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SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION

Emerging Technology Summary

Vitrification of Soils Contaminated by Hazardous and/or Radioactive Wastes

A performance summary of an advanced multifuel-capable combustion and melting system (CMS) for the vitrification of hazardous wastes is presented. Vortec Corporation has evaluated its patented CMS for use in the remediation of soils contaminated with heavy metals and radionuclides under the EPA's SITE program and other waste treatment technology evaluation programs. The Vortec CMS has successfully demonstrated the ability to effectively treat hazardous and/or radioactive soils and produce a stable vitrified product with excellent leach resistance. The ability to process contaminated soils either as dry granular solids or in the form of a slurry has been demonstrated with a DRE of greater than 99.99% for organic compounds. All the glass produced passed the TCLP test with the concentration of contaminants in the leachates significantly reduced from those of the corresponding feedstocks which did not pass TCLP. The vitrified product also demonstrated superior radionuclide leach resistance, as no detectable quantities of the surrogate radionuclide were found by an ANSI/ANS-16.1 test.

This Summary was developed by the National Risk Management Research Laboratory's Sustainable Technology Division, Cincinnati, OH, to announce key findings of the SITE Emerging Technology program that is fully documented in a separate report (see Project Report ordering information at back).

Introduction

Vortec Corporation has developed an advanced multifuel-capable combustion and melting system (CMS) for the vitrification of hazardous wastes. Vortec has evaluated the CMS for the remediation of soils contaminated with heavy metals under the EPA's SITE Programs, and for the remediation of soils contaminated with heavy metals, organic compounds, and radionuclides under other waste treatment technology evaluation programs.

The soil remediation programs focused on demonstrating the ability of the Vortec CMS to immobilize heavy metals and radionuclides by incorporating these contaminants into the matrix of a glass—the vitrified product. The glass is formed by the vitrification of the soil which contains the hazardous constituents. Depending upon the composition of the contaminated soil, the addition of inexpensive glass-forming agents may be required. The Vortec CMS produces a vitrified product which has long-term stability, reduces the leachability of the heavy metals (and radionuclides) below regulatory limits, and results in a volume reduction of the waste material. In the vitrification of contaminated soils that are hazardous by characteristic and do not contain radionuclides, the vitrified product would no longer be classified as a hazardous waste. The Vortec CMS also completely oxidizes any organic components (hazardous or not) in the waste. The Vortec CMS has demonstrated a destruction removal efficiency (DRE) greater than 99.99% for all organic compounds in the soil.

The unique features of the CMS make it particularly suitable for the rapid and efficient heating of fine granular materials, and subsequent vitrification into a glass product. A process diagram of the Vortec CMS-based soil vitrification system is shown in Figure I.

The basic components of the system include:

- the Vortec multifuel-capable CMS, consisting of a counter-rotating vortex combustor and a cyclone melter;
- an upstream storage and feeding subsystem;
- a separator/reservoir assembly;

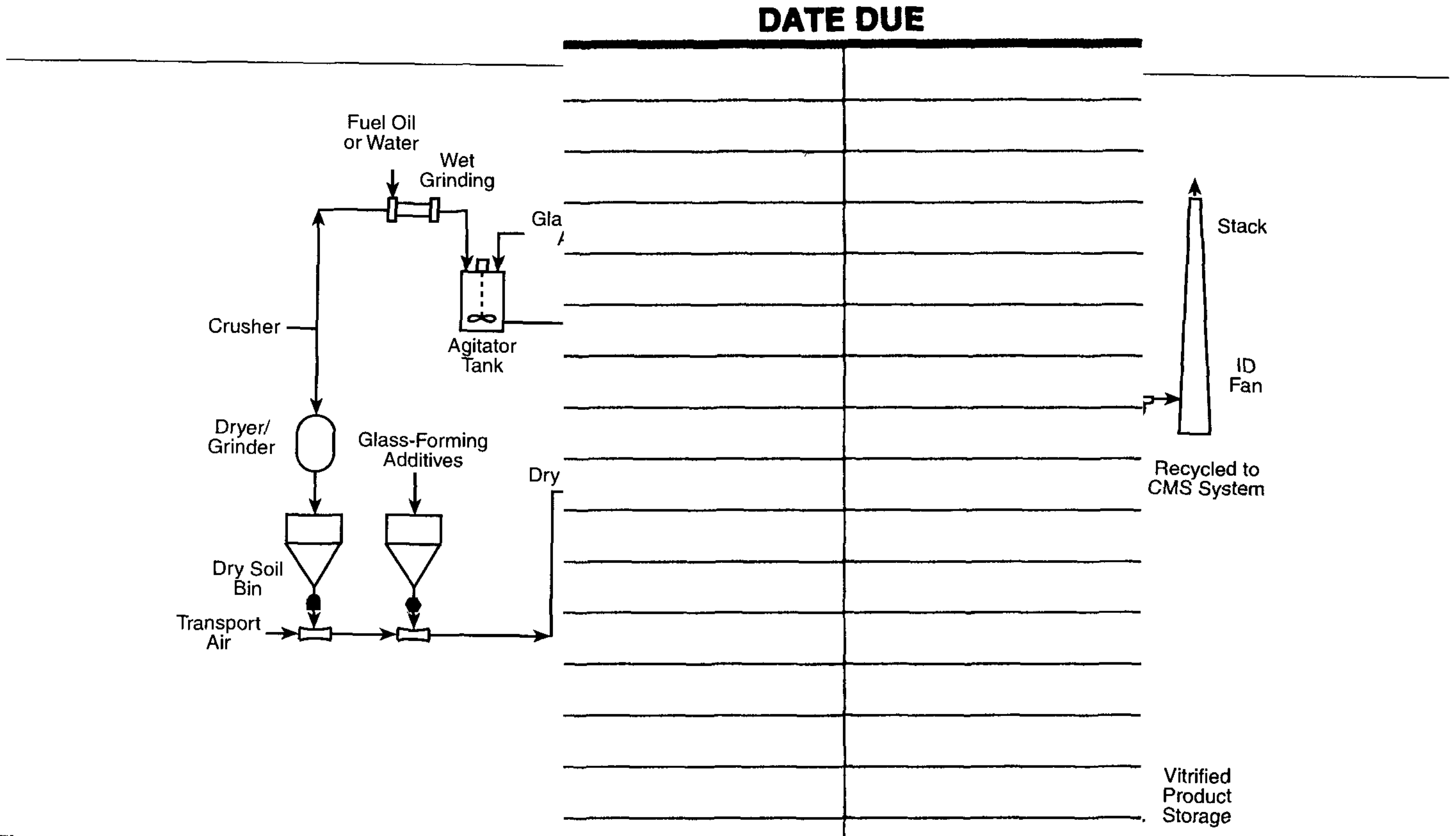

Figure 1. Vortec's CMS-based contaminated soil vitrificatic

- a cullet handling subsystem;
- a heat recoverysubsystem;
- a flue gas conditioning assembly; and
- an air pollution control subsystem.

Except for the CMS 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, oil, waste oils, and waste solvents. The CMS is also capable of using any combination of these fuels. Natural gas is customarily used in demonstration testing because of its convenience.

Complete combustion and in-flight suspension preheating of the contaminated soils, and any glass-forming additives, takes place in the combustor. The feedstock ingredients are introduced into the combustor through an injector and are rapidly heated in the flame zone. Any carbon-based materials are rapidly volatilized and oxidized. The inert materials are heated to nominally 2300•F to 2800•F, depending on the characteristics of the soil, prior to entering the cyclone melter. Since combustion air is preheated to nominally 1000•F to 1400•F, high local flame temperatures of more than 4000•F can be achieved in the combustor. However, due to the rapid temperature quenching of the combustion products by the inert soil particles and the staged combustion inherent in the CMS design, the NOx emissions have been demonstrated in pilot scale testing to be lower than DOE's boiler emissions standard of 0.6 lbs NOx/MMBtu. NOx emissions lower than 2 lbs NOx/ton glass have also been demonstrated.

The preheated solid materials from the combustor enter the cyclone melter, where they are distributed to the chamber walls by the cyclone action of the combustion products, thus forming a molten layer of vitrified soil (glass). The glass and the combustion products exit the cyclone melter through a tangential exit channel and enter the separator/reservoir. The separator/reservoir separates the combustion products from the molten glass and provides additional residence time for the completion of glass-forming reactions. The glass exits the separator/reservoir through either a tap hole in the floor or an overflow weir along a side wall. The combustion products exit through an exhaust port, which discharges into a conventional radiation-type recuperator for combustion air preheating.

A flue gas conditioning assembly reduces the temperature of the flue gas exiting the radiation recuperator to satisfy the temperature requirements of particulate control devices. Commercially available particulate control devices are incorporated into the design as dictated by local environmental regulations. A high efficiency venturi scrubber can be used for particulate control in some applications. Wet or dry electrostatic precipitators (ESPs) or baghouses can be used to achieve higher levels of particulate emissions control. Additional air pollution control, such as acid gas scrubbers, may be easily incorporated if required.

Two different techniques for transporting the contaminated soil into the CMS have been investigated. In one feed system, the soil was pneumatically fed to the CMS as dry granular solids. However, many soils found at contaminated sites are not in this preferred (dry) form. Therefore, a second feed system was developed to handle wet soils in the form of a slurry. The slurry feed system provides a means of mixing the wet contaminated soil and a liquid (water), and then delivering and atomizing this slurry into the CMS. By processing wet soils in a slurry form, the preparation and blending of the wet soil and the glass-forming materials, as well as the introduction of the resulting mixture into the CMS, are simplified. The Vortec CMS process demonstrated its ability to process both the dry and slurried feed materials, while forming a fully-reacted vitrified product.

Procedure

Laboratory melts were conducted by Vortec on EPA's Synthetic Soil Matrix (SSM) to determine whether the addition of glass-forming agents is required to produce a vitrified product that will consistently pass the Toxic Characteristic Leaching Procedure (TCLP). Table 1 presents the composition of EPA's SSM and the resulting feedstock formulation used in Vortec's SITE testing. Vortec, in cooperation with DuPont Chemicals, established the types and quantities of heavy metal compounds (shown later in Table 2) that were used to produce the contaminated surrogate soil. Blending of the surrogate soil, limestone and the heavy metal compounds was performed just prior to the initiation of testing, thus minimizing the possibility of further contamination in the feedstock.

The Vortec SITE program has conducted two tests at Vortec's nominal 15-20 tons per day pilot facility using surrogate soil spiked with heavy metal compounds. The first test employed the pneumatic feed system to process dry feedstock, while the second test used the slurry feed system to process an aqueous slurry containing contaminated surrogate soil. Prior to the slurry feed test, an initial combustion stability test was successfully completed and demonstrated the ability of the combustor to accept the designated water flow rate of 400 pounds per hour. Additional combustion stability testing was performed using a slurry of 60% cullet (ground waste glass) and 40% water. Cullet was used as the sole constituent, rather than clean soil, to avoid contamination of the materials being used in concurrent testing. The stability testing using the cullet/water slurry was also successful and verified the slurry system design parameters. Finally, a slurry containing 60% contaminated surrogate soil/limestone mixture and 40% water was used to perform the second of Vortec's contaminated soil SITE tests. Sampling and chemical analyses of the influent and effluent streams from both pilot scale contaminated soil tests were performed by DuPont's Water Quality Laboratory, Chambers Works, NJ; and Geraghty and Miller, Inc., Pittsburgh, PA. Under other demonstration programs, the feedstocks consisted of different SSMs, glass-forming additives, surrogate heavy metal compounds, organic compounds, and surrogate radionuclides.

Results and Discussion

The tests conducted under the EPA SITE Program, as well as all tests performed under other demonstration programs, have satisfied all technical and data quality objectives. Table 2 presents the metal concentrations in the feedstocks and the vitrified products produced during the Vortec SITE tests. Table 2 also includes the results of the TCLP tests performed on the feedstocks and the vitrified products. Due to the high cadmium content in the dry feedstock leachate and the high cadmium and lead content in the slurried feedstock leachate, both feedstocks failed TCLP testing. Therefore, these feedstocks would be considered hazardous if classified as waste products. However, all of the glass produced during Vortec's testing passed TCLP testing, with the concentration of heavy metals in the leachates significantly reduced from those of the corresponding feedstocks. The elevated chromium content in the vitrified products is due to the leaching of this element from the refractory present in the CMS during the SITE testing. Under other demonstration programs, the vitrified product was also evaluated by the ANSI/ANS-16.1 test for the leachability of the surrogate radionuclide.

No detectable quantities of the surrogate radionuclide were found in any of the leachates collected during the ANSI/ANS-16.1 test procedures.

Table 3 presents system mass balances and emission data for the Vortec SITE tests. The production of carbon dioxide, water vapor and the volatilization of other materials present in the feedstock resulted in the loss on ignition displayed in the table. Both uncontrolled and controlled stack particulate loadings are presented. During the SITE testing, a venturi scrubber was used as the pollution control device in the CMS exhaust system. A wet ESP has since been placed in the system, and based on subsequent testing of a variety of materials, the anticipated emissions under the conditions that existed during the SITE tests would be lower than 0.003 gr/dscf.

As the contaminated soils are processed within the CMS, the metal contaminants partition to either the carryover stream or the glass stream. The volatility of the metals and their oxides is the primary factor controlling the partitioning of these contaminants. The non-volatile metals, chromium, copper, and nickel, are found primarily in the vitrified product, while the semi-volatile metals, cadmium and lead, have a significantly higher percentage partitioning to the carryover. Table 4 summarizes the partitioning of the metal contaminants among all the effluent streams from the Vortec CMS. Through the use of a high efficiency particulate removal system, such as an ESP (wet or dry) or a baghouse, the carryover can be effectively recycled back into the molten vitrified product within the CMS using a proprietary technology developed by Vortec. With the implementation of this particulate-carryover recycle technology, the Vortec CMS has the potential to become a zero waste discharge process. While the recycling of the particulate carry-over into the vitrified product was not performed during Vortec's SITE testing, other programs are currently demonstrating this carryover recycle feature.

Conclusions and Recommendations

Pilot scale vitrification testing has demonstrated that, with the addition of appropriate glass-forming additives, surrogate soils representative of EPA Superfund and other hazardous waste sites can be effectively vitrified by the Vortec CMS. A high capture rate of the heavy metal contaminants into the glass product is achievable with the glass consistently passing the TCLP testing requirements for the leaching of RCRA metals. The CMS has demonstrated DREs greater than 99.99% for organic compounds. In addition, the CMS has demonstrated the ability to effectively process surrogate soil in both wet and dry forms. With the implementation of a proprietary particulate recycling technology, the Vortec CMS-based contaminated soil vitrification system can become a zero waste discharge process.

Table 1. EPA's Synthetic Soil Matrix (SSM) and the Feedstock Compositions used during Vortec's SITE Program

SSM	Composition wt%
SiO_2	57.43
Al_2O_3	11.74
K_2O	1.55
Na_2O	0.84
CaO	20.26
Fe_2O_3	2.32
MgO	5.29
Other oxides	0.57

Feedstock	Dry feed test wt%	Slurry feed test wt%
SSM	80.0	48.0
Limestone	20.0	12.0
Water	0.0	40.0

Table 2. Summary of Contaminant Concentrations and TCLP Data for the Feedstocks used and the Vitrified Products Collected under Vortec's SITE Program

Metal Contaminants	Concentration in Feedstock	Feedstock TCLP Result	Concentration in Glass	Glass TCLP Result	TCLP RCRA Limit
Dry Feed Test	PPM[a]	PPM[b]	PPM[c]	PPM[d]	PPM
Arsenic	273	0.97	259	0.00	5.
Cadmium	187	1.55	75	0.00	1.0
Chromium	867	0.02	1615	0.04	5.0
Copper	395	0.06	366	0.04	N/
Lead	2132	0.10	872	0.00	5.0
Nickel	128	1.73	189	0.00	N/
Zinc	2395	8.71	1615	0.12	N/
Slurry Feed Test (dry basis)	PPM	PPM	PPM	PPM	PPM
Arsenic	112	1.1	275	0.0	5.0
Cadmium	116	2.7	27	0.008	1.
Chromium**	546	0.04	1209	0.19	5.0
Copper	235	3.7	381	0.15	N/A
Lead	1106	7.5	505	0.13	5.0
Nickel	85	3.5	229	0.15	N/A
Zinc	1300	26.3	1506	0.83	N/A

[a] Average of 13 samples.
[b] Average of 19 samples.
[c] Average of 11 samples.
[d] Average of 18 samples.
N/A - not applicable.
** Excess levels of chromium leached from refractory into glass.

Table 3. CMS Performance During Vortec's SITE Program Testing

Mass		Dry feed test	Slurry feed test
Feedstock	lbs/hr	947	450
Glass produced	lbs/hr	721	212
Loss on ignition	lbs/hr	195	235
Emissions data			
Uncontrolled particulate	% of Feedstock	3.3	0.06
Controlled particulate using venturi scrubber	% of Feedstock	0.3	0.01
Controlled particulate estimate using wet ESP	grains/dscf	<0.003	<0.001

Table 4. Partitioning of Heavy Metals among the CMS Effluent Streams During Vortec's SITE Program

	Dry feed test			Slurry feed test		
Metal	Glass	Scrubber	Stack gas	Glass	Scrubber	Stack gas
Arsenic	69.9	27.3	2.8	91.0	5.4	3.6
Cadmium	50.9	24.6	24.5	41.2	16.3	42.5
Chromium	89.4	9.8	0.8	85.5	11.4	3.1
Copper	85.4	12.5	2.1	96.0	2.2	1.8
Lead	44.7	31.6	23.7	52.7	23.5	23.8
Nickel	87.5	12.2	0.3	98.5	0.0	1.5
Zinc	78.0	16.6	5.4	92.7	3.7	3.6

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Details of the completed SITE Emerging Technology project are given in an article published in Glass Production Technology International, 1994 pp. 103-106.
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