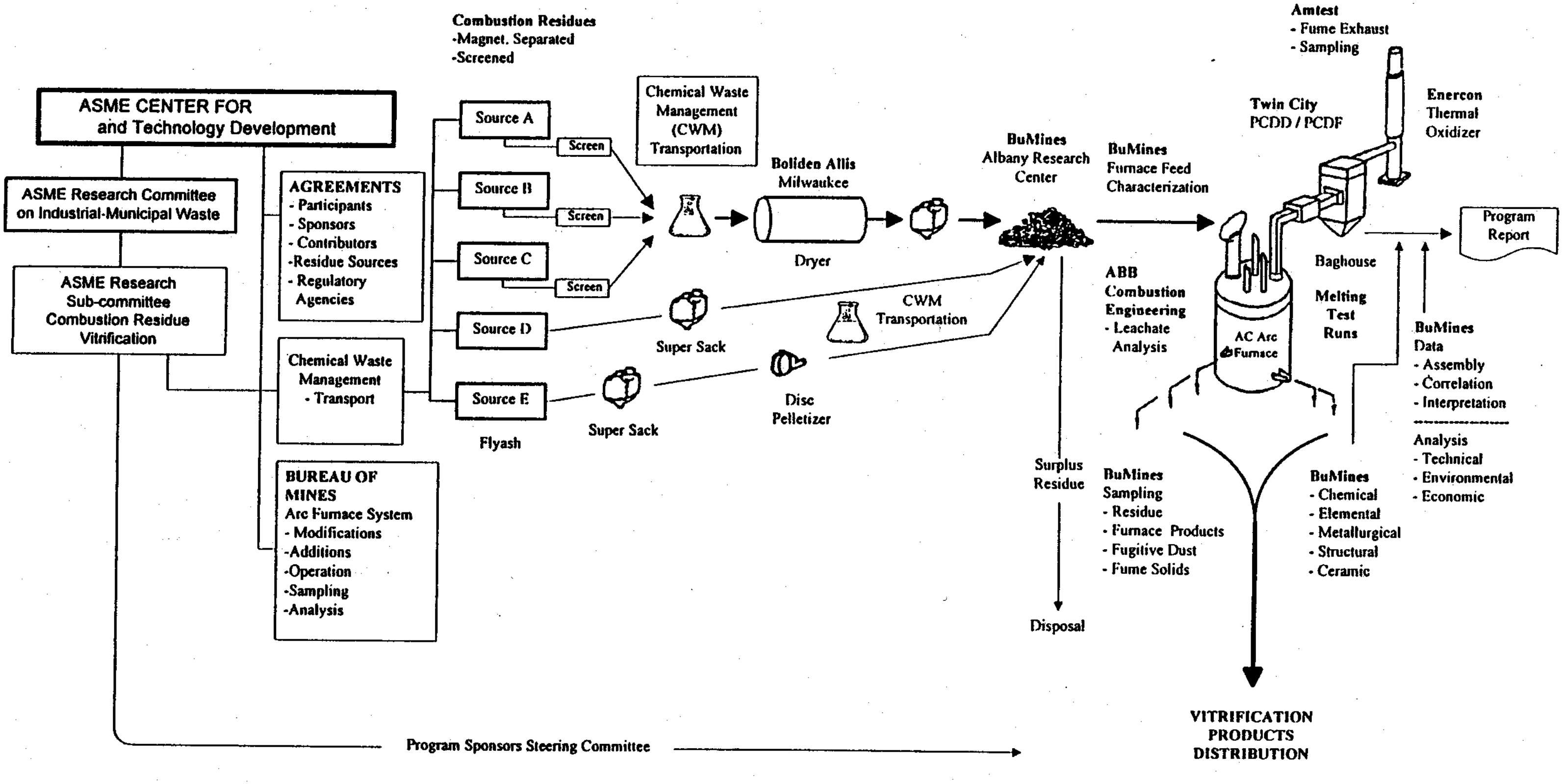

FIGURE 1
PROGRAM IMPLEMENTATION DIAGRAM

- The combined dry residue from a regional wastewater treatment plant sludge combustor, the dry particulate and residue from the dry acid gas absorber of a WTE plant burning refuse-derived fuel (RDF) were doublebagged and shipped directly to the BuMines melting facility.

- The melting facility was comprised of a feed system, and electric arc furnace system, fume emissions controlsystem and water cooling tower (Figure 2 - Process System Schematic). The residue feed conveyor system with interim storage and metering bin provided continuous feeding to the furnace of screened residues of one inch and smaller in size with densities averaging 80lbs./cu ft at feed rates up to 2000 pounds/hour.

- A stationary, sealed, refractory-lined arc melting furnace with a five cubic foot hearth, watercooled walls and roof, and air-cooled bottom, was constructed and an existing 3-phase, 800kVA power supply was modified to provide the higher voltage anticipated for effectively melting the combustor residues. The furnace was fitted with a water-copper tapping fixture for continuous tapping of vitrified product. The slowly accumulating inventoryof molten metal was periodically withdrawn through the lower taphole at the furnace hearth floor (Plumley-Progress Report 92), (Hartman-BuM RI-9476).

- The emissions control system was designed to accommodate 125 to 250 scfm of furnace exhaust fume since with a sealed furnace and having no air introduced it was difficult to predict the volume of fume to be encountered. The system consisted of six inch diameter cleanable duct, baghouse, 123,000 Btu/hr heat exchanger to assure exhaust fume temperatures can be held within a prescribed range to protect the baghouse, a lime injection system for acid gas control, a thermal oxidizer system to provide one second residence time at 1800'F was incorporated in the stack to assure control of any remaining trace emission constituents .

- To assure safe operation, inert nitrogen gas was injected into the fume system to limit oxygen concentration below 5% thereby avoiding possible formation of a flammable gas mixture.

FIGURE 2 -PROCESS SYSTEM SCHEMATIC

METHOD AND PROCEDURES

- The dried, screened, as-received residues were extensively characterized by BUMALRC to determine physical properties and chemical composition as per Table 1 and Table 2.

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

- During the 100 hour melting campaign the five municipal waste combustor residues were melted sequentially to determine for each, the technical and operational feasibility of submerged electric arc melting and to provide vitrified products for beneficial use evaluation.

- The vitrified products were continuously tapped while the slowly accumulated 'inventory of metal was tapped intermittently from the furnace hearth.

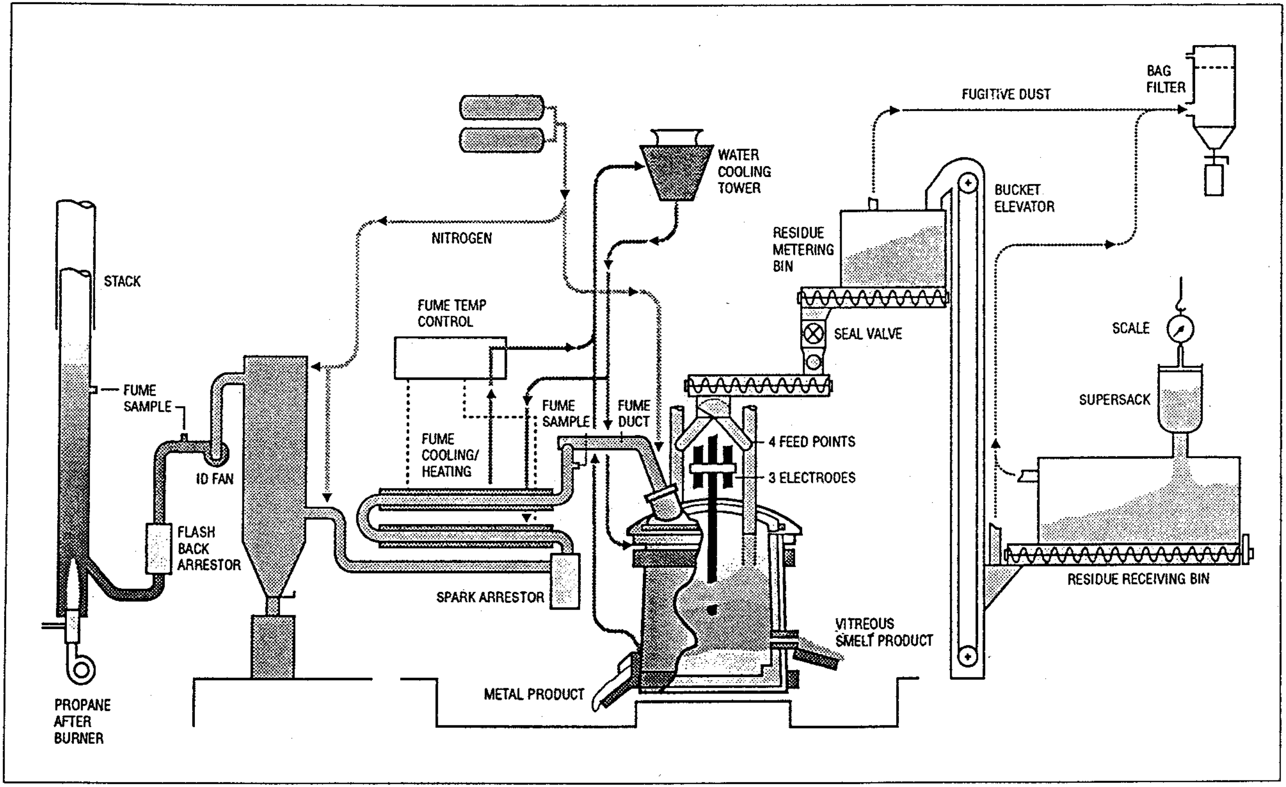

FIGURE 2- PROCESS SYSTEM SCHEMATIC

FINDINGS

* In general, melting of municipal waste combustor (MWC) residues, WWTP sludge combustor residue, as well as the RDF baghouse residue produced five principal products:

Vitreous	Up to 86%
Metallic	Up to 7%
Matte Interface	Up to 2%
Fume Solids and Gas	Up to 5%

* The combined MWC Residues A, B, C and the RDF baghouse Residues E (including additives) produced dense black glassy vitrified products similar to obsidian or basalt not unlike some forms of volcanic lava. The WWTP sludge combustor residue melted at a somewhat lower temperature and produced a predominantly crystalline product with a distinct X-ray pattern. These observations were confirmed by microscopic and X-ray diffraction examination.

* During the melting test of Residue A the fume solids were collected during the first 8 hours and recycled gradually into the system residue receiving bin to enhance mixing with the fresh feedstock. The combination residue and recycled fume solids were melted during the following 8 hour period.

TABLE 1

PHYSICAL PROPERTIES OF RESIDUES

RESIDUE	MOISTURE(1)	LOI(2)	MAGNETIC	NON-MAGNETIC	BULK DENSITY
	WT%	%	WT %	WT%	lb/ft3
A	1.5	5.66	10.2	89.8	78
B	1.38	1.44	17.4	82.6	109
C	0.92	2.51	12.7	87.3	71
D	0.42	0.71	51.9	48.1	31
E	1.58	5.22	2.7	97.3	41

(1) 105C for 12 hrs (2) Loss on Ignition test 1000C for 1 hr.

TABLE 2

CHEMICAL COMPOSITION OF RESIDUES

RESIDUE CONCENTRATION, ppm (mg/kg), 10,000ppm =1%

Element	A	B	C	D	E-1	E-2
Ag	16	10	28	217	14	8
As	34	32	40	8	54	31
Ba	809	729	517	1,294	544	31,076
Br	28	73	86	8	660	376
Cd	26	21	46	24	69	39
Cr	232	324	238	1,371	194	111
Hg	*6*	3	13	<1	20	11
Mo	*<50*	*<50*	*<50*	*<50*	*<50*	*<50*
Ni	259	257	219	404	296	169
Pb	4,094	3,801	2,171	211	1,940	1,106
Sb	142	105	192	16	405	231
Se	2	<1	1	8	11	6
Sn	257	210	245	<200	200	114
Zn	4,160	5,900	3,1421	2,209	5,203	2,966

E-1:Residue E without additives, E-2:ResidueE with additives. Each of the values listed for Residues A,B and C is the arithmetic mean of four individual analyses of bottom ash combined with the correct percentage of dryer baghouse dust.

* As is common in such demonstration programs, for one reason or another, frequent unscheduled interruptions were experienced. Consequently the actual steady state periods during the test runs on each residue were quite short. Nevertheless, the furnace was forgiving, yielding relatively uniform melt products in spite of the erratic conditions encountered.

* The electric power required to melt the residues was influenced significantly by mechanical/operational factors. Periods of furnace down time, slowing feeding rates yet keeping the furnace at temperature as well as thermochemical reactions within the furnace increased the power consumption. The operating power ranged from 616 to 1040 kWh/ton. This variation is believed to result largely from intermittent furnace operations encountered and the non-equilibrium thermal conditions experienced prior to the measurement.

* The project furnace designer estimates that at a residue feed rate of 1,300 lbs. per hour an optimally designed furnace system could reduce power consumption to as low as 500 kWh/ton under normal continuous operation for most types of combustion residues. This rate of power usage ranges from 1/3 to 1/5 of that produced from the energy recovered from burning the municipal waste corresponding to the amount of residue being vitrified.

* To assess environmental implications, the products from the electric furnace were tested in accordance with EPA's TCLP and a summary is provided in Table 3. The leaching potential of the vitrified products and metals were below the EPA limit for each of the eight regulated metals.

* TCLP specified extracts of the small quantity of fume solids in most cases exceed the TCLP limit for Lead (Pb) and Cadmium (Cd). Although the weight percent of fume solids were quite small, if the metals therein were to be- further concentrated, these solids may then have the potential as a source of raw material for recovery of Pb, Cd and possibly zinc (Zn) and tin (Sn).

* Under the circumstances of this program, no attempt was made to identify and employ additives which might enhance absorption of these as metal oxides into the furnace melt products. This activity should be included in future vitrification investigative programs.

* Thermal oxidizer-stack emissions were controlled to meet current regulatory requirements and were monitored for acid gases, metals and dioxins.

* The Oregon DOT Laboratories subjected the vitrified products to the appropriate ASTM tests for aggregate in Portland cement or asphaltic concretes. These test indicate they may be suitable also for the wearing course for roadways.

* Other apparent uses include aggregate for flowable construction fill, road ice control walkway or garden tiles, roofmg granules, grit for air blast cleaning, high temperature mineral wool insulation and possibly other uses. As with natural aggregate, uncovered storage should be acceptable since there should be little concern regarding rainwater run-off contamination.

* Although only constituting a small percent of the total weight, the "matte" fraction may have some value to metal refmers and smelters by virtue of its copper and precious metal content.

* Accumulated ingots of the ferrous fraction may be considered as a scrap source by foundries, mini-mills or municipally specified for use in non-stress applications such as fence posts, tree grates, bench or table supports, counter weights, stanchions, etc.

* The cost projections in the BuMines estimate summarized in Table 4, are based upon wet residues having 20% moisture, and on installation of adjacent stand alone electric furnace equipment systems each having independent air quality controls. Assuming an electric power cost of $0.05/kWh, depending on system capacity, the calculated owning and operating costs range from $98/residue ton for a plant processing 350 ton per day of MWC residue to $175/residue ton for a plant processing 60 tpd of residue.

* These costs, when expressed as additional tipping fees for MSW delivered to the WTE plant could range from$10/ton MSW to $45/ton MSW. No allowance is included for landfill cost avoidance or possible substitution value/revenue received for products having beneficial use. The extent of front-end and back-end recycling as well as other methods for calculating cost of capital may also alter these cost projections.

* Current potential market value of some products using vitrified materials **is** listed 'in Table 5. If sufficient quantities of vitrified materials were available, it might stimulate formation of local enterprises to convert it into products having higher market value.

TABLE 3

RESIDUE AND VITRIFIED PRODUCT LEACHING ANALYSIS - TCLP (ppm)

	RESIDUE A	**SLUDGE RESIDUE D**		**FLY ASH RESIDUE E**		**USEPA**
	VITRIFIED	AS RECEN-ED	VITRIFIED	As RECEIVED	VITRIFIED	**CRITERIA**
Arsenic	0.09	<0.09	<0.09	<0.09	<0.09	*5*
Barium	0.4	0.08	0.08	1.6	0.3	100
Cadmium	0.007	<0.007	0.001	0.06	0,007	1
Chromium	<0.02	0.02	0.02	0.06	0.1	*5*
Lead	0.3	0.3	0.04	8.2	0.1	*5*
Mercury	*0.0005*	<0.003	0.0003	0.008	0,008	0.2
Selenium	0.07	0.07	0.07	<0.07	0.07	1
Silver	<0.01	0.01	0.01	0.01	0.01	5

Residue A - Modern Mass Burn WTE Plant, Residue D - Regional WWTP Sewage Sludge Incinerator,
Residue E – Modern RDF WTE Plant: Flyash and AQC Deposits.

TABLE 4

GENERIC ECONOMIC ESTIMATES

PLANT CAPACITY -DRY RESIDUE (AT 20% H20)	300 TPD - 350 TPD	150 TPD - 175 TPD	50 TPD 60 TPD
Total Capital Costs	$31,513,000	$17,336,000	$10,930,000
Operating Costs ($/dried ton)			
Raw Materials	$7.22	$7.22	$7.22
Utilities:			
Electricity (840 kWh/ton@$0.05/kWh)	$42.32	$42.80	$44.59
Water and Gas	$10.24	$9.82	$10.53
Direct Labor	$7.11	*$11.50*	$26.39
Plant Maintenance:			
Labor	$6.89	$8.12	$16.21
Materials	$5.74	$6.77	$13.51
Depreciation (20-year life)	$15.36	$16.91	$32.18
Other costs*	$20.97	$26.61	$55.10
Total operating cost/dried ton	$116.00	$130.00	$206.00
Cost/ton of residue @ 20% H,O	$98.00	$110.00	$175.00
Cost/ton MSW at combustion plant MSW at 10-25% residue	$10.00-$25.00	$11.00-$28.00	$18.00-$45.00

payroll overhead, op rating supplies, indircct costs, taxes, insurance - see U.S. Bureau ofnfines - Appendix D offinal re P.L.

TABLE 5

POTENTIAL MARKET VALUE OF VITRIFICATION PRODUCTS

PRODUCT	DOLLARS./TON
Crushed Aggregate	$12
Fritted for Air Blast Grit	$45
Cast Block or Tile	*$150*
Spun into High Temperature Mineral Wool Insulation	
Loose form/bulk blowing	$200
Blanket form	$1,000
Vacuum formed products	*$1,500*
Board - mediumn density	$2,000
Vitrification Metal Product as Scrap	$75.00

CONCLUSIONS

For commercial implementation for a specific residue it would be prudent to conduct a continuous 24 hours/day melting test program for three to five days to ascertain specific furnace performance and thereby 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 on Vitrification of Combustion Ash/Residue, conducted in response to public concern regarding potential leachability and the desire to maximize recycling/reuse, demonstrated that vitrification by electric arc furnace melting is technically and operationally feasible for significantly decreasing the volume and leachability of municipal waste combustor residues and can provide new materials which have potential beneficial use in lieu of burial.

The peer reviewed comprehensive report of this ASME/Bureau of Mines program was issued in the Summer of 1994 as CRTD - Vol. 24.

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