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RECYCLING OF BOILER AND INCINERATOR ASH INTO VALUE ADDED GLASS PRODUCTS

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ABSTRACT

The disposal of industrial solid wastes presents a major challenge to industrialized nations. Boiler ash and incinerator ash represents a major portion of the solid wastes which must be ultimately reused or landfilled. This paper discusses the recycling of coal-fired boiler and incinerator ashes into value added glass products via the use of a newly developed, fossil fuel fired, high temperature melting process. The patented technology is based on advanced in-flight suspension glass melting technology which has been developed by Vortec Corporation with funding support from the U.S. Department of Energy and the Environmental Protection Agency. The Vortec patented Cyclone Melting System (CMS™) has a number of significant advantages for recycling solid wastes including: the oxidation of organic and metal contaminants, formation of non-leachable glasses which can be sold as value added products, high melting efficiencies, multi-fuel capability, low operating and maintenance costs and low NO_X emissions. This paper summarizes some of the challenges facing process industries and utilities in the recycling and reuse of industrial solid wastes. The results of laboratory and pilot scale testing with several pulverized coal-fired boiler ashes, several municipal solid waste incinerator ashes, and a sewage sludge incinerator ash are summarized. Information on ash properties, melting characteristics, system performance, toxicity characteristics leaching procedure (TCLP) testing results, flue gas emissions, recycled products, and economics are presented. The application of the CMS™ to the production of several value added glass and ceramic products is also discussed.

INTRODUCTION

Boiler and incinerator ashes represent major solid waste streams for the United States. More than 80 million tons of coal-fired boiler ash and flue gas desulfurization (FGD) sludge are generated annually. In addition, approximately 200 million tons/year of municipal wastes are generated, most of which are landfilled. Only 15% or 30 million tons/year of municipal solid waste (MSW) is incinerated, resulting in approximately 9 million tons/year of ash. The ash generated from sewage sludge incinerators amounts to about 1 million tons/year. The incineration of solid wastes in municipal solid waste incinerators, sewage sludge incinerators, and hazardous waste incinerators provides an effective means of reducing landfill space requirements. The ashes which are generated by these incineration processes, however, still leave significant waste disposal problems. The ashes produced tend to have low bulk densities, can have significant levels of unburned organics or carbon, and can have heavy metal concentrations which render them hazardous by their leaching characteristics [boiler ashes typically pass the TCLP tests for Resource Conservation and Recovery Act (RCRA) metals].

As a result of these characteristics, there is significant concern over the long term liability associated with the landfill disposal of incinerator ashes.

This paper discusses some of the advantages of vitrifying these wastes prior to reuse in various building material and road construction applications. Vitrification of the waste has the advantages of oxidizing the residual organics and producing a glass product which intrinsically chemically bonds any RCRA metals, thereby ensuring that the products produced pass TCLP testing requirements. Through the use of additives, the final chemical and physical characteristics can be altered to yield engineered glass and ceramic products which can demand higher prices and have expanded market applications.

Coal-Fired Boiler Waste Generation and Utilization

There are over 500 pulverized coal burning power stations in the United States producing flyash, coarse ash (bottom ash or boiler slag), and flue gas desulfurization (FGD) sludge. The solid wastes produced from pulverized coal-fired boilers account for a major portion of the coal derived waste products in the United States. The total annual quantities of solid wastes produced as a result of electric power generation are approximately:

Flyash	60 million tons per year
Bottom Ash	15 million tons per year
Boiler Slag	4 million tons per year
FGD Sludge	4 million tons per year (dry basis)

In order to reduce the enormous landfill disposal requirements, substantial efforts have been made to utilize coal generated solid waste materials in other industrial and commercial applications. Private industry, electric utilities, and organizations such as the American Coal Ash Association, the U.S. Department of Energy and the Electric Power Research Institute have been active in this area for over thirty years. In 1985, about 27% of the 83 million tons of solid waste produced were recycled or utilized in other applications. Of all the waste materials, boiler slag had the highest level of utilization, amounting to approximately 65% of the total slag produced. The bottom ash, flyash and FGD sludge have much lower levels of utilization. Only 31% of the bottom ash produced could be utilized, and of the 60 million tons of flyash generated, only about 23% or 14 million tons could be used in other applications. The remaining 46 million tons of flyash had to be landfilled at a cost of typically $12 to $66/ton. In 1992, nationwide average for ash disposal was $31.20/ton (Fitzgerald, 1995).

Most of the successful flyash utilization efforts have been directed toward high volume usage applications with minimal processing requirements such as fills, embankments, landfill cover, soil stabilization, highway base courses, grouting and hydraulic fills. Applications which require moderate materials processing have also been investigated. Some of these applications have included the use of flyash for production of cement and concrete construction and building materials. Areas of specialty application and investigation have included filler materials for paints and plastics, mineral extraction, production of flyash derived magnetite and the manufacture of mineral wool. A summary of past flyash utilization technologies is presented in Reference[2] (EPRI, 1987).

With the advent of low NOx emissions burners, the problems of flyash disposal for utilities have been exacerbated due to the increase in unburned carbon in the flyash. Five or more years ago, it was common to have unburned carbon contents in the flyash less than 3%. With the use of low NO_x burners, it is now not uncommon to have ashes with carbon contents in excess of 10%. The higher unburned carbon content can have an adverse effect on the use of flyash for the production of concrete which presently utilizes about 7 million tons annually (Tyson, 1995). The use of ash in concrete largely falls under the requirements of ASTM Standard C-618 which specifies that Class F flyash used as a cement replacement material should have a carbon content less than 6%. Of further concern with down stream NO_x reduction systems is the use of urea or ammonia injection which creates an ammonia residual in the coal ash. This ammonia can further limit the reuse of ash, particularly in the concrete industry where its use may be precluded.

Municipal Solid Waste (MSW) Incinerator Ash Generation and Utilization

The primary sources of incinerator ash are municipal waste incinerators, sewage sludge incinerators and hazardous waste incinerators. There are over 380 waste incinerators in the United States, listed in four major categories: (1) waste-to-energy (WTE), (2) waste incineration without energy recovery, (3) refuse derived fuel (RDF) processing facilities and (4) landfill gas recovery. Approximately 200 of these facilities are in the waste-to-energy category. The total processing capacity of the WTE plants is in excess of 30 million tons per year. The total ash generated by these facilities, including both bottom and flyash is about 30% of the input feed (i.e., about 9 million tons per year). Typically the bottom ash from a moving grate type incinerator is about 26% of the feed input. The major problems associated with the reuse of municipal incinerator ash are: the moisture content (typically about 20%) and metal contamination (typically about 3%) in the bottom ash, RCRA metal contamination in the flyash, and the presence of chlorine and sulfur bearing species in the bottom ash and flyash. Essentially all of the ash generated by municipal incinerators is landfilled at a cost of typically $20 to $80 per ton. In countries where landfill space is limited, municipal incinerator ash disposal can be as high as $300/ton (e.g., Japan).

The bottom ash in municipal incinerators is wetted down and sluiced out of the bottom of the boiler. The flyash is dry, but is generally mixed with the bottom ash prior to disposal. In effect, the ash coming out of a MSW incinerator is typically a "slop" containing a mixture of ash, metallic objects (e.g., bed springs, cans, bumpers, etc.) and unburned trash (e.g., tree stumps, diapers, etc.). In some WTE facilities, white goods (refrigerators, stoves, etc.) are separated prior to incineration and down stream ferrous metal separation of the ash is used to remove about 75% of the metallic components. The flyash is generally dry and free flowing and amounts to about 4% of the total trash input or 13% of the total ash generation.

Sewage Sludge Incinerator Ash Generation and Utilization

Most large municipal sewage treatment plants incinerate the sewage sludge which is removed from their wastewater streams. Typically municipally owned sewage sludge incinerators generate between 10 and 100 tons of ash per day. There are approximately 150 operating plants of this size in the United States. The ash which is left after incineration must be disposed of and, like any waste stream, is subject to increasing environmental regulation. The ash contains various metals which can leach out and contaminate ground water if not properly treated. The levels of metal oxides present in the ash will vary with each plant depending on the nature of the waste water they receive. Heavily industrial areas will potentially have higher concentrations of metals compared to plants treating primarily domestic influent. Typical values of metals of concern in the sludge ash are given in Table 1. Under the guidelines of RCRA, the ash may be classified as a hazardous waste if the concentrations of the regulated contaminants in the extract of the waste from the TCLP exceed the maximum values established by the EPA. Space requirements for ash storage and fugitive dust emissions from ash piles are additional concerns for the municipalities. There is a high level of interest in alternatives to disposal in controlled leachate landfills. The cost of this disposal is currently running between $60 to $150 per ton.

TABLE 1. TYPICAL METAL CONCENTRATIONS IN WASTEWATER SLUDGE INCINERATOR ASH (PPM)

Metal	Domestic	Industrial
Arsenic	1.4	31.0
Cadmium	5.0	101.1
Chromium	226.0	799.7
Lead	409.0	254.8
Nickel	171.0	646.7

PROCESS DESCRIPTION

The innovative melting process for recycling boiler and incinerator ashes into value added glass products utilizes Vortec Corporation's advanced, multi-fuel capable Cyclone Melting System (CMS™) as the core element in the overall process design.

The unique features of the CMS™ make it particularly suitable for rapid and efficient heating of granules and fine particles (typically ≤ 1 mm and subsequent vitrification into a glass product. Vortec has demonstrated the ability to effectively melt a variety of boiler and incinerator ashes at temperatures up to approximately 1649°C (3000°F). A process diagram of a Vortec CMS™ based commercial ash vitrification and recycling system is shown in Figure 1. The basic elements of a CMS™ based recycling plant for producing granules and aggregates include:

1. the Vortec multi-fuel capable CMS™ consisting of a counter-rotating vortex (CRV) combustor and cyclone melter,
2. an upstream storage and feeding subsystem,
3. a separator/reservoir assembly,
4. a cullet handling and delivery subsystem,
5. a heat recovery subsystem, and
6. an air quality control subsystem.

Except for the CMS™, an artist rendering of which is shown in Figure 2, and the separator/reservoir, all other subsystems or assemblies are commercially available or modified versions of commercially available equipment.

The basic CMS™ can be modified to accommodate the use of a variety of fuels, including pulverized coal, coal slurry fuels, natural gas, and oil. Combustion and in-flight suspension preheating of the batch ingredients take place in a counter-rotating vortex (CRV) combustor/preheater. The ash and other feedstock materials are introduced into the CRV combustor/preheater through an injector assembly and are rapidly heated in the flame zone. Organic materials are rapidly volatilized and incinerated, and the inert materials are heated to nominally 1260°C to 1538°C (2300°F-2800°F), depending on the feedstocks utilized, prior to entering the cyclone melter. Combustion air for the process is preheated to nominally 538°C to 760°C (1000°F-1400°F) with waste flue gas heat in a radiation recuperator typical of those used in the insulation fiberglass industry. Therefore, high local flame temperatures (>2200°C) are achieved in the CRV combustor. However, NO_X emissions have been demonstrated in the pilot scale CMS™ to be low; typically less than 200 ppm, because of rapid temperature quenching of the combustion products by the inert waste glass particles and staged combustion. Experimental data obtained during the course of feasibility experiments with the pilot scale CMS™ indicate that NO_X emissions with coal combustion are lower than the California emission standards for glass melting furnaces.

The preheated solid materials from the CRV combustor/preheater enter the cyclone melter where they are distributed to the chamber walls by gas dynamic cyclonic action to form a molten glass layer. The glass produced and the exhaust products exit the cyclone melter through a tangential exit channel and enter the separator/reservoir. The separator/reservoir separates the combustion products from the melted glass and provides a reservoir of hot glass for proper interfacing with product forming equipment. The hot exhaust products exit through an exhaust port which ties into a conventional radiation type recuperator with a nominal 538°C to 760°C (1000°F-1400°F) delivered air preheat capability.

The ash and additives required to provide a feedstock suitable for glass production are delivered to storage bins located within the processing facility. The ash and additives are mixed on a batch basis, stored in a feedstock storage bin, and then delivered via pneumatic transport or other means to the CMS™. Pulverized coal, when used as the primary fuel, is delivered from a storage bin to the CMS™ via pneumatic transport.

Commercially available emissions control equipment are incorporated into the design as dictated by local environmental regulations. Pilot plant testing to date indicates that a venturi scrubber will be suitable for some applications; however, spray dryer scrubbers, wet electrostatic precipitators (ESP), or dry ESPs may be necessary to achieve additional emissions control, depending on the nature of the feedstock and local environmental control regulations.

LABORATORY AND PILOT SCALE TEST RESULTS

Laboratory and pilot scale vitrification tests have been performed with several incinerator and boiler

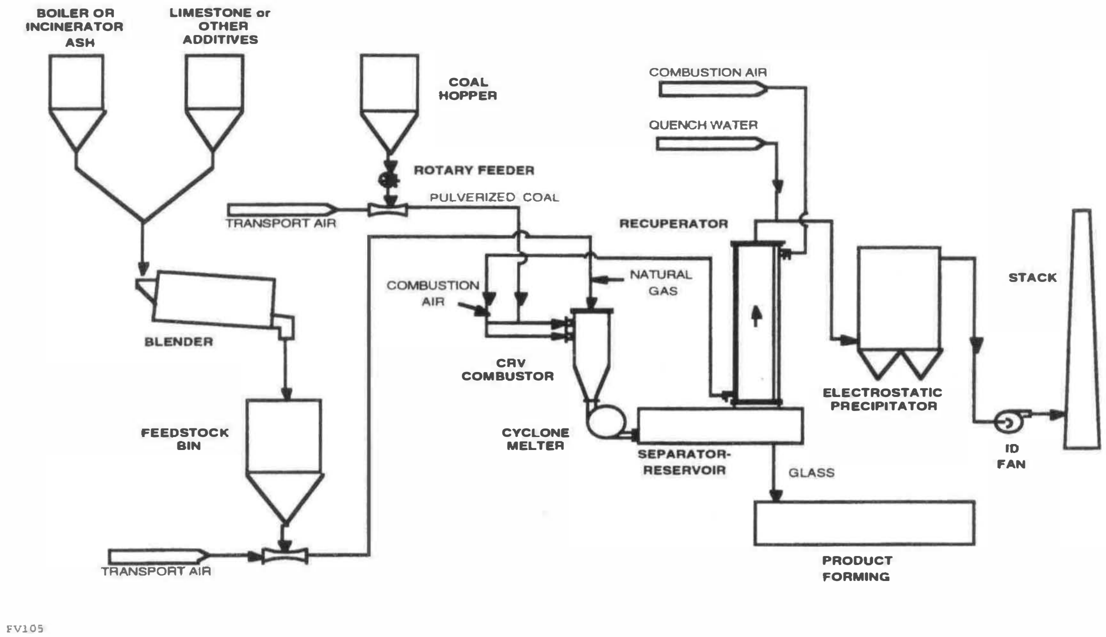

FIGURE 1. VORTEC ASH VITRIFICATION AND RECYCLING SYSTEM

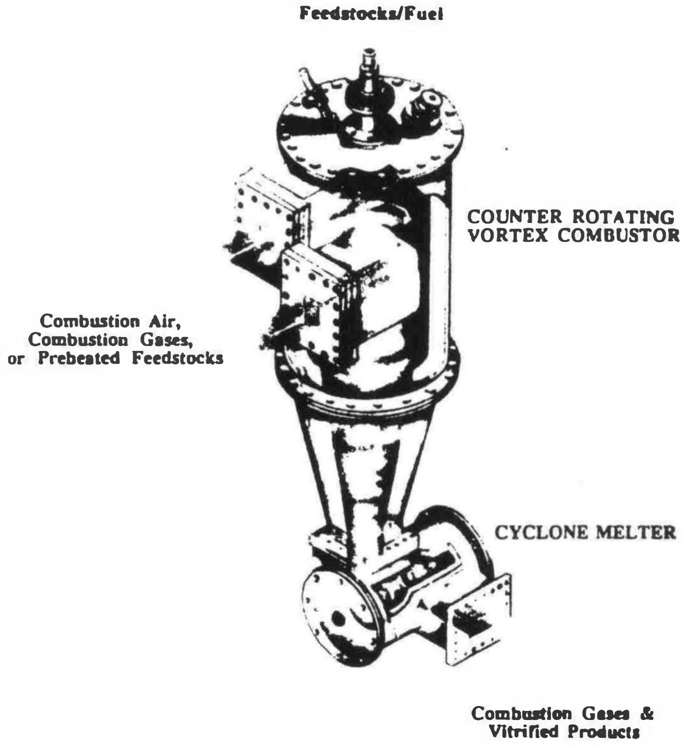

FIGURE 2. ARTIST RENDERING OF BASIC CMS™

ashes. The ashes processed have included coal-fired boiler flyash, municipal solid waste incinerator (MSWI) ash, and sewage sludge incinerator (SSI) ash. The MSWI bottom ash was screened and processed to provide a dry feedstock with particle size less than 1mm. The laboratory scale vitrification tests were performed using a commercially available electric-melting furnace. The pilot scale tests were performed using Vortec's Cyclone Melting System (CMS™) facilities located in Harmarville, PA. Chemical analyses, TCLP, and other chemical data were performed using outside laboratory services. Particle size analyses were performed by Vortec using standard screens and selective samples were measured by outside laboratories using laser light scattering techniques.

Ash Analyses And Properties

Chemical composition data for several of the ashes which have been tested are summarized in Table 2. The first two boiler flyashes were obtained from Pennsylvania utilities (PA-1 and PA-2) firing eastern bituminous coals. The second boiler flyash (VA-1) was obtained from a large industrial boiler located in Virginia. The industrial boiler also used an eastern bituminous coal. The coal ash compositions are typical for pulverized coal-fired boilers using this class of fuel. The high unburned carbon content (i.e., 37%) in the industrial boiler ash is noteworthy. The MSWI ashes processed included flyash from a facility in Canada (CA-1), flyash from northeastern United States (NE-1), and mixed bottom/flyash from northeastern United States (NE-2). The sewage sludge incinerator ash (SSI-1) was obtained from a large municipal sewage sludge incinerator located in New Jersey.

Compared to the MSWI and SSI ashes, the coal-fired boiler flyashes were found to have higher Al_2O_3 concentrations, but lower combined CaO and Na_2O concentrations. The coal-fired boiler flyashes processed have high ash fusion temperatures, typically in excess of 1600°C (2912°F). To reduce the fusion temperature of the coal-fired boiler flyashes, a glass modifier (typically 30% by weight) was added to the coal ashes to reduce the 10 Pa-s (100 poise) temperature to nominally 1400°C (2550°F). The higher glass modifier (CaO, K_2O, and Na_2O) concentrations in the MSWI and SSI ashes reduce the amount of additives required to achieve reasonable glass fluid properties. Ten percent glass modifiers were added to the CA-1 flyash, and 20% were added to the SSI ash. No additional modifiers were required to suitably melt the NE-1 and NE-2 ashes.

The SO_3 concentrations in the MSWI ashes were found to be in the range of 1.9%-6.3%. The higher value corresponds to the NE-1 flyash which incorporated the use of a lime scrubber for acid gas cleanup. The chlorine concentrations in the MSWI ashes ranged from 1.9% for the NE-2 ash to 6.8% for the NE-1 ash. Chlorine concentrations were not measured for the Canadian MSWI flyash.

The size distribution of the coal-fired boiler flyashes were nominally 90% less than 100 µm, with an average particle diameter of 45 µm. The average particle diameter of the NE-1 ash was approximately 70 µm with 90% being less than 250 µm. The average diameters of the NE-2 ash, CA-1 ash, and the SSI ash were 90 µm, 100 µm, and 360 µm, respectively.

A summary of the TCLP test results for the various ashes evaluated is presented in Table 3. The concentrations of lead and cadmium in the leachate from the Canadian MSWI flyash and the concentration of lead from the NE-1 flyash exceeded the 40 CFR limitations. Results of the TCLP tests performed with the PA-1 coal-fired boiler flyash, NE-2 combined MSWI ash, and the SSI flyash indicate that all the RCRA metals readily passed the leaching test requirements.

Vitrification Test Results

Prior to the construction of commercial plants, pilot-scale vitrification tests are performed with specific ashes using Vortec's nominal 20 ton/day CMS™ at a high temperature process test facility located in Harmarville, PA. The test system includes all the components shown in Figure 1, except for the recuperator; combustion air is preheated in the test facility via an indirect-fired air heater. Particulate emission control in the test system is provided by a venturi scrubber and/or a wet electrostatic precipitator (ESP).

TABLE 2. CHEMICAL COMPOSITIONS OF VARIOUS ASH FEEDSTOCKS (WT. PERCENT)

	Coal Fired Boiler Flyash	Coal Fired Boiler Flyash	Coal Fired Boiler Flyash	MSW Incinerator Flyash	MSW Incinerator Flyash	MSW Incinerator Mixed Ash	S. Sludge Incinerator Ash
Specie	PA-1	PA-2	VA-1	CA-1	NE-1	NE-2	NJ-1
SiO2	51.80	47.77	32.50	37.03	29.50	43.60	39.51
K2O	2.68	2.77	1.54	3.47	1.57	1.63	0.54
Na2O	0.40	0.41	0.31	4.34	4.05	3.92	0.98
Al2O3	25.60	26.13	17.60	16.50	11.60	8.76	9.34
CaO	1.74	2.89	0.88	13.30	28.20	13.11	14.03
MgO	0.80	0.92	0.54	2.42	1.80	7.74	2.52
Fe2O3	10.30	12.87	3.46	1.72	2.77	7.29	8.83
P2O5	0.10						12.58
TiO2	0.20	1.23		3.43			
As2O3					0.1100	0.0016	
BaO					0.1100	0.0880	0.2100
CdO				0.0160	0.0065		0.0005
Cr2O3			0.0190		0.0900	0.0620	0.5000
PbO			0.0440	0.3800	0.3600	0.2900	0.1100
HgO					<0.020	<0.003	0.0001
SeO2					<0.0001	<0.0002	0.0002
Ag2O					<0.0030	<0.0010	0.0085
SO3	1.50		1.41	3.67	6.25	1.89	0.19
C	2.00	6.20	37.50	10.10	1.99	1.66	
Cl		0.09			6.80	1.90	
Moisture	0.50		4.00	3.00	0.55	2.25	10.00
L.O.I	2.47				5.59	7.10	4.90
Total	100.09	101.28	99.80	99.38	101.35	101.29	104.25

TABLE 3. FEEDSTOCK TCLP RESULTS

Metals	**Regulatory Level**	**Coal-Fired Flyash**	**MSWI Flyash**	**MSWI Flyash**	**MSWI Mixed Ash**	**Sewage Sludge Ash**
		(PA-1)	**(CA-1)**	**(NE-1)**	**(NE-2)**	**(NJ-1)**
Arsenic	5.0	<0.050	0.04	<0.050	<0.051	0.050
Barium	100.0	<0.1	<1.00	<1.30	0.54	<1.20
Cadmium	1.0	<0.050	**8.9**	<0.050	<0.005	<0.070
Chromium	5.0	<0.10	0.04	<0.10	0.011	<0.10
Lead	5.0	<0.03	**14.1**	**8.40**	<0.027	0.50
Mercury	0.2	<0.0002	X	0.0030	<0.0003	<0.0003
Selenium	1.0	<0.050	<0.01	<0.050	<0.048	<0.057
Silver	5.0	<0.01	X	0.10	<0.01	<0.10
All units of mg/l						

Various levels of glass modifiers are added to the ashes prior to vitrification to produce a glass composition that will melt at a reasonable temperature, i.e., 1300°C to 1500°C, while still having the chemical stability and homogeneity required to satisfy TCLP testing for the RCRA metals.

A total of thirteen trials were performed with the coal-fired boiler flyashes; five pilot scale tests were performed with MSWI ashes and two test runs were conducted with the SSI ashes. During the tests, the feedstock flowrate was maintained at approximately 0.126 kg/s (1000 lb/hr) for a period of up to 8 hours during which time one or several Method 5 EPA tests were performed. All Method 5 testing was conducted by Geraghty & Miller, Inc. Environmental Services. The fuel input during the tests typically varied from 880 kW to 1025 kW (3.0 to 4.0 $\times 10^6$ Btu/hr) resulting in a heat rate of 6 to 8 million Btu/ton of feedstock. Commercial scale systems will have heat rates of 4 to 6 million Btu/ton. Particulate emissions were determined by measuring the amount of solids collected in the scrubber sludge as well as that captured in the stack with an isokinetic probe during the Method 5 test.

A summary of the TCLP test results for the various vitrified products produced is presented in Table 4. As can be seen from a review of the data in the table, all the vitrified products passed the TCLP testing by a comfortable margin.

The total uncontrolled particulate emissions during pilot scale operations were in the range of 1.0% to 4.5% of the total feedstock input. The highest particulate emissions occurred with the processing of the MSWI ashes. Most of the carryover (86%-97%) was collected in the Venturi scrubber with a 10" H_2O ΔP. With the addition of a wet electrostatic precipitator, the particulate emissions were projected to be less than 16 mg/m^3 (0.007 gr/dscf) for coal-fired boiler flyash vitrification, 7 mg/m^3 (0.003 gr/dscf) for SSI ash, and 14 mg/m^3 (0.006 gr/dscf) for MSWI ashes.

The particulates collected in the scrubber during operations with the coal-fired boiler and SSI ashes were found to be relatively high in CaO, SiO_2, and Fe_2O_3 concentrations. The particulates collected in the stack were found to have higher K_2O and Na_2O concentrations, indicating the smaller particulates may result from the recondensation of the more volatile alkali oxides.

The average uncontrolled NO_x and SO_x emissions during coal-fired boiler ash vitrification were measured to be 0.218 kg/kJ (0.509 lb/million Btu) and 0.065 kg/kJ (0.151 lb/million Btu), respectively. During vitrification of the SSI ash, they were measured to be 0.138 kg/kJ (0.321 lb/million Btu) and 0.022 kg/kJ (0.052 lb/million Btu), respectively. The low values indicate that acid gas scrubbing will likely not be required to meet current U.S. emissions control regulations. In the case of MSWI ash vitrification, the potential for high chlorine concentrations in the MSWI ashes will likely dictate the need for acid gas scrubbing of the flue gas.

Overall, 25% to 35% of the lead introduced into the CMS™ during vitrification of the MSWI ashes was retained in the vitrified product and 30% to 50% in the scrubber effluent. Chemical composition analyses of the carryover collected in the scrubber showed high concentrations of PbO (40% by weight during vitrification of the NE-1 ash). The concentrations of heavy metals may be sufficient to allow for their economical recovery from the carryover. Alternatively, the carryover can be recycled back into the Vortec CMS™ to achieve a higher capture rate in the vitrified product. Results of a pilot-scale vitrification test with Vortec's CMS™ under an EPA SBIR program indicate that greater than 90% of the lead contained in MSWI ash can be incorporated into the glass product via recycling of the carryover.

RECYCLING APPLICATIONS

There are a number of potential end uses for the vitrified products produced by the Vortec CMS™. Some of the end use applications which have been evaluated by Vortec are summarized in Table 5. The information in Table 5 includes the potential size of the U.S. market and expected prices for the products manufactured. As can be noted from the data, the end product uses represent large volume applications for the vitrified products. It is estimated that more than 50 Tg (55 million tons) could be annually used

TABLE 4. VITRIFIED PRODUCT TCLP RESULTS

Metals	Regulatory Level	Coal-Fired Boiler Flyash	MSWI Flyash (CA-1)	MSWI Flyash (NE-1)	MSWI Ash (NE-2)	Sewage Sludge Ash (NJ-1)
	Vitrified Product	Vitrified Product	Vitrified Product	Vitrified Product	Vitrified Product	Vitrified Product
Arsenic	5.0	<0.050	0.17	<0.076	<0.05	<0.050
Barium	100.0	<0.1	0.073	<0.110	0.054	0.029
Cadmium	1.0	0.007	<0.005	<0.003	<0.005	<0.005
Chromium	5.0	0.01	0.03	<0.005	<0.01	<0.010
Lead	5.0	<0.03	<0.034	0.029	0.098	<0.027
Mercury	0.2	<0.0002	0.0003	<0.0003	<0.0003	<0.0003
Selenium	1.0	<0.050	<0.06	<0.050	0.23	<0.048
Silver	5.0	<0.01	<0.006	<0.10	<0.005	<0.005
All units mg/l						

TABLE 5. GLASS BASED END PRODUCTS (U.S. MARKETS)

Product	Ton/Yr	Price
Portland Cement Aggregate	11 million	$4 - $10/ton
Ready Mix Cement Aggregate	50 million	$4- $10/ton
Back Fill & Structural Fill	> 10 million	$3 - $5/ton
Asphalt Paving Aggregate	> 10 million	$4 - $6/ton
Dense Concrete Aggregates	40 million	$4 - $6/ton
Clay Brick Filler	> 10 million	$4 - $6/ton
Lightweight Concrete Aggregates	3 million	$10 - $20/ton
Asphalt Shingle Granules	2.3 million	$30-80/ton
Abrasives	150,000	$40-$80/ton
Landscaping Stones	500,000	$50-$500/ton
Mineral Wool Products	1 million	$150-$500/ton
Roofing Tiles	2 million	$250-$300/ton
Ceramic Facing & Wall Tiles	2 million	$250-$1000/ton

in these applications within the United States. The ability to penetrate these markets, however, depends on the balance between the revenues received for processing the waste plus the revenues from the sale of the product and the capital and operating cost of the vitrification process. The selling prices for aggregate type products are rather low, i.e., typically less than $20/ton. Vortec has focused its product development efforts on engineered glass and ceramic products which can demand selling prices in excess of $20/ton. The lower price, higher volume products have also been addressed but to a lesser extent.

Quality control and acceptance testing of vitrified products from Vortec's CMS™ have been conducted with respect to use in the manufacture of asphalt paving aggregate, clay brick filler, asphalt shingle granules, abrasives, mineral wool products and ceramic wall & floor tiles. Typically, vitrified product end use application must address the nature, quantity, and cost for disposal of the ash waste material as well as the location and market for the end use products generated. The sale of the recycled materials can range from a low of $5.50/Mg ($5/ton) for aggregate substitutes for road construction to several hundred dollars per ton for mineral wool, abrasives and ceramic tile products. The following is a brief summary of the results of selected vitrified product evaluations.

Clay Brick Filler

Results of evaluations of the vitrified product as a clay brick filler indicate that with 10% vitrified material in the brick admix, the bricks passed all the ASTM specifications for manhole, building, and facing brick products. It was also found that vitrified product addition reduced the firing temperature of the bricks by 28°C, resulting in an energy savings of approximately 3%.

Hot - Mix Asphalt Aggregate

With respect to aggregate utilization for hot-mix asphalt production, the vitrified material was found to satisfy all the criteria for Types B and C coarse aggregate as specified by the Pennsylvania Department of Transportation. It satisfied all the criteria for Type A aggregate, with the exception of the abrasion resistance, where it was within 10% of the criteria. However, it is felt that this criteria can be satisfied with additional control of vitrified product cooling.

Asphalt Shingle Granules

With proper chemistry adjustments and adjustments in glass cooling rates, the vitrified products can be engineered to meet the translucency, friability, and color specifications for asphalt shingle granules. The construction of a CMS™ plant for the manufacture of asphalt shingle granules in the northeastern United States is being planned with strategic partners.

Mineral Wool Manufacturing

Fiberizing trials at pilot scale performed in 1994 demonstrated the feasibility of producing mineral wool products from boiler ashes. The composition of the ashes were adjusted to approximate mineral wool products produced from basalt and blast furnace slag. Commercial application for mineral wool production is being pursued via strategic alliances with existing mineral wool manufacturers.

Ceramic Tile Manufacturing

Commercial quality tile products manufactured from recycled industrial wastes have been manufactured by Vortec and Welko Industriale s.p.a. (ITALY), a major supplier of ceramic tile manufacturing equipment. This new product is called "EKOTILE" because it is an ecologically and environmentally sound approach for solving industrial waste disposal problems. EKOTILE was introduced to the ceramic tile manufacturing industry in October 1995 as part of the world ceramic tile manufacturing exhibition, TECNARGILLA '95, held in Rimini, Italy. Based on the response received at this world exhibition, it is anticipated that the new tile product will rapidly gain world-wide acceptance because it provides tile manufacturers access to alternative feedstock sources, significantly reduces manufacturing costs, and is environmentally responsible. In addition, EKOTILE meets or exceeds the quality control requirements for existing ceramic tile products.

The proprietary process for manufacturing EKOTILE uses the Vortec patented vitrification process for transforming the industrial waste into an engineered ceramic feedstock for the tile forming process. Welko provides the technology and equipment for processing the ceramic feedstock into a finished tile product. The strategic alliance between Vortec and Welko combines the necessary engineering and technical capability for building turn-key ceramic tile manufacturing lines using the new technology.

The initial product introduction will be high wear resistant floor tiles which feature technical specifications equivalent to or even better than 'granites'. Subsequent EKOTILE products will include high quality wall tiles. EKOTILE can be decorated and glazed using the most advanced existing production technology, thereby ensuring the widest possible market acceptance. Moreover, due to its degree of hardness (500 kg/sq. cm) and 1% water absorption, this material easily ranks among the top single fired floor tiles offered in the market today.

The introduction of this new tile product and manufacturing process represents the culmination of more than 10 years of waste recycling research and development efforts by Vortec and Welko. A wide variety of industrial wastes are amenable for use in the process, including but not limited to: coal fired boiler ash, municipal solid waste incinerator ash, aluminum industry smelting waste, steel industry slag/dust, foundry sand, and other industrial wastes. A major advantage offered by this system is that the raw material, in most cases, can be obtained free of charge. Some suppliers may even pay a fee to dispose of this raw material. Thus, the capital cost for the transformation plant can be recovered in a very short period of time.

Because of their wide experience and extensive research into the utilization of these materials, WELKO and Vortec can offer a warranty on the EKOTILE manufacturing process. These new tile products have an aesthetic appearance exactly like tiles produced with traditional ceramic raw materials. In addition, EKOTILE is stronger than existing tiles, can be used for outdoor applications, and satisfies stringent quality control requirements for flatness, geometry and shrinkage.

ECONOMICS

Results of life cycle cost analyses of a commercial Vortec CMS™ based ash vitrification plant have shown that ash vitrification can be an attractive alternative to landfilling for many applications. As an example, an economic analysis of a MSWI flyash vitrification plant was performed based on the process shown in Figure 3. An isometric sketch showing the size of the vitrification plant relative to WTE facility is shown in Figure 4. The plant would process 0.8 kg/s (75 ton/day) of flyash produced by a 21 kg/s (2000 ton/day) MSWI waste-to-energy facility. The vitrification feed system takes flyash directly from the MSWI air quality control system (ACQS), mixes the flyash with additives (80% flyash, 20% additives), and transports the mixture to the CMS™. Since flyash as collected in a MSWI facility is suitable in size and physical characteristics for blending with additives and feeding into the CMS™, other feedstock preparation (screening, crushing, etc.) is not required. Waste heat in the flue gas from the air preheater (recuperator) in the vitrification system can be used to generate steam for integration into the power cycle of the waste-to-energy facility. Two alternatives for vitrification system flue gas cleanup were evaluated. Since the flue gas flow rate from the vitrification system is approximately 1% of that from the MSW incinerator, it may be feasible to introduce the flue gas from the vitrification system into the MSWI ACQS. This scenario is the first alternative evaluated (Case A). This scenario would eliminate the need for and cost of an independent ACQS for the vitrification system, the second alternative evaluated (Case B). Particulates removed from the flue gas in an independent ACQS are recycled into the CMS™.

The results of the systems engineering analysis performed to provide input to the economic analysis are summarized in Table 6. Approximately 0.2 kg/s (19 tons/day) of additives would be mixed with the 0.8 kg/s (75 tons/day) of flyash from the MSW incinerator. Natural gas utilization in the vitrification system would be approximately 4.5 MW (14 million Btu/hr), based on higher heating

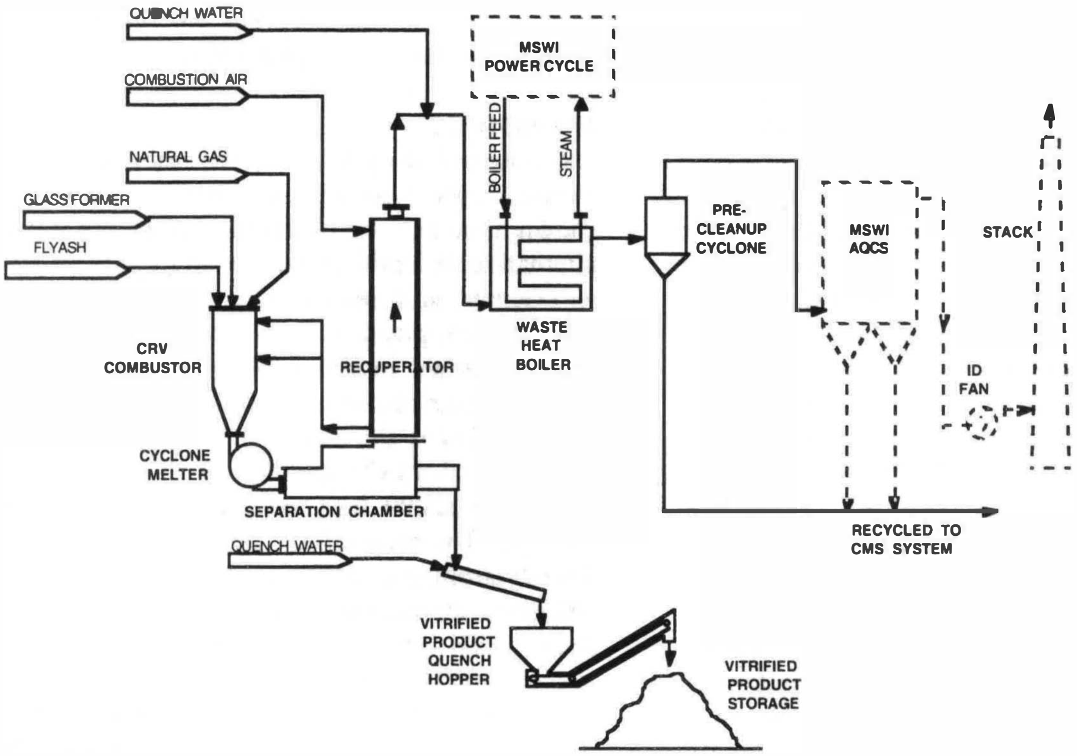

FIGURE 3. VORTEC CMS™ BASED MSWI FLYASH VITRIFICATION PROCESS

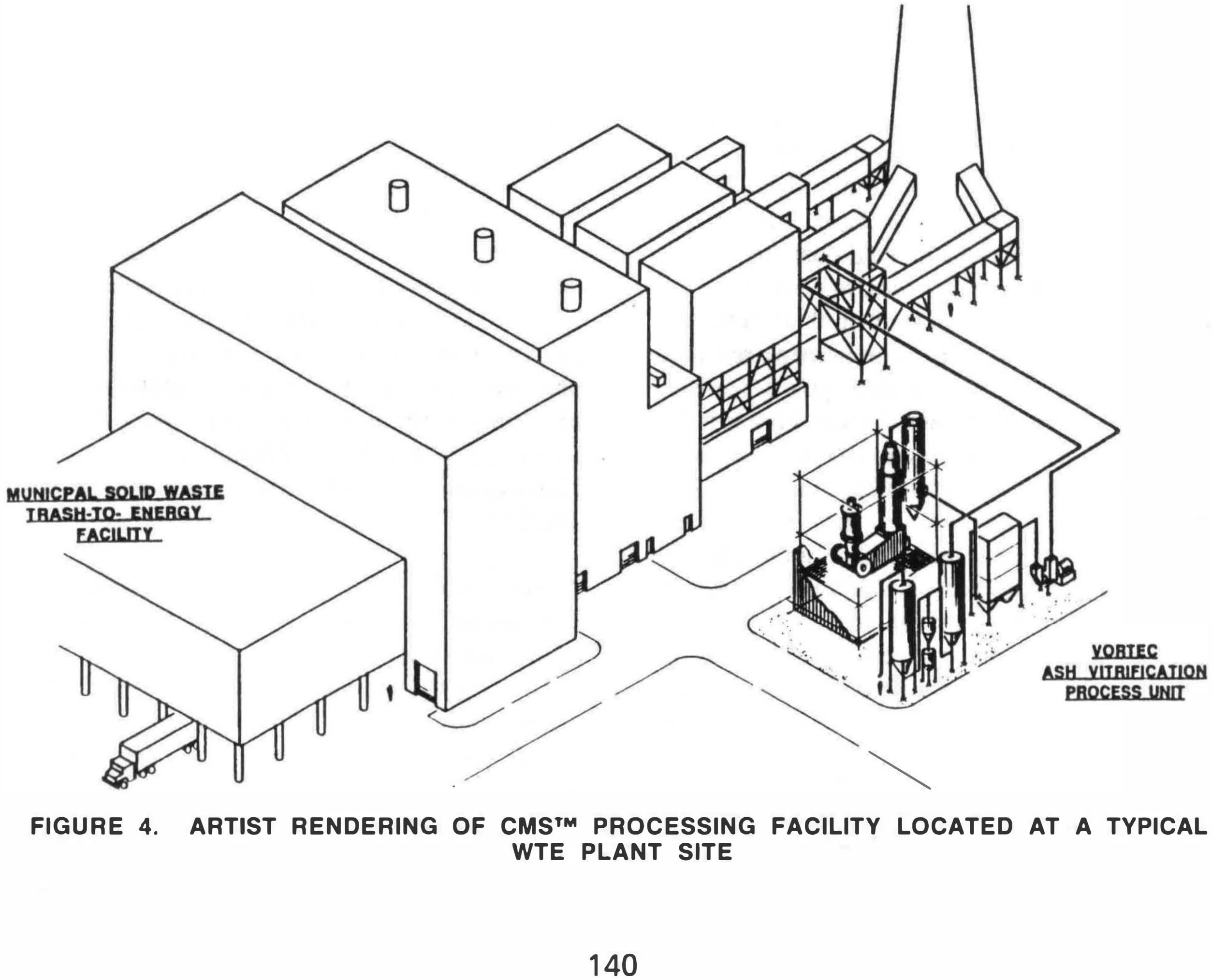

FIGURE 4. ARTIST RENDERING OF CMS™ PROCESSING FACILITY LOCATED AT A TYPICAL WTE PLANT SITE

TABLE 6. BASELINE MSWI FLYASH VITRIFICATION SYSTEM PERFORMANCE SUMMARY

Flyash Feedrate	0.8 kg/s (75 Ton/Day)
Glass Former Feedrate	0.2 kg/s (19 Ton/Day)
Natural Gas Thermal Input to Vitrification System	4.5 MW (13.83 Million Btu/Hr)
Vitrification System Heat Rate (Natural Gas Thermal Input/Flyash Throughput)	5 MJ/kg Flyash (4.4 Million Btu/Ton Flyash)
Steam Generated in Vitrification System	0.7 kg/s (5322 Lb/Hr)
Incremental Net Power Generated	216 kWe 0.6%

value, resulting in a heat rate of approximately 5 MJ/kg (4.4 million Btu/ton) of flyash. The vitrification system would produce approximately 0.7 kg/s (5,300 lbs/hr) of steam for use by the waste-to-energy facility, resulting in an incremental power generation of approximately 216 kWe, or 0.6% of the total facility power generation.

Results of the life cycle cost analysis of the 0.8 kg/s (75 ton/day) MSWI flyash vitrification plant are summarized in Table 7. Estimates of the installed capital costs are for complete installed plants, including all major and ancillary systems, buildings, and modifications to the MSWI waste-to-energy facility required to integrate the vitrification plant flyash feed system and steam generation system with the appropriate systems within the waste-to-energy facility. The installed capital cost of approximately $6.0 million for Case A also includes modifications required to the MSWI facility to integrate the vitrification system flue gas handling system with the MSWI ACQS. The installed capital cost of $8.0 million for Case B includes the installed cost of an independent ACQS for the vitrification system. It should be noted that all costs are very sensitive to site specifics and can vary significantly with type, configuration, and location of the facility.

TABLE 7. BASELINE MSWI ASH VITRIFICATION SYSTEM COST SUMMARY

0.8 kg/s (75 Ton/Day) Flyash Capacity
80% Flyash/20% Glass Former

	CASE A **Integrated AQCS**	**CASE B** **Independent AQCS**
Uninstalled Capital Cost	$3.5 Million	$4.7 Million
Installed Capital Cost	$6.0 Million	$8.0 Million
Oper./Maintenance Cost	$39/Mg ($35/Ton) Flyash	$43/Mg ($39/Ton) Flyash
	$31/Mg ($28/Ton) Product	$34/Mg ($31/Ton) Product
Total Processing Cost		
(Life Cycle Cost)	$49/Mg ($45/Ton) Flyash	$58/Mg ($53/Ton) Flyash
	$42/Mg ($38/Ton) Product	$47/Mg ($42/Ton) Product

Operating and maintenance (O&M) costs include utilities, consumables, operating labor, labor and materials for routine maintenance, and labor and materials for refractory replacement on a five year cycle.

The total processing unit costs (life cycle costs) are a total of the installed capital costs per unit capacity annualized over a 20 year plant life and the O&M unit costs. The life cycle costs do not include credit for revenue received from the sale of the vitrified product. Both the $49/Mg ($45/ton) and $58/Mg ($53/ton) of flyash total processing costs for Cases A and B, respectively, are attractive in many parts of the United States where the cost of non-hazardous landfilling is exceeding $110/Mg ($100/ton). Accounting for a product value of $11/Mg to $33/Mg ($10 to $30 per ton) for aggregates and granules, and avoided disposal cost of $110/Mg ($100/ton) of flyash, a simple payback period of 1 to 2 years on uninstalled capital cost can be realized.

The processing of combined ash (i.e., bottom and flyash) represents a much larger waste source for the vitrification application. The major challenge in this case is the high moisture content and the metals contamination in the bottom ash. Recently Vortec has developed a process for economically processing the combined ash. A separate paper describing this process will be published in the future.

Additional benefits can be realized in the processing of higher value products such as mineral wool and ceramic tile products.

CONCLUSIONS AND SUMMARY

From the laboratory and pilot scale vitrification testing, it has been concluded that a variety of ashes can be effectively vitrified with the Vortec Cyclone Melting System (CMS™). With the addition of suitable glass formers or glass modifiers, the ashes can be melted at reasonable temperatures, a high percentage of heavy metals in the ash can be incorporated in the vitrified products, and the vitrified products consistently pass TCLP testing requirements for the RCRA metals.

The glass products produced are homogeneous and the frits generated can be recycled into value added products for road and building construction applications.

From the results of economic analyses, it has been concluded that the low cost of ash vitrification with the Vortec CMS™, coupled with the mitigation of long term liability concerns, makes the Vortec vitrification process an attractive alternative to landfill disposal of boiler and incinerator ashes.

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